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To fully understand Java, one must understand the reasons behind its creation, the forces that shaped it, and the legacy that it inherits. Like the successful computer languages that came before, Java is a blend of the best elements of its rich heritage combined with the innovative concepts required by its unique mission. While the remaining chapters of this book describe the practical aspects of Java—including its syntax, key libraries, and applications—this chapter explains how and why Java came about, what makes it so important, and how it has evolved over the years.

Although Java has become inseparably linked with the online environment of the Internet, it is important to remember that Java is first and foremost a programming language. Computer language innovation and development occurs for two fundamental reasons:

- To adapt to changing environments and uses
- To implement refinements and improvements in the art of programming

As you will see, the development of Java was driven by both elements in nearly equal measure.

**Java’s Lineage**

Java is related to C++, which is a direct descendant of C. Much of the character of Java is inherited from these two languages. From C, Java derives its syntax. Many of Java’s object-oriented features were influenced by C++. In fact, several of Java’s defining characteristics come from—or are responses to—its predecessors. Moreover, the creation of Java was deeply rooted in the process of refinement and adaptation that has been occurring in computer programming languages for the past several decades. For these reasons, this section reviews the sequence of events and forces that led to Java. As you will see, each innovation in language design was driven by the need to solve a fundamental problem that the preceding languages could not solve. Java is no exception.

**The Birth of Modern Programming: C**

The C language shook the computer world. Its impact should not be underestimated, because it fundamentally changed the way programming was approached and thought
The creation of C was a direct result of the need for a structured, efficient, high-level language that could replace assembly code when creating systems programs. As you probably know, when a computer language is designed, trade-offs are often made, such as the following:

- Ease-of-use versus power
- Safety versus efficiency
- Rigidity versus extensibility

Prior to C, programmers usually had to choose between languages that optimized one set of traits or the other. For example, although FORTRAN could be used to write fairly efficient programs for scientific applications, it was not very good for system code. And while BASIC was easy to learn, it wasn’t very powerful, and its lack of structure made its usefulness questionable for large programs. Assembly language can be used to produce highly efficient programs, but it is not easy to learn or use effectively. Further, debugging assembly code can be quite difficult.

Another compounding problem was that early computer languages such as BASIC, COBOL, and FORTRAN were not designed around structured principles. Instead, they relied upon the GOTO as a primary means of program control. As a result, programs written using these languages tended to produce “spaghetti code”—a mass of tangled jumps and conditional branches that make a program virtually impossible to understand. While languages like Pascal are structured, they were not designed for efficiency, and failed to include certain features necessary to make them applicable to a wide range of programs. (Specifically, given the standard dialects of Pascal available at the time, it was not practical to consider using Pascal for systems-level code.)

So, just prior to the invention of C, no one language had reconciled the conflicting attributes that had dogged earlier efforts. Yet the need for such a language was pressing. By the early 1970s, the computer revolution was beginning to take hold, and the demand for software was rapidly outpacing programmers’ ability to produce it. A great deal of effort was being expended in academic circles in an attempt to create a better computer language. But, and perhaps most importantly, a secondary force was beginning to be felt. Computer hardware was finally becoming common enough that a critical mass was being reached. No longer were computers kept behind locked doors. For the first time, programmers were gaining virtually unlimited access to their machines. This allowed the freedom to experiment. It also allowed programmers to begin to create their own tools. On the eve of C’s creation, the stage was set for a quantum leap forward in computer languages.

Invented and first implemented by Dennis Ritchie on a DEC PDP-11 running the UNIX operating system, C was the result of a development process that started with an older language called BCPL, developed by Martin Richards. BCPL influenced a language called B, invented by Ken Thompson, which led to the development of C in the 1970s. For many
years, the de facto standard for C was the one supplied with the UNIX operating system and described in *The C Programming Language* by Brian Kernighan and Dennis Ritchie (Prentice-Hall, 1978). C was formally standardized in December 1989, when the American National Standards Institute (ANSI) standard for C was adopted.

The creation of C is considered by many to have marked the beginning of the modern age of computer languages. It successfully synthesized the conflicting attributes that had so troubled earlier languages. The result was a powerful, efficient, structured language that was relatively easy to learn. It also included one other, nearly intangible aspect: it was a programmer’s language. Prior to the invention of C, computer languages were generally designed either as academic exercises or by bureaucratic committees. C is different. It was designed, implemented, and developed by real, working programmers, reflecting the way that they approached the job of programming. Its features were honed, tested, thought about, and rethought by the people who actually used the language. The result was a language that programmers liked to use. Indeed, C quickly attracted many followers who had a near-religious zeal for it. As such, it found wide and rapid acceptance in the programmer community. In short, C is a language designed by and for programmers. As you will see, Java inherited this legacy.

**C++: The Next Step**

During the late 1970s and early 1980s, C became the dominant computer programming language, and it is still widely used today. Since C is a successful and useful language, you might ask why a need for something else existed. The answer is *complexity*. Throughout the history of programming, the increasing complexity of programs has driven the need for better ways to manage that complexity. C++ is a response to that need. To better understand why managing program complexity is fundamental to the creation of C++, consider the following.

Approaches to programming have changed dramatically since the invention of the computer. For example, when computers were first invented, programming was done by manually toggling in the binary machine instructions by use of the front panel. As long as programs were just a few hundred instructions long, this approach worked. As programs grew, assembly language was invented so that a programmer could deal with larger, increasingly complex programs by using symbolic representations of the machine instructions. As programs continued to grow, high-level languages were introduced that gave the programmer more tools with which to handle complexity. The first widespread language was, of course, FORTRAN. While FORTRAN was an impressive first step, it is hardly a language that encourages clear and easy-to-understand programs. The 1960s gave birth to *structured programming*. This is the method of programming championed by languages such as C. The use of structured languages enabled programmers to write, for the first time, moderately complex programs fairly easily. However, even with structured programming methods, once a project reaches a certain size, its complexity exceeds what a programmer can manage. By the early 1980s, many projects
were pushing the structured approach past its limits. To solve this problem, a new way to program was invented, called object-oriented programming (OOP). Object-oriented programming is discussed in detail later in this book, but here is a brief definition: OOP is a programming methodology that helps organize complex programs through the use of inheritance, encapsulation, and polymorphism.

In the final analysis, although C is one of the world’s great programming languages, there is a limit to its ability to handle complexity. Once the size of a program exceeds a certain point, it becomes so complex that it is difficult to grasp as a totality. While the precise size at which this occurs differs, depending upon both the nature of the program and the programmer, there is always a threshold at which a program becomes unmanageable. C++ added features that enabled this threshold to be broken, allowing programmers to comprehend and manage larger programs.

C++ was invented by Bjarne Stroustrup in 1979, while he was working at Bell Laboratories in Murray Hill, New Jersey. Stroustrup initially called the new language “C with Classes.” However, in 1983, the name was changed to C++. C++ extends C by adding object-oriented features. Because C++ is built on the foundation of C, it includes all of C’s features, attributes, and benefits. This is a crucial reason for the success of C++ as a language. The invention of C++ was not an attempt to create a completely new programming language. Instead, it was an enhancement to an already highly successful one.

**The Stage Is Set for Java**

By the end of the 1980s and the early 1990s, object-oriented programming using C++ took hold. Indeed, for a brief moment it seemed as if programmers had finally found the perfect language. Because C++ blended the high efficiency and stylistic elements of C with the object-oriented paradigm, it was a language that could be used to create a wide range of programs. However, just as in the past, forces were brewing that would, once again, drive computer language evolution forward. Within a few years, the World Wide Web and the Internet would reach critical mass. This event would precipitate another revolution in programming.

**The Creation of Java**

Java was conceived by James Gosling, Patrick Naughton, Chris Warth, Ed Frank, and Mike Sheridan at Sun Microsystems, Inc. in 1991. It took 18 months to develop the first working version. This language was initially called “Oak,” but was renamed “Java” in 1995. Between the initial implementation of Oak in the fall of 1992 and the public announcement of Java in the spring of 1995, many more people contributed to the design and evolution of the language. Bill Joy, Arthur van Hoff, Jonathan Payne, Frank Yellin, and Tim Lindholm were key contributors to the maturing of the original prototype.

Somewhat surprisingly, the original impetus for Java was not the Internet! Instead, the primary motivation was the need for a platform-independent (that is, architecture-neutral) language that could be used to create software to be embedded in various consumer
electronic devices, such as microwave ovens and remote controls. As you can probably guess, many different types of CPUs are used as controllers. The trouble with C and C++ (and most other languages) is that they are designed to be compiled for a specific target. Although it is possible to compile a C++ program for just about any type of CPU, to do so requires a full C++ compiler targeted for that CPU. The problem is that compilers are expensive and time-consuming to create. An easier—and more cost-efficient—solution was needed. In an attempt to find such a solution, Gosling and others began work on a portable, platform-independent language that could be used to produce code that would run on a variety of CPUs under differing environments. This effort ultimately led to the creation of Java.

About the time that the details of Java were being worked out, a second, and ultimately more important, factor was emerging that would play a crucial role in the future of Java. This second force was, of course, the World Wide Web. Had the Web not taken shape at about the same time that Java was being implemented, Java might have remained a useful but obscure language for programming consumer electronics. However, with the emergence of the World Wide Web, Java was propelled to the forefront of computer language design, because the Web, too, demanded portable programs.

Most programmers learn early in their careers that portable programs are as elusive as they are desirable. While the quest for a way to create efficient, portable (platform-independent) programs is nearly as old as the discipline of programming itself, it had taken a back seat to other, more pressing problems. Further, because (at that time) much of the computer world had divided itself into the three competing camps of Intel, Macintosh, and UNIX, most programmers stayed within their fortified boundaries, and the urgent need for portable code was reduced. However, with the advent of the Internet and the Web, the old problem of portability returned with a vengeance. After all, the Internet consists of a diverse, distributed universe populated with various types of computers, operating systems, and CPUs. Even though many kinds of platforms are attached to the Internet, users would like them all to be able to run the same program. What was once an irritating but low-priority problem had become a high-profile necessity.

By 1993, it became obvious to members of the Java design team that the problems of portability frequently encountered when creating code for embedded controllers are also found when attempting to create code for the Internet. In fact, the same problem that Java was initially designed to solve on a small scale could also be applied to the Internet on a large scale. This realization caused the focus of Java to switch from consumer electronics to Internet programming. So, while the desire for an architecture-neutral programming language provided the initial spark, the Internet ultimately led to Java's large-scale success. As mentioned earlier, Java derives much of its character from C and C++. This is by intent. The Java designers knew that using the familiar syntax of C and echoing the object-oriented features of C++ would make their language appealing to the legions of experienced C/C++ programmers. In addition to the surface similarities, Java shares some of the other attributes that helped make C and C++ successful. First, Java was designed, tested, and
refined by real, working programmers. It is a language grounded in the needs and experiences of the people who devised it. Thus, Java is a programmer’s language. Second, Java is cohesive and logically consistent. Third, except for those constraints imposed by the Internet environment, Java gives you, the programmer, full control. If you program well, your programs reflect it. If you program poorly, your programs reflect that, too. Put differently, Java is not a language with training wheels. It is a language for professional programmers.

Because of the similarities between Java and C++, it is tempting to think of Java as simply the “Internet version of C++.” However, to do so would be a large mistake. Java has significant practical and philosophical differences. While it is true that Java was influenced by C++, it is not an enhanced version of C++. For example, Java is neither upwardly nor downwardly compatible with C++. Of course, the similarities with C++ are significant, and if you are a C++ programmer, then you will feel right at home with Java. One other point: Java was not designed to replace C++. Java was designed to solve a certain set of problems. C++ was designed to solve a different set of problems. Both will coexist for many years to come.

As mentioned at the start of this chapter, computer languages evolve for two reasons: to adapt to changes in environment and to implement advances in the art of programming. The environmental change that prompted Java was the need for platform-independent programs destined for distribution on the Internet. However, Java also embodies changes in the way that people approach the writing of programs. For example, Java enhanced and refined the object-oriented paradigm used by C++, added integrated support for multithreading, and provided a library that simplified Internet access. In the final analysis, though, it was not the individual features of Java that made it so remarkable. Rather, it was the language as a whole. Java was the perfect response to the demands of the then newly emerging, highly distributed computing universe. Java was to Internet programming what C was to system programming: a revolutionary force that changed the world.

**The C# Connection**

The reach and power of Java continues to be felt in the world of computer language development. Many of its innovative features, constructs, and concepts have become part of the baseline for any new language. The success of Java is simply too important to ignore. Perhaps the most important example of Java’s influence is C#. Created by Microsoft to support the .NET Framework, C# is closely related to Java. For example, both share the same general syntax, support distributed programming, and utilize the same object model. There are, of course, differences between Java and C#, but the overall “look and feel” of these languages is very similar. This “cross-pollination” from Java to C# is the strongest testimonial to date that Java redefined the way we think about and use a computer language.

**How Java Changed the Internet**
The Internet helped catapult Java to the forefront of programming, and Java, in turn, had a profound effect on the Internet. In addition to simplifying web programming in general, Java innovated a new type of networked program called the applet that changed the way the online world thought about content. Java also addressed some of the thorniest issues associated with the Internet: portability and security. Let’s look more closely at each of these.

**Java Applets**

An *applet* is a special kind of Java program that is designed to be transmitted over the Internet and automatically executed by a Java-compatible web browser. Furthermore, an applet is downloaded on demand, without further interaction with the user. If the user clicks a link that contains an applet, the applet will be automatically downloaded and run in the browser. Applets are intended to be small programs. They are typically used to display data provided by the server, handle user input, or provide simple functions, such as a loan calculator, that execute locally, rather than on the server. In essence, the applet allows some functionality to be moved from the server to the client.

The creation of the applet changed Internet programming because it expanded the universe of objects that can move about freely in cyberspace. In general, there are two very broad categories of objects that are transmitted between the server and the client: passive information and dynamic, active programs. For example, when you read your e-mail, you are viewing passive data. Even when you download a program, the program’s code is still only passive data until you execute it. By contrast, the applet is a dynamic, self-executing program. Such a program is an active agent on the client computer, yet it is initiated by the server.

As desirable as dynamic, networked programs are, they also present serious problems in the areas of security and portability. Obviously, a program that downloads and executes automatically on the client computer must be prevented from doing harm. It must also be able to run in a variety of different environments and under different operating systems. As you will see, Java solved these problems in an effective and elegant way. Let’s look a bit more closely at each.

**Security**

As you are likely aware, every time you download a “normal” program, you are taking a risk, because the code you are downloading might contain a virus, Trojan horse, or other harmful code. At the core of the problem is the fact that malicious code can cause its damage because it has gained unauthorized access to system resources. For example, a virus program might gather private information, such as credit card numbers, bank account balances, and passwords, by searching the contents of your computer’s local file system. In order for Java to enable applets to be downloaded and executed on the client computer safely, it was necessary to prevent an applet from launching such an attack.

Java achieved this protection by confining an applet to the Java execution environment and
not allowing it access to other parts of the computer. (You will see how this is accomplished shortly.) The ability to download applets with confidence that no harm will be done and that no security will be breached may have been the single most innovative aspect of Java.

**Portability**
Portability is a major aspect of the Internet because there are many different types of computers and operating systems connected to it. If a Java program were to be run on virtually any computer connected to the Internet, there needed to be some way to enable that program to execute on different systems. For example, in the case of an applet, the same applet must be able to be downloaded and executed by the wide variety of CPUs, operating systems, and browsers connected to the Internet. It is not practical to have different versions of the applet for different computers. The *same* code must work on *all* computers. Therefore, some means of generating portable executable code was needed. As you will soon see, the same mechanism that helps ensure security also helps create portability.

**Java’s Magic: The Bytecode**
The key that allows Java to solve both the security and the portability problems just described is that the output of a Java compiler is not executable code. Rather, it is bytecode. *Bytecode* is a highly optimized set of instructions designed to be executed by the Java runtime system, which is called the *Java Virtual Machine (JVM)*. In essence, the original JVM was designed as an *interpreter for bytecode*. This may come as a bit of a surprise since many modern languages are designed to be compiled into executable code because of performance concerns. However, the fact that a Java program is executed by the JVM helps solve the major problems associated with web-based programs. Here is why.

Translating a Java program into bytecode makes it much easier to run a program in a wide variety of environments because only the JVM needs to be implemented for each platform. Once the run-time package exists for a given system, any Java program can run on it. Remember, although the details of the JVM will differ from platform to platform, all understand the same Java bytecode. If a Java program were compiled to native code, then different versions of the same program would have to exist for each type of CPU connected to the Internet. This is, of course, not a feasible solution. Thus, the execution of bytecode by the JVM is the easiest way to create truly portable programs.

The fact that a Java program is executed by the JVM also helps to make it secure. Because the JVM is in control, it can contain the program and prevent it from generating side effects outside of the system. As you will see, safety is also enhanced by certain restrictions that exist in the Java language.

In general, when a program is compiled to an intermediate form and then interpreted by a virtual machine, it runs slower than it would run if compiled to executable code. However, with Java, the differential between the two is not so great. Because bytecode has been highly optimized, the use of bytecode enables the JVM to execute programs much faster than you
might expect. Although Java was designed as an interpreted language, there is nothing about Java that prevents on-the-fly compilation of bytecode into native code in order to boost performance. For this reason, the HotSpot technology was introduced not long after Java’s initial release. HotSpot provides a Just-In-Time (JIT) compiler for bytecode. When a JIT compiler is part of the JVM, selected portions of bytecode are compiled into executable code in real time, on a piece-by-piece, demand basis. It is important to understand that it is not practical to compile an entire Java program into executable code all at once, because Java performs various run-time checks that can be done only at run time. Instead, a JIT compiler compiles code as it is needed, during execution. Furthermore, not all sequences of bytecode are compiled—only those that will benefit from compilation. The remaining code is simply interpreted. However, the just-in-time approach still yields a significant performance boost. Even when dynamic compilation is applied to bytecode, the portability and safety features still apply, because the JVM is still in charge of the execution environment.

Servlets: Java on the Server Side
As useful as applets can be, they are just one half of the client/server equation. Not long after the initial release of Java, it became obvious that Java would also be useful on the server side. The result was the servlet. A servlet is a small program that executes on the server. Just as applets dynamically extend the functionality of a web browser, servlets dynamically extend the functionality of a web server. Thus, with the advent of the servlet, Java spanned both sides of the client/server connection. Servlets are used to create dynamically generated content that is then served to the client. For example, an online store might use a servlet to look up the price for an item in a database. The price information is then used to dynamically generate a web page that is sent to the browser. Although dynamically generated content is available through mechanisms such as CGI (Common Gateway Interface), the servlet offers several advantages, including increased performance. Because servlets (like all Java programs) are compiled into bytecode and executed by the JVM, they are highly portable. Thus, the same servlet can be used in a variety of different server environments. The only requirements are that the server support the JVM and a servlet container.

The Java Buzzwords
No discussion of Java’s history is complete without a look at the Java buzzwords. Although the fundamental forces that necessitated the invention of Java are portability and security, other factors also played an important role in molding the final form of the language. The key considerations were summed up by the Java team in the following list of buzzwords:

• Simple
• Secure
Two of these buzzwords have already been discussed: secure and portable. Let’s examine what each of the others implies.

**Simple**
Java was designed to be easy for the professional programmer to learn and use effectively. Assuming that you have some programming experience, you will not find Java hard to master. If you already understand the basic concepts of object-oriented programming, learning Java will be even easier. Best of all, if you are an experienced C++ programmer, moving to Java will require very little effort. Because Java inherits the C/C++ syntax and many of the object-oriented features of C++, most programmers have little trouble learning Java.

**Object-Oriented**
Although influenced by its predecessors, Java was not designed to be source-code compatible with any other language. This allowed the Java team the freedom to design with a blank slate. One outcome of this was a clean, usable, pragmatic approach to objects. Borrowing liberally from many seminal object-software environments of the last few decades, Java manages to strike a balance between the purist’s “everything is an object” paradigm and the pragmatist’s “stay out of my way” model. The object model in Java is simple and easy to extend, while primitive types, such as integers, are kept as high-performance nonobjects.

**Robust**
The multiplatformed environment of the Web places extraordinary demands on a program, because the program must execute reliably in a variety of systems. Thus, the ability to create robust programs was given a high priority in the design of Java. To gain reliability, Java restricts you in a few key areas to force you to find your mistakes early in program development. At the same time, Java frees you from having to worry about many of the most common causes of programming errors. Because Java is a strictly typed language, it checks your code at compile time. However, it also checks your code at run time. Many hard-to-track-down bugs that often turn up in hard-to-reproduce run-time situations are
simply impossible to create in Java. Knowing that what you have written will behave in a predictable way under diverse conditions is a key feature of Java. To better understand how Java is robust, consider two of the main reasons for program failure: memory management mistakes and mishandled exceptional conditions (that is, runtime errors). Memory management can be a difficult, tedious task in traditional programming environments. For example, in C/C++, the programmer will often manually allocate and free all dynamic memory. This sometimes leads to problems, because programmers will either forget to free memory that has been previously allocated or, worse, try to free some memory that another part of their code is still using. Java virtually eliminates these problems by managing memory allocation and deallocation for you. (In fact, deallocation is completely automatic, because Java provides garbage collection for unused objects.) Exceptional conditions in traditional environments often arise in situations such as division by zero or “file not found,” and they must be managed with clumsy and hard-to-read constructs. Java helps in this area by providing object-oriented exception handling. In a well-written Java program, all run-time errors can—and should—be managed by your program.

Multithreaded
Java was designed to meet the real-world requirement of creating interactive, networked programs. To accomplish this, Java supports multithreaded programming, which allows you to write programs that do many things simultaneously. The Java run-time system comes with an elegant yet sophisticated solution for multiprocess synchronization that enables you to construct smoothly running interactive systems. Java’s easy-to-use approach to multithreading allows you to think about the specific behavior of your program, not the multitasking subsystem.

Architecture-Neutral
A central issue for the Java designers was that of code longevity and portability. At the time of Java’s creation, one of the main problems facing programmers was that no guarantee existed that if you wrote a program today, it would run tomorrow—even on the same machine. Operating system upgrades, processor upgrades, and changes in core system resources can all combine to make a program malfunction. The Java designers made several hard decisions in the Java language and the Java Virtual Machine in an attempt to alter this situation. Their goal was “write once; run anywhere, any time, forever.” To a great extent, this goal was accomplished.

Interpreted and High Performance
As described earlier, Java enables the creation of cross-platform programs by compiling into an intermediate representation called Java bytecode. This code can be executed on any system that implements the Java Virtual Machine. Most previous attempts at cross-platform solutions have done so at the expense of performance. As explained earlier, the Java bytecode was carefully designed so that it would be easy to translate directly into native
machine code for very high performance by using a just-in-time compiler. Java run-time systems that provide this feature lose none of the benefits of the platform-independent code.

**Distributed**
Java is designed for the distributed environment of the Internet because it handles TCP/IP protocols. In fact, accessing a resource using a URL is not much different from accessing a file. Java also supports Remote Method Invocation (RMI). This feature enables a program to invoke methods across a network.

**Dynamic**
Java programs carry with them substantial amounts of run-time type information that is used to verify and resolve accesses to objects at run time. This makes it possible to dynamically link code in a safe and expedient manner. This is crucial to the robustness of the Java environment, in which small fragments of bytecode may be dynamically updated on a running system.

**The Evolution of Java**
The initial release of Java was nothing short of revolutionary, but it did not mark the end of Java’s era of rapid innovation. Unlike most other software systems that usually settle into a pattern of small, incremental improvements, Java continued to evolve at an explosive pace. Soon after the release of Java 1.0, the designers of Java had already created Java 1.1. The features added by Java 1.1 were more significant and substantial than the increase in the minor revision number would have you think. Java 1.1 added many new library elements, redefined the way events are handled, and reconfigured many features of the 1.0 library. It also deprecated (rendered obsolete) several features originally defined by Java 1.0. Thus, Java 1.1 both added to and subtracted from attributes of its original specification.

The next major release of Java was Java 2, where the “2” indicates “second generation.” The creation of Java 2 was a watershed event, marking the beginning of Java’s “modern age.” The first release of Java 2 carried the version number 1.2. It may seem odd that the first release of Java 2 used the 1.2 version number. The reason is that it originally referred to the internal version number of the Java libraries, but then was generalized to refer to the entire release. With Java 2, Sun repackaged the Java product as J2SE (Java 2 Platform Standard Edition), and the version numbers began to be applied to that product.

Java 2 added support for a number of new features, such as Swing and the Collections Framework, and it enhanced the Java Virtual Machine and various programming tools. Java 2 also contained a few deprecations. The most important affected the `Thread` class in which the methods `suspend()`, `resume()`, and `stop()` were deprecated.

J2SE 1.3 was the first major upgrade to the original Java 2 release. For the most part, it added to existing functionality and “tightened up” the development environment. In general, programs written for version 1.2 and those written for version 1.3 are source-code compatible. Although version 1.3 contained a smaller set of changes than the preceding
three major releases, it was nevertheless important. The release of J2SE 1.4 further enhanced Java. This release contained several important upgrades, enhancements, and additions. For example, it added the new keyword `assert`, chained exceptions, and a channel-based I/O subsystem. It also made changes to the Collections Framework and the networking classes. In addition, numerous small changes were made throughout. Despite the significant number of new features, version 1.4 maintained nearly 100 percent source-code compatibility with prior versions.

The next release of Java was J2SE 5, and it was revolutionary. Unlike most of the previous Java upgrades, which offered important, but measured improvements, J2SE 5 fundamentally expanded the scope, power, and range of the language. To grasp the magnitude of the changes that J2SE 5 made to Java, consider the following list of its major new features:

- Generics
- Annotations
- Autoboxing and auto-unboxing
- Enumerations
- Enhanced, for-each style `for` loop
- Variable-length arguments (varargs)
- Static import
- Formatted I/O
- Concurrency utilities

This is not a list of minor tweaks or incremental upgrades. Each item in the list represented a significant addition to the Java language. Some, such as generics, the enhanced `for`, and varargs, introduced new syntax elements. Others, such as autoboxing and auto-unboxing, altered the semantics of the language. Annotations added an entirely new dimension to programming. In all cases, the impact of these additions went beyond their direct effects. They changed the very character of Java itself.

The importance of these new features is reflected in the use of the version number “5.” The next version number for Java would normally have been 1.5. However, the new features were so significant that a shift from 1.4 to 1.5 just didn’t seem to express the magnitude of the change. Instead, Sun elected to increase the version number to 5 as a way of emphasizing that a major event was taking place. Thus, it was named J2SE 5, and the developer’s kit was called JDK 5. However, in order to maintain consistency, Sun decided to use 1.5 as its internal version number, which is also referred to as the developer version number. The “5” in J2SE 5 is called the product version number.

The next release of Java was called Java SE 6. Sun once again decided to change the name of the Java platform. First, notice that the “2” was dropped. Thus, the platform was now
named Java SE, and the official product name was Java Platform, Standard Edition 6. The Java Development Kit was called JDK 6. As with J2SE 5, the 6 in Java SE 6 is the product version number. The internal, developer version number is 1.6.

Java SE 6 built on the base of J2SE 5, adding incremental improvements. Java SE 6 added no major features to the Java language proper, but it did enhance the API libraries, added several new packages, and offered improvements to the runtime. It also went through several updates during its (in Java terms) long life cycle, with several upgrades added along the way. In general, Java SE 6 served to further solidify the advances made by J2SE 5.

Java SE 7 was the next release of Java, with the Java Development Kit being called JDK 7, and an internal version number of 1.7. Java SE 7 was the first major release of Java since Sun Microsystems was acquired by Oracle. Java SE 7 contained many new features, including significant additions to the language and the API libraries. Upgrades to the Java run-time system that support non-Java languages were also included, but it is the language and library additions that were of most interest to Java programmers.

The new language features were developed as part of Project Coin. The purpose of Project Coin was to identify a number of small changes to the Java language that would be incorporated into JDK 7. Although these features were collectively referred to as “small,” the effects of these changes have been quite large in terms of the code they impact. In fact, for many programmers, these changes may well have been the most important new features in Java SE 7. Here is a list of the language features added by JDK 7:

- A String can now control a switch statement.
- Binary integer literals.
- Underscores in numeric literals.
- An expanded try statement, called try-with-resources, that supports automatic resource management. (For example, streams can be closed automatically when they are no longer needed.)
- Type inference (via the diamond operator) when constructing a generic instance.
- Enhanced exception handling in which two or more exceptions can be caught by a single catch (multi-catch) and better type checking for exceptions that are rethrown.
- Although not a syntax change, the compiler warnings associated with some types of varargs methods were improved, and you have more control over the warnings.

As you can see, even though the Project Coin features were considered small changes to the language, their benefits were much larger than the qualifier “small” would suggest. In particular, the try-with-resources statement has profoundly affected the way that stream-based code is written. Also, the ability to use a String
to control a switch statement was a long-desired improvement that simplified coding in many situations.

Java SE 7 made several additions to the Java API library. Two of the most important were the enhancements to the NIO Framework and the addition of the Fork/Join Framework. NIO (which originally stood for New I/O) was added to Java in version 1.4. However, the changes added by Java SE 7 fundamentally expanded its capabilities. So significant were the changes, that the term NIO.2 is often used.

The Fork/Join Framework provides important support for parallel programming. Parallel programming is the name commonly given to the techniques that make effective use of computers that contain more than one processor, including multicore systems. The advantage that multicore environments offer is the prospect of significantly increased program performance. The Fork/Join Framework addressed parallel programming by

- Simplifying the creation and use of tasks that can execute concurrently
- Automatically making use of multiple processors

Therefore, by using the Fork/Join Framework, you can easily create scaleable applications that automatically take advantage of the processors available in the execution environment. Of course, not all algorithms lend themselves to parallelization, but for those that do, a significant improvement in execution speed can be obtained.

Java SE 8

The newest release of Java is Java SE 8, with the developer’s kit being called JDK 8. It has an internal version number of 1.8. JDK 8 represents a very significant upgrade to the Java language because of the inclusion of a far-reaching new language feature: the lambda expression. The impact of lambda expressions will be profound, changing both the way that programming solutions are conceptualized and how Java code is written. As explained in detail in Chapter 15, lambda expressions add functional programming features to Java. In the process, lambda expressions can simplify and reduce the amount of source code needed to create certain constructs, such as some types of anonymous classes. The addition of lambda expressions also causes a new operator (the –>) and a new syntax element to be added to the language. Lambda expressions help ensure that Java will remain the vibrant, nimble language that users have come to expect.

The inclusion of lambda expressions has also had a wide-ranging effect on the Java libraries, with new features being added to take advantage of them. One of the most important is the new stream API, which is packaged in java.util.stream. The stream API supports pipeline operations on data and is optimized for lambda expressions. Another very important new package is java.util.function. It defines a number of functional interfaces, which provide additional support for lambda expressions. Other new lambda-related features are found throughout the API library.
Another lambda-inspired feature affects **interface**. Beginning with JDK 8, it is now possible to define a default implementation for a method specified by an interface. If no implementation for a default method is created, then the default defined by the interface is used. This feature enables interfaces to be gracefully evolved over time because a new method can be added to an interface without breaking existing code. It can also streamline the implementation of an interface when the defaults are appropriate. Other new features in JDK 8 include a new time and date API, type annotations, and the ability to use parallel processing when sorting an array, among others. JDK 8 also bundles support for JavaFX 8, the latest version of Java’s new GUI application framework. JavaFX is expected to soon play an important part in nearly all Java applications, ultimately replacing Swing for most GUI-based projects. Part IV of this book provides an introduction to it.

In the final analysis, Java SE 8 is a major release that profoundly expands the capabilities of the language and changes the way that Java code is written. Its effects will be felt throughout the Java universe and for years to come. It truly is that important of a upgrade. The material in this book has been updated to reflect Java SE 8, with many new features, updates, and additions indicated throughout.

**A Culture of Innovation**

Since the beginning, Java has been at the center of a culture of innovation. Its original release redefined programming for the Internet. The Java Virtual Machine (JVM) and bytecode changed the way we think about security and portability. The applet (and then the servlet) made the Web come alive. The Java Community Process (JCP) redefined the way that new ideas are assimilated into the language. The world of Java has never stood still for very long. Java SE 8 is the latest release in Java’s ongoing, dynamic history.
As in all other computer languages, the elements of Java do not exist in isolation. Rather, they work together to form the language as a whole. However, this interrelatedness can make it difficult to describe one aspect of Java without involving several others. Often a discussion of one feature implies prior knowledge of another. For this reason, this chapter presents a quick overview of several key features of Java. The material described here will give you a foothold that will allow you to write and understand simple programs. Most of the topics discussed will be examined in greater detail in the remaining chapters of Part I.

Object-Oriented Programming
Object-oriented programming (OOP) is at the core of Java. In fact, all Java programs are to at least some extent object-oriented. OOP is so integral to Java that it is best to understand its basic principles before you begin writing even simple Java programs. Therefore, this chapter begins with a discussion of the theoretical aspects of OOP.

Two Paradigms
All computer programs consist of two elements: code and data. Furthermore, a program can be conceptually organized around its code or around its data. That is, some programs are written around “what is happening” and others are written around “who is being affected.” These are the two paradigms that govern how a program is constructed. The first way is called the process-oriented model. This approach characterizes a program as a series of linear steps (that is, code). The process-oriented model can be thought of as code acting on data. Procedural languages such as C employ this model to considerable success. However, as mentioned in Chapter 1, problems with this approach appear as programs grow larger and more complex.

To manage increasing complexity, the second approach, called object-oriented programming, was conceived. Object-oriented programming organizes a program around its data (that is, objects) and a set of well-defined interfaces to that data. An object-oriented program can be characterized as data controlling access to code. As you will see, by switching the controlling entity to data, you can achieve several organizational benefits.

Abstraction
An essential element of object-oriented programming is abstraction. Humans manage
complexity through abstraction. For example, people do not think of a car as a set of tens of thousands of individual parts. They think of it as a well-defined object with its own unique behavior. This abstraction allows people to use a car to drive to the grocery store without being overwhelmed by the complexity of the parts that form the car. They can ignore the details of how the engine, transmission, and braking systems work. Instead, they are free to utilize the object as a whole.

A powerful way to manage abstraction is through the use of hierarchical classifications. This allows you to layer the semantics of complex systems, breaking them into more manageable pieces. From the outside, the car is a single object. Once inside, you see that the car consists of several subsystems: steering, brakes, sound system, seat belts, heating, cellular phone, and so on. In turn, each of these subsystems is made up of more specialized units. For instance, the sound system consists of a radio, a CD player, and/or a tape or MP3 player. The point is that you manage the complexity of the car (or any other complex system) through the use of hierarchical abstractions.

Hierarchical abstractions of complex systems can also be applied to computer programs. The data from a traditional process-oriented program can be transformed by abstraction into its component objects. A sequence of process steps can become a collection of messages between these objects. Thus, each of these objects describes its own unique behavior. You can treat these objects as concrete entities that respond to messages telling them to do something. This is the essence of object-oriented programming.

Object-oriented concepts form the heart of Java just as they form the basis for human understanding. It is important that you understand how these concepts translate into programs. As you will see, object-oriented programming is a powerful and natural paradigm for creating programs that survive the inevitable changes accompanying the life cycle of any major software project, including conception, growth, and aging. For example, once you have well-defined objects and clean, reliable interfaces to those objects, you can gracefully decommission or replace parts of an older system without fear.

**The Three OOP Principles**

All object-oriented programming languages provide mechanisms that help you implement the object-oriented model. They are encapsulation, inheritance, and polymorphism. Let’s take a look at these concepts now.

**Encapsulation**

*Encapsulation* is the mechanism that binds together code and the data it manipulates, and keeps both safe from outside interference and misuse. One way to think about encapsulation is as a protective wrapper that prevents the code and data from being arbitrarily accessed by other code defined outside the wrapper. Access to the code and data inside the wrapper is tightly controlled through a well-defined interface. To relate this to the real world, consider the automatic transmission on an automobile. It encapsulates hundreds of bits of information about your engine, such as how much you are accelerating, the pitch of the
surface you are on, and the position of the shift lever. You, as the user, have only one
method of affecting this complex encapsulation: by moving the gear-shift lever. You can’t
affect the transmission by using the turn signal or windshield wipers, for example. Thus, the
gear-shift lever is a well-defined (indeed, unique) interface to the transmission. Further,
what occurs inside the transmission does not affect objects outside the transmission. For
example, shifting gears does not turn on the headlights! Because an automatic transmission
is encapsulated, dozens of car manufacturers can implement one in any way they please.
However, from the driver’s point of view, they all work the same. This same idea can be
applied to programming. The power of encapsulated code is that everyone knows how to
access it and thus can use it regardless of the implementation details—and without fear of
unexpected side effects.
In Java, the basis of encapsulation is the class. Although the class will be examined in great
detail later in this book, the following brief discussion will be helpful now. A class defines
the structure and behavior (data and code) that will be shared by a set of objects. Each
object of a given class contains the structure and behavior defined by the class, as if it were
stamped out by a mold in the shape of the class. For this reason, objects are sometimes
referred to as instances of a class. Thus, a class is a logical construct; an object has physical
reality.
When you create a class, you will specify the code and data that constitute that class.
Collectively, these elements are called members of the class. Specifically, the data defined by
the class are referred to as member variables or instance variables. The code that operates
on that data is referred to as member methods or just methods. (If you are familiar with
C/C++, it may help to know that what a Java programmer calls a method, a C/C++
programmer calls a function.) In properly written Java programs, the methods define how
the member variables can be used. This means that the behavior and interface of a class are
defined by the methods that operate on its instance data.
Since the purpose of a class is to encapsulate complexity, there are mechanisms for hiding
the complexity of the implementation inside the class. Each method or variable in a class
may be marked private or public. The public interface of a class represents everything that
external users of the class need to know, or may know. The private methods and data can
only be accessed by code that is a member of the class. Therefore, any other code that is not
a member of the class cannot access a private method or variable. Since the private
members of a class may only be accessed by other parts of your program through the class’
public methods, you can ensure that no improper actions take place. Of course, this means
that the public interface should be carefully designed not to expose too much of the inner
workings of a class (see Figure 2-1).
Inheritance

Inheritance is the process by which one object acquires the properties of another object. This is important because it supports the concept of hierarchical classification. As mentioned earlier, most knowledge is made manageable by hierarchical (that is, top-down) classifications. For example, a Golden Retriever is part of the classification dog, which in turn is part of the mammal class, which is under the larger class animal. Without the use of hierarchies, each object would need to define all of its characteristics explicitly. However, by use of inheritance, an object need only define those qualities that make it unique within its class. It can inherit its general attributes from its parent. Thus, it is the inheritance mechanism that makes it possible for one object to be a specific instance of a more general case. Let’s take a closer look at this process.

Most people naturally view the world as made up of objects that are related to each other in a hierarchical way, such as animals, mammals, and dogs. If you wanted to describe animals in an abstract way, you would say they have some attributes, such as size, intelligence, and type of skeletal system. Animals also have certain behavioral aspects; they eat, breathe, and sleep. This description of attributes and behavior is the class definition for animals.

If you wanted to describe a more specific class of animals, such as mammals, they would have more specific attributes, such as type of teeth and mammary glands. This is known as a subclass of animals, where animals are referred to as mammals’ superclass.
Since mammals are simply more precisely specified animals, they *inherit* all of the attributes from animals. A deeply inherited subclass inherits all of the attributes from each of its ancestors in the *class hierarchy*.

Inheritance interacts with encapsulation as well. If a given class encapsulates some attributes, then any subclass will have the same attributes plus any that it adds as part of its specialization (see Figure 2-2). This is a key concept that lets object-oriented programs grow in complexity linearly rather than geometrically. A new subclass inherits all of the attributes of all of its ancestors. It does not have unpredictable interactions with the majority of the rest of the code in the system.
Polymorphism

*Polymorphism* (from Greek, meaning “many forms”) is a feature that allows one interface to be used for a general class of actions. The specific action is determined by the exact nature of the situation. Consider a stack (which is a last-in, first-out list). You might have a program that requires three types of stacks. One stack is used for integer values, one for
floating-point values, and one for characters. The algorithm that implements each stack is the same, even though the data being stored differs. In a non–object-oriented language, you would be required to create three different sets of stack routines, with each set using different names. However, because of polymorphism, in Java you can specify a general set of stack routines that all share the same names.

More generally, the concept of polymorphism is often expressed by the phrase “one interface, multiple methods.” This means that it is possible to design a generic interface to a group of related activities. This helps reduce complexity by allowing the same interface to be used to specify a **general class of action**. It is the compiler’s job to select the **specific action** (that is, method) as it applies to each situation. You, the programmer, do not need to make this selection manually. You need only remember and utilize the general interface.

Extending the dog analogy, a dog’s sense of smell is polymorphic. If the dog smells a cat, it will bark and run after it. If the dog smells its food, it will salivate and run to its bowl. The same sense of smell is at work in both situations. The difference is what is being smelled, that is, the type of data being operated upon by the dog’s nose! This same general concept can be implemented in Java as it applies to methods within a Java program.

### Polymorphism, Encapsulation, and Inheritance Work Together

When properly applied, polymorphism, encapsulation, and inheritance combine to produce a programming environment that supports the development of far more robust and scaleable programs than does the process-oriented model. A well-designed hierarchy of classes is the basis for reusing the code in which you have invested time and effort developing and testing. Encapsulation allows you to migrate your implementations over time without breaking the code that depends on the public interface of your classes. Polymorphism allows you to create clean, sensible, readable, and resilient code.

Of the two real-world examples, the automobile more completely illustrates the power of object-oriented design. Dogs are fun to think about from an inheritance standpoint, but cars are more like programs. All drivers rely on inheritance to drive different types (subclasses) of vehicles. Whether the vehicle is a school bus, a Mercedes sedan, a Porsche, or the family minivan, drivers can all more or less find and operate the steering wheel, the brakes, and the accelerator. After a bit of gear grinding, most people can even manage the difference between a stick shift and an automatic, because they fundamentally understand their common superclass, the transmission.

People interface with encapsulated features on cars all the time. The brake and gas pedals hide an incredible array of complexity with an interface so simple you can operate them with your feet! The implementation of the engine, the style of brakes, and the size of the tires have no effect on how you interface with the class definition of the pedals. The final attribute, polymorphism, is clearly reflected in the ability of car manufacturers to offer a wide array of options on basically the same vehicle. For example, you can get an antilock braking system or traditional brakes, power or rack-and-pinion steering, and 4-, 6-, or 8-cylinder engines. Either way, you will still press the brake pedal to stop, turn the
steering wheel to change direction, and press the accelerator when you want to move. The same interface can be used to control a number of different implementations.

As you can see, it is through the application of encapsulation, inheritance, and polymorphism that the individual parts are transformed into the object known as a car. The same is also true of computer programs. By the application of object-oriented principles, the various parts of a complex program can be brought together to form a cohesive, robust, maintainable whole.

As mentioned at the start of this section, every Java program is object-oriented. Or, put more precisely, every Java program involves encapsulation, inheritance, and polymorphism. Although the short example programs shown in the rest of this chapter and in the next few chapters may not seem to exhibit all of these features, they are nevertheless present. As you will see, many of the features supplied by Java are part of its built-in class libraries, which do make extensive use of encapsulation, inheritance, and polymorphism.

A First Simple Program

Now that the basic object-oriented underpinning of Java has been discussed, let's look at some actual Java programs. Let's start by compiling and running the short sample program shown here. As you will see, this involves a little more work than you might imagine.

```java
/*
 * This is a simple Java program.
 * Call this file "Example.java".
 */

class Example {
    // Your program begins with a call to main().
    public static void main(String args[]) {
        System.out.println("This is a simple Java program.");
    }
}
```

NOTE   The descriptions that follow use the standard Java SE 8 Development Kit (JDK 8), which is available from Oracle. If you are using an integrated development environment (IDE), then you will need to follow a different procedure for compiling and executing Java programs. In this case, consult your IDE's documentation for details.
For most computer languages, the name of the file that holds the source code to a program is immaterial. However, this is not the case with Java. The first thing that you must learn about Java is that the name you give to a source file is very important. For this example, the name of the source file should be `Example.java`. Let’s see why.

In Java, a source file is officially called a `compilation unit`. It is a text file that contains (among other things) one or more class definitions. (For now, we will be using source files that contain only one class.) The Java compiler requires that a source file use the `.java` filename extension.

As you can see by looking at the program, the name of the class defined by the program is also `Example`. This is not a coincidence. In Java, all code must reside inside a class. By convention, the name of the main class should match the name of the file that holds the program. You should also make sure that the capitalization of the filename matches the class name. The reason for this is that Java is case-sensitive. At this point, the convention that filenames correspond to class names may seem arbitrary. However, this convention makes it easier to maintain and organize your programs.

### Compiling the Program

To compile the `Example` program, execute the compiler, `javac`, specifying the name of the source file on the command line, as shown here:

```
C:\>javac Example.java
```

The `javac` compiler creates a file called `Example.class` that contains the bytecode version of the program. As discussed earlier, the Java bytecode is the intermediate representation of your program that contains instructions the Java Virtual Machine will execute. Thus, the output of `javac` is not code that can be directly executed.

To actually run the program, you must use the Java application launcher called `java`. To do so, pass the class name `Example` as a command-line argument, as shown here:

```
C:\>java Example
```

When the program is run, the following output is displayed:

```
This is a simple Java program
```

When Java source code is compiled, each individual class is put into its own output file named after the class and using the `.class` extension. This is why it is a good idea to give your Java source files the same name as the class they contain—the name of the source file will match the name of the `.class` file. When you execute `java` as just shown, you are actually specifying the name of the class that you want to execute. It will automatically search for a file by that name that has the `.class` extension. If it finds the file, it will execute the code contained in the specified class.
A Closer Look at the First Sample Program

Although Example.java is quite short, it includes several key features that are common to all Java programs. Let’s closely examine each part of the program.

The program begins with the following lines:

```java
/*
   This is a simple Java program.
   Call this file "Example.java".
*/
```

This is a comment. Like most other programming languages, Java lets you enter a remark into a program’s source file. The contents of a comment are ignored by the compiler. Instead, a comment describes or explains the operation of the program to anyone who is reading its source code. In this case, the comment describes the program and reminds you that the source file should be called Example.java. Of course, in real applications, comments generally explain how some part of the program works or what a specific feature does.

Java supports three styles of comments. The one shown at the top of the program is called a multiline comment. This type of comment must begin with /* and end with */. Anything between these two comment symbols is ignored by the compiler. As the name suggests, a multiline comment may be several lines long.

The next line of code in the program is shown here:

```java
class Example {
```

This line uses the keyword class to declare that a new class is being defined. Example is an identifier that is the name of the class. The entire class definition, including all of its members, will be between the opening curly brace ({) and the closing curly brace (}). For the moment, don’t worry too much about the details of a class except to note that in Java, all program activity occurs within one. This is one reason why all Java programs are (at least a little bit) object-oriented.

The next line of code in the program is the single-line comment, shown here:

```java
// Your program begins with a call to main().
```

This is the second type of comment supported by Java. A single-line comment begins with a // and ends at the end of the line. As a general rule, programmers use multiline comments for longer remarks and single-line comments for brief, line-by-line descriptions. The third type of comment, a documentation comment, will be discussed in the “Comments” section later in this chapter.

The next line of code is shown here:
public static void main(String args[]) {

This line begins the main() method. As the comment preceding it suggests, this is the line at which the program will begin executing. All Java applications begin execution by calling main(). The full meaning of each part of this line cannot be given now, since it involves a detailed understanding of Java’s approach to encapsulation. However, since most of the examples in the first part of this book will use this line of code, let’s take a brief look at each part now.

The public keyword is an access modifier, which allows the programmer to control the visibility of class members. When a class member is preceded by public, then that member may be accessed by code outside the class in which it is declared. (The opposite of public is private, which prevents a member from being used by code defined outside of its class.) In this case, main() must be declared as public, since it must be called by code outside of its class when the program is started. The keyword static allows main() to be called without having to instantiate a particular instance of the class. This is necessary since main() is called by the Java Virtual Machine before any objects are made. The keyword void simply tells the compiler that main() does not return a value. As you will see, methods may also return values. If all this seems a bit confusing, don’t worry. All of these concepts will be discussed in detail in subsequent chapters.

As stated, main() is the method called when a Java application begins. Keep in mind that Java is case-sensitive. Thus, Main is different from main. It is important to understand that the Java compiler will compile classes that do not contain a main() method. But java has no way to run these classes. So, if you had typed Main instead of main, the compiler would still compile your program. However, java would report an error because it would be unable to find the main() method.

Any information that you need to pass to a method is received by variables specified within the set of parentheses that follow the name of the method. These variables are called parameters. If there are no parameters required for a given method, you still need to include the empty parentheses. In main(), there is only one parameter, albeit a complicated one. String args[] declares a parameter named args, which is an array of instances of the class String. (Arrays are collections of similar objects.) Objects of type String store character strings. In this case, args receives any command-line arguments present when the program is executed. This program does not make use of this information, but other programs shown later in this book will.

The last character on the line is the {. This signals the start of main()’s body. All of the code that comprises a method will occur between the method’s opening curly brace and its closing curly brace.

One other point: main() is simply a starting place for your program. A complex program will have dozens of classes, only one of which will need to have a main() method to get things started. Furthermore, in some cases, you won’t need main() at all. For example,
when creating applets—Java programs that are embedded in web browsers—you won’t use `main()` since the web browser uses a different means of starting the execution of applets. The next line of code is shown here. Notice that it occurs inside `main()`.

```
System.out.println("This is a simple Java program.");
```

This line outputs the string "This is a simple Java program." followed by a new line on the screen. Output is actually accomplished by the built-in `println()` method. In this case, `println()` displays the string which is passed to it. As you will see, `println()` can be used to display other types of information, too. The line begins with `System.out`. While too complicated to explain in detail at this time, briefly, `System` is a predefined class that provides access to the system, and `out` is the output stream that is connected to the console. As you have probably guessed, console output (and input) is not used frequently in most real-world Java applications. Since most modern computing environments are windowed and graphical in nature, console I/O is used mostly for simple utility programs, demonstration programs, and server-side code. Later in this book, you will learn other ways to generate output using Java. But for now, we will continue to use the console I/O methods.

Notice that the `println()` statement ends with a semicolon. All statements in Java end with a semicolon. The reason that the other lines in the program do not end in a semicolon is that they are not, technically, statements.

The first `}` in the program ends `main()`, and the last `}` ends the `Example` class definition.

**A Second Short Program**

Perhaps no other concept is more fundamental to a programming language than that of a variable. As you may know, a variable is a named memory location that may be assigned a value by your program. The value of a variable may be changed during the execution of the program. The next program shows how a variable is declared and how it is assigned a value. The program also illustrates some new aspects of console output. As the comments at the top of the program state, you should call this file `Example2.java`. 
When you run this program, you will see the following output:

```
This is num: 100
The value of num * 2 is 200
```

Let's take a close look at why this output is generated. The first new line in the program is shown here:

```
int num; // this declares a variable called num
```

This line declares an integer variable called `num`. Java (like most other languages) requires that variables be declared before they are used. Following is the general form of a variable declaration:

```
type var-name;
```

Here, `type` specifies the type of variable being declared, and `var-name` is the name of the variable. If you want to declare more than one variable of the specified type, you may use a comma-separated list of variable names. Java defines several data types, including integer, character, and floating-point. The keyword `int` specifies an integer type.

In the program, the line

```
num = 100; // this assigns num the value 100
```
assigns to `num` the value 100. In Java, the assignment operator is a single equal sign. The next line of code outputs the value of `num` preceded by the string "This is num:"

```
System.out.println("This is num: " + num);
```

In this statement, the plus sign causes the value of `num` to be appended to the string that precedes it, and then the resulting string is output. (Actually, `num` is first converted from an integer into its string equivalent and then concatenated with the string that precedes it. This process is described in detail later in this book.) This approach can be generalized. Using the `+` operator, you can join together as many items as you want within a single `println()` statement. The next line of code assigns `num` the value of `num` times 2. Like most other languages, Java uses the `*` operator to indicate multiplication. After this line executes, `num` will contain the value 200.

Here are the next two lines in the program:

```
System.out.print ("The value of num * 2 is ");
System.out.println (num);
```

Several new things are occurring here. First, the built-in method `print()` is used to display the string "The value of num * 2 is ". This string is not followed by a newline. This means that when the next output is generated, it will start on the same line. The `print()` method is just like `println()`, except that it does not output a newline character after each call. Now look at the call to `println()`. Notice that `num` is used by itself. Both `print()` and `println()` can be used to output values of any of Java's built-in types.

### Two Control Statements

Although Chapter 5 will look closely at control statements, two are briefly introduced here so that they can be used in example programs in Chapters 3 and 4. They will also help illustrate an important aspect of Java: blocks of code.

#### The if Statement

The Java `if` statement works much like the IF statement in any other language. Further, it is syntactically identical to the `if` statements in C, C++, and C#. Its simplest form is shown here:

```
if(condition) statement;
```

Here, `condition` is a Boolean expression. If `condition` is true, then the statement is executed. If `condition` is false, then the statement is bypassed. Here is an example:

```
if(num < 100) System.out.println("num is less than 100");
```
In this case, if `num` contains a value that is less than 100, the conditional expression is true, and `println()` will execute. If `num` contains a value greater than or equal to 100, then the `println()` method is bypassed.

As you will see in Chapter 4, Java defines a full complement of relational operators which may be used in a conditional expression. Here are a few:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;</code></td>
<td>Less than</td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td>Greater than</td>
</tr>
<tr>
<td><code>==</code></td>
<td>Equal to</td>
</tr>
</tbody>
</table>

Notice that the test for equality is the double equal sign.

Here is a program that illustrates the `if` statement:

```java
/*
   Demonstrate the if.

   Call this file "IfSample.java".
*/
class IfSample {
    public static void main(String args []) {
        int x, y;
        x = 10;
        y = 20;

        if(x < y) System.out.println("x is less than y");
        x = x * 2;
        if(x == y) System.out.println("x now equal to y");
        x = x * 2;
        if(x > y) System.out.println("x now greater than y");

        // this won't display anything
        if(x == y) System.out.println("you won't see this");
    }
}
```

The output generated by this program is shown here:
Notice one other thing in this program. The line

```
    int x, y;
```

declares two variables, \( x \) and \( y \), by use of a comma-separated list.

**The for Loop**

As you may know from your previous programming experience, loop statements are an important part of nearly any programming language. Java is no exception. In fact, as you will see in Chapter 5, Java supplies a powerful assortment of loop constructs. Perhaps the most versatile is the **for** loop. The simplest form of the **for** loop is shown here:

```
    for(initialization; condition; iteration) statement;
```

In its most common form, the *initialization* portion of the loop sets a loop control variable to an initial value. The *condition* is a Boolean expression that tests the loop control variable. If the outcome of that test is true, the **for** loop continues to iterate. If it is false, the loop terminates. The *iteration* expression determines how the loop control variable is changed each time the loop iterates. Here is a short program that illustrates the **for** loop:

```java
/*
   Demonstrate the for loop.

   Call this file "ForTest.java".
*/
class ForTest {
    public static void main(String args[]) {
        int x;

        for(x = 0; x<10; x = x+1)
            System.out.println("This is x: " + x);
    }
}
```

This program generates the following output:
In this example, \( x \) is the loop control variable. It is initialized to zero in the initialization portion of the \texttt{for}. At the start of each iteration (including the first one), the conditional test \( x < 10 \) is performed. If the outcome of this test is true, the \texttt{println()} statement is executed, and then the iteration portion of the loop is executed, which increases \( x \) by 1. This process continues until the conditional test is false.

As a point of interest, in professionally written Java programs you will almost never see the iteration portion of the loop written as shown in the preceding program. That is, you will seldom see statements like this:

\[
x = x + 1;
\]

The reason is that Java includes a special increment operator which performs this operation more efficiently. The increment operator is \texttt{++}. (That is, two plus signs back to back.) The increment operator increases its operand by one. By use of the increment operator, the preceding statement can be written like this:

\[
x++;
\]

Thus, the \texttt{for} in the preceding program will usually be written like this:

\[
\texttt{for}(x = 0; \ x < 10; \ x++)
\]

You might want to try this. As you will see, the loop still runs exactly the same as it did before.

Java also provides a decrement operator, which is specified as \texttt{--}. This operator decreases its operand by one.

\textbf{Using Blocks of Code}

Java allows two or more statements to be grouped into \textit{blocks of code}, also called \textit{code blocks}. This is done by enclosing the statements between opening and closing curly braces. Once a block of code has been created, it becomes a logical unit that can be used any place
that a single statement can. For example, a block can be a target for Java’s **if** and **for** statements. Consider this **if** statement:

```java
if(x < y) { // begin a block
    x = y;
    y = 0;
} // end of block
```

Here, if \( x \) is less than \( y \), then both statements inside the block will be executed. Thus, the two statements inside the block form a logical unit, and one statement cannot execute without the other also executing. The key point here is that whenever you need to logically link two or more statements, you do so by creating a block.

Let’s look at another example. The following program uses a block of code as the target of a **for** loop.

```java
/*
 * Demonstrate a block of code.

 Call this file "BlockTest.java"
 */
class BlockTest {
    public static void main(String args[]) {
        int x, y;

        y = 20;

        // the target of this loop is a block
        for(x = 0; x<10; x++) {
            System.out.println("This is x: ", + x);
            System.out.println("This is y: ", + y);
            y = y - 2;
        }
    }
}
```

The output generated by this program is shown here:
In this case, the target of the for loop is a block of code and not just a single statement. Thus, each time the loop iterates, the three statements inside the block will be executed. This fact is, of course, evidenced by the output generated by the program. As you will see later in this book, blocks of code have additional properties and uses. However, the main reason for their existence is to create logically inseparable units of code.

**Lexical Issues**

Now that you have seen several short Java programs, it is time to more formally describe the atomic elements of Java. Java programs are a collection of whitespace, identifiers, literals, comments, operators, separators, and keywords. The operators are described in the next chapter. The others are described next.

**Whitespace**

Java is a free-form language. This means that you do not need to follow any special indentation rules. For instance, the Example program could have been written all on one line or in any other strange way you felt like typing it, as long as there was at least one whitespace character between each token that was not already delineated by an operator or separator. In Java, whitespace is a space, tab, or newline.

**Identifiers**

Identifiers are used to name things, such as classes, variables, and methods. An identifier may be any descriptive sequence of uppercase and lowercase letters, numbers, or the underscore and dollar-sign characters. (The dollar-sign character is not intended for general
use.) They must not begin with a number, lest they be confused with a numeric literal. Again, Java is case-sensitive, so **VALUE** is a different identifier than **Value**. Some examples of valid identifiers are

| AvgTemp | count | a1 | $test | this_is_ok |

Invalid identifier names include these:

| 2count | high-temp | Not/ok |

**NOTE** Beginning with JDK 8, the use of an underscore by itself as an identifier is not recommended.

**Literals**

A constant value in Java is created by using a literal representation of it. For example, here are some literals:

| 100 | 98.6 | ‘X’ | “This is a test” |

Left to right, the first literal specifies an integer, the next is a floating-point value, the third is a character constant, and the last is a string. A literal can be used anywhere a value of its type is allowed.

**Comments**

As mentioned, there are three types of comments defined by Java. You have already seen two: single-line and multiline. The third type is called a *documentation comment*. This type of comment is used to produce an HTML file that documents your program. The documentation comment begins with a `/**` and ends with a `*/`. Documentation comments are explained in the Appendix.

**Separators**

In Java, there are a few characters that are used as separators. The most commonly used separator in Java is the semicolon. As you have seen, it is used to terminate statements. The separators are shown in the following table:
The Java Keywords

There are 50 keywords currently defined in the Java language (see Table 2-1). These keywords, combined with the syntax of the operators and separators, form the foundation of the Java language. These keywords cannot be used as identifiers. Thus, they cannot be used as names for a variable, class, or method.

### Table 2-1 Java Keywords

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>(</td>
<td>Parentheses</td>
<td>Used to contain lists of parameters in method definition and invocation. Also used for defining precedence in expressions, containing expressions in control statements, and surrounding cast types.</td>
</tr>
<tr>
<td>[</td>
<td>Braces</td>
<td>Used to contain the values of automatically initialized arrays. Also used to define a block of code, for classes, methods, and local scopes.</td>
</tr>
<tr>
<td>[ ]</td>
<td>Brackets</td>
<td>Used to declare array types. Also used when dereferencing array values.</td>
</tr>
<tr>
<td>;</td>
<td>Semicolon</td>
<td>Terminates statements.</td>
</tr>
<tr>
<td>.</td>
<td>Colon</td>
<td>Separates consecutive identifiers in a variable declaration. Also used to chain statements together inside a for statement.</td>
</tr>
<tr>
<td>.</td>
<td>Period</td>
<td>Used to separate package names from subpackages and classes. Also used to separate a variable or method from a reference variable.</td>
</tr>
<tr>
<td>::</td>
<td>Colon</td>
<td>Used to create a method or constructor reference. (Added by JDK 5.)</td>
</tr>
<tr>
<td>true</td>
<td></td>
<td></td>
</tr>
<tr>
<td>false</td>
<td></td>
<td></td>
</tr>
<tr>
<td>null</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The keywords `const` and `goto` are reserved but not used. In the early days of Java, several other keywords were reserved for possible future use. However, the current specification for Java defines only the keywords shown in Table 2-1.

In addition to the keywords, Java reserves the following: `true`, `false`, and `null`. These are values defined by Java. You may not use these words for the names of variables, classes, and so on.

The Java Class Libraries
The sample programs shown in this chapter make use of two of Java’s built-in methods: `println()` and `print()`. As mentioned, these methods are available through `System.out`. `System` is a class predefined by Java that is automatically included in your programs. In the larger view, the Java environment relies on several built-in class libraries that contain many built-in methods that provide support for such things as I/O, string handling, networking, and graphics. The standard classes also provide support for a graphical user interface (GUI). Thus, Java as a totality is a combination of the Java language itself, plus its standard classes. As you will see, the class libraries provide much of the functionality that comes with Java. Indeed, part of becoming a Java programmer is learning to use the standard Java classes. Throughout Part I of this book, various elements of the standard library classes and methods are described as needed. In Part II, several class libraries are described in detail.
This chapter examines three of Java’s most fundamental elements: data types, variables, and arrays. As with all modern programming languages, Java supports several types of data. You may use these types to declare variables and to create arrays. As you will see, Java’s approach to these items is clean, efficient, and cohesive.

**Java Is a Strongly Typed Language**
It is important to state at the outset that Java is a strongly typed language. Indeed, part of Java’s safety and robustness comes from this fact. Let’s see what this means. First, every variable has a type, every expression has a type, and every type is strictly defined. Second, all assignments, whether explicit or via parameter passing in method calls, are checked for type compatibility. There are no automatic coercions or conversions of conflicting types as in some languages. The Java compiler checks all expressions and parameters to ensure that the types are compatible. Any type mismatches are errors that must be corrected before the compiler will finish compiling the class.

**The Primitive Types**
Java defines eight *primitive* types of data: byte, short, int, long, char, float, double, and boolean. The primitive types are also commonly referred to as *simple* types, and both terms will be used in this book. These can be put in four groups:

- **Integers** This group includes byte, short, int, and long, which are for whole-valued signed numbers.
- **Floating-point numbers** This group includes float and double, which represent numbers with fractional precision.
- **Characters** This group includes char, which represents symbols in a character set, like letters and numbers.
- **Boolean** This group includes boolean, which is a special type for representing true/false values.

You can use these types as-is, or to construct arrays or your own class types. Thus,
they form the basis for all other types of data that you can create. The primitive types represent single values—not complex objects. Although Java is otherwise completely object-oriented, the primitive types are not. They are analogous to the simple types found in most other non–object-oriented languages. The reason for this is efficiency. Making the primitive types into objects would have degraded performance too much.

The primitive types are defined to have an explicit range and mathematical behavior. Languages such as C and C++ allow the size of an integer to vary based upon the dictates of the execution environment. However, Java is different. Because of Java’s portability requirement, all data types have a strictly defined range. For example, an `int` is always 32 bits, regardless of the particular platform. This allows programs to be written that are guaranteed to run without porting on any machine architecture. While strictly specifying the size of an integer may cause a small loss of performance in some environments, it is necessary in order to achieve portability.

Let’s look at each type of data in turn.

### Integers
Java defines four integer types: `byte`, `short`, `int`, and `long`. All of these are signed, positive and negative values. Java does not support unsigned, positive-only integers. Many other computer languages support both signed and unsigned integers. However, Java’s designers felt that unsigned integers were unnecessary. Specifically, they felt that the concept of `unsigned` was used mostly to specify the behavior of the high-order bit, which defines the sign of an integer value. As you will see in Chapter 4, Java manages the meaning of the high-order bit differently, by adding a special “unsigned right shift” operator. Thus, the need for an unsigned integer type was eliminated.

The **width** of an integer type should not be thought of as the amount of storage it consumes, but rather as the **behavior** it defines for variables and expressions of that type. The Java run-time environment is free to use whatever size it wants, as long as the types behave as you declared them. The width and ranges of these integer types vary widely, as shown in this table:

<table>
<thead>
<tr>
<th>Name</th>
<th>Width</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>long</td>
<td>64</td>
<td>–9,223,372,036,854,775,808 to 9,223,372,036,854,775,807</td>
</tr>
<tr>
<td>int</td>
<td>32</td>
<td>–2,147,483,648 to 2,147,483,647</td>
</tr>
<tr>
<td>short</td>
<td>16</td>
<td>–32,768 to 32,767</td>
</tr>
<tr>
<td>byte</td>
<td>8</td>
<td>–128 to 127</td>
</tr>
</tbody>
</table>

Let’s look at each type of integer.

**byte**
The smallest integer type is **byte**. This is a signed 8-bit type that has a range from \(-128\) to \(+127\).
127. Variables of type `byte` are especially useful when you’re working with a stream of data from a network or file. They are also useful when you’re working with raw binary data that may not be directly compatible with Java’s other built-in types. Byte variables are declared by use of the `byte` keyword. For example, the following declares two `byte` variables called `b` and `c`:

```java
byte b, c;
```

`short`

`short` is a signed 16-bit type. It has a range from –32,768 to 32,767. It is probably the least-used Java type. Here are some examples of `short` variable declarations:

```java
short s;
short t;
```

`int`

The most commonly used integer type is `int`. It is a signed 32-bit type that has a range from –2,147,483,648 to 2,147,483,647. In addition to other uses, variables of type `int` are commonly employed to control loops and to index arrays. Although you might think that using a `byte` or `short` would be more efficient than using an `int` in situations in which the larger range of an `int` is not needed, this may not be the case. The reason is that when `byte` and `short` values are used in an expression, they are promoted to `int` when the expression is evaluated. (Type promotion is described later in this chapter.) Therefore, `int` is often the best choice when an integer is needed.

`long`

`long` is a signed 64-bit type and is useful for those occasions where an `int` type is not large enough to hold the desired value. The range of a `long` is quite large. This makes it useful when big, whole numbers are needed. For example, here is a program that computes the number of miles that light will travel in a specified number of days:
This program generates the following output:

In 1000 days light will travel about 16070400000000 miles.

Clearly, the result could not have been held in an `int` variable.

**Floating-Point Types**

Floating-point numbers, also known as *real* numbers, are used when evaluating expressions that require fractional precision. For example, calculations such as square root, or transcendentals such as sine and cosine, result in a value whose precision requires a floating-point type. Java implements the standard (IEEE–754) set of floating-point types and operators. There are two kinds of floating-point types, `float` and `double`, which represent single- and double-precision numbers, respectively. Their width and ranges are shown here:

<table>
<thead>
<tr>
<th>Name</th>
<th>Width in Bits</th>
<th>Approximate Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>double</td>
<td>64</td>
<td>4.9e-324 to 1.8e+308</td>
</tr>
<tr>
<td>float</td>
<td>32</td>
<td>1.4e-045 to 3.4e+038</td>
</tr>
</tbody>
</table>

Each of these floating-point types is examined next.
**float**
The type `float` specifies a *single-precision* value that uses 32 bits of storage. Single precision is faster on some processors and takes half as much space as double precision, but will become imprecise when the values are either very large or very small. Variables of type `float` are useful when you need a fractional component, but don’t require a large degree of precision. For example, `float` can be useful when representing dollars and cents. Here are some example `float` variable declarations:

```java
float hightemp, lowtemp;
```

**double**
Double precision, as denoted by the `double` keyword, uses 64 bits to store a value. Double precision is actually faster than single precision on some modern processors that have been optimized for high-speed mathematical calculations. All transcendental math functions, such as `sin()`, `cos()`, and `sqrt()`, return `double` values. When you need to maintain accuracy over many iterative calculations, or are manipulating large-valued numbers, `double` is the best choice. Here is a short program that uses `double` variables to compute the area of a circle:

```java
// Compute the area of a circle.
class Area {
    public static void main(String args[]) {
        double pi, r, a;

        r = 10.8; // radius of circle
        pi = 3.1416; // pi, approximately
        a = pi * r * r; // compute area

        System.out.println("Area of circle is " + a);
    }
}
```

**Characters**
In Java, the data type used to store characters is `char`. However, C/C++ programmers beware: `char` in Java is not the same as `char` in C or C++. In C/C++, `char` is 8 bits wide. This is *not* the case in Java. Instead, Java uses *Unicode* to represent characters. Unicode defines a fully international character set that can represent all of the characters found in all human languages. It is a unification of dozens of character sets, such as Latin, Greek, Arabic, Cyrillic, Hebrew, Katakana, Hangul, and many more. At the time of Java’s creation, Unicode required 16 bits. Thus, in Java `char` is a 16-bit type. The range of a `char` is 0 to 65,536. There are no negative `chars`. The standard set of characters known as ASCII still
ranges from 0 to 127 as always, and the extended 8-bit character set, ISO-Latin-1, ranges from 0 to 255. Since Java is designed to allow programs to be written for worldwide use, it makes sense that it would use Unicode to represent characters. Of course, the use of Unicode is somewhat inefficient for languages such as English, German, Spanish, or French, whose characters can easily be contained within 8 bits. But such is the price that must be paid for global portability.

NOTE  More information about Unicode can be found at http://www.unicode.org.

Here is a program that demonstrates char variables:

```java
// Demonstrate char data type.
class CharDemo {
    public static void main(String args[]) {
        char ch1, ch2;

        ch1 = 88; // code for X
        ch2 = 'Y';

        System.out.print("ch1 and ch2: ");
        System.out.println(ch1 + " " + ch2);
    }
}
```

This program displays the following output:

```
ch1 and ch2: X Y
```

Notice that `ch1` is assigned the value 88, which is the ASCII (and Unicode) value that corresponds to the letter X. As mentioned, the ASCII character set occupies the first 127 values in the Unicode character set. For this reason, all the “old tricks” that you may have used with characters in other languages will work in Java, too.

Although `char` is designed to hold Unicode characters, it can also be used as an integer type on which you can perform arithmetic operations. For example, you can add two characters together, or increment the value of a character variable. Consider the following program:
// char variables behave like integers.
class CharDemo2 {
    public static void main(String args[]) {
        char ch1;
        // ch1 is first given the value X.
        ch1 = 'X';
        System.out.println("ch1 contains " + ch1);
        // ch1 is incremented.
        ch1++; // increment ch1
        System.out.println("ch1 is now " + ch1);
    }
}

In the program, ch1 is first given the value X. Next, ch1 is incremented. This results in ch1 containing Y, the next character in the ASCII (and Unicode) sequence.

NOTE In the formal specification for Java, char is referred to as an integral type, which means that it is in the same general category as int, short, long, and byte. However, because its principal use is for representing Unicode characters, char is commonly considered to be in a category of its own.

Booleans
Java has a primitive type, called boolean, for logical values. It can have only one of two possible values, true or false. This is the type returned by all relational operators, as in the case of a < b. boolean is also the type required by the conditional expressions that govern the control statements such as if and for.

Here is a program that demonstrates the boolean type:
The output generated by this program is shown here:

```
b is false
b is true
This is executed.
10 > 9 is true
```

There are three interesting things to notice about this program. First, as you can see, when a boolean value is output by `println()`, "true" or "false" is displayed. Second, the value of a boolean variable is sufficient, by itself, to control the `if` statement. There is no need to write an `if` statement like this:

```
if (b == true) ...
```

Third, the outcome of a relational operator, such as `<`, is a boolean value. This is why the expression `10 > 9` displays the value "true." Further, the extra set of parentheses around `10 > 9` is necessary because the + operator has a higher precedence than the >.

A Closer Look at Literals
Literals were mentioned briefly in Chapter 2. Now that the built-in types have been formally described, let’s take a closer look at them.

**Integer Literals**
Integers are probably the most commonly used type in the typical program. Any whole number value is an integer literal. Examples are 1, 2, 3, and 42. These are all decimal values, meaning they are describing a base 10 number. Two other bases that can be used in integer literals are octal (base eight) and hexadecimal (base 16). Octal values are denoted in Java by a leading zero. Normal decimal numbers cannot have a leading zero. Thus, the seemingly valid value 09 will produce an error from the compiler, since 9 is outside of octal's 0 to 7 range. A more common base for numbers used by programmers is hexadecimal, which matches cleanly with modulo 8 word sizes, such as 8, 16, 32, and 64 bits. You signify a hexadecimal constant with a leading zero-x, (0x or 0X). The range of a hexadecimal digit is 0 to 15, so A through F (or a through f) are substituted for 10 through 15.

Integer literals create an int value, which in Java is a 32-bit integer value. Since Java is strongly typed, you might be wondering how it is possible to assign an integer literal to one of Java's other integer types, such as byte or long, without causing a type mismatch error. Fortunately, such situations are easily handled. When a literal value is assigned to a byte or short variable, no error is generated if the literal value is within the range of the target type. An integer literal can always be assigned to a long variable. However, to specify a long literal, you will need to explicitly tell the compiler that the literal value is of type long. You do this by appending an upper- or lowercase L to the literal. For example, 0x7ffffffffffffffL or 9223372036854775807L is the largest long. An integer can also be assigned to a char as long as it is within range.

Beginning with JDK 7, you can also specify integer literals using binary. To do so, prefix the value with 0b or 0B. For example, this specifies the decimal value 10 using a binary literal:

```java
int x = 0b1010;
```

Among other uses, the addition of binary literals makes it easier to enter values used as bitmasks. In such a case, the decimal (or hexadecimal) representation of the value does not visually convey its meaning relative to its use. The binary literal does. Also beginning with JDK 7, you can embed one or more underscores in an integer literal. Doing so makes it easier to read large integer literals. When the literal is compiled, the underscores are discarded. For example, given

```java
int x = 123_456_789;
```

the value given to x will be 123,456,789. The underscores will be ignored. Underscores can only be used to separate digits. They cannot come at the beginning or the end of a literal. It is, however, permissible for more than one underscore to be used between two digits. For example, this is valid:

```java
int x = 123__456__789;
```

The use of underscores in an integer literal is especially useful when encoding such things as
telephone numbers, customer ID numbers, part numbers, and so on. They are also useful for providing visual groupings when specifying binary literals. For example, binary values are often visually grouped in four-digits units, as shown here:

```java
int x = 0b1101_0101_0001_1010;
```

### Floating-Point Literals

Floating-point numbers represent decimal values with a fractional component. They can be expressed in either standard or scientific notation. Standard notation consists of a whole number component followed by a decimal point followed by a fractional component. For example, 2.0, 3.14159, and 0.6667 represent valid standard-notation floating-point numbers. Scientific notation uses a standard-notation, floating-point number plus a suffix that specifies a power of 10 by which the number is to be multiplied. The exponent is indicated by an $E$ or $e$ followed by a decimal number, which can be positive or negative. Examples include $6.022E23$, $314159E–05$, and $2e+100$.

Floating-point literals in Java default to `double` precision. To specify a `float` literal, you must append an `F` or `f` to the constant. You can also explicitly specify a `double` literal by appending a `D` or `d`. Doing so is, of course, redundant. The default `double` type consumes 64 bits of storage, while the smaller `float` type requires only 32 bits.

Hexadecimal floating-point literals are also supported, but they are rarely used. They must be in a form similar to scientific notation, but a `P` or `p`, rather than an $E$ or $e$, is used. For example, `0x12.2P2` is a valid floating-point literal. The value following the `P`, called the binary exponent, indicates the power-of-two by which the number is multiplied. Therefore, `0x12.2P2` represents 72.5.

Beginning with JDK 7, you can embed one or more underscores in a floating-point literal. This feature works the same as it does for integer literals, which were just described. Its purpose is to make it easier to read large floating-point literals. When the literal is compiled, the underscores are discarded. For example, given

```java
double num = 9_423_497_862.0;
```

the value given to `num` will be 9,423,497,862.0. The underscores will be ignored. As is the case with integer literals, underscores can only be used to separate digits. They cannot come at the beginning or the end of a literal. It is, however, permissible for more than one underscore to be used between two digits. It is also permissible to use underscores in the fractional portion of the number. For example,

```java
double num = 9_423_497.1_0_9;
```

is legal. In this case, the fractional part is `.109`.

### Boolean Literals
Boolean literals are simple. There are only two logical values that a boolean value can have, true and false. The values of true and false do not convert into any numerical representation. The true literal in Java does not equal 1, nor does the false literal equal 0. In Java, the Boolean literals can only be assigned to variables declared as boolean or used in expressions with Boolean operators.

**Character Literals**

Characters in Java are indices into the Unicode character set. They are 16-bit values that can be converted into integers and manipulated with the integer operators, such as the addition and subtraction operators. A literal character is represented inside a pair of single quotes. All of the visible ASCII characters can be directly entered inside the quotes, such as 'a', 'z', and '@'. For characters that are impossible to enter directly, there are several escape sequences that allow you to enter the character you need, such as \' for the single-quote character itself and \n for the newline character. There is also a mechanism for directly entering the value of a character in octal or hexadecimal. For octal notation, use the backslash followed by the three-digit number. For example, \141 is the letter 'a'. For hexadecimal, you enter a backslash-u ( \u), then exactly four hexadecimal digits. For example, \u0061 is the ISO-Latin-1 'a' because the top byte is zero. \ua432 is a Japanese Katakana character. Table 3-1 shows the character escape sequences.

<table>
<thead>
<tr>
<th>Escape Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\ddd</td>
<td>Octal character (ddd)</td>
</tr>
<tr>
<td>\uxxxxx</td>
<td>Hexadecimal Unicode character (xxxx)</td>
</tr>
<tr>
<td>'</td>
<td>Single quote</td>
</tr>
<tr>
<td>&quot;</td>
<td>Double quote</td>
</tr>
<tr>
<td>\</td>
<td>Backslash</td>
</tr>
<tr>
<td>\r</td>
<td>Carriage return</td>
</tr>
<tr>
<td>\n</td>
<td>New line (also known as line feed)</td>
</tr>
<tr>
<td>\f</td>
<td>Form feed</td>
</tr>
<tr>
<td>\t</td>
<td>Tab</td>
</tr>
<tr>
<td>\b</td>
<td>Backspace</td>
</tr>
</tbody>
</table>

**Table 3-1  Character Escape Sequences**

**String Literals**

String literals in Java are specified like they are in most other languages—by enclosing a sequence of characters between a pair of double quotes. Examples of string literals are

"Hello World"
"two\nlines"
"\"This is in quotes\""
The escape sequences and octal/hexadecimal notations that were defined for character literals work the same way inside of string literals. One important thing to note about Java strings is that they must begin and end on the same line. There is no line-continuation escape sequence as there is in some other languages.

NOTE As you may know, in some other languages, including C/C++, strings are implemented as arrays of characters. However, this is not the case in Java. Strings are actually object types. As you will see later in this book, because Java implements strings as objects, Java includes extensive string-handling capabilities that are both powerful and easy to use.

Variables

The variable is the basic unit of storage in a Java program. A variable is defined by the combination of an identifier, a type, and an optional initializer. In addition, all variables have a scope, which defines their visibility, and a lifetime. These elements are examined next.

Declaring a Variable

In Java, all variables must be declared before they can be used. The basic form of a variable declaration is shown here:

```
    type identifier [= value][, identifier [= value] ...];
```

Here, `type` is one of Java’s atomic types, or the name of a class or interface. (Class and interface types are discussed later in Part I of this book.) The `identifier` is the name of the variable. You can initialize the variable by specifying an equal sign and a value. Keep in mind that the initialization expression must result in a value of the same (or compatible) type as that specified for the variable. To declare more than one variable of the specified type, use a comma-separated list.

Here are several examples of variable declarations of various types. Note that some include an initialization.

```
   int a, b, c;    // declares three ints, a, b, and c.
   int d = 3, e, f = 5;    // declares three more ints, initializing d and f.
   byte z = 22;    // initializes z.
   double pi = 3.14159;    // declares an approximation of pi.
   char x = 'X';    // the variable x has the value 'X'.
```
The identifiers that you choose have nothing intrinsic in their names that indicates their type. Java allows any properly formed identifier to have any declared type.

**Dynamic Initialization**
Although the preceding examples have used only constants as initializers, Java allows variables to be initialized dynamically, using any expression valid at the time the variable is declared.

For example, here is a short program that computes the length of the hypotenuse of a right triangle given the lengths of its two opposing sides:

```java
// Demonstrate dynamic initialization.
class dynInit {
    public static void main(String args[]) {
        double a = 3.0, b = 4.0;
        // c is dynamically initialized
        double c = Math.sqrt(a * a + b * b);
        System.out.println("Hypotenuse is " + c);
    }
}
```

Here, three local variables—`a`, `b`, and `c`—are declared. The first two, `a` and `b`, are initialized by constants. However, `c` is initialized dynamically to the length of the hypotenuse (using the Pythagorean theorem). The program uses another of Java's built-in methods, `sqrt()`, which is a member of the `Math` class, to compute the square root of its argument. The key point here is that the initialization expression may use any element valid at the time of the initialization, including calls to methods, other variables, or literals.

**The Scope and Lifetime of Variables**
So far, all of the variables used have been declared at the start of the `main()` method. However, Java allows variables to be declared within any block. As explained in Chapter 2, a block is begun with an opening curly brace and ended by a closing curly brace. A block defines a scope. Thus, each time you start a new block, you are creating a new scope. A scope determines what objects are visible to other parts of your program. It also determines the lifetime of those objects.

Many other computer languages define two general categories of scopes: global and local. However, these traditional scopes do not fit well with Java's strict, object-oriented model. While it is possible to create what amounts to being a global scope, it is by far the exception, not the rule. In Java, the two major scopes are those defined by a class and those defined by a method. Even this distinction is somewhat artificial. However, since the class scope has several unique properties and attributes that do not apply to the scope defined by a method,
this distinction makes some sense. Because of the differences, a discussion of class scope (and variables declared within it) is deferred until Chapter 6, when classes are described. For now, we will only examine the scopes defined by or within a method.

The scope defined by a method begins with its opening curly brace. However, if that method has parameters, they too are included within the method’s scope. Although this book will look more closely at parameters in Chapter 6, for the sake of this discussion, they work the same as any other method variable.

As a general rule, variables declared inside a scope are not visible (that is, accessible) to code that is defined outside that scope. Thus, when you declare a variable within a scope, you are localizing that variable and protecting it from unauthorized access and/or modification. Indeed, the scope rules provide the foundation for encapsulation.

Scopes can be nested. For example, each time you create a block of code, you are creating a new, nested scope. When this occurs, the outer scope encloses the inner scope. This means that objects declared in the outer scope will be visible to code within the inner scope. However, the reverse is not true. Objects declared within the inner scope will not be visible outside it.

To understand the effect of nested scopes, consider the following program:

```java
// Demonstrate block scope.
class Scope {
    public static void main(String args[]) {
        int x; // known to all code within main

        x = 10;
        if (x == 10) { // start new scope
            int y = 20; // known only to this block

            // x and y both known here.
            System.out.println("x and y: " + x + " " + y);
            x = y * 2;
        }
        // y = 100; // Error! y not known here

        // x is still known here.
        System.out.println("x is " + x);
    }
}
```

As the comments indicate, the variable `x` is declared at the start of `main()`’s scope and is accessible to all subsequent code within `main()`. Within the `if` block, `y` is declared. Since a block defines a scope, `y` is only visible to other code within its block. This is why outside of its block, the line `y = 100;` is commented out. If you remove the leading comment symbol, a compile-time error will occur, because `y` is not visible outside of its block. Within the `if`
A block, x can be used because code within a block (that is, a nested scope) has access to variables declared by an enclosing scope.

Within a block, variables can be declared at any point, but are valid only after they are declared. Thus, if you define a variable at the start of a method, it is available to all of the code within that method. Conversely, if you declare a variable at the end of a block, it is effectively useless, because no code will have access to it. For example, this fragment is invalid because count cannot be used prior to its declaration:

```
// This fragment is wrong!
count = 100; // oops! cannot use count before it is declared!
int count;
```

Here is another important point to remember: variables are created when their scope is entered, and destroyed when their scope is left. This means that a variable will not hold its value once it has gone out of scope. Therefore, variables declared within a method will not hold their values between calls to that method. Also, a variable declared within a block will lose its value when the block is left. Thus, the lifetime of a variable is confined to its scope. If a variable declaration includes an initializer, then that variable will be reinitialized each time the block in which it is declared is entered. For example, consider the next program:

```
// Demonstrate lifetime of a variable.
class LifeTime {
    public static void main(String args[]) {
        int x;
        for(x = 0; x < 3; x++) {
            int y = -1; // y is initialized each time block is entered
            System.out.println("y is: " + y); // this always prints -1
            y = 100;
            System.out.println("y is now: " + y);
        }
    }
}
```

The output generated by this program is shown here:

```
y is: -1
y is now: 100
y is: -1
y is now: 100
y is: -1
y is now: 100
```
As you can see, y is reinitialized to –1 each time the inner for loop is entered. Even though it is subsequently assigned the value 100, this value is lost.

One last point: Although blocks can be nested, you cannot declare a variable to have the same name as one in an outer scope. For example, the following program is illegal:

```java
// This program will not compile
class ScopeErr {
    public static void main(String args[]) {
        int bar = 1;
        { // creates a new scope
            int bar = 2; // Compile-time error - bar already defined!
        }
    }
}
```

**Type Conversion and Casting**

If you have previous programming experience, then you already know that it is fairly common to assign a value of one type to a variable of another type. If the two types are compatible, then Java will perform the conversion automatically. For example, it is always possible to assign an `int` value to a `long` variable. However, not all types are compatible, and thus, not all type conversions are implicitly allowed. For instance, there is no automatic conversion defined from `double` to `byte`. Fortunately, it is still possible to obtain a conversion between incompatible types. To do so, you must use a cast, which performs an explicit conversion between incompatible types. Let’s look at both automatic type conversions and casting.

**Java’s Automatic Conversions**

When one type of data is assigned to another type of variable, an automatic type conversion will take place if the following two conditions are met:

- The two types are compatible.
- The destination type is larger than the source type.

When these two conditions are met, a widening conversion takes place. For example, the `int` type is always large enough to hold all valid `byte` values, so no explicit cast statement is required.

For widening conversions, the numeric types, including integer and floating-point types, are compatible with each other. However, there are no automatic conversions from the numeric types to `char` or `boolean`. Also, `char` and `boolean` are not compatible with each other.

As mentioned earlier, Java also performs an automatic type conversion when storing a literal integer constant into variables of type `byte`, `short`, `long`, or `char`.

**Casting Incompatible Types**
Although the automatic type conversions are helpful, they will not fulfill all needs. For example, what if you want to assign an `int` value to a `byte` variable? This conversion will not be performed automatically, because a `byte` is smaller than an `int`. This kind of conversion is sometimes called a *narrowing conversion*, since you are explicitly making the value narrower so that it will fit into the target type.

To create a conversion between two incompatible types, you must use a cast. A *cast* is simply an explicit type conversion. It has this general form:

\[
\text{(target-type) value}
\]

Here, *target-type* specifies the desired type to convert the specified value to. For example, the following fragment casts an `int` to a `byte`. If the integer's value is larger than the range of a `byte`, it will be reduced modulo (the remainder of an integer division by the) `byte`'s range.

```java
int a;
byte b;
// ...
b = (byte) a;
```

A different type of conversion will occur when a floating-point value is assigned to an integer type: *truncation*. As you know, integers do not have fractional components. Thus, when a floating-point value is assigned to an integer type, the fractional component is lost. For example, if the value 1.23 is assigned to an integer, the resulting value will simply be 1. The 0.23 will have been truncated. Of course, if the size of the whole number component is too large to fit into the target integer type, then that value will be reduced modulo the target type's range.

The following program demonstrates some type conversions that require casts:
This program generates the following output:

```
Conversion of int to byte.
i and b 257
Conversion of double to int.
d and i 323.142 323
Conversion of double to byte.
d and b 323.142 67
```

Let's look at each conversion. When the value 257 is cast into a `byte` variable, the result is the remainder of the division of 257 by 256 (the range of a `byte`), which is 1 in this case. When the `d` is converted to an `int`, its fractional component is lost. When `d` is converted to a `byte`, its fractional component is lost, and the value is reduced modulo 256, which in this case is 67.

**Automatic Type Promotion in Expressions**

In addition to assignments, there is another place where certain type conversions may occur: in expressions. To see why, consider the following. In an expression, the precision required of an intermediate value will sometimes exceed the range of either operand. For example, examine the following expression:
The result of the intermediate term \( a \times b \) easily exceeds the range of either of its \texttt{byte} operands. To handle this kind of problem, Java automatically promotes each \texttt{byte}, \texttt{short}, or \texttt{char} operand to \texttt{int} when evaluating an expression. This means that the subexpression \( a \times b \) is performed using integers—not bytes. Thus, 2,000, the result of the intermediate expression, 50 \( \times \) 40, is legal even though \( a \) and \( b \) are both specified as type \texttt{byte}.

As useful as the automatic promotions are, they can cause confusing compile-time errors. For example, this seemingly correct code causes a problem:

```java
byte b = 50;
b = b * 2; // Error! Cannot assign an int to a byte!
```

The code is attempting to store 50 \( \times \) 2, a perfectly valid \texttt{byte} value, back into a \texttt{byte} variable. However, because the operands were automatically promoted to \texttt{int} when the expression was evaluated, the result has also been promoted to \texttt{int}. Thus, the result of the expression is now of type \texttt{int}, which cannot be assigned to a \texttt{byte} without the use of a cast. This is true even if, as in this particular case, the value being assigned would still fit in the target type.

In cases where you understand the consequences of overflow, you should use an explicit cast, such as

```java
byte b = 50;
b = (byte) (b * 2);
```

which yields the correct value of 100.

**The Type Promotion Rules**

Java defines several type promotion rules that apply to expressions. They are as follows:

First, all \texttt{byte}, \texttt{short}, and \texttt{char} values are promoted to \texttt{int}, as just described. Then, if one operand is a \texttt{long}, the whole expression is promoted to \texttt{long}. If one operand is a \texttt{float}, the entire expression is promoted to \texttt{float}. If any of the operands are \texttt{double}, the result is \texttt{double}.

The following program demonstrates how each value in the expression gets promoted to match the second argument to each binary operator:
Let's look closely at the type promotions that occur in this line from the program:

\[
\text{double result} = (f * b) + (i / c) - (d * s);
\]

In the first subexpression, \(f * b\), \(b\) is promoted to a \texttt{float} and the result of the subexpression is \texttt{float}. Next, in the subexpression \(i/c\), \(c\) is promoted to \texttt{int}, and the result is of type \texttt{int}. Then, in \(d * s\), the value of \(s\) is promoted to \texttt{double}, and the type of the subexpression is \texttt{double}. Finally, these three intermediate values, \texttt{float}, \texttt{int}, and \texttt{double}, are considered. The outcome of \texttt{float} plus an \texttt{int} is a \texttt{float}. Then the resultant \texttt{float} minus the last \texttt{double} is promoted to \texttt{double}, which is the type for the final result of the expression.

**Arrays**

An array is a group of like-typed variables that are referred to by a common name. Arrays of any type can be created and may have one or more dimensions. A specific element in an array is accessed by its index. Arrays offer a convenient means of grouping related information.

**NOTE** If you are familiar with C/C++, be careful. Arrays in Java work differently than they do in those languages.

**One-Dimensional Arrays**

A one-dimensional array is, essentially, a list of like-typed variables. To create an array, you first must create an array variable of the desired type. The general form of a one-dimensional array declaration is

\[
\text{type var-name[]};
\]
Here, type declares the element type (also called the base type) of the array. The element type determines the data type of each element that comprises the array. Thus, the element type for the array determines what type of data the array will hold. For example, the following declares an array named month_days with the type “array of int”:

```java
int month_days[];
```

Although this declaration establishes the fact that month_days is an array variable, no array actually exists. To link month_days with an actual, physical array of integers, you must allocate one using new and assign it to month_days. new is a special operator that allocates memory. You will look more closely at new in a later chapter, but you need to use it now to allocate memory for arrays. The general form of new as it applies to one-dimensional arrays appears as follows:

```java
array-var = new type [size];
```

Here, type specifies the type of data being allocated, size specifies the number of elements in the array, and array-var is the array variable that is linked to the array. That is, to use new to allocate an array, you must specify the type and number of elements to allocate. The elements in the array allocated by new will automatically be initialized to zero (for numeric types), false (for boolean), or null (for reference types, which are described in a later chapter). This example allocates a 12-element array of integers and links them to month_days:

```java
month_days = new int[12];
```

After this statement executes, month_days will refer to an array of 12 integers. Further, all elements in the array will be initialized to zero.

Let’s review: Obtaining an array is a two-step process. First, you must declare a variable of the desired array type. Second, you must allocate the memory that will hold the array, using new, and assign it to the array variable. Thus, in Java all arrays are dynamically allocated. If the concept of dynamic allocation is unfamiliar to you, don’t worry. It will be described at length later in this book.

Once you have allocated an array, you can access a specific element in the array by specifying its index within square brackets. All array indexes start at zero. For example, this statement assigns the value 28 to the second element of month_days:

```java
month_days[1] = 28;
```

The next line displays the value stored at index 3:
Putting together all the pieces, here is a program that creates an array of the number of days in each month:

```java
// Demonstrate a one-dimensional array.
class Array {
    public static void main(String args[]) {
        int month_days[];
        month_days = new int[12];
        month_days[0] = 31;
        month_days[1] = 28;
        month_days[2] = 31;
        month_days[3] = 30;
        month_days[4] = 31;
        month_days[5] = 30;
        month_days[6] = 31;
        month_days[7] = 31;
        month_days[8] = 30;
        month_days[9] = 31;
        month_days[10] = 30;
        month_days[11] = 31;
        System.out.println("April has " + month_days[3] + " days.");
    }
}
```

When you run this program, it prints the number of days in April. As mentioned, Java array indexes start with zero, so the number of days in April is `month_days[3]` or 30.

It is possible to combine the declaration of the array variable with the allocation of the array itself, as shown here:

```java
    int month_days[] = new int[12];
```

This is the way that you will normally see it done in professionally written Java programs.

Arrays can be initialized when they are declared. The process is much the same as that used to initialize the simple types. An array initializer is a list of comma-separated expressions surrounded by curly braces. The commas separate the values of the array elements. The array will automatically be created large enough to hold the number of elements you specify in the array initializer. There is no need to use `new`. For example, to store the number of days in each month, the following code creates an initialized array of integers:
When you run this program, you see the same output as that generated by the previous version. Java strictly checks to make sure you do not accidentally try to store or reference values outside of the range of the array. The Java run-time system will check to be sure that all array indexes are in the correct range. For example, the run-time system will check the value of each index into `month_days` to make sure that it is between 0 and 11 inclusive. If you try to access elements outside the range of the array (negative numbers or numbers greater than the length of the array), you will cause a run-time error.

Here is one more example that uses a one-dimensional array. It finds the average of a set of numbers.

```java
// Average an array of values.
class Average {
    public static void main(String args[]) {
        double nums[] = {10.1, 11.2, 12.3, 13.4, 14.5};
        double result = 0;
        int i;
        for(i=0; i<5; i++)
            result = result + nums[i];
        System.out.println("Average is " + result / 5);
    }
}
```

### Multidimensional Arrays

In Java, *multidimensional arrays* are actually arrays of arrays. These, as you might expect, look and act like regular multidimensional arrays. However, as you will see, there are a couple of subtle differences. To declare a multidimensional array variable, specify each additional index using another set of square brackets. For example, the following declares a two-dimensional array variable called `twoD`:

```java
int twoD[][] = new int[4][5];
```

This allocates a 4 by 5 array and assigns it to `twoD`. Internally, this matrix is implemented
as an array of arrays of int. Conceptually, this array will look like the one shown in Figure 3-1.

![Figure 3-1 A conceptual view of a 4 by 5, two-dimensional array](image)

The following program numbers each element in the array from left to right, top to bottom, and then displays these values:
This program generates the following output:

```
0 1 2 3 4
5 6 7 8 9
10 11 12 13 14
15 16 17 18 15
```

When you allocate memory for a multidimensional array, you need only specify the memory for the first (leftmost) dimension. You can allocate the remaining dimensions separately. For example, this following code allocates memory for the first dimension of `twoD` when it is declared. It allocates the second dimension manually.

```java
int twoD[][] = new int[4][];
twoD[0] = new int[5];
twoD[1] = new int[5];
twoD[2] = new int[5];
twoD[3] = new int[5];
```

While there is no advantage to individually allocating the second dimension arrays in this situation, there may be in others. For example, when you allocate dimensions manually, you do not need to allocate the same number of elements for each dimension. As stated earlier, since multidimensional arrays are actually arrays of arrays, the length of each array is under your control. For example, the following program creates a two-dimensional array in which
the sizes of the second dimension are unequal:

```java
// Manually allocate differing size second dimensions.
class TwoDAgain {
    public static void main(String args[]) {
        int twoD[][] = new int[4][];
        twoD[0] = new int[1];
        twoD[1] = new int[2];
        twoD[2] = new int[3];
        twoD[3] = new int[4];

        int i, j, k = 0;

        for (i = 0; i < 4; i++)
            for (j = 0; j < i + 1; j++)
                twoD[i][j] = k;
            k++;

        for (i = 0; i < 4; i++)
            for (j = 0; j < i + 1; j++)
                System.out.print(twoD[i][j] + " ");
        System.out.println();
    }
}
```

This program generates the following output:

```
0 1 2
3 4 5
6 7 8 9
```

The array created by this program looks like this:
The use of uneven (or irregular) multidimensional arrays may not be appropriate for many applications, because it runs contrary to what people expect to find when a multidimensional array is encountered. However, irregular arrays can be used effectively in some situations. For example, if you need a very large two-dimensional array that is sparsely populated (that is, one in which not all of the elements will be used), then an irregular array might be a perfect solution.

It is possible to initialize multidimensional arrays. To do so, simply enclose each dimension's initializer within its own set of curly braces. The following program creates a matrix where each element contains the product of the row and column indexes. Also notice that you can use expressions as well as literal values inside of array initializers.

```java
// Initialize a two-dimensional array.
class Matrix {
    public static void main(String args[]) {
        double m[] [] = {
            { 0*0, 1*0, 2*0, 3*0 },
            { 0*1, 1*1, 2*1, 3*1 },
            { 0*2, 1*2, 2*2, 3*2 },
            { 0*3, 1*3, 2*3, 3*3 }
        };
        int i, j;
        for(i=0; i<4; i++) {
            for(j=0; j<4; j++)
                System.out.print(m[i][j] + " ");
            System.out.println();
        }
    }
}
```
When you run this program, you will get the following output:

```
0.0 0.0 0.0 0.0
0.0 1.0 2.0 3.0
0.0 2.0 4.0 6.0
0.0 3.0 6.0 9.0
```

As you can see, each row in the array is initialized as specified in the initialization lists.

Let's look at one more example that uses a multidimensional array. The following program creates a 3 by 4 by 5, three-dimensional array. It then loads each element with the product of its indexes. Finally, it displays these products.

```java
// Demonstrate a three-dimensional array.
class ThreeDMatrix {
    public static void main(String args[]) {
        int threeD[][][] = new int[3][4][5];
        int i, j, k;

        for(i=0; i<3; i++)
            for(j=0; j<4; j++)
                for(k=0; k<5; k++)
                    threeD[i][j][k] = i * j * k;

        for(i=0; i<3; i++) {
            for(j=0; j<4; j++) {
                for(k=0; k<5; k++)
                    System.out.print(threeD[i][j][k] + " ");
            }
            System.out.println();
        }
    }
}
```

This program generates the following output:
Alternative Array Declaration Syntax

There is a second form that may be used to declare an array:

```java
type[] var-name;
```

Here, the square brackets follow the type specifier, and not the name of the array variable. For example, the following two declarations are equivalent:

```java
int a1[] = new int[3];
int[] a2 = new int[3];
```

The following declarations are also equivalent:

```java
char twod1[][] = new char[3][4];
char[][] twod2 = new char[3][4];
```

This alternative declaration form offers convenience when declaring several arrays at the same time. For example,

```java
int[] nums, nums2, nums3; // create three arrays
```

creates three array variables of type `int`. It is the same as writing

```java
int nums[], nums2[], nums3[]; // create three arrays
```

The alternative declaration form is also useful when specifying an array as a return type for a method. Both forms are used in this book.

A Few Words About Strings

As you may have noticed, in the preceding discussion of data types and arrays there has been no mention of strings or a string data type. This is not because Java does not support
such a type—it does. It is just that Java's string type, called **String**, is not a primitive type. Nor is it simply an array of characters. Rather, **String** defines an object, and a full description of it requires an understanding of several object-related features. As such, it will be covered later in this book, after objects are described. However, so that you can use simple strings in example programs, the following brief introduction is in order.

The **String** type is used to declare string variables. You can also declare arrays of strings. A quoted string constant can be assigned to a **String** variable. A variable of type **String** can be assigned to another variable of type **String** variable. You can use an object of type **String** as an argument to **println()**. For example, consider the following fragment:

```java
String str = "this is a test";
System.out.println(str);
```

Here, `str` is an object of type **String**. It is assigned the string "this is a test". This string is displayed by the **println()** statement.

As you will see later, **String** objects have many special features and attributes that make them quite powerful and easy to use. However, for the next few chapters, you will be using them only in their simplest form.

**A Note to C/C++ Programmers About Pointers**

If you are an experienced C/C++ programmer, then you know that these languages provide support for pointers. However, no mention of pointers has been made in this chapter. The reason for this is simple: Java does not support or allow pointers. (Or more properly, Java does not support pointers that can be accessed and/or modified by the programmer.) Java cannot allow pointers, because doing so would allow Java programs to breach the firewall between the Java execution environment and the host computer. (Remember, a pointer can be given any address in memory—even addresses that might be outside the Java run-time system.) Since C/C++ make extensive use of pointers, you might be thinking that their loss is a significant disadvantage to Java. However, this is not true. Java is designed in such a way that as long as you stay within the confines of the execution environment, you will never need to use a pointer, nor would there be any benefit in using one.
Java provides a rich operator environment. Most of its operators can be divided into the following four groups: arithmetic, bitwise, relational, and logical. Java also defines some additional operators that handle certain special situations. This chapter describes all of Java's operators except for the type comparison operator `instanceof`, which is examined in Chapter 13 and the new arrow operator (–>), which is described in Chapter 15.

### Arithmetic Operators

Arithmetic operators are used in mathematical expressions in the same way that they are used in algebra. The following table lists the arithmetic operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Addition (also unary plus)</td>
</tr>
<tr>
<td>–</td>
<td>Subtraction (also unary minus)</td>
</tr>
<tr>
<td>*</td>
<td>Multiplication</td>
</tr>
<tr>
<td>/</td>
<td>Division</td>
</tr>
<tr>
<td>%</td>
<td>Modulus</td>
</tr>
<tr>
<td>++</td>
<td>Increment</td>
</tr>
<tr>
<td>+=</td>
<td>Addition assignment</td>
</tr>
<tr>
<td>-=</td>
<td>Subtraction assignment</td>
</tr>
<tr>
<td>*=</td>
<td>Multiplication assignment</td>
</tr>
<tr>
<td>/=</td>
<td>Division assignment</td>
</tr>
<tr>
<td>%=</td>
<td>Modulus assignment</td>
</tr>
<tr>
<td>– –</td>
<td>Decrement</td>
</tr>
</tbody>
</table>

The operands of the arithmetic operators must be of a numeric type. You cannot use them on `boolean` types, but you can use them on `char` types, since the `char` type in Java is, essentially, a subset of `int`. 


The Basic Arithmetic Operators
The basic arithmetic operations—addition, subtraction, multiplication, and division—all behave as you would expect for all numeric types. The unary minus operator negates its single operand. The unary plus operator simply returns the value of its operand. Remember that when the division operator is applied to an integer type, there will be no fractional component attached to the result.

The following simple example program demonstrates the arithmetic operators. It also illustrates the difference between floating-point division and integer division.

```java
// Demonstrate the basic arithmetic operators.
class BasicMath {
    public static void main(String args[]) {
        // arithmetic using integers
        System.out.println("Integer Arithmetic");
        int a = 1 + 1;
        int b = a * 3;
        int c = b / 4;
        int d = c - a;
        int e = -d;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
        System.out.println("d = " + d);
        System.out.println("e = " + e);

        // arithmetic using doubles
        System.out.println("\nFloating Point Arithmetic");
        double da = 1 + 1;
        double db = da * 3;
        double dc = db / 4;
        double dd = dc - a;
        double de = -dd;
        System.out.println("da = " + da);
        System.out.println("db = " + db);
        System.out.println("dc = " + dc);
        System.out.println("dd = " + dd);
        System.out.println("de = " + de);
    }
}
```

When you run this program, you will see the following output:
The Modulus Operator
The modulus operator, %, returns the remainder of a division operation. It can be applied to floating-point types as well as integer types. The following example program demonstrates the %:

```java
// Demonstrate the % operator.
class Modulus {
    public static void main(String args[]) {
        int x = 42;
double y = 42.25;

        System.out.println("x mod 10 = " + x % 10);
        System.out.println("y mod 10 = " + y % 10);
    }
}
```

When you run this program, you will get the following output:

```
x mod 10 = 2
y mod 10 = 2.25
```

Arithmetic Compound Assignment Operators
Java provides special operators that can be used to combine an arithmetic operation with an assignment. As you probably know, statements like the following are quite common in programming:

```
a = a + 4;
```

In Java, you can rewrite this statement as shown here:
This version uses the += compound assignment operator. Both statements perform the same action: they increase the value of a by 4.

Here is another example,

```java
a = a % 2;
```

which can be expressed as

```java
a %= 2;
```

In this case, the %= obtains the remainder of a / 2 and puts that result back into a.

There are compound assignment operators for all of the arithmetic, binary operators. Thus, any statement of the form

```java
var = var op expression;
```

can be rewritten as

```java
var op= expression;
```

The compound assignment operators provide two benefits. First, they save you a bit of typing, because they are “shorthand” for their equivalent long forms. Second, in some cases they are more efficient than are their equivalent long forms. For these reasons, you will often see the compound assignment operators used in professionally written Java programs.

Here is a sample program that shows several op= assignments in action:

```java
// Demonstrate several assignment operators.
class OpEquals {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c = 3;

        a += 5;
        b *= 4;
        c += a * b;
        c %= 6;
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
    }
}
```
The output of this program is shown here:

```java
a = 6
b = 8
c = 3
```

**Increment and Decrement**
The `++` and the `--` are Java’s increment and decrement operators. They were introduced in Chapter 2. Here they will be discussed in detail. As you will see, they have some special properties that make them quite interesting. Let’s begin by reviewing precisely what the increment and decrement operators do.

The increment operator increases its operand by one. The decrement operator decreases its operand by one. For example, this statement:

```java
x = x + 1;
```

can be rewritten like this by use of the increment operator:

```java
x++;  // This is equivalent to: x = x + 1;
```

Similarly, this statement:

```java
x = x - 1;
```

is equivalent to

```java
x--;  // This is equivalent to: x = x - 1;
```

These operators are unique in that they can appear both in *postfix* form, where they follow the operand as just shown, and *prefix* form, where they precede the operand. In the foregoing examples, there is no difference between the prefix and postfix forms. However, when the increment and/or decrement operators are part of a larger expression, then a subtle, yet powerful, difference between these two forms appears. In the prefix form, the operand is incremented or decremented before the value is obtained for use in the expression. In postfix form, the previous value is obtained for use in the expression, and then the operand is modified. For example:

```java
x = 42;
y = ++x;  // This is equivalent to: y = x++;
```

In this case, `y` is set to `43` as you would expect, because the increment occurs *before* `x` is assigned to `y`. Thus, the line `y = ++x;` is the equivalent of these two statements:
However, when written like this,

\[
\begin{align*}
x &= x + 1; \\
y &= x;
\end{align*}
\]

the value of \( x \) is obtained before the increment operator is executed, so the value of \( y \) is 42.

Of course, in both cases \( x \) is set to 43. Here, the line \( y = x++; \) is the equivalent of these two statements:

\[
\begin{align*}
y &= x; \\
x &= x + 1;
\end{align*}
\]

The following program demonstrates the increment operator.

```java
// Demonstrate ++.
class IncDec {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c;
        int d;
        c = ++b;
        d = a++;
        c++;  // Increment c
        System.out.println("a = " + a);
        System.out.println("b = " + b);
        System.out.println("c = " + c);
        System.out.println("d = " + d);
    }
}
```

The output of this program follows:

\[
\begin{align*}
a &= 2 \\
b &= 3 \\
c &= 4 \\
d &= 1
\end{align*}
\]

**The Bitwise Operators**

Java defines several *bitwise operators* that can be applied to the integer types: `long`, `int`, `short`, `char`, and `byte`. These operators act upon the individual bits of their operands. They are summarized in the following table:
<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>~</td>
<td>Bitwise unary NOT</td>
</tr>
<tr>
<td>&amp;</td>
<td>Bitwise AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>Bitwise exclusive OR</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>Shift right</td>
</tr>
<tr>
<td>&gt;&gt;&gt;</td>
<td>Shift right zero fill</td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>Shift left</td>
</tr>
<tr>
<td>&amp;=</td>
<td>Bitwise AND assignment</td>
</tr>
<tr>
<td></td>
<td>=</td>
</tr>
<tr>
<td>^=</td>
<td>Bitwise exclusive OR assignment</td>
</tr>
<tr>
<td>&gt;&gt;=</td>
<td>Shift right assignment</td>
</tr>
<tr>
<td>&gt;&gt;&gt;=</td>
<td>Shift right zero fill assignment</td>
</tr>
<tr>
<td>&lt;&lt;=</td>
<td>Shift left assignment</td>
</tr>
</tbody>
</table>

Since the bitwise operators manipulate the bits within an integer: it is important to understand what effects such manipulations may have on a value. Specifically, it is useful to know how Java stores integer values and how it represents negative numbers. So, before continuing, let’s briefly review these two topics.

All of the integer types are represented by binary numbers of varying bit widths. For example, the `byte` value for 42 in binary is 00101010, where each position represents a power of two, starting with $2^0$ at the rightmost bit. The next bit position to the left would be $2^1$, or 2, continuing toward the left with $2^2$, or 4, then 8, 16, 32, and so on. So 42 has 1 bits set at positions 1, 3, and 5 (counting from 0 at the right); thus, 42 is the sum of $2^1 + 2^3 + 2^5$, which is $2 + 8 + 32$.

All of the integer types (except `char`) are signed integers. This means that they can represent negative values as well as positive ones. Java uses an encoding known as two's complement, which means that negative numbers are represented by inverting (changing 1’s to 0’s and vice versa) all of the bits in a value, then adding 1 to the result. For example, $-42$ is represented by inverting all of the bits in 42, or 00101010, which yields 11010101, then adding 1, which results in 11010110, or $-42$. To decode a negative number, first invert all of the bits, then add 1. For example, $-42$, or 11010110 inverted, yields 00101001, or 41, so when you add 1 you get 42.

The reason Java (and most other computer languages) uses two's complement is easy to see when you consider the issue of zero crossing. Assuming a `byte` value, zero is represented by 00000000. In one’s complement, simply inverting all of the bits creates 11111111, which creates negative zero. The trouble is that negative zero is invalid in integer math. This
problem is solved by using two’s complement to represent negative values. When using two’s complement, 1 is added to the complement, producing 100000000. This produces a 1 bit too far to the left to fit back into the byte value, resulting in the desired behavior, where –0 is the same as 0, and 11111111 is the encoding for –1. Although we used a byte value in the preceding example, the same basic principle applies to all of Java’s integer types. Because Java uses two’s complement to store negative numbers—and because all integers are signed values in Java—applying the bitwise operators can easily produce unexpected results. For example, turning on the high-order bit will cause the resulting value to be interpreted as a negative number, whether this is what you intended or not. To avoid unpleasant surprises, just remember that the high-order bit determines the sign of an integer no matter how that high-order bit gets set.

The Bitwise Logical Operators
The bitwise logical operators are &, |, ^, and ~. The following table shows the outcome of each operation. In the discussion that follows, keep in mind that the bitwise operators are applied to each individual bit within each operand.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>A</th>
<th>B</th>
<th>A</th>
<th>B</th>
<th>A &amp; B</th>
<th>A ^ B</th>
<th>~A</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
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<td>0</td>
<td>1</td>
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<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

The Bitwise NOT
Also called the bitwise complement, the unary NOT operator, ~, inverts all of the bits of its operand. For example, the number 42, which has the following bit pattern:

00101010

becomes

11010101

after the NOT operator is applied.

The Bitwise AND
The AND operator, &, produces a 1 bit if both operands are also 1. A zero is produced in all other cases. Here is an example:
The Bitwise OR
The OR operator, |, combines bits such that if either of the bits in the operands is a 1, then the resultant bit is a 1, as shown here:

\[
\begin{array}{c|c}
00101010 & 42 \\
& 00001111 \\
\hline
00101111 & 47
\end{array}
\]

The Bitwise XOR
The XOR operator, ^, combines bits such that if exactly one operand is 1, then the result is 1. Otherwise, the result is zero. The following example shows the effect of the ^ operator. This example also demonstrates a useful attribute of the XOR operation. Notice how the bit pattern of 42 is inverted wherever the second operand has a 1 bit. Wherever the second operand has a 0 bit, the first operand is unchanged. You will find this property useful when performing some types of bit manipulations.

\[
\begin{array}{c|c}
00101010 & 42 \\
^ & 00001111 \\
\hline
00100101 & 37
\end{array}
\]

Using the Bitwise Logical Operators
The following program demonstrates the bitwise logical operators:
In this example, a and b have bit patterns that present all four possibilities for two binary
digits: 0-0, 0-1, 1-0, and 1-1. You can see how the | and & operate on each bit by the results
in c and d. The values assigned to e and f are the same and illustrate how the ^ works. The
string array named binary holds the human-readable, binary representation of the
numbers 0 through 15. In this example, the array is indexed to show the binary
representation of each result. The array is constructed such that the correct string
representation of a binary value n is stored in binary[n]. The value of ~a is ANDeD with
oxof (0000 1111 in binary) in order to reduce its value to less than 16, so it can be printed
by use of the binary array. Here is the output from this program:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>0111</td>
</tr>
<tr>
<td>b</td>
<td>0110</td>
</tr>
<tr>
<td>a</td>
<td>b</td>
</tr>
<tr>
<td>a&amp;b</td>
<td>0010</td>
</tr>
<tr>
<td>a^b</td>
<td>0101</td>
</tr>
<tr>
<td>~a&amp;b</td>
<td>a&amp;~b</td>
</tr>
<tr>
<td>~a</td>
<td>1100</td>
</tr>
</tbody>
</table>

**The Left Shift**
The left shift operator, <<, shifts all of the bits in a value to the left a specified number of
times. It has this general form:

\[ \text{value} << \text{num} \]
Here, \(num\) specifies the number of positions to left-shift the value in \(value\). That is, the \(<<\) moves all of the bits in the specified value to the left by the number of bit positions specified by \(num\). For each shift left, the high-order bit is shifted out (and lost), and a zero is brought in on the right. This means that when a left shift is applied to an \texttt{int} operand, bits are lost once they are shifted past bit position 31. If the operand is a \texttt{long}, then bits are lost after bit position 63.

Java’s automatic type promotions produce unexpected results when you are shifting \texttt{byte} and \texttt{short} values. As you know, \texttt{byte} and \texttt{short} values are promoted to \texttt{int} when an expression is evaluated. Furthermore, the result of such an expression is also an \texttt{int}. This means that the outcome of a left shift on a \texttt{byte} or \texttt{short} value will be an \texttt{int}, and the bits shifted left will not be lost until they shift past bit position 31. Furthermore, a negative \texttt{byte} or \texttt{short} value will be sign-extended when it is promoted to \texttt{int}. Thus, the high-order bits will be filled with 1’s. For these reasons, to perform a left shift on a \texttt{byte} or \texttt{short} implies that you must discard the high-order bytes of the \texttt{int} result. For example, if you left-shift a \texttt{byte} value, that value will first be promoted to \texttt{int} and then shifted. This means that you must discard the top three bytes of the result if what you want is the result of a shifted \texttt{byte} value. The easiest way to do this is to simply cast the result back into a \texttt{byte}. The following program demonstrates this concept:

```java
// Left shifting a byte value.
public class ByteShift {  
    public static void main(String args[]) {  
        byte a = 64, b;
        int i;

        i = a << 2;
        b = (byte) (a << 2);
        System.out.println("Original value of a: " + a);
        System.out.println("i and b: " + i + " " + b);
    }
}
```

The output generated by this program is shown here:

```
Original value of a: 64
i and b: 256 0
```

Since \(a\) is promoted to \texttt{int} for the purposes of evaluation, left-shifting the value 64 (0100 0000) twice results in \(i\) containing the value 256 (1 0000 0000). However, the value in \(b\) contains 0 because after the shift, the low-order byte is now zero. Its only 1 bit has been shifted out.

Since each left shift has the effect of doubling the original value, programmers frequently
use this fact as an efficient alternative to multiplying by 2. But you need to watch out. If you shift a 1 bit into the high-order position (bit 31 or 63), the value will become negative. The following program illustrates this point:

```java
// Left shifting as a quick way to multiply by 2.
class MultByTwo {
    public static void main(String args[]) {
        int i;
        int num = 0xFFFF0000;

        for(i=0; i<4; i++) {
            num = num << 1;
            System.out.println(num);
        }
    }
}
```

The program generates the following output:

```
536870908
1073741816
2147483648
-32
```

The starting value was carefully chosen so that after being shifted left 4 bit positions, it would produce –32. As you can see, when a 1 bit is shifted into bit 31, the number is interpreted as negative.

**The Right Shift**

The right shift operator, `>>`, shifts all of the bits in a value to the right a specified number of times. Its general form is shown here:

```
value >> num
```

Here, `num` specifies the number of positions to right-shift the value in `value`. That is, the `>>` moves all of the bits in the specified value to the right the number of bit positions specified by `num`.

The following code fragment shifts the value 32 to the right by two positions, resulting in `a` being set to 8:

```java
int a = 32;
a = a >> 2; // a now contains 8
```

When a value has bits that are “shifted off,” those bits are lost. For example, the next code
fragment shifts the value 35 to the right two positions, which causes the two low-order bits to be lost, resulting again in \( a \) being set to 8:

```c
int a = 35;
a = a >> 2; // a contains 8
```

Looking at the same operation in binary shows more clearly how this happens:

```
00100011  35
>> 2
00001000  8
```

Each time you shift a value to the right, it divides that value by two—and discards any remainder. In some cases, you can take advantage of this for high-performance integer division by 2.

When you are shifting right, the top (leftmost) bits exposed by the right shift are filled in with the previous contents of the top bit. This is called \textit{sign extension} and serves to preserve the sign of negative numbers when you shift them right. For example, \(-8 \gg 1\) is \(-4\), which, in binary, is

```
11110000  -8
>> 1
11111000  -4
```

It is interesting to note that if you shift \(-1\) right, the result always remains \(-1\), since sign extension keeps bringing in more ones in the high-order bits.

Sometimes it is not desirable to sign-extend values when you are shifting them to the right. For example, the following program converts a \texttt{byte} value to its hexadecimal string representation. Notice that the shifted value is masked by ANDing it with \texttt{0xff} to discard any sign-extended bits so that the value can be used as an index into the array of hexadecimal characters.
The Unsigned Right Shift

As you have just seen, the `>>` operator automatically fills the high-order bit with its previous contents each time a shift occurs. This preserves the sign of the value. However, sometimes this is undesirable. For example, if you are shifting something that does not represent a numeric value, you may not want sign extension to take place. This situation is common when you are working with pixel-based values and graphics. In these cases, you will generally want to shift a zero into the high-order bit no matter what its initial value was. This is known as an unsigned shift. To accomplish this, you will use Java's unsigned, shift-right operator, `>>>`, which always shifts zeros into the high-order bit.

The following code fragment demonstrates the `>>>`. Here, `a` is set to –1, which sets all 32 bits to 1 in binary. This value is then shifted right 24 bits, filling the top 24 bits with zeros, ignoring normal sign extension. This sets `a` to 255.

```java
int a = -1;
a = a >>> 24;
```

Here is the same operation in binary form to further illustrate what is happening:

```
11111111 11111111 11111111 11111111 -1 in binary as an int
>>>24
00000000 00000000 00000000 11111111 255 in binary as an int
```

The `>>>` operator is often not as useful as you might like, since it is only meaningful for 32- and 64-bit values. Remember, smaller values are automatically promoted to `int` in expressions. This means that sign-extension occurs and that the shift will take place on a 32-bit rather than on an 8- or 16-bit value. That is, one might expect an unsigned right shift on a `byte` value to zero-fill beginning at bit 7. But this is not the case, since it is a 32-bit value that is actually being shifted.
The following program demonstrates this effect:

```java
// Unsigned shifting a byte value.
class ByteUShift {
    static public void main(String args[]) {
        char hex[] = {
            '0', '1', '2', '3', '4', '5', '6', '7',
            '8', '9', 'a', 'b', 'c', 'd', 'e', 'f'
        };
        byte b = (byte) 0xff;
        byte c = (byte) (b >> 4);
        byte d = (byte) (b >>> 4);
        byte e = (byte) ((b & 0xff) >> 4);

        System.out.println("b = 0x" + hex[(b >> 4) & 0x0f] + hex[b & 0x0f]);
        System.out.println("b >> 4 = 0x" + hex[(c >> 4) & 0x0f] + hex[c & 0x0f]);
        System.out.println("b >>> 4 = 0x" + hex[(d >> 4) & 0x0f] + hex[d & 0x0f]);
        System.out.println("(b & 0xff) >> 4 = 0x" + hex[(e >> 4) & 0x0f] + hex[e & 0x0f]);
    }
}
```

The following output of this program shows how the `>>>` operator appears to do nothing when dealing with bytes. The variable `b` is set to an arbitrary negative `byte` value for this demonstration. Then `c` is assigned the `byte` value of `b` shifted right by four, which is `0xff` because of the expected sign extension. Then `d` is assigned the `byte` value of `b` unsigned shifted right by four, which you might have expected to be `0x0f`, but is actually `0xff` because of the sign extension that happened when `b` was promoted to `int` before the shift. The last expression sets `e` to the `byte` value of `b` masked to 8 bits using the AND operator, then shifted right by four, which produces the expected value of `0x0f`. Notice that the unsigned shift right operator was not used for `d`, since the state of the sign bit after the AND was known.

```
  b = 0xff
  b >> 4 = 0xff
  b >>> 4 = 0xff
  (b & 0xff) >> 4 = 0x0f
```

**Bitwise Operator Compound Assignments**

All of the binary bitwise operators have a compound form similar to that of the algebraic
operators, which combines the assignment with the bitwise operation. For example, the following two statements, which shift the value in a right by four bits, are equivalent:

```java
a = a >> 4;
a >>= 4;
```

Likewise, the following two statements, which result in a being assigned the bitwise expression a OR b, are equivalent:

```java
a = a | b;
a |= b;
```

The following program creates a few integer variables and then uses compound bitwise operator assignments to manipulate the variables:

```java
class OpBitEquals {
    public static void main(String args[]) {
        int a = 1;
        int b = 2;
        int c = 3;

        a |= 4;
b >>= 1;
c <<= 1;
a ^= c;
System.out.println("a = " + a);
System.out.println("b = " + b);
System.out.println("c = " + c);
    }
}
```

The output of this program is shown here:

```java
a = 3
b = 1
c = 6
```

**Relational Operators**

The relational operators determine the relationship that one operand has to the other. Specifically, they determine equality and ordering. The relational operators are shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal to</td>
</tr>
</tbody>
</table>
The outcome of these operations is a **boolean** value. The relational operators are most frequently used in the expressions that control the **if** statement and the various loop statements.

Any type in Java, including integers, floating-point numbers, characters, and Booleans can be compared using the equality test, `==`, and the inequality test, `!=`. Notice that in Java equality is denoted with two equal signs, not one. (Remember: a single equal sign is the assignment operator.) Only numeric types can be compared using the ordering operators. That is, only integer, floating-point, and character operands may be compared to see which is greater or less than the other.

As stated, the result produced by a relational operator is a **boolean** value. For example, the following code fragment is perfectly valid:

```java
int a = 4;
int b = 1;
boolean c = a < b;
```

In this case, the result of `a<b` (which is **false**) is stored in `c`.

If you are coming from a C/C++ background, please note the following. In C/C++, these types of statements are very common:

```c
int done;
//...
if(!done)... // Valid in C/C++
if(done)... // but not in Java.
```

In Java, these statements must be written like this:

```java
if(done == 0)... // This is Java-style.
if(done != 0)...```

The reason is that Java does not define true and false in the same way as C/C++. In C/ C++, true is any nonzero value and false is zero. In Java, **true** and **false** are nonnumeric values that do not relate to zero or nonzero. Therefore, to test for zero or nonzero, you must explicitly employ one or more of the relational operators.
**Boolean Logical Operators**

The Boolean logical operators shown here operate only on boolean operands. All of the binary logical operators combine two boolean values to form a resultant boolean value.

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>Logical AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>Logical XOR (exclusive OR)</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td>Short-circuit AND</td>
</tr>
<tr>
<td>!</td>
<td>Logical unary NOT</td>
</tr>
<tr>
<td>&amp;=</td>
<td>AND assignment</td>
</tr>
<tr>
<td></td>
<td>=</td>
</tr>
<tr>
<td>^=</td>
<td>XOR assignment</td>
</tr>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal to</td>
</tr>
<tr>
<td>?:</td>
<td>Ternary if-then-else</td>
</tr>
</tbody>
</table>

The logical Boolean operators, &, |, and ^, operate on boolean values in the same way that they operate on the bits of an integer. The logical ! operator inverts the Boolean state: !true == false and !false == true. The following table shows the effect of each logical operation:

<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>A</th>
<th>B</th>
<th>A &amp; B</th>
<th>A ^ B</th>
<th>!A</th>
</tr>
</thead>
<tbody>
<tr>
<td>False</td>
<td>False</td>
<td>False</td>
<td>False</td>
<td>False</td>
<td>True</td>
<td></td>
</tr>
<tr>
<td>True</td>
<td>False</td>
<td>True</td>
<td>False</td>
<td>True</td>
<td>False</td>
<td></td>
</tr>
<tr>
<td>False</td>
<td>True</td>
<td>True</td>
<td>False</td>
<td>True</td>
<td>False</td>
<td></td>
</tr>
<tr>
<td>True</td>
<td>True</td>
<td>True</td>
<td>True</td>
<td>False</td>
<td>False</td>
<td></td>
</tr>
</tbody>
</table>

Here is a program that is almost the same as the BitLogic example shown earlier, but it operates on boolean logical values instead of binary bits:
After running this program, you will see that the same logical rules apply to `boolean` values as they did to bits. As you can see from the following output, the string representation of a Java `boolean` value is one of the literal values `true` or `false`:

```
a = true
b = false
a|b = true
a&b = false
a^b = true
!a&b|a&&!b = true
!a = false
```

**Short-Circuit Logical Operators**

Java provides two interesting Boolean operators not found in some other computer languages. These are secondary versions of the Boolean AND and OR operators, and are commonly known as *short-circuit* logical operators. As you can see from the preceding table, the OR operator results in `true` when `A` is `true`, no matter what `B` is. Similarly, the AND operator results in `false` when `A` is `false`, no matter what `B` is. If you use the `||` and `&&` forms, rather than the `|` and `&` forms of these operators, Java will not bother to evaluate the right-hand operand when the outcome of the expression can be determined by the left operand alone. This is very useful when the right-hand operand depends on the value of the left one in order to function properly. For example, the following code fragment shows how you can take advantage of short-circuit logical evaluation to be sure that a division operation
will be valid before evaluating it:

\[
\text{if } \text{denom} != 0 \&\& \text{num} / \text{denom} > 10
\]

Since the short-circuit form of AND (\&\&) is used, there is no risk of causing a run-time exception when \text{denom} is zero. If this line of code were written using the single \& version of AND, both sides would be evaluated, causing a run-time exception when \text{denom} is zero. It is standard practice to use the short-circuit forms of AND and OR in cases involving Boolean logic, leaving the single-character versions exclusively for bitwise operations. However, there are exceptions to this rule. For example, consider the following statement:

\[
\text{if}(\text{c}==1 \& \text{e}++ < 100) \text{ d} = 100;
\]

Here, using a single \& ensures that the increment operation will be applied to \text{e} whether \text{c} is equal to 1 or not.

---

**NOTE** The formal specification for Java refers to the short-circuit operators as the *conditional-and* and the *conditional-or*.

---

**The Assignment Operator**

You have been using the assignment operator since Chapter 2. Now it is time to take a formal look at it. The *assignment operator* is the single equal sign, =. The assignment operator works in Java much as it does in any other computer language. It has this general form:

\[
\text{var} = \text{expression};
\]

Here, the type of \text{var} must be compatible with the type of \text{expression}.

The assignment operator does have one interesting attribute that you may not be familiar with: it allows you to create a chain of assignments. For example, consider this fragment:

```
int x, y, z;

x = y = z = 100; // set x, y, and z to 100
```

This fragment sets the variables \text{x}, \text{y}, and \text{z} to 100 using a single statement. This works because the = is an operator that yields the value of the right-hand expression. Thus, the value of \text{z} = 100 is 100, which is then assigned to \text{y}, which in turn is assigned to \text{x}. Using a “chain of assignment” is an easy way to set a group of variables to a common value.
The ? Operator

Java includes a special ternary (three-way) operator that can replace certain types of if-then-else statements. This operator is the ?. It can seem somewhat confusing at first, but the ? can be used very effectively once mastered. The ? has this general form:

```
expression1 ? expression2 : expression3
```

Here, expression1 can be any expression that evaluates to a boolean value. If expression1 is true, then expression2 is evaluated; otherwise, expression3 is evaluated. The result of the ? operation is that of the expression evaluated. Both expression2 and expression3 are required to return the same (or compatible) type, which can’t be void.

Here is an example of the way that the ? is employed:

```
ratio = denom == 0 ? 0 : num / denom;
```

When Java evaluates this assignment expression, it first looks at the expression to the left of the question mark. If denom equals zero, then the expression between the question mark and the colon is evaluated and used as the value of the entire ? expression. If denom does not equal zero, then the expression after the colon is evaluated and used for the value of the entire ? expression. The result produced by the ? operator is then assigned to ratio.

Here is a program that demonstrates the ? operator. It uses it to obtain the absolute value of a variable.

```java
// Demonstrate ?.
class Ternary{
    public static void main(String args[]){
        int i, k;
        i = 10;
        k = i < 0 ? -i : i; // get absolute value of i
        System.out.print("Absolute value of ");
        System.out.println(i + " is "+k);

        i = -10;
        k = i < 0 ? -i : i; // get absolute value of i
        System.out.print("Absolute value of ");
        System.out.println(i + " is "+k);
    }
}
```

The output generated by the program is shown here:

```
Absolute value of 10 is 10
Absolute value of -10 is 10
```
Operator Precedence

Table 4-1 shows the order of precedence for Java operators, from highest to lowest. Operators in the same row are equal in precedence. In binary operations, the order of evaluation is left to right (except for assignment, which evaluates right to left). Although they are technically separators, the [], (), and . can also act like operators. In that capacity, they would have the highest precedence. Also, notice the arrow operator (->). It was added by JDK 8 and is used in lambda expressions.

<table>
<thead>
<tr>
<th>Highest</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>++ (postfix)</td>
<td>-- (postfix)</td>
<td></td>
</tr>
<tr>
<td>++ (prefix)</td>
<td>-- (prefix)</td>
<td>&lt;</td>
</tr>
<tr>
<td>=</td>
<td>/</td>
<td>%</td>
</tr>
<tr>
<td>a</td>
<td>=</td>
<td>&lt;=</td>
</tr>
<tr>
<td>&gt;&gt;</td>
<td>&gt;&gt;&gt;</td>
<td>&lt;&lt;</td>
</tr>
<tr>
<td>&gt;</td>
<td>&gt;=</td>
<td>&lt;=</td>
</tr>
<tr>
<td>==</td>
<td>!=</td>
<td>instanceof</td>
</tr>
<tr>
<td>&amp;</td>
<td>^</td>
<td></td>
</tr>
<tr>
<td>&amp;&amp;</td>
<td></td>
<td></td>
</tr>
<tr>
<td>!</td>
<td>!</td>
<td></td>
</tr>
<tr>
<td>?:</td>
<td>=&gt;</td>
<td>op=</td>
</tr>
</tbody>
</table>

Table 4-1 The Precedence of the Java Operators

Using Parentheses

Parentheses raise the precedence of the operations that are inside them. This is often necessary to obtain the result you desire. For example, consider the following expression:

\[ a \gg b + 3 \]

This expression first adds 3 to \( b \) and then shifts \( a \) right by that result. That is, this expression can be rewritten using redundant parentheses like this:

\[ a \gg (b + 3) \]

However, if you want to first shift \( a \) right by \( b \) positions and then add 3 to that result, you will need to parenthesize the expression like this:

\[ (a \gg b) + 3 \]

In addition to altering the normal precedence of an operator, parentheses can sometimes be
used to help clarify the meaning of an expression. For anyone reading your code, a complicated expression can be difficult to understand. Adding redundant but clarifying parentheses to complex expressions can help prevent confusion later. For example, which of the following expressions is easier to read?

\[
\begin{align*}
\text{a} & | \text{a} + \text{c} >> \text{b} \ & \text{7} \\
(\text{a} & | ( (\text{a} + \text{c}) >> \text{b} ) & \text{7}))
\end{align*}
\]

One other point: parentheses (redundant or not) do not degrade the performance of your program. Therefore, adding parentheses to reduce ambiguity does not negatively affect your program.
A programming language uses control statements to cause the flow of execution to advance and branch based on changes to the state of a program. Java’s program control statements can be put into the following categories: selection, iteration, and jump. Selection statements allow your program to choose different paths of execution based upon the outcome of an expression or the state of a variable. Iteration statements enable program execution to repeat one or more statements (that is, iteration statements form loops). Jump statements allow your program to execute in a nonlinear fashion. All of Java’s control statements are examined here.

**Java’s Selection Statements**

Java supports two selection statements: if and switch. These statements allow you to control the flow of your program’s execution based upon conditions known only during runtime. You will be pleasantly surprised by the power and flexibility contained in these two statements.

**if**

The if statement was introduced in Chapter 2. It is examined in detail here. The if statement is Java’s conditional branch statement. It can be used to route program execution through two different paths. Here is the general form of the if statement:

```
if (condition) statement1;
else statement2;
```

Here, each statement may be a single statement or a compound statement enclosed in curly braces (that is, a block). The condition is any expression that returns a boolean value. The else clause is optional.

The if works like this: If the condition is true, then statement1 is executed. Otherwise, statement2 (if it exists) is executed. In no case will both statements be executed. For example, consider the following:
Here, if $a$ is less than $b$, then $a$ is set to zero. Otherwise, $b$ is set to zero. In no case are they both set to zero. Most often, the expression used to control the if will involve the relational operators. However, this is not technically necessary. It is possible to control the if using a single boolean variable, as shown in this code fragment:

```java
boolean dataAvailable;
//...
if (dataAvailable)
    ProcessData();
else
    waitForMoreData();
```

Remember, only one statement can appear directly after the if or the else. If you want to include more statements, you’ll need to create a block, as in this fragment:

```java
int bytesAvailable;
//...
if (bytesAvailable > 0) {
    ProcessData();
    bytesAvailable -= n;
} else
    waitForMoreData();
```

Here, both statements within the if block will execute if `bytesAvailable` is greater than zero. Some programmers find it convenient to include the curly braces when using the if, even when there is only one statement in each clause. This makes it easy to add another statement at a later date, and you don’t have to worry about forgetting the braces. In fact, forgetting to define a block when one is needed is a common cause of errors. For example, consider the following code fragment:
It seems clear that the statement \texttt{bytesAvailable = n;} was intended to be executed inside the \texttt{else} clause, because of the indentation level. However, as you recall, whitespace is insignificant to Java, and there is no way for the compiler to know what was intended. This code will compile without complaint, but it will behave incorrectly when run. The preceding example is fixed in the code that follows:

\begin{verbatim}
int bytesAvailable;
// ...
if (bytesAvailable > 0) {
    ProcessData();
    bytesAvailable -= n;
} else {
    forMoreData();
    bytesAvailable = n;
}
\end{verbatim}

\textbf{Nested ifs}

A nested if is an if statement that is the target of another if or else. Nested ifs are very common in programming. When you nest ifs, the main thing to remember is that an else statement always refers to the nearest if statement that is within the same block as the else and that is not already associated with an else. Here is an example:

\begin{verbatim}
if(i == 10) {
    if(j < 20) a = b;
    else if(k > 100) c = d; // this if is
    else a = c; // associated with this else
} else a = d; // this else refers to if(i == 10)
\end{verbatim}

As the comments indicate, the final else is not associated with if(j<20) because it is not in the same block (even though it is the nearest if without an else). Rather, the final else is associated with if(i==10). The inner else refers to if(k>100) because it is the closest if within the same block.
The if-else-if Ladder
A common programming construct that is based upon a sequence of nested ifs is the if-else-if ladder. It looks like this:

```
if(condition)
    statement;
else if(condition)
    statement;
else if(condition)
    statement;
.
.
.
else
    statement;
```

The if statements are executed from the top down. As soon as one of the conditions controlling the if is true, the statement associated with that if is executed, and the rest of the ladder is bypassed. If none of the conditions is true, then the final else statement will be executed. The final else acts as a default condition; that is, if all other conditional tests fail, then the last else statement is performed. If there is no final else and all other conditions are false, then no action will take place.
Here is a program that uses an if-else-if ladder to determine which season a particular month is in.
Here is the output produced by the program:

April is in the Spring.

You might want to experiment with this program before moving on. As you will find, no matter what value you give `month`, one and only one assignment statement within the ladder will be executed.

**switch**

The `switch` statement is Java's multiway branch statement. It provides an easy way to dispatch execution to different parts of your code based on the value of an expression. As such, it often provides a better alternative than a large series of `if-else-if` statements. Here is the general form of a `switch` statement:
For versions of Java prior to JDK 7, `expression` must be of type `byte`, `short`, `int`, `char`, or an enumeration. (Enumerations are described in Chapter 12.) Beginning with JDK 7, `expression` can also be of type `String`. Each value specified in the `case` statements must be a unique constant expression (such as a literal value). Duplicate `case` values are not allowed. The type of each value must be compatible with the type of `expression`.

The `switch` statement works like this: The value of the expression is compared with each of the values in the `case` statements. If a match is found, the code sequence following that `case` statement is executed. If none of the constants matches the value of the expression, then the `default` statement is executed. However, the `default` statement is optional. If no `case` matches and no `default` is present, then no further action is taken.

The `break` statement is used inside the `switch` to terminate a statement sequence. When a `break` statement is encountered, execution branches to the first line of code that follows the entire `switch` statement. This has the effect of “jumping out” of the `switch`.

Here is a simple example that uses a `switch` statement:

```java
switch (expression) {
    case value1:
        // statement sequence
        break;
    case value2:
        // statement sequence
        break;
    case valueN:
        // statement sequence
        break;
        default:
        // default statement sequence
}
```
The output produced by this program is shown here:

```
i is zero.
i is one.
i is two.
i is three.
i is greater than 3.
i is greater than 3.
```

As you can see, each time through the loop, the statements associated with the `case` constant that matches `i` are executed. All others are bypassed. After `i` is greater than 3, no `case` statements match, so the `default` statement is executed.

The `break` statement is optional. If you omit the `break`, execution will continue on into the next `case`. It is sometimes desirable to have multiple `cases` without `break` statements between them. For example, consider the following program:
This program generates the following output:

```
  i is less than 5
  i is less than 5
  i is less than 5
  i is less than 5
  i is less than 5
  i is less than 10
  i is less than 10
  i is less than 10
  i is less than 10
  i is less than 10
  i is 10 or more
  i is 10 or more
```

As you can see, execution falls through each `case` until a `break` statement (or the end of the `switch`) is reached.

While the preceding example is, of course, contrived for the sake of illustration, omitting the `break` statement has many practical applications in real programs. To sample its more realistic usage, consider the following rewrite of the season example shown earlier. This
version uses a **switch** to provide a more efficient implementation.

```java
// An improved version of the season program.
class Switch {
    public static void main(String args[]) {
        int month = 4;
        String season;

        switch (month) {
            case 12:
            case 1:
            case 2:
                season = "Winter";
                break;
            case 3:
            case 4:
            case 5:
                season = "Spring";
                break;
            case 6:
            case 7:
            case 8:
                season = "Summer";
                break;
            case 9:
            case 10:
            case 11:
                season = "Autumn";
                break;
            default:
                season = "Bogus Month";
        }
        System.out.println("April is in the " + season + ".");
    }
}
```

As mentioned, beginning with JDK 7, you can use a string to control a **switch** statement. For example,
As you would expect, the output from the program is

two

The string contained in `str` (which is "two" in this program) is tested against the `case` constants. When a match is found (as it is in the second `case`), the code sequence associated with that sequence is executed. Being able to use strings in a `switch` statement streamlines many situations. For example, using a string-based `switch` is an improvement over using the equivalent sequence of `if/else` statements. However, switching on strings can be more expensive than switching on integers. Therefore, it is best to switch on strings only in cases in which the controlling data is already in string form. In other words, don’t use strings in a `switch` unnecessarily.

**Nested switch Statements**
You can use a `switch` as part of the statement sequence of an outer `switch`. This is called a nested `switch`. Since a `switch` statement defines its own block, no conflicts arise between the `case` constants in the inner `switch` and those in the outer `switch`. For example, the following fragment is perfectly valid:

```java
// Use a string to control a switch statement.

class StringSwitch {
    public static void main(String args[]) {

        String str = "two";

        switch(str) {
            case "one":
                System.out.println("one");
                break;
            case "two":
                System.out.println("two");
                break;
            case "three":
                System.out.println("three");
                break;
            default:
                System.out.println("no match");
                break;
        }
    }
}
```
Here, the \texttt{case 1:} statement in the inner switch does not conflict with the \texttt{case 1:} statement in the outer switch. The \texttt{count} variable is compared only with the list of cases at the outer level. If \texttt{count} is 1, then \texttt{target} is compared with the inner list cases.

In summary, there are three important features of the \texttt{switch} statement to note:

- The \texttt{switch} differs from the \texttt{if} in that \texttt{switch} can only test for equality, whereas \texttt{if} can evaluate any type of Boolean expression. That is, the \texttt{switch} looks only for a match between the value of the expression and one of its \texttt{case} constants.
- No two \texttt{case} constants in the same \texttt{switch} can have identical values. Of course, a \texttt{switch} statement and an enclosing outer \texttt{switch} can have \texttt{case} constants in common.
- A \texttt{switch} statement is usually more efficient than a set of nested \texttt{ifs}.

The last point is particularly interesting because it gives insight into how the Java compiler works. When it compiles a \texttt{switch} statement, the Java compiler will inspect each of the \texttt{case} constants and create a “jump table” that it will use for selecting the path of execution depending on the value of the expression. Therefore, if you need to select among a large group of values, a \texttt{switch} statement will run much faster than the equivalent logic coded using a sequence of \texttt{if-elses}.

The compiler can do this because it knows that the \texttt{case} constants are all the same type and simply must be compared for equality with the \texttt{switch} expression. The compiler has no such knowledge of a long list of \texttt{if} expressions.

\textbf{Iteration Statements}

Java’s iteration statements are \texttt{for}, \texttt{while}, and \texttt{do-while}. These statements create what we commonly call \textit{loops}. As you probably know, a loop repeatedly executes the same set of instructions until a termination condition is met. As you will see, Java has a loop to fit any programming need.
The **while** loop is Java’s most fundamental loop statement. It repeats a statement or block while its controlling expression is true. Here is its general form:

```
while(condition) {
    // body of loop
}
```

The *condition* can be any Boolean expression. The body of the loop will be executed as long as the conditional expression is true. When *condition* becomes false, control passes to the next line of code immediately following the loop. The curly braces are unnecessary if only a single statement is being repeated.

Here is a **while** loop that counts down from 10, printing exactly ten lines of "tick":

```
// Demonstrate the while loop.
class While {
    public static void main(String args[]) {
        int n = 10;

        while(n > 0) {
            System.out.println("tick "+ n);
            n--;
        }
    }
}
```

When you run this program, it will “tick” ten times:

```
tick 10
tick 9
tick 8
tick 7
tick 6
tick 5
tick 4
tick 3
tick 2
tick 1
```

Since the **while** loop evaluates its conditional expression at the top of the loop, the body of the loop will not execute even once if the condition is false to begin with. For example, in the following fragment, the call to `println()` is never executed:
int a = 10, b = 20;

while(a > b)
    System.out.println("This will not be displayed");

The body of the `while` (or any other of Java’s loops) can be empty. This is because a null statement (one that consists only of a semicolon) is syntactically valid in Java. For example, consider the following program:

```java
// The target of a loop can be empty.
class NoBody {
    public static void main(String args[]) {
        int i, j;

        i = 100;
        j = 200;

        // find midpoint between i and j
        while(++i < --j); // no body in this loop

        System.out.println("Midpoint is " + i);
    }
}
```

This program finds the midpoint between `i` and `j`. It generates the following output:

```
Midpoint is 150
```

Here is how this `while` loop works. The value of `i` is incremented, and the value of `j` is decremented. These values are then compared with one another. If the new value of `i` is still less than the new value of `j`, then the loop repeats. If `i` is equal to or greater than `j`, the loop stops. Upon exit from the loop, `i` will hold a value that is midway between the original values of `i` and `j`. (Of course, this procedure only works when `i` is less than `j` to begin with.) As you can see, there is no need for a loop body; all of the action occurs within the conditional expression, itself. In professionally written Java code, short loops are frequently coded without bodies when the controlling expression can handle all of the details itself.

**do-while**

As you just saw, if the conditional expression controlling a `while` loop is initially false, then the body of the loop will not be executed at all. However, sometimes it is desirable to execute the body of a loop at least once, even if the conditional expression is false to begin with. In other words, there are times when you would like to test the termination expression.
at the end of the loop rather than at the beginning. Fortunately, Java supplies a loop that does just that: the **do-while**. The **do-while** loop always executes its body at least once, because its conditional expression is at the bottom of the loop. Its general form is

```
  do {
      // body of loop
  } while (condition);
```

Each iteration of the **do-while** loop first executes the body of the loop and then evaluates the conditional expression. If this expression is true, the loop will repeat. Otherwise, the loop terminates. As with all of Java’s loops, `condition` must be a Boolean expression.

Here is a reworked version of the “tick” program that demonstrates the **do-while** loop. It generates the same output as before.

```java
// Demonstrate the do-while loop.
class DoWhile {
    public static void main(String args[]) {
        int n = 10;

        do {
            System.out.println("tick " + n);
            n--;
        } while(n > 0);
    }
}
```

The loop in the preceding program, while technically correct, can be written more efficiently as follows:

```
  do {
      System.out.println("tick " + n);
  } while(--n > 0);
```

In this example, the expression `(--n > 0)` combines the decrement of `n` and the test for zero into one expression. Here is how it works. First, the `--n` statement executes, decrementing `n` and returning the new value of `n`. This value is then compared with zero. If it is greater than zero, the loop continues; otherwise, it terminates.

The **do-while** loop is especially useful when you process a menu selection, because you will usually want the body of a menu loop to execute at least once. Consider the following program, which implements a very simple help system for Java’s selection and iteration
Here is a sample run produced by this program:
In the program, the `do-while` loop is used to verify that the user has entered a valid choice. If not, then the user is reprompted. Since the menu must be displayed at least once, the `do-while` is the perfect loop to accomplish this.

A few other points about this example: Notice that characters are read from the keyboard by calling `System.in.read()`. This is one of Java’s console input functions. Although Java’s console I/O methods won’t be discussed in detail until Chapter 13, `System.in.read()` is used here to obtain the user’s choice. It reads characters from standard input (returned as integers, which is why the return value was cast to `char`). By default, standard input is line buffered, so you must press ENTER before any characters that you type will be sent to your program.

Java’s console input can be a bit awkward to work with. Further, most real-world Java programs will be graphical and window-based. For these reasons, not much use of console input has been made in this book. However, it is useful in this context. One other point to consider: Because `System.in.read()` is being used, the program must specify the `throws java.io.IOException` clause. This line is necessary to handle input errors. It is part of Java’s exception handling features, which are discussed in Chapter 10.

```java
for
You were introduced to a simple form of the `for` loop in Chapter 2. As you will see, it is a powerful and versatile construct.

Beginning with JDK 5, there are two forms of the `for` loop. The first is the traditional form that has been in use since the original version of Java. The second is the newer “for-each” form. Both types of `for` loops are discussed here, beginning with the traditional form.

Here is the general form of the traditional `for` statement:
```
If only one statement is being repeated, there is no need for the curly braces.
The **for** loop operates as follows. When the loop first starts, the *initialization* portion of the loop is executed. Generally, this is an expression that sets the value of the *loop control variable*, which acts as a counter that controls the loop. It is important to understand that the initialization expression is executed only once. Next, *condition* is evaluated. This must be a Boolean expression. It usually tests the loop control variable against a target value. If this expression is true, then the body of the loop is executed. If it is false, the loop terminates.
Next, the *iteration* portion of the loop is executed. This is usually an expression that increments or decrements the loop control variable. The loop then iterates, first evaluating the conditional expression, then executing the body of the loop, and then executing the iteration expression with each pass. This process repeats until the controlling expression is false.
Here is a version of the “tick” program that uses a **for** loop:

```java
// Demonstrate the for loop.
class ForTick {
    public static void main(String args[]) {
        int n;

        for(n=10; n>0; n--)
            System.out.println("tick " + n);
    }
}
```

**Declaring Loop Control Variables Inside the for Loop**

Often the variable that controls a **for** loop is needed only for the purposes of the loop and is not used elsewhere. When this is the case, it is possible to declare the variable inside the initialization portion of the **for**. For example, here is the preceding program recoded so that the loop control variable `n` is declared as an **int** inside the **for**:

```java
// Declare a loop control variable inside the for.
class ForTick {
    public static void main(String args[]) {

        // here, n is declared inside of the for loop
        for(int n=10; n>0; n--)
            System.out.println("tick " + n);
    }
}
```

When you declare a variable inside a **for** loop, there is one important point to remember:
the scope of that variable ends when the for statement does. (That is, the scope of the
variable is limited to the for loop.) Outside the for loop, the variable will cease to exist. If
you need to use the loop control variable elsewhere in your program, you will not be able to
declare it inside the for loop.
When the loop control variable will not be needed elsewhere, most Java programmers
declare it inside the for. For example, here is a simple program that tests for prime
numbers. Notice that the loop control variable, i, is declared inside the for since it is not
needed elsewhere.

```
// Test for primes.
class FindPrimes {
    public static void main(String args[]) {
        int num;
        boolean isPrime;

        num = 14;

        if(num < 2) isPrime = false;
        else isPrime = true;

        for(int i=2; i <= num/i; i++) {
            if((num % i) == 0) {
                isPrime = false;
                break;
            }
        }

        if(isPrime) System.out.println("Prime");
        else System.out.println("Not Prime");
    }
}
```

**Using the Comma**
There will be times when you will want to include more than one statement in the
initialization and iteration portions of the for loop. For example, consider the loop in the
following program:
As you can see, the loop is controlled by the interaction of two variables. Since the loop is
governed by two variables, it would be useful if both could be included in the for statement,

itslta instead of b being handled manually. Fortunately, Java provides a way to accomplish

this. To allow two or more variables to control a for loop, Java permits you to include

multiple statements in both the initialization and iteration portions of the for. Each

statement is separated from the next by a comma.

Using the comma, the preceding for loop can be more efficiently coded, as shown here:

```java
class Sample {
    public static void main(String args[]) {
        int a, b;
        b = 4;
        for(a=1; a<b; a++) {
            System.out.println("a = " + a);
            System.out.println("b = " + b);
            b--;
        }
    }
}
```

In this example, the initialization portion sets the values of both a and b. The two comma-

separated statements in the iteration portion are executed each time the loop repeats. The

program generates the following output:

```
a = 1
b = 4
a = 2
b = 3
```

// Using the comma.
class Comma {
    public static void main(String args[]) {
        int a, b;
        for(a=1, b=4; a<b; a++, b--) {
            System.out.println("a = " + a);
            System.out.println("b = " + b);
        }
    }
}
NOTE If you are familiar with C/C++, then you know that in those languages the comma is an operator that can be used in any valid expression. However, this is not the case with Java. In Java, the comma is a separator.

Some for Loop Variations
The for loop supports a number of variations that increase its power and applicability. The reason it is so flexible is that its three parts—the initialization, the conditional test, and the iteration—do not need to be used for only those purposes. In fact, the three sections of the for can be used for any purpose you desire. Let’s look at some examples.

One of the most common variations involves the conditional expression. Specifically, this expression does not need to test the loop control variable against some target value. In fact, the condition controlling the for can be any Boolean expression. For example, consider the following fragment:

```java
boolean done = false;
for(int i=1; !done; i++) {
   // ...
   if(interrupted()) done = true;
}
```

In this example, the for loop continues to run until the boolean variable done is set to true. It does not test the value of i.

Here is another interesting for loop variation. Either the initialization or the iteration expression or both may be absent, as in this next program:
Here, the initialization and iteration expressions have been moved out of the `for`. Thus, parts of the `for` are empty. While this is of no value in this simple example—indeed, it would be considered quite poor style—there can be times when this type of approach makes sense. For example, if the initial condition is set through a complex expression elsewhere in the program or if the loop control variable changes in a nonsequential manner determined by actions that occur within the body of the loop, it may be appropriate to leave these parts of the `for` empty.

Here is one more `for` loop variation. You can intentionally create an infinite loop (a loop that never terminates) if you leave all three parts of the `for` empty. For example:

```java
for( ; ; ) {
    // ...
}
```

This loop will run forever because there is no condition under which it will terminate. Although there are some programs, such as operating system command processors, that require an infinite loop, most “infinite loops” are really just loops with special termination requirements. As you will soon see, there is a way to terminate a loop—even an infinite loop like the one shown—that does not make use of the normal loop conditional expression.

**The For-Each Version of the for Loop**

Beginning with JDK 5, a second form of `for` was defined that implements a “for-each” style loop. As you may know, contemporary language theory has embraced the for-each concept, and it has become a standard feature that programmers have come to expect. A for-each style loop is designed to cycle through a collection of objects, such as an array, in strictly sequential fashion, from start to finish. Unlike some languages, such as C#, that implement a for-each loop by using the keyword `foreach`, Java adds the for-each capability by

```java
// Parts of the for loop can be empty.
class ForVar {
    public static void main(String args[]) {
        int i;
        boolean done = false;

        i = 0;
        for( ; !done; ) {
            System.out.println("i is " + i);
            if(i == 10) done = true;
            i++;
        }
    }
}
```
enhancing the for statement. The advantage of this approach is that no new keyword is required, and no preexisting code is broken. The for-each style of for is also referred to as the enhanced for loop.

The general form of the for-each version of the for is shown here:

\[
\text{for(type itr-var : collection) state} \text{ment-block}
\]

Here, type specifies the type and itr-var specifies the name of an iteration variable that will receive the elements from a collection, one at a time, from beginning to end. The collection being cycled through is specified by collection.

There are various types of collections that can be used with the for, but the only type used in this chapter is the array. (Other types of collections that can be used with the for, such as those defined by the Collections Framework, are discussed later in this book.) With each iteration of the loop, the next element in the collection is retrieved and stored in itr-var. The loop repeats until all elements in the collection have been obtained.

Because the iteration variable receives values from the collection, type must be the same as (or compatible with) the elements stored in the collection. Thus, when iterating over arrays, type must be compatible with the element type of the array.

To understand the motivation behind a for-each style loop, consider the type of for loop that it is designed to replace. The following fragment uses a traditional for loop to compute the sum of the values in an array:

```java
int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
int sum = 0;
for(int i=0; i < 10; i++) sum += nums[i];
```

To compute the sum, each element in nums is read, in order, from start to finish. Thus, the entire array is read in strictly sequential order. This is accomplished by manually indexing the nums array by i, the loop control variable.

The for-each style for automates the preceding loop. Specifically, it eliminates the need to establish a loop counter, specify a starting and ending value, and manually index the array. Instead, it automatically cycles through the entire array, obtaining one element at a time, in sequence, from beginning to end. For example, here is the preceding fragment rewritten using a for-each version of the for:

```java
int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
int sum = 0;
for(int x: nums) sum += x;
```
With each pass through the loop, \( x \) is automatically given a value equal to the next element in \texttt{nums}. Thus, on the first iteration, \( x \) contains 1; on the second iteration, \( x \) contains 2; and so on. Not only is the syntax streamlined, but it also prevents boundary errors.

Here is an entire program that demonstrates the for-each version of the \texttt{for} just described:

```java
// Use a for-each style for loop.
class ForEach {
    public static void main(String args[]) {
        int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
        int sum = 0;

        // use for-each style for to display and sum the values
        for (int x : nums) {
            System.out.println("Value is: "+x);
            sum += x;
        }

        System.out.println("Summation: "+sum);
    }
}
```

The output from the program is shown here:

```
Value is: 1
Value is: 2
Value is: 3
Value is: 4
Value is: 5
Value is: 6
Value is: 7
Value is: 8
Value is: 9
Value is: 10
Summation: 55
```

As this output shows, the for-each style \texttt{for} automatically cycles through an array in sequence from the lowest index to the highest.

Although the for-each \texttt{for} loop iterates until all elements in an array have been examined, it is possible to terminate the loop early by using a \texttt{break} statement. For example, this program sums only the first five elements of \texttt{nums}:
As is evident, the for loop stops after the fifth element has been obtained. The break statement can also be used with Java's other loops, and it is discussed in detail later in this chapter.

There is one important point to understand about the for-each style loop. Its iteration variable is “read-only” as it relates to the underlying array. An assignment to the iteration variable has no effect on the underlying array. In other words, you can’t change the contents of the array by assigning the iteration variable a new value. For example, consider this program:

```java
// Use break with a for-each style for.
class ForEach2 {
    public static void main(String args[]) {
        int sum = 0;
        int nums[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 }
;
        // use for to display and sum the values
        for(int x : nums) {
            System.out.println("Value is: "+x);
            sum += x;
            if(x == 5) break; // stop the loop when 5 is obtained
        }
        System.out.println("Summation of first 5 elements: "+sum);
    }
}
```

This is the output produced:

```
Value is: 1
Value is: 2
Value is: 3
Value is: 4
Value is: 5
Summation of first 5 elements: 15
```
The first for loop increases the value of the iteration variable by a factor of 10. However, this assignment has no effect on the underlying array `nums`, as the second for loop illustrates. The output, shown here, proves this point:

```
1 2 3 4 5 6 7 8 9 10
1 2 3 4 5 6 7 8 9 10
```

**Iterating Over Multidimensional Arrays**

The enhanced version of the for also works on multidimensional arrays. Remember, however, that in Java, multidimensional arrays consist of arrays of arrays. (For example, a two-dimensional array is an array of one-dimensional arrays.) This is important when iterating over a multidimensional array, because each iteration obtains the next array, not an individual element. Furthermore, the iteration variable in the for loop must be compatible with the type of array being obtained. For example, in the case of a two-dimensional array, the iteration variable must be a reference to a one-dimensional array. In general, when using the for-each for to iterate over an array of N dimensions, the objects obtained will be arrays of N–1 dimensions. To understand the implications of this, consider the following program. It uses nested for loops to obtain the elements of a two-dimensional array in row-order, from first to last.
// Use for-each style for on a two-dimensional array.
class ForEach3 {
    public static void main(String args[]) {
        int sum = 0;
        int nums[][] = new int[3][5];

        // give nums some values
        for (int i = 0; i < 3; i++)
            for (int j = 0; j < 5; j++)
                nums[i][j] = (i+1)*(j+1);

        // use for-each for to display and sum the values
        for (int x[] : nums) {
            for (int y : x) {
                System.out.println("Value is: " + y);
                sum += y;
            }
        }
        System.out.println("Summation: " + sum);
    }
}

The output from this program is shown here:

| Value is: | 1 |
| Value is: | 2 |
| Value is: | 3 |
| Value is: | 4 |
| Value is: | 5 |
| Value is: | 2 |
| Value is: | 4 |
| Value is: | 6 |
| Value is: | 8 |
| Value is: | 10 |
| Value is: | 3 |
| Value is: | 6 |
| Value is: | 9 |
| Value is: | 12 |
| Value is: | 15 |
| Summation: | 90 |

In the program, pay special attention to this line:

```java
for (int x[] : nums) {
```

Notice how x is declared. It is a reference to a one-dimensional array of integers. This is necessary because each iteration of the for obtains the next array in nums, beginning with the array specified by nums[0]. The inner for loop then cycles through each of these arrays, displaying the values of each element.

**Applying the Enhanced for**

Since the for-each style for can only cycle through an array sequentially, from start to finish, you might think that its use is limited, but this is not true. A large number of algorithms require exactly this mechanism. One of the most common is searching. For example, the following program uses a for loop to search an unsorted array for a value. It stops if the value is found.

```java
// Search an array using for-each style for.
public class Search {
    public static void main(String args[]) {
        int nums[] = { 6, 8, 3, 7, 5, 6, 1, 4 };
        int val = 5;
        boolean found = false;

        // use for-each style for to search nums for val
        for (int x : nums) {
            if (x == val) {
                found = true;
                break;
            }
        }

        if (found)
            System.out.println("Value found!");
    }
}
```

The for-each style for is an excellent choice in this application because searching an unsorted array involves examining each element in sequence. (Of course, if the array were sorted, a binary search could be used, which would require a different style loop.) Other types of applications that benefit from for-each style loops include computing an average, finding the minimum or maximum of a set, looking for duplicates, and so on. Although we have been using arrays in the examples in this chapter, the for-each style for is especially useful when operating on collections defined by the Collections Framework, which is described in Part II. More generally, the for can cycle through the elements of any collection of objects, as long as that collection satisfies a certain set of constraints, which are described in Chapter 18.

**Nested Loops**
Like all other programming languages, Java allows loops to be nested. That is, one loop may be inside another. For example, here is a program that nests for loops:

```java
// Loops may be nested.
class Nested {
    public static void main(String args[]) {
        int i, j;

        for(i=0; i<10; i++) {
            for(j=i; j<10; j++)
                System.out.print(".");
            System.out.println();
        }
    }
}
```

The output produced by this program is shown here:

```
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
. . . . . . . . . .
```

**Jump Statements**

Java supports three jump statements: break, continue, and return. These statements transfer control to another part of your program. Each is examined here.

**NOTE** In addition to the jump statements discussed here, Java supports one other way that you can change your program’s flow of execution: through exception handling. Exception handling provides a structured method by which run-time errors can be trapped and handled by your program. It is supported by the keywords try, catch, throw, throws, and finally. In essence, the exception handling mechanism allows your program to perform a nonlocal branch. Since exception handling is a
Using break

In Java, the `break` statement has three uses. First, as you have seen, it terminates a statement sequence in a `switch` statement. Second, it can be used to exit a loop. Third, it can be used as a "civilized" form of `goto`. The last two uses are explained here.

Using break to Exit a Loop

By using `break`, you can force immediate termination of a loop, bypassing the conditional expression and any remaining code in the body of the loop. When a `break` statement is encountered inside a loop, the loop is terminated and program control resumes at the next statement following the loop. Here is a simple example:

```java
// Using break to exit a loop.
class BreakLoop {
    public static void main(String args[]) {
        for(int i=0; i<100; i++) {
            if(i == 10) break; // terminate loop if i is 10
            System.out.println("i: "+i);
        }
        System.out.println("Loop complete.");
    }
}
```

This program generates the following output:

```
i: 0
i: 1
i: 2
i: 3
i: 4
i: 5
i: 6
i: 7
i: 8
i: 9
Loop complete.
```

As you can see, although the `for` loop is designed to run from 0 to 99, the `break` statement causes it to terminate early, when `i` equals 10.

The `break` statement can be used with any of Java’s loops, including intentionally infinite loops. For example, here is the preceding program coded by use of a `while` loop. The output
from this program is the same as just shown.

```
// Using break to exit a while loop.
class BreakLoop2 {
    public static void main(String args[]) {
        int i = 0;

        while(i < 100) {
            if(i == 10) break; // terminate loop if i is 10
            System.out.println("i: "+i);
            i++;
        }

        System.out.println("Loop complete.");
    }
}
```

When used inside a set of nested loops, the `break` statement will only break out of the innermost loop. For example:

```
// Using break with nested loops.
class BreakLoop3 {
    public static void main(String args[]) {
        for(int i=0; i<3; i++) {
            System.out.print("Pass " + i + ": ");
            for(int j=0; j<100; j++) {
                if(j == 10) break; // terminate loop if j is 10
                System.out.print(j + " ");
            }

            System.out.println();
        }

        System.out.println("Loops complete.");
    }
}
```

This program generates the following output:

```
Pass 0: 0 1 2 3 4 5 6 7 8 9
Pass 1: 0 1 2 3 4 5 6 7 8 9
Pass 2: 0 1 2 3 4 5 6 7 8 9
Loops complete.
```

As you can see, the `break` statement in the inner loop only causes termination of that loop. The outer loop is unaffected.
Here are two other points to remember about `break`. First, more than one `break` statement may appear in a loop. However, be careful. Too many `break` statements have the tendency to destructure your code. Second, the `break` that terminates a `switch` statement affects only that `switch` statement and not any enclosing loops.

Remember, `break` was not designed to provide the normal means by which a loop is terminated. The loop’s conditional expression serves this purpose. The `break` statement should be used to cancel a loop only when some sort of special situation occurs.

**Using break as a Form of Goto**

In addition to its uses with the `switch` statement and loops, the `break` statement can also be employed by itself to provide a “civilized” form of the goto statement. Java does not have a goto statement because it provides a way to branch in an arbitrary and unstructured manner. This usually makes goto-ridden code hard to understand and hard to maintain. It also prohibits certain compiler optimizations. There are, however, a few places where the goto is a valuable and legitimate construct for flow control. For example, the goto can be useful when you are exiting from a deeply nested set of loops. To handle such situations, Java defines an expanded form of the `break` statement. By using this form of `break`, you can, for example, break out of one or more blocks of code. These blocks need not be part of a loop or a `switch`. They can be any block. Further, you can specify precisely where execution will resume, because this form of `break` works with a label. As you will see, `break` gives you the benefits of a goto without its problems.

The general form of the labeled `break` statement is shown here:

```
break label;
```

Most often, `label` is the name of a label that identifies a block of code. This can be a standalone block of code but it can also be a block that is the target of another statement. When this form of `break` executes, control is transferred out of the named block. The labeled block must enclose the `break` statement, but it does not need to be the immediately enclosing block. This means, for example, that you can use a labeled `break` statement to exit from a set of nested blocks. But you cannot use `break` to transfer control out of a block that does not enclose the `break` statement.

To name a block, put a label at the start of it. A `label` is any valid Java identifier followed by a colon. Once you have labeled a block, you can then use this label as the target of a `break` statement. Doing so causes execution to resume at the end of the labeled block. For
example, the following program shows three nested blocks, each with its own label. The `break` statement causes execution to jump forward, past the end of the block labeled `second`, skipping the two `println()` statements.

```java
// Using break as a civilized form of goto.
class Break {
    public static void main(String args[]) {
        boolean t = true;
        first: {
            second: {
                third: {
                    System.out.println("Before the break.");
                    if(t) break second; // break out of second block
                    System.out.println("This won't execute");
                }
                System.out.println("This won't execute");
            }
            System.out.println("This is after second block.");
        }
    }
}
```

Running this program generates the following output:

```
Before the break.
This is after second block.
```

One of the most common uses for a labeled `break` statement is to exit from nested loops.

For example, in the following program, the outer loop executes only once:

```java
// Using break to exit from nested loops
class BreakLoop4 {
    public static void main(String args[]) {
        outer: for(int i=0; i<3; i++) {
            System.out.println("Pass "+i+": ");
            for(int j=0; j<100; j++) {
                if(j == 10) break outer; // exit both loops
                System.out.print(j + " ");
            }
            System.out.println("This will not print");
        }
        System.out.println("Loops complete.");
    }
}
```
This program generates the following output:

Pass 0: 0 1 2 3 4 5 6 7 8 9 Loops complete.

As you can see, when the inner loop breaks to the outer loop, both loops have been terminated. Notice that this example labels the for statement, which has a block of code as its target. Keep in mind that you cannot break to any label which is not defined for an enclosing block. For example, the following program is invalid and will not compile:

```java
// This program contains an error.
class BreakErr {
    public static void main(String args[]) {
        one: for(int i=0; i<3; i++) {
            System.out.print("Pass "+i+": ");
        }
        for(int j=0; j<100; j++) {
            if(j == 10) break one; // WRONG
            System.out.print(j + " ");
        }
    }
}
```

Since the loop labeled one does not enclose the break statement, it is not possible to transfer control out of that block.

**Using continue**

Sometimes it is useful to force an early iteration of a loop. That is, you might want to continue running the loop but stop processing the remainder of the code in its body for this particular iteration. This is, in effect, a goto just past the body of the loop, to the loop’s end. The continue statement performs such an action. In while and do-while loops, a continue statement causes control to be transferred directly to the conditional expression that controls the loop. In a for loop, control goes first to the iteration portion of the for statement and then to the conditional expression. For all three loops, any intermediate code is bypassed.

Here is an example program that uses continue to cause two numbers to be printed on each line:
This code uses the % operator to check if \( i \) is even. If it is, the loop continues without printing a newline. Here is the output from this program:

```
0 1
2 3
4 5
6 7
8 5
```

As with the `break` statement, `continue` may specify a label to describe which enclosing loop to continue. Here is an example program that uses `continue` to print a triangular multiplication table for 0 through 9:

```
// Using continue with a label.
class ContinueLabel {
    public static void main(String args[]) {
        outer: for (int i=0; i<10; i++) {
            for (int j=0; j<10; j++) {
                if (i > j) {
                    System.out.println();
                    continue outer;
                }
                System.out.print(" ");
            }
            System.out.println();
        }
    }
}
```

The `continue` statement in this example terminates the loop counting \( j \) and continues with the next iteration of the loop counting \( i \). Here is the output of this program:
Good uses of `continue` are rare. One reason is that Java provides a rich set of loop statements which fit most applications. However, for those special circumstances in which early iteration is needed, the `continue` statement provides a structured way to accomplish it.

`return`
The last control statement is `return`. The `return` statement is used to explicitly return from a method. That is, it causes program control to transfer back to the caller of the method. As such, it is categorized as a jump statement. Although a full discussion of `return` must wait until methods are discussed in Chapter 6, a brief look at `return` is presented here.

At any time in a method, the `return` statement can be used to cause execution to branch back to the caller of the method. Thus, the `return` statement immediately terminates the method in which it is executed. The following example illustrates this point. Here, `return` causes execution to return to the Java run-time system, since it is the run-time system that calls `main()`:

```java
// Demonstrate return.
class Return {
    public static void main(String args[]) {
        boolean t = true;

        System.out.println("Before the return.");

        if(t) return; // return to caller

        System.out.println("This won't execute.");
    }
}
```

The output from this program is shown here:
Before the return.

As you can see, the final `println()` statement is not executed. As soon as `return` is executed, control passes back to the caller.

One last point: In the preceding program, the `if(t)` statement is necessary. Without it, the Java compiler would flag an “unreachable code” error because the compiler would know that the last `println()` statement would never be executed. To prevent this error, the `if` statement is used here to trick the compiler for the sake of this demonstration.
CHAPTER

6
Introducing Classes

The class is at the core of Java. It is the logical construct upon which the entire Java language is built because it defines the shape and nature of an object. As such, the class forms the basis for object-oriented programming in Java. Any concept you wish to implement in a Java program must be encapsulated within a class. Because the class is so fundamental to Java, this and the next few chapters will be devoted to it. Here, you will be introduced to the basic elements of a class and learn how a class can be used to create objects. You will also learn about methods, constructors, and the \texttt{this} keyword.

\textbf{Class Fundamentals}

Classes have been used since the beginning of this book. However, until now, only the most rudimentary form of a class has been shown. The classes created in the preceding chapters primarily exist simply to encapsulate the \texttt{main( )} method, which has been used to demonstrate the basics of the Java syntax. As you will see, classes are substantially more powerful than the limited ones presented so far. Perhaps the most important thing to understand about a class is that it defines a new data type. Once defined, this new type can be used to create objects of that type. Thus, a class is a \textit{template} for an object, and an object is an \textit{instance} of a class. Because an object is an instance of a class, you will often see the two words \texttt{object} and \texttt{instance} used interchangeably.

\textbf{The General Form of a Class}

When you define a class, you declare its exact form and nature. You do this by specifying the data that it contains and the code that operates on that data. While very simple classes may contain only code or only data, most real-world classes contain both. As you will see, a class’ code defines the interface to its data.

A class is declared by use of the \texttt{class} keyword. The classes that have been used up to this point are actually very limited examples of its complete form. Classes can (and usually do) get much more complex. A simplified general form of a \texttt{class} definition is shown here:
The data, or variables, defined within a class are called *instance variables*. The code is contained within *methods*. Collectively, the methods and variables defined within a class are called *members* of the class. In most classes, the instance variables are acted upon and accessed by the methods defined for that class. Thus, as a general rule, it is the methods that determine how a class’ data can be used.

Variables defined within a class are called instance variables because each instance of the class (that is, each object of the class) contains its own copy of these variables. Thus, the data for one object is separate and unique from the data for another. We will come back to this point shortly, but it is an important concept to learn early.

All methods have the same general form as `main()`, which we have been using thus far. However, most methods will not be specified as `static` or `public`. Notice that the general form of a class does not specify a `main()` method. Java classes do not need to have a `main()` method. You only specify one if that class is the starting point for your program. Further, some kinds of Java applications, such as applets, don’t require a `main()` method at all.

**A Simple Class**

Let’s begin our study of the class with a simple example. Here is a class called `Box` that defines three instance variables: `width`, `height`, and `depth`. Currently, `Box` does not contain any methods (but some will be added soon).
As stated, a class defines a new type of data. In this case, the new data type is called `Box`. You will use this name to declare objects of type `Box`. It is important to remember that a class declaration only creates a template; it does not create an actual object. Thus, the preceding code does not cause any objects of type `Box` to come into existence. To actually create a `Box` object, you will use a statement like the following:

```java
Box mybox = new Box(); // create a Box object called mybox
```

After this statement executes, `mybox` will be an instance of `Box`. Thus, it will have “physical” reality. For the moment, don’t worry about the details of this statement. As mentioned earlier, each time you create an instance of a class, you are creating an object that contains its own copy of each instance variable defined by the class. Thus, every `Box` object will contain its own copies of the instance variables `width`, `height`, and `depth`. To access these variables, you will use the `dot (.)` operator. The dot operator links the name of the object with the name of an instance variable. For example, to assign the `width` variable of `mybox` the value 100, you would use the following statement:

```java
mybox.width = 100;
```

This statement tells the compiler to assign the copy of `width` that is contained within the `mybox` object the value of 100. In general, you use the dot operator to access both the instance variables and the methods within an object. One other point: Although commonly referred to as the `dot operator`, the formal specification for Java categorizes the `.` as a separator. However, since the use of the term “dot operator” is widespread, it is used in this book. Here is a complete program that uses the `Box` class:
You should call the file that contains this program `BoxDemo.java`, because the `main()` method is in the class called `BoxDemo`, not the class called `Box`. When you compile this program, you will find that two `.class` files have been created, one for `Box` and one for `BoxDemo`. The Java compiler automatically puts each class into its own `.class` file. It is not necessary for both the `Box` and the `BoxDemo` class to actually be in the same source file. You could put each class in its own file, called `Box.java` and `BoxDemo.java`, respectively.

To run this program, you must execute `BoxDemo.class`. When you do, you will see the following output:

```
Volume is 3000.0
```

As stated earlier, each object has its own copies of the instance variables. This means that if you have two `Box` objects, each has its own copy of `depth, width, and height`. It is important to understand that changes to the instance variables of one object have no effect on the instance variables of another. For example, the following program declares two `Box`
The output produced by this program is shown here:

```
Volume is 3000.0
Volume is 162.0
```

As you can see, `mybox1`'s data is completely separate from the data contained in `mybox2`.

**Declaring Objects**

As just explained, when you create a class, you are creating a new data type. You can use
this type to declare objects of that type. However, obtaining objects of a class is a two-step process. First, you must declare a variable of the class type. This variable does not define an object. Instead, it is simply a variable that can refer to an object. Second, you must acquire an actual, physical copy of the object and assign it to that variable. You can do this using the new operator. The new operator dynamically allocates (that is, allocates at run time) memory for an object and returns a reference to it. This reference is, more or less, the address in memory of the object allocated by new. This reference is then stored in the variable. Thus, in Java, all class objects must be dynamically allocated. Let’s look at the details of this procedure.

In the preceding sample programs, a line similar to the following is used to declare an object of type Box:

```java
Box mybox = new Box();
```

This statement combines the two steps just described. It can be rewritten like this to show each step more clearly:

```java
Box mybox; // declare reference to object
mybox = new Box(); // allocate a Box object
```

The first line declares mybox as a reference to an object of type Box. At this point, mybox does not yet refer to an actual object. The next line allocates an object and assigns a reference to it to mybox. After the second line executes, you can use mybox as if it were a Box object. But in reality, mybox simply holds, in essence, the memory address of the actual Box object. The effect of these two lines of code is depicted in Figure 6-1.

![Figure 6-1](image-url)
NOTE Those readers familiar with C/C++ have probably noticed that object references appear to be similar to pointers. This suspicion is, essentially, correct. An object reference is similar to a memory pointer. The main difference—and the key to Java’s safety—is that you cannot manipulate references as you can actual pointers. Thus, you cannot cause an object reference to point to an arbitrary memory location or manipulate it like an integer.

A Closer Look at new

As just explained, the new operator dynamically allocates memory for an object. It has this general form:

```
class-var = new classname ( );
```

Here, class-var is a variable of the class type being created. The classname is the name of the class that is being instantiated. The class name followed by parentheses specifies the constructor for the class. A constructor defines what occurs when an object of a class is created. Constructors are an important part of all classes and have many significant attributes. Most real-world classes explicitly define their own constructors within their class definition. However, if no explicit constructor is specified, then Java will automatically supply a default constructor. This is the case with Box. For now, we will use the default constructor. Soon, you will see how to define your own constructors.

At this point, you might be wondering why you do not need to use new for such things as integers or characters. The answer is that Java’s primitive types are not implemented as objects. Rather, they are implemented as “normal” variables. This is done in the interest of efficiency. As you will see, objects have many features and attributes that require Java to treat them differently than it treats the primitive types. By not applying the same overhead to the primitive types that applies to objects, Java can implement the primitive types more efficiently. Later, you will see object versions of the primitive types that are available for your use in those situations in which complete objects of these types are needed.

It is important to understand that new allocates memory for an object during run time. The advantage of this approach is that your program can create as many or as few objects as it needs during the execution of your program. However, since memory is finite, it is possible that new will not be able to allocate memory for an object because insufficient memory exists. If this happens, a run-time exception will occur. (You will learn how to handle exceptions in Chapter 10.) For the sample programs in this book, you won’t need to worry about running out of memory, but you will need to consider this possibility in real-world
programs that you write.

Let's once again review the distinction between a class and an object. A class creates a new data type that can be used to create objects. That is, a class creates a logical framework that defines the relationship between its members. When you declare an object of a class, you are creating an instance of that class. Thus, a class is a logical construct. An object has physical reality. (That is, an object occupies space in memory.) It is important to keep this distinction clearly in mind.

**Assigning Object Reference Variables**

Object reference variables act differently than you might expect when an assignment takes place. For example, what do you think the following fragment does?

```java
Box b1 = new Box();
Box b2 = b1;
```

You might think that `b2` is being assigned a reference to a copy of the object referred to by `b1`. That is, you might think that `b1` and `b2` refer to separate and distinct objects. However, this would be wrong. Instead, after this fragment executes, `b1` and `b2` will both refer to the same object. The assignment of `b1` to `b2` did not allocate any memory or copy any part of the original object. It simply makes `b2` refer to the same object as does `b1`. Thus, any changes made to the object through `b2` will affect the object to which `b1` is referring, since they are the same object.

This situation is depicted here:

![Diagram](image)

Although `b1` and `b2` both refer to the same object, they are not linked in any other way. For example, a subsequent assignment to `b1` will simply unhook `b1` from the original object without affecting the object or affecting `b2`. For example:

```java
Box b1 = new Box();
Box b2 = b1;
// ...
b1 = null;
```
Here, \(b_1\) has been set to \textbf{null}, but \(b_2\) still points to the original object.

**REMEMBER** When you assign one object reference variable to another object reference variable, you are not creating a copy of the object, you are only making a copy of the reference.

### Introducing Methods

As mentioned at the beginning of this chapter, classes usually consist of two things: instance variables and methods. The topic of methods is a large one because Java gives them so much power and flexibility. In fact, much of the next chapter is devoted to methods. However, there are some fundamentals that you need to learn now so that you can begin to add methods to your classes.

This is the general form of a method:

```java
    type name(parameter-list) {
        // body of method
    }
```

Here, \textit{type} specifies the type of data returned by the method. This can be any valid type, including class types that you create. If the method does not return a value, its return type must be \textbf{void}. The name of the method is specified by \textit{name}. This can be any legal identifier other than those already used by other items within the current scope. The \textit{parameter-list} is a sequence of type and identifier pairs separated by commas. Parameters are essentially variables that receive the value of the arguments passed to the method when it is called. If the method has no parameters, then the parameter list will be empty.

Methods that have a return type other than \textbf{void} return a value to the calling routine using the following form of the \textbf{return} statement:

```java
    return value;
```

Here, \textit{value} is the value returned.

In the next few sections, you will see how to create various types of methods, including those that take parameters and those that return values.

### Adding a Method to the Box Class

Although it is perfectly fine to create a class that contains only data, it rarely happens. Most of the time, you will use methods to access the instance variables defined by the class. In fact, methods define the interface to most classes. This allows the class implementor to hide
the specific layout of internal data structures behind cleaner method abstractions. In addition to defining methods that provide access to data, you can also define methods that are used internally by the class itself.

Let’s begin by adding a method to the **Box** class. It may have occurred to you while looking at the preceding programs that the computation of a box’s volume was something that was best handled by the **Box** class rather than the **BoxDemo** class. After all, since the volume of a box is dependent upon the size of the box, it makes sense to have the **Box** class compute it. To do this, you must add a method to **Box**, as shown here:
This program generates the following output, which is the same as the previous version.

\[
\text{Volume is 3000.0} \\
\text{Volume is 162.0}
\]

Look closely at the following two lines of code:

```java
mybox1.volume();
mybox2.volume();
```
The first line here invokes the `volume()` method on `mybox1`. That is, it calls `volume()` relative to the `mybox1` object, using the object’s name followed by the dot operator. Thus, the call to `mybox1.volume()` displays the volume of the box defined by `mybox1`, and the call to `mybox2.volume()` displays the volume of the box defined by `mybox2`. Each time `volume()` is invoked, it displays the volume for the specified box.

If you are unfamiliar with the concept of calling a method, the following discussion will help clear things up. When `mybox1.volume()` is executed, the Java run-time system transfers control to the code defined inside `volume()`. After the statements inside `volume()` have executed, control is returned to the calling routine, and execution resumes with the line of code following the call. In the most general sense, a method is Java’s way of implementing subroutines.

There is something very important to notice inside the `volume()` method: the instance variables `width`, `height`, and `depth` are referred to directly, without preceding them with an object name or the dot operator. When a method uses an instance variable that is defined by its class, it does so directly, without explicit reference to an object and without use of the dot operator. This is easy to understand if you think about it. A method is always invoked relative to some object of its class. Once this invocation has occurred, the object is known. Thus, within a method, there is no need to specify the object a second time. This means that `width`, `height`, and `depth` inside `volume()` implicitly refer to the copies of those variables found in the object that invokes `volume()`.

Let’s review: When an instance variable is accessed by code that is not part of the class in which that instance variable is defined, it must be done through an object, by use of the dot operator. However, when an instance variable is accessed by code that is part of the same class as the instance variable, that variable can be referred to directly. The same thing applies to methods.

**Returning a Value**

While the implementation of `volume()` does move the computation of a box’s volume inside the `Box` class where it belongs, it is not the best way to do it. For example, what if another part of your program wanted to know the volume of a box, but not display its value? A better way to implement `volume()` is to have it compute the volume of the box and return the result to the caller. The following example, an improved version of the preceding program, does just that:
// Now, volume() returns the volume of a box.

class Box {
    double width;
    double height;
    double depth;

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class BoxDemo4 {
    public static void main(String args[]) {
        Box mybox1 = new Box();
        Box mybox2 = new Box();
        double vol;

        // assign values to mybox1's instance variables
        mybox1.width = 10;
        mybox1.height = 20;
        mybox1.depth = 15;

        /* assign different values to mybox2's
        instance variables */
        mybox2.width = 3;
        mybox2.height = 6;
        mybox2.depth = 9;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is " + vol);
    }
}

As you can see, when volume( ) is called, it is put on the right side of an assignment statement. On the left is a variable, in this case vol, that will receive the value returned by volume( ). Thus, after

    vol = mybox1.volume();
executes, the value of `mybox1.volume()` is 3,000 and this value then is stored in `vol`.

There are two important things to understand about returning values:

• The type of data returned by a method must be compatible with the return type specified by the method. For example, if the return type of some method is `boolean`, you could not return an integer.
• The variable receiving the value returned by a method (such as `vol`, in this case) must also be compatible with the return type specified for the method.

One more point: The preceding program can be written a bit more efficiently because there is actually no need for the `vol` variable. The call to `volume()` could have been used in the `println()` statement directly, as shown here:

```java
System.out.println("Volume is" + mybox1.volume());
```

In this case, when `println()` is executed, `mybox1.volume()` will be called automatically and its value will be passed to `println()`.

### Adding a Method That Takes Parameters

While some methods don’t need parameters, most do. Parameters allow a method to be generalized. That is, a parameterized method can operate on a variety of data and/or be used in a number of slightly different situations. To illustrate this point, let’s use a very simple example. Here is a method that returns the square of the number 10:

```java
int square() {
    return 10 * 10;
}
```

While this method does, indeed, return the value of 10 squared, its use is very limited. However, if you modify the method so that it takes a parameter, as shown next, then you can make `square()` much more useful.

```java
int square(int i) {
    return i * i;
}
```

Now, `square()` will return the square of whatever value it is called with. That is, `square()` is now a general-purpose method that can compute the square of any integer value, rather than just 10.

Here is an example:
In the first call to `square( )`, the value 5 will be passed into parameter `i`. In the second call, `i` will receive the value 9. The third invocation passes the value of `y`, which is 2 in this example. As these examples show, `square( )` is able to return the square of whatever data it is passed.

It is important to keep the two terms *parameter* and *argument* straight. A *parameter* is a variable defined by a method that receives a value when the method is called. For example, in `square( )`, `i` is a parameter. An *argument* is a value that is passed to a method when it is invoked. For example, `square(100)` passes 100 as an argument. Inside `square( )`, the parameter `i` receives that value.

You can use a parameterized method to improve the `Box` class. In the preceding examples, the dimensions of each box had to be set separately by use of a sequence of statements, such as:

```java
int x, y;
x = square(5); // x equals 25
x = square(9); // x equals 81
y = 2;
x = square(y); // x equals 4
```

While this code works, it is troubling for two reasons. First, it is clumsy and error prone. For example, it would be easy to forget to set a dimension. Second, in well-designed Java programs, instance variables should be accessed only through methods defined by their class. In the future, you can change the behavior of a method, but you can't change the behavior of an exposed instance variable.

Thus, a better approach to setting the dimensions of a box is to create a method that takes the dimensions of a box in its parameters and sets each instance variable appropriately. This concept is implemented by the following program:
As you can see, the `setDim()` method is used to set the dimensions of each box. For example, when

```java
mybox1.setDim(10, 20, 15);
```

is executed, 10 is copied into parameter `w`, 20 is copied into `h`, and 15 is copied into `d`. 

```java
// This program uses a parameterized method.

class Box {
    double width;
    double height;
    double depth;

    // compute and return volume
    double volume() {
        return width * height * depth;
    }

    // sets dimensions of box
    void setDim(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }
}

class BoxDemo5 {
    public static void main(String args[]) {
        Box mybox1 = new Box();
        Box mybox2 = new Box();
        double vol;

        // initialize each box
        mybox1.setDim(10, 20, 15);
        mybox2.setDim(3, 6, 9);

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is " + vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is " + vol);
    }
}
Inside `setDim()` the values of `w`, `h`, and `d` are then assigned to `width`, `height`, and `depth`, respectively.

For many readers, the concepts presented in the preceding sections will be familiar. However, if such things as method calls, arguments, and parameters are new to you, then you might want to take some time to experiment before moving on. The concepts of the method invocation, parameters, and return values are fundamental to Java programming.

**Constructors**

It can be tedious to initialize all of the variables in a class each time an instance is created. Even when you add convenience functions like `setDim()`, it would be simpler and more concise to have all of the setup done at the time the object is first created. Because the requirement for initialization is so common, Java allows objects to initialize themselves when they are created. This automatic initialization is performed through the use of a constructor.

A *constructor* initializes an object immediately upon creation. It has the same name as the class in which it resides and is syntactically similar to a method. Once defined, the constructor is automatically called when the object is created, before the `new` operator completes. Constructors look a little strange because they have no return type, not even `void`. This is because the implicit return type of a class’ constructor is the class type itself. It is the constructor’s job to initialize the internal state of an object so that the code creating an instance will have a fully initialized, usable object immediately.

You can rework the `Box` example so that the dimensions of a box are automatically initialized when an object is constructed. To do so, replace `setDim()` with a constructor. Let’s begin by defining a simple constructor that simply sets the dimensions of each box to the same values. This version is shown here:
/* Here, Box uses a constructor to initialize the
dimensions of a box.
*/
class Box {
    double width;
    double height;
    double depth;

    // This is the constructor for Box.
    Box() {
        System.out.println("Constructing Box");
        width = 10;
        height = 10;
        depth = 10;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class BoxDemo6 {
    public static void main(String args[]) {
        // declare, allocate, and initialize Box objects
        Box mybox1 = new Box();
        Box mybox2 = new Box();

        double vol;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is "+vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is "+vol);
    }
}

When this program is run, it generates the following results:

<table>
<thead>
<tr>
<th>Constructing Box</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constructing Box</td>
</tr>
<tr>
<td>Volume is 1000.0</td>
</tr>
<tr>
<td>Volume is 1000.0</td>
</tr>
</tbody>
</table>
As you can see, both mybox1 and mybox2 were initialized by the Box() constructor when they were created. Since the constructor gives all boxes the same dimensions, 10 by 10 by 10, both mybox1 and mybox2 will have the same volume. The println() statement inside Box() is for the sake of illustration only. Most constructors will not display anything. They will simply initialize an object.

Before moving on, let’s reexamine the new operator. As you know, when you allocate an object, you use the following general form:

```java
class-var = new classname ();
```

Now you can understand why the parentheses are needed after the class name. What is actually happening is that the constructor for the class is being called. Thus, in the line

```java
Box mybox1 = new Box();
```

new Box() is calling the Box() constructor. When you do not explicitly define a constructor for a class, then Java creates a default constructor for the class. This is why the preceding line of code worked in earlier versions of Box that did not define a constructor. The default constructor automatically initializes all instance variables to their default values, which are zero, null, and false, for numeric types, reference types, and boolean, respectively. The default constructor is often sufficient for simple classes, but it usually won’t do for more sophisticated ones. Once you define your own constructor, the default constructor is no longer used.

**Parameterized Constructors**

While the Box() constructor in the preceding example does initialize a Box object, it is not very useful—all boxes have the same dimensions. What is needed is a way to construct Box objects of various dimensions. The easy solution is to add parameters to the constructor. As you can probably guess, this makes it much more useful. For example, the following version of Box defines a parameterized constructor that sets the dimensions of a box as specified by those parameters. Pay special attention to how Box objects are created.
/* Here, Box uses a parameterized constructor to initialize the dimensions of a box.
 */
class Box {
    double width;
    double height;
    double depth;

    // This is the constructor for Box.
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}
class BoxDemo7 {
    public static void main(String args[]) {
        // declare, allocate, and initialize Box objects
        Box mybox1 = new Box(10, 20, 15);
        Box mybox2 = new Box(3, 6, 9);

        double vol;

        // get volume of first box
        vol = mybox1.volume();
        System.out.println("Volume is "+ vol);

        // get volume of second box
        vol = mybox2.volume();
        System.out.println("Volume is "+ vol);
    }
}

The output from this program is shown here:

Volume is 3000.0
Volume is 162.0

As you can see, each object is initialized as specified in the parameters to its constructor. For example, in the following line,
the values 10, 20, and 15 are passed to the `Box()` constructor when `new` creates the object. Thus, `mybox1`'s copy of `width`, `height`, and `depth` will contain the values 10, 20, and 15, respectively.

**The this Keyword**
Sometimes a method will need to refer to the object that invoked it. To allow this, Java defines the `this` keyword. `this` can be used inside any method to refer to the current object. That is, `this` is always a reference to the object on which the method was invoked. You can use `this` anywhere a reference to an object of the current class' type is permitted.

To better understand what `this` refers to, consider the following version of `Box()`:

```java
// A redundant use of this.
Box(double w, double h, double d) {
    this.width = w;
    this.height = h;
    this.depth = d;
}
```

This version of `Box()` operates exactly like the earlier version. The use of `this` is redundant, but perfectly correct. Inside `Box()`, `this` will always refer to the invoking object. While it is redundant in this case, `this` is useful in other contexts, one of which is explained in the next section.

**Instance Variable Hiding**
As you know, it is illegal in Java to declare two local variables with the same name inside the same or enclosing scopes. Interestingly, you can have local variables, including formal parameters to methods, which overlap with the names of the class' instance variables. However, when a local variable has the same name as an instance variable, the local variable hides the instance variable. This is why `width`, `height`, and `depth` were not used as the names of the parameters to the `Box()` constructor inside the `Box` class. If they had been, then `width`, for example, would have referred to the formal parameter, hiding the instance variable `width`. While it is usually easier to simply use different names, there is another way around this situation. Because `this` lets you refer directly to the object, you can use it to resolve any namespace collisions that might occur between instance variables and local variables. For example, here is another version of `Box()`, which uses `width`, `height`, and `depth` for parameter names and then uses `this` to access the instance variables by the same name:
A word of caution: The use of this in such a context can sometimes be confusing, and some programmers are careful not to use local variables and formal parameter names that hide instance variables. Of course, other programmers believe the contrary—that it is a good convention to use the same names for clarity, and use this to overcome the instance variable hiding. It is a matter of taste which approach you adopt.

**Garbage Collection**

Since objects are dynamically allocated by using the new operator, you might be wondering how such objects are destroyed and their memory released for later reallocation. In some languages, such as C++, dynamically allocated objects must be manually released by use of a delete operator. Java takes a different approach; it handles deallocation for you automatically. The technique that accomplishes this is called garbage collection. It works like this: when no references to an object exist, that object is assumed to be no longer needed, and the memory occupied by the object can be reclaimed. There is no explicit need to destroy objects as in C++. Garbage collection only occurs sporadically (if at all) during the execution of your program. It will not occur simply because one or more objects exist that are no longer used. Furthermore, different Java run-time implementations will take varying approaches to garbage collection, but for the most part, you should not have to think about it while writing your programs.

**The finalize( ) Method**

Sometimes an object will need to perform some action when it is destroyed. For example, if an object is holding some non-Java resource such as a file handle or character font, then you might want to make sure these resources are freed before an object is destroyed. To handle such situations, Java provides a mechanism called finalization. By using finalization, you can define specific actions that will occur when an object is just about to be reclaimed by the garbage collector.

To add a finalizer to a class, you simply define the finalize( ) method. The Java run time calls that method whenever it is about to recycle an object of that class. Inside the finalize( ) method, you will specify those actions that must be performed before an object is destroyed. The garbage collector runs periodically, checking for objects that are no longer referenced by any running state or indirectly through other referenced objects. Right before an asset is freed, the Java run time calls the finalize( ) method on the object.

The finalize( ) method has this general form:

```java
// Use this to resolve name-space collisions.
Box(double width, double height, double depth) {
    this.width = width;
    this.height = height;
    this.depth = depth;
}
```

```java
A word of caution: The use of this in such a context can sometimes be confusing, and some programmers are careful not to use local variables and formal parameter names that hide instance variables. Of course, other programmers believe the contrary—that it is a good convention to use the same names for clarity, and use this to overcome the instance variable hiding. It is a matter of taste which approach you adopt.

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The finalize( ) method has this general form:

```java
// Use this to resolve name-space collisions.
Box(double width, double height, double depth) {
    this.width = width;
    this.height = height;
    this.depth = depth;
}
```
Here, the keyword `protected` is a specifier that limits access to `finalize()` . This and the other access modifiers are explained in Chapter 7.

It is important to understand that `finalize()` is only called just prior to garbage collection. It is not called when an object goes out-of-scope, for example. This means that you cannot know when—or even if—`finalize()` will be executed. Therefore, your program should provide other means of releasing system resources, etc., used by the object. It must not rely on `finalize()` for normal program operation.

### NOTE

If you are familiar with C++, then you know that C++ allows you to define a destructor for a class, which is called when an object goes out-of-scope. Java does not support this idea or provide for destructors. The `finalize()` method only approximates the function of a destructor. As you get more experienced with Java, you will see that the need for destructor functions is minimal because of Java’s garbage collection subsystem.

### A Stack Class

While the `Box` class is useful to illustrate the essential elements of a class, it is of little practical value. To show the real power of classes, this chapter will conclude with a more sophisticated example. As you recall from the discussion of object-oriented programming (OOP) presented in Chapter 2, one of OOP’s most important benefits is the encapsulation of data and the code that manipulates that data. As you have seen, the class is the mechanism by which encapsulation is achieved in Java. By creating a class, you are creating a new data type that defines both the nature of the data being manipulated and the routines used to manipulate it. Further, the methods define a consistent and controlled interface to the class’ data. Thus, you can use the class through its methods without having to worry about the details of its implementation or how the data is actually managed within the class. In a sense, a class is like a “data engine.” No knowledge of what goes on inside the engine is required to use the engine through its controls. In fact, since the details are hidden, its inner workings can be changed as needed. As long as your code uses the class through its
methods, internal details can change without causing side effects outside the class. To see a practical application of the preceding discussion, let’s develop one of the archetypal examples of encapsulation: the stack. A stack stores data using first-in, last-out ordering. That is, a stack is like a stack of plates on a table—the first plate put down on the table is the last plate to be used. Stacks are controlled through two operations traditionally called push and pop. To put an item on top of the stack, you will use push. To take an item off the stack, you will use pop. As you will see, it is easy to encapsulate the entire stack mechanism. Here is a class called Stack that implements a stack for up to ten integers:

```java
// This class defines an integer stack that can hold 10 values
class Stack {
    int stack[] = new int[10];
    int tos;

    // Initialize top-of-stack
    Stack() {
        tos = -1;
    }

    // Push an item onto the stack
    void push(int item) {
        if (tos == 9)
            System.out.println("Stack is full.");
        else
            stack[++tos] = item;
    }

    // Pop an item from the stack
    int pop() {
        if (tos < 0) {
            System.out.println("Stack underflow.");
            return 0;
        }
        else
            return stack[tos--];
    }
}
```

As you can see, the Stack class defines two data items and three methods. The stack of integers is held by the array stack. This array is indexed by the variable tos, which always contains the index of the top of the stack. The Stack() constructor initializes tos to -1, which indicates an empty stack. The method push() puts an item on the stack. To retrieve an item, call pop(). Since access to the stack is through push() and pop(), the fact that the stack is held in an array is actually not relevant to using the stack. For example, the stack could be held in a more complicated data structure, such as a linked list, yet the interface defined by push() and pop() would remain the same.
The class **TestStack**, shown here, demonstrates the **Stack** class. It creates two integer stacks, pushes some values onto each, and then pops them off.

```java
class TestStack {
    public static void main(String args[]) {
        Stack mystack1 = new Stack();
        Stack mystack2 = new Stack();

        // push some numbers onto the stack
        for (int i=0; i<10; i++) mystack1.push(i);
        for (int i=10; i<20; i++) mystack2.push(i);

        // pop those numbers off the stack
        System.out.println("Stack in mystack1: ");
        for (int i=0; i<10; i++)
            System.out.println(mystack1.pop());

        System.out.println("Stack in mystack2: ");
        for (int i=0; i<10; i++)
            System.out.println(mystack2.pop());
    }
}
```

This program generates the following output:
As you can see, the contents of each stack are separate.

One last point about the **Stack** class. As it is currently implemented, it is possible for the array that holds the stack, `stck`, to be altered by code outside of the **Stack** class. This leaves **Stack** open to misuse or mischief. In the next chapter, you will see how to remedy this situation.
This chapter continues the discussion of methods and classes begun in the preceding chapter. It examines several topics relating to methods, including overloading, parameter passing, and recursion. The chapter then returns to the class, discussing access control, the use of the keyword `static`, and one of Java’s most important built-in classes: `String`.

Overloading Methods

In Java, it is possible to define two or more methods within the same class that share the same name, as long as their parameter declarations are different. When this is the case, the methods are said to be overloaded, and the process is referred to as *method overloading*. Method overloading is one of the ways that Java supports polymorphism. If you have never used a language that allows the overloading of methods, then the concept may seem strange at first. But as you will see, method overloading is one of Java’s most exciting and useful features.

When an overloaded method is invoked, Java uses the type and/or number of arguments as its guide to determine which version of the overloaded method to actually call. Thus, overloaded methods must differ in the type and/or number of their parameters. While overloaded methods may have different return types, the return type alone is insufficient to distinguish two versions of a method. When Java encounters a call to an overloaded method, it simply executes the version of the method whose parameters match the arguments used in the call.

Here is a simple example that illustrates method overloading:
This program generates the following output:

```
No parameters
a: 10
a and b: 10 20
double a: 123.25
Result of ob.test(123.25): 15190.5625
```

As you can see, `test()` is overloaded four times. The first version takes no parameters, the second takes one integer parameter, the third takes two integer parameters, and the fourth takes one `double` parameter. The fact that the fourth version of `test()` also returns a value is of no consequence relative to overloading, since return types do not play a role in
overload resolution.
When an overloaded method is called, Java looks for a match between the arguments used
to call the method and the method’s parameters. However, this match need not always be
exact. In some cases, Java’s automatic type conversions can play a role in overload
resolution. For example, consider the following program:

```java
// Automatic type conversions apply to overloading.
class OverloadDemo {
    void test() {
        System.out.println("No parameters");
    }

    // Overload test for two integer parameters.
    void test(int a, int b) {
        System.out.println("a and b: " + a + " " + b);
    }

    // Overload test for a double parameter
    void test(double a) {
        System.out.println("Inside test(double) a: " + a);
    }
}

class Overload {
    public static void main(String args[]) {
        OverloadDemo ob = new OverloadDemo();
        int i = 88;
        ob.test();
        ob.test(10, 20);
        ob.test(i); // this will invoke test(double)
        ob.test(123.2); // this will invoke test(double)
    }
}
```

This program generates the following output:

```
No parameters
a and b: 10 20
Inside test(double) a: 88
Inside test(double) a: 123.2
```

As you can see, this version of `OverloadDemo` does not define `test(int)`. Therefore, when
**test( )** is called with an integer argument inside **Overload**, no matching method is found. However, Java can automatically convert an integer into a **double**, and this conversion can be used to resolve the call. Therefore, after **test(int)** is not found, Java elevates **i** to **double** and then calls **test(double)**. Of course, if **test(int)** had been defined, it would have been called instead. Java will employ its automatic type conversions only if no exact match is found.

Method overloading supports polymorphism because it is one way that Java implements the “one interface, multiple methods” paradigm. To understand how, consider the following. In languages that do not support method overloading, each method must be given a unique name. However, frequently you will want to implement essentially the same method for different types of data. Consider the absolute value function. In languages that do not support overloading, there are usually three or more versions of this function, each with a slightly different name. For instance, in C, the function **abs( )** returns the absolute value of an integer, **labs( )** returns the absolute value of a long integer, and **fabs( )** returns the absolute value of a floating-point value. Since C does not support overloading, each function has its own name, even though all three functions do essentially the same thing. This makes the situation more complex, conceptually, than it actually is. Although the underlying concept of each function is the same, you still have three names to remember. This situation does not occur in Java, because each absolute value method can use the same name. Indeed, Java’s standard class library includes an absolute value method, called **abs( )**. This method is overloaded by Java’s **Math** class to handle all numeric types. Java determines which version of **abs( )** to call based upon the type of argument.

The value of overloading is that it allows related methods to be accessed by use of a common name. Thus, the name **abs** represents the **general action** that is being performed. It is left to the compiler to choose the right **specific** version for a particular circumstance. You, the programmer, need only remember the general operation being performed. Through the application of polymorphism, several names have been reduced to one. Although this example is fairly simple, if you expand the concept, you can see how overloading can help you manage greater complexity.

When you overload a method, each version of that method can perform any activity you desire. There is no rule stating that overloaded methods must relate to one another. However, from a stylistic point of view, method overloading implies a relationship. Thus, while you can use the same name to overload unrelated methods, you should not. For example, you could use the name **sqr** to create methods that return the **square** of an integer and the **square root** of a floating-point value. But these two operations are fundamentally different. Applying method overloading in this manner defeats its original purpose. In practice, you should only overload closely related operations.

**Overloading Constructors**

In addition to overloading normal methods, you can also overload constructor methods. In fact, for most real-world classes that you create, overloaded constructors will be the norm,
not the exception. To understand why, let’s return to the **Box** class developed in the preceding chapter. Following is the latest version of **Box**:

```java
class Box {
    double width;
    double height;
    double depth;

    // This is the constructor for Box.
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}
```

As you can see, the **Box( )** constructor requires three parameters. This means that all declarations of **Box** objects must pass three arguments to the **Box( )** constructor. For example, the following statement is currently invalid:

```java
Box ob = new Box();
```

Since **Box( )** requires three arguments, it’s an error to call it without them. This raises some important questions. What if you simply wanted a box and did not care (or know) what its initial dimensions were? Or, what if you want to be able to initialize a cube by specifying only one value that would be used for all three dimensions? As the **Box** class is currently written, these other options are not available to you.

Fortunately, the solution to these problems is quite easy: simply overload the **Box** constructor so that it handles the situations just described. Here is a program that contains an improved version of **Box** that does just that:
The output produced by this program is shown here:
As you can see, the proper overloaded constructor is called based upon the parameters specified when `new` is executed.

**Using Objects as Parameters**

So far, we have only been using simple types as parameters to methods. However, it is both correct and common to pass objects to methods. For example, consider the following short program:

```java
// Objects may be passed to methods.
class Test {
    int a, b;

    Test(int i, int j) {
        a = i;
        b = j;
    }

    // return true if o is equal to the invoking object
    boolean equals(Test o) {
        if (o.a == a && o.b == b) return true;
        else return false;
    }
}

class PassOb {
    public static void main(String args[]) {
        Test ob1 = new Test(100, 22);
        Test ob2 = new Test(100, 22);
        Test ob3 = new Test(-1, -1);

        System.out.println("ob1 == ob2: " + ob1.equals(ob2));
        System.out.println("ob1 == ob3: " + ob1.equals(ob3));
    }
}
```

This program generates the following output:

```
    ob1 == ob2: true
    ob1 == ob3: false
```

As you can see, the `equals()` method inside `Test` compares two objects for equality and
returns the result. That is, it compares the invoking object with the one that it is passed. If they contain the same values, then the method returns true. Otherwise, it returns false. Notice that the parameter o in equalTo() specifies Test as its type. Although Test is a class type created by the program, it is used in just the same way as Java’s built-in types.

One of the most common uses of object parameters involves constructors. Frequently, you will want to construct a new object so that it is initially the same as some existing object. To do this, you must define a constructor that takes an object of its class as a parameter. For example, the following version of Box allows one object to initialize another:
// Here, Box allows one object to initialize another.

class Box {
    double width;
    double height;
    double depth;

    // Notice this constructor. It takes an object of type Box.
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

class overloadCons2 {
    public static void main(String args[]) {
        // create boxes using the various constructors
As you will see when you begin to create your own classes, providing many forms of constructors is usually required to allow objects to be constructed in a convenient and efficient manner.

A Closer Look at Argument Passing

In general, there are two ways that a computer language can pass an argument to a subroutine. The first way is call-by-value. This approach copies the value of an argument into the formal parameter of the subroutine. Therefore, changes made to the parameter of the subroutine have no effect on the argument. The second way an argument can be passed is call-by-reference. In this approach, a reference to an argument (not the value of the argument) is passed to the parameter. Inside the subroutine, this reference is used to access the actual argument specified in the call. This means that changes made to the parameter will affect the argument used to call the subroutine. As you will see, although Java uses call-by-value to pass all arguments, the precise effect differs between whether a primitive type or a reference type is passed.

When you pass a primitive type to a method, it is passed by value. Thus, a copy of the argument is made, and what occurs to the parameter that receives the argument has no effect outside the method. For example, consider the following program:

```
Box mybox1 = new Box(10, 20, 15);
Box mybox2 = new Box();
Box mycube = new Box(7);

Box myclone = new Box(mybox1); // create copy of mybox1

double vol;

// get volume of first box
vol = mybox1.volume();
System.out.println("Volume of mybox1 is " + vol);

// get volume of second box
vol = mybox2.volume();
System.out.println("Volume of mybox2 is " + vol);

// get volume of cube
vol = mycube.volume();
System.out.println("Volume of cube is " + vol);

// get volume of clone
vol = myclone.volume();
System.out.println("Volume of clone is " + vol);
```
The output from this program is shown here:

```java
// Primitive types are passed by value.
class Test {
    void meth(int i, int j) {
        i *= 2;
        j /= 2;
    }
}

class CallByValue {
    public static void main(String args[]) {
        Test ob = new Test();
        int a = 15, b = 20;
        System.out.println("a and b before call: " + a + " " + b);
        ob.meth(a, b);
        System.out.println("a and b after call: " + a + " " + b);
    }
}
```

As you can see, the operations that occur inside `meth()` have no effect on the values of `a` and `b` used in the call; their values here did not change to 30 and 10.

When you pass an object to a method, the situation changes dramatically, because objects are passed by what is effectively call-by-reference. Keep in mind that when you create a variable of a class type, you are only creating a reference to an object. Thus, when you pass this reference to a method, the parameter that receives it will refer to the same object as that referred to by the argument. This effectively means that objects act as if they are passed to methods by use of call-by-reference. Changes to the object inside the method `do` affect the object used as an argument. For example, consider the following program:
This program generates the following output:

```
ob.a and ob.b before call: 15 20
ob.a and ob.b after call: 30 10
```

As you can see, in this case, the actions inside `meth()` have affected the object used as an argument.

---

**REMEMBER** When an object reference is passed to a method, the reference itself is passed by use of call-by-value. However, since the value being passed refers to an object, the copy of that value will still refer to the same object that its corresponding argument does.
Returning Objects
A method can return any type of data, including class types that you create. For example, in the following program, the `incrByTen()` method returns an object in which the value of `a` is ten greater than it is in the invoking object.

```java
// Returning an object.
class Test {
    int a;

    Test(int i) {
        a = i;
    }

    Test incrByTen() {
        Test temp = new Test(a+10);
        return temp;
    }
}

class RetOb {
    public static void main(String args[]) {
        Test ob1 = new Test(2);
        Test ob2;

        ob2 = ob1.incrByTen();
        System.out.println("ob1.a: " + ob1.a);
        System.out.println("ob2.a: " + ob2.a);
        ob2 = ob2.incrByTen();
        System.out.println("ob2.a after second increase: ", + ob2.a);
    }
}
```

The output generated by this program is shown here:

```
ob1.a: 2
ob2.a: 12
ob2.a after second increase: 22
```

As you can see, each time `incrByTen()` is invoked, a new object is created, and a reference to it is returned to the calling routine.

The preceding program makes another important point: Since all objects are dynamically
allocated using `new`, you don’t need to worry about an object going out-of-scope because the method in which it was created terminates. The object will continue to exist as long as there is a reference to it somewhere in your program. When there are no references to it, the object will be reclaimed the next time garbage collection takes place.

**Recursion**

Java supports *recursion*. Recursion is the process of defining something in terms of itself. As it relates to Java programming, recursion is the attribute that allows a method to call itself. A method that calls itself is said to be *recursive*.

The classic example of recursion is the computation of the factorial of a number. The factorial of a number $N$ is the product of all the whole numbers between 1 and $N$. For example, 3 factorial is $1 \times 2 \times 3 \times$, or 6. Here is how a factorial can be computed by use of a recursive method:

```java
// A simple example of recursion.
class Factorial {
    // this is a recursive method
    int fact(int n) {
        int result;
        if (n == 1) return 1;
        result = fact(n - 1) * n;
        return result;
    }
}

class Recursion {
    public static void main(String args[]) {
        Factorial f = new Factorial();
        System.out.println("Factorial of 3 is " + f.fact(3));
        System.out.println("Factorial of 4 is " + f.fact(4));
        System.out.println("Factorial of 5 is " + f.fact(5));
    }
}
```

The output from this program is shown here:

```
Factorial of 3 is 6
Factorial of 4 is 24
Factorial of 5 is 120
```

If you are unfamiliar with recursive methods, then the operation of `fact()` may seem a bit confusing. Here is how it works. When `fact()` is called with an argument of 1, the function
returns 1; otherwise, it returns the product of $\text{fact}(n-1) \times n$. To evaluate this expression, $\text{fact}( )$ is called with $n-1$. This process repeats until $n$ equals 1 and the calls to the method begin returning.

To better understand how the $\text{fact}( )$ method works, let’s go through a short example. When you compute the factorial of 3, the first call to $\text{fact}( )$ will cause a second call to be made with an argument of 2. This invocation will cause $\text{fact}( )$ to be called a third time with an argument of 1. This call will return 1, which is then multiplied by 2 (the value of $n$ in the second invocation). This result (which is 2) is then returned to the original invocation of $\text{fact}( )$ and multiplied by 3 (the original value of $n$). This yields the answer, 6. You might find it interesting to insert println( ) statements into $\text{fact}( )$, which will show at what level each call is and what the intermediate answers are.

When a method calls itself, new local variables and parameters are allocated storage on the stack, and the method code is executed with these new variables from the start. As each recursive call returns, the old local variables and parameters are removed from the stack, and execution resumes at the point of the call inside the method. Recursive methods could be said to “telescope” out and back.

Recursive versions of many routines may execute a bit more slowly than the iterative equivalent because of the added overhead of the additional method calls. Many recursive calls to a method could cause a stack overrun. Because storage for parameters and local variables is on the stack and each new call creates a new copy of these variables, it is possible that the stack could be exhausted. If this occurs, the Java run-time system will cause an exception. However, you probably will not have to worry about this unless a recursive routine runs wild.

The main advantage to recursive methods is that they can be used to create clearer and simpler versions of several algorithms than can their iterative relatives. For example, the QuickSort sorting algorithm is quite difficult to implement in an iterative way. Also, some types of AI-related algorithms are most easily implemented using recursive solutions.

When writing recursive methods, you must have an if statement somewhere to force the method to return without the recursive call being executed. If you don’t do this, once you call the method, it will never return. This is a very common error in working with recursion. Use println( ) statements liberally during development so that you can watch what is going on and abort execution if you see that you have made a mistake.

Here is one more example of recursion. The recursive method $\text{printArray}( )$ prints the first $i$ elements in the array values.
This program generates the following output:

```
[0] 0
[1] 1
[2] 2
[3] 3
[4] 4
[5] 5
[6] 6
[7] 7
[8] 8
[9] 9
```

**Introducing Access Control**

As you know, encapsulation links data with the code that manipulates it. However, encapsulation provides another important attribute: access control. Through encapsulation, you can control what parts of a program can access the members of a class. By controlling access, you can prevent misuse. For example, allowing access to data only through a well-defined set of methods, you can prevent the misuse of that data. Thus, when correctly
implemented, a class creates a “black box” which may be used, but the inner workings of
which are not open to tampering. However, the classes that were presented earlier do not
completely meet this goal. For example, consider the Stack class shown at the end of
Chapter 6. While it is true that the methods push() and pop() do provide a controlled
interface to the stack, this interface is not enforced. That is, it is possible for another part of
the program to bypass these methods and access the stack directly. Of course, in the wrong
hands, this could lead to trouble. In this section, you will be introduced to the mechanism
by which you can precisely control access to the various members of a class.
How a member can be accessed is determined by the access modifier attached to its
declaration. Java supplies a rich set of access modifiers. Some aspects of access control are
related mostly to inheritance or packages. (A package is, essentially, a grouping of classes.)
These parts of Java’s access control mechanism will be discussed later. Here, let’s begin by
examining access control as it applies to a single class. Once you understand the
fundamentals of access control, the rest will be easy.
Java’s access modifiers are public, private, and protected. Java also defines a default
access level. protected applies only when inheritance is involved. The other access
modifiers are described next.
Let’s begin by defining public and private. When a member of a class is modified by
public, then that member can be accessed by any other code. When a member of a class is
specified as private, then that member can only be accessed by other members of its class.
Now you can understand why main() has always been preceded by the public modifier. It
is called by code that is outside the program—that is, by the Java run-time system. When no
access modifier is used, then by default the member of a class is public within its own
package, but cannot be accessed outside of its package. (Packages are discussed in the
following chapter.)
In the classes developed so far, all members of a class have used the default access mode.
However, this is not what you will typically want to be the case. Usually, you will want to
restrict access to the data members of a class—allowing access only through methods. Also,
there will be times when you will want to define methods that are private to a class.
An access modifier precedes the rest of a member’s type specification. That is, it must begin
a member’s declaration statement. Here is an example:

```java
public int i;
private double j;
private int myMethod(int a, char b) { //...}
```

To understand the effects of public and private access, consider the following program:
/* This program demonstrates the difference between public and private.
 */
class Test {
    int a; // default access
    public int b; // public access
    private int c; // private access

    // methods to access c
    void setc(int i) { // set c's value
        c = i;
    }
    int getc() { // get c's value
        return c;
    }
}
class AccessTest {
    public static void main(String args[]) {
        Test ob = new Test();

        // These are OK, a and b may be accessed directly
        ob.a = 10;
        ob.b = 20;

        // This is not OK and will cause an error
        // ob.c = 100; // Error!

        // You must access c through its methods
        ob.setc(100); // OK
        System.out.println("a, b, and c: " + ob.a + " + ob.b + " + ob.getc()");
    }
}

As you can see, inside the Test class, a uses default access, which for this example is the same as specifying public. b is explicitly specified as public. Member c is given private access. This means that it cannot be accessed by code outside of its class. So, inside the AccessTest class, c cannot be used directly. It must be accessed through its public methods: setc() and getc(). If you were to remove the comment symbol from the beginning of the following line,

    // ob.c = 100; // Error!

then you would not be able to compile this program because of the access violation. To see how access control can be applied to a more practical example, consider the
following improved version of the **Stack** class shown at the end of Chapter 6.

```java
// This class defines an integer stack that can hold 10 values.
class Stack {
   /* Now, both stk and tos are private. This means
      that they cannot be accidentally or maliciously
      altered in a way that would be harmful to the stack.
   */
   private int stk[] = new int[10];
   private int tos;

   // Initialize top-of-stack
   Stack() {
      tos = -1;
   }

   // Push an item onto the stack
   void push(int item) {
      if(tos==9)
         System.out.println("Stack is full.");
      else
         stk[++tos] = item;
   }

   // Pop an item from the stack
   int pop() {
      if(tos < 0) {
         System.out.println("Stack underflow.");
         return 0;
      }
      else
         return stk[tos--];
   }
}
```

As you can see, now both **stk**, which holds the stack, and **tos**, which is the index of the top of the stack, are specified as **private**. This means that they cannot be accessed or altered except through **push()** and **pop()**. Making **tos** private, for example, prevents other parts of your program from inadvertently setting it to a value that is beyond the end of the **stk** array.

The following program demonstrates the improved **Stack** class. Try removing the commented-out lines to prove to yourself that the **stk** and **tos** members are, indeed, inaccessible.
Although methods will usually provide access to the data defined by a class, this does not always have to be the case. It is perfectly proper to allow an instance variable to be public when there is good reason to do so. For example, most of the simple classes in this book were created with little concern about controlling access to instance variables for the sake of simplicity. However, in most real-world classes, you will need to allow operations on data only through methods. The next chapter will return to the topic of access control. As you will see, it is particularly important when inheritance is involved.

Understanding static

There will be times when you will want to define a class member that will be used independently of any object of that class. Normally, a class member must be accessed only in conjunction with an object of its class. However, it is possible to create a member that can be used by itself, without reference to a specific instance. To create such a member, precede its declaration with the keyword `static`. When a member is declared `static`, it can be accessed before any objects of its class are created, and without reference to any object. You can declare both methods and variables to be `static`. The most common example of a `static` member is `main()`. `main()` is declared as `static` because it must be called before any objects exist.
Instance variables declared as static are, essentially, global variables. When objects of its class are declared, no copy of a static variable is made. Instead, all instances of the class share the same static variable.

Methods declared as static have several restrictions:

- They can only directly call other static methods.
- They can only directly access static data.
- They cannot refer to this or super in any way. (The keyword super relates to inheritance and is described in the next chapter.)

If you need to do computation in order to initialize your static variables, you can declare a static block that gets executed exactly once, when the class is first loaded. The following example shows a class that has a static method, some static variables, and a static initialization block:

```java
// Demonstrate static variables, methods, and blocks.
class UseStatic {
    static int a = 3;
    static int b;

    static void meth(int x) {
        System.out.println("x = " + x);
        System.out.println("a = " + a);
        System.out.println("b = " + b);
    }

    static {
        System.out.println("Static block initialized.");
        b = a * 4;
    }

    public static void main(String args[]) {
        meth(42);
    }
}
```

As soon as the UseStatic class is loaded, all of the static statements are run. First, a is set to 3, then the static block executes, which prints a message and then initializes b to a*4 or 12. Then main() is called, which calls meth(), passing 42 to x. The three println() statements refer to the two static variables a and b, as well as to the local variable x.

Here is the output of the program:
Outside of the class in which they are defined, static methods and variables can be used independently of any object. To do so, you need only specify the name of their class followed by the dot operator. For example, if you wish to call a static method from outside its class, you can do so using the following general form:

    classname.method()

Here, classname is the name of the class in which the static method is declared.

As you can see, this format is similar to that used to call non-static methods through object-reference variables. A static variable can be accessed in the same way—by use of the dot operator on the name of the class. This is how Java implements a controlled version of global methods and global variables.

Here is an example. Inside main(), the static method callme() and the static variable b are accessed through their class name StaticDemo.

```java
class StaticDemo {
    static int a = 42;
    static int b = 99;

    static void callme() {
        System.out.println("a = " + a);
    }
}

class StaticByName {
    public static void main(String args[]) {
        StaticDemo.callme();
        System.out.println("b = " + StaticDemo.b);
    }
}
```

Here is the output of this program:

```
a = 42
b = 99
```

**Introducing final**

A field can be declared as final. Doing so prevents its contents from being modified, making it, essentially, a constant. This means that you must initialize a final field when it is
declared. You can do this in one of two ways: First, you can give it a value when it is declared. Second, you can assign it a value within a constructor. The first approach is the most common. Here is an example:

```java
final int FILE_NEW = 1;
final int FILE_OPEN = 2;
final int FILE_SAVE = 3;
final int FILE_SAVEAS = 4;
final int FILE.Quit = 5;
```

Subsequent parts of your program can now use `FILE_OPEN`, etc., as if they were constants, without fear that a value has been changed. It is a common coding convention to choose all uppercase identifiers for `final` fields, as this example shows.

In addition to fields, both method parameters and local variables can be declared `final`. Declaring a parameter `final` prevents it from being changed within the method. Declaring a local variable `final` prevents it from being assigned a value more than once.

The keyword `final` can also be applied to methods, but its meaning is substantially different than when it is applied to variables. This additional usage of `final` is described in the next chapter, when inheritance is described.

### Arrays Revisited

Arrays were introduced earlier in this book, before classes had been discussed. Now that you know about classes, an important point can be made about arrays: they are implemented as objects. Because of this, there is a special array attribute that you will want to take advantage of. Specifically, the size of an array—that is, the number of elements that an array can hold—is found in its `length` instance variable. All arrays have this variable, and it will always hold the size of the array. Here is a program that demonstrates this property:

```java
// This program demonstrates the length array member.
class Length {
    public static void main(String args[]) {
        int a1[] = new int[10];
        int a2[] = {3, 5, 7, 1, 8, 99, 44, -10};
        int a3[] = {4, 3, 2, 1};

        System.out.println("length of a1 is " + a1.length);
        System.out.println("length of a2 is " + a2.length);
        System.out.println("length of a3 is " + a3.length);
    }
}
```

This program displays the following output:
As you can see, the size of each array is displayed. Keep in mind that the value of length has nothing to do with the number of elements that are actually in use. It only reflects the number of elements that the array is designed to hold.

You can put the length member to good use in many situations. For example, here is an improved version of the Stack class. As you might recall, the earlier versions of this class always created a ten-element stack. The following version lets you create stacks of any size. The value of stk.length is used to prevent the stack from overflowing.
Notice that the program creates two stacks: one five elements deep and the other eight elements deep. As you can see, the fact that arrays maintain their own length information makes it easy to create stacks of any size.

**Introducing Nested and Inner Classes**
It is possible to define a class within another class; such classes are known as nested classes. The scope of a nested class is bounded by the scope of its enclosing class. Thus, if class B is defined within class A, then B does not exist independently of A. A nested class has access to the members, including private members, of the class in which it is nested. However, the enclosing class does not have access to the members of the nested class. A nested class that is declared directly within its enclosing class scope is a member of its enclosing class. It is also possible to declare a nested class that is local to a block.

There are two types of nested classes: static and non-static. A static nested class is one that has the static modifier applied. Because it is static, it must access the non-static members of its enclosing class through an object. That is, it cannot refer to non-static members of its enclosing class directly. Because of this restriction, static nested classes are seldom used. The most important type of nested class is the inner class. An inner class is a non-static nested class. It has access to all of the variables and methods of its outer class and may refer to them directly in the same way that other non-static members of the outer class do.

The following program illustrates how to define and use an inner class. The class named Outer has one instance variable named outer_x, one instance method named test(), and defines one inner class called Inner.

```java
// Demonstrate an inner class.
class Outer {
    int outer_x = 100;

    void test() {
        Inner inner = new Inner();
        inner.display();
    }

    // this is an inner class
    class Inner {
        void display() {
            System.out.println("display: outer_x = " + outer_x);
        }
    }
}

class InnerClassDemo {
    public static void main(String args[]) {
        Outer outer = new Outer();
        outer.test();
    }
}
```

Output from this application is shown here:
In the program, an inner class named `Inner` is defined within the scope of class `Outer`. Therefore, any code in class `Inner` can directly access the variable `outer_x`. An instance method named `display( )` is defined inside `Inner`. This method displays `outer_x` on the standard output stream. The `main( )` method of `InnerClassDemo` creates an instance of class `Outer` and invokes its `test( )` method. That method creates an instance of class `Inner` and the `display( )` method is called.

It is important to realize that an instance of `Inner` can be created only in the context of class `Outer`. The Java compiler generates an error message otherwise. In general, an inner class instance is often created by code within its enclosing scope, as the example does. As explained, an inner class has access to all of the members of its enclosing class, but the reverse is not true. Members of the inner class are known only within the scope of the inner class and may not be used by the outer class. For example,

```java
// This program will not compile.
class Outer {
    int outer_x = 100;

    void test() {
        Inner inner = new Inner();
        inner.display();
    }

    // this is an inner class
    class Inner {
        int y = 10; // y is local to Inner

        void display() {
            System.out.println("display: outer_x = " + outer_x);
        }
    }

    void showy() {
        System.out.println(y); // error, y not known here!
    }
}

class InnerClassDemo {
    public static void main(String args[]) {
        Outer outer = new Outer();
        outer.test();
    }
}
```
Here, y is declared as an instance variable of Inner. Thus, it is not known outside of that class and it cannot be used by showy(). Although we have been focusing on inner classes declared as members within an outer class scope, it is possible to define inner classes within any block scope. For example, you can define a nested class within the block defined by a method or even within the body of a for loop, as this next program shows:

```java
// Define an inner class within a for loop.
class Outer {
    int outer_x = 100;
    void test() {
        for(int i=0; i<10; i++) {
            class Inner {
                void display() {
                    System.out.println("display: outer_x = " + outer_x);
                }
            } // Inner
            Inner inner = new Inner();
            inner.display();
        } // for
    } // test
}

class InnerClassDemo {
    public static void main(String args[]) {
        Outer outer = new Outer();
        outer.test();
    }
}
```

The output from this version of the program is shown here:

```
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
display: outer_x = 100
```

While nested classes are not applicable to all situations, they are particularly helpful when handling events. We will return to the topic of nested classes in Chapter 24. There you will
see how inner classes can be used to simplify the code needed to handle certain types of events. You will also learn about anonymous inner classes, which are inner classes that don’t have a name.

One final point: Nested classes were not allowed by the original 1.0 specification for Java. They were added by Java 1.1.

Exploring the String Class
Although the String class will be examined in depth in Part II of this book, a short exploration of it is warranted now, because we will be using strings in some of the example programs shown toward the end of Part I. String is probably the most commonly used class in Java’s class library. The obvious reason for this is that strings are a very important part of programming.

The first thing to understand about strings is that every string you create is actually an object of type String. Even string constants are actually String objects. For example, in the statement

```java
System.out.println("This is a String, too");
```

the string "This is a String, too" is a String object. The second thing to understand about strings is that objects of type String are immutable; once a String object is created, its contents cannot be altered. While this may seem like a serious restriction, it is not, for two reasons:

• If you need to change a string, you can always create a new one that contains the modifications.
• Java defines peer classes of String, called StringBuffer and StringBuilder, which allow strings to be altered, so all of the normal string manipulations are still available in Java. (StringBuffer and StringBuilder are described in Part II of this book.)

Strings can be constructed in a variety of ways. The easiest is to use a statement like this:

```java
String myString = "this is a test";
```

Once you have created a String object, you can use it anywhere that a string is allowed. For example, this statement displays myString:

```java
System.out.println(myString);
```

Java defines one operator for String objects: +. It is used to concatenate two strings. For example, this statement
String myString = "I" + " like " + "Java."

results in myString containing "I like Java."
The following program demonstrates the preceding concepts:

```java
// Demonstrating Strings.
class StringDemo {
    public static void main(String args[]) {
        String strOb1 = "First String";
        String strOb2 = "Second String";
        String strOb3 = strOb1 + " and " + strOb2;

        System.out.println(strOb1);
        System.out.println(strOb2);
        System.out.println(strOb3);
    }
}
```
The output produced by this program is shown here:

```
First String
Second String
First String and Second String
```

The String class contains several methods that you can use. Here are a few. You can test two strings for equality by using equals(). You can obtain the length of a string by calling the length() method. You can obtain the character at a specified index within a string by calling charAt(). The general forms of these three methods are shown here:

```java
boolean equals(secondStr)
int length()
char charAt(index)
```

Here is a program that demonstrates these methods:
// Demonstrating some String methods.
class StringDemo2 {
    public static void main(String args[]) {
        String strObj1 = "First String";
        String strObj2 = "Second string";
        String strObj3 = strObj1;

        System.out.println("Length of strObj1: " +
                            strObj1.length());

        System.out.println("Char at index 3 in strObj1: " +
                            strObj1.charAt(3));

        if(strObj1.equals(strObj2))
            System.out.println("strObj1 == strObj2");
        else
            System.out.println("strObj1 != strObj2");

        if(strObj1.equals(strObj3))
            System.out.println("strObj1 == strObj3");
        else
            System.out.println("strObj1 != strObj3");
    }
}

This program generates the following output:

```
Length of strObj1: 12
Char at index 3 in strObj1: e
strObj1 != strObj2
strObj1 == strObj3
```

Of course, you can have arrays of strings, just like you can have arrays of any other type of object. For example:
As you will see in the following section, string arrays play an important part in many Java programs.

**Using Command-Line Arguments**

Sometimes you will want to pass information into a program when you run it. This is accomplished by passing command-line arguments to `main()`. A command-line argument is the information that directly follows the program’s name on the command line when it is executed. To access the command-line arguments inside a Java program is quite easy—they are stored as strings in a `String` array passed to the `args` parameter of `main()`. The first command-line argument is stored at `args[0]`, the second at `args[1]`, and so on. For example, the following program displays all of the command-line arguments that it is called with:

```java
// Display all command-line arguments.
public static void main(String args[]) {
    for(int i=0; i<args.length; i++)
        System.out.println("args[" + i + "]: " +
                        args[i]);
}
```

Try executing this program, as shown here:

```
java CommandLine this is a test 100 -1
```
Varargs: Variable-Length Arguments

Beginning with JDK 5, Java has included a feature that simplifies the creation of methods that need to take a variable number of arguments. This feature is called varargs and it is short for variable-length arguments. A method that takes a variable number of arguments is called a variable-arity method, or simply a varargs method.

Situations that require that a variable number of arguments be passed to a method are not unusual. For example, a method that opens an Internet connection might take a user name, password, filename, protocol, and so on, but supply defaults if some of this information is not provided. In this situation, it would be convenient to pass only the arguments to which the defaults did not apply. Another example is the printf() method that is part of Java’s I/O library. As you will see in Chapter 20, it takes a variable number of arguments, which it formats and then outputs.

Prior to JDK 5, variable-length arguments could be handled two ways, neither of which was particularly pleasing. First, if the maximum number of arguments was small and known, then you could create overloaded versions of the method, one for each way the method could be called. Although this works and is suitable for some cases, it applies to only a narrow class of situations.

In cases where the maximum number of potential arguments was larger, or unknowable, a second approach was used in which the arguments were put into an array, and then the array was passed to the method. This approach is illustrated by the following program:
The output from the program is shown here:

```
Number of args: 1 Contents: 10
Number of args: 3 Contents: 1 2 3
Number of args: 0 Contents:
```

In the program, the method `vaTest()` is passed its arguments through the array `v`. This old-style approach to variable-length arguments does enable `vaTest()` to take an arbitrary number of arguments. However, it requires that these arguments be manually packaged into an array prior to calling `vaTest()`. Not only is it tedious to construct an array each time `vaTest()` is called, it is potentially error-prone. The varargs feature offers a simpler, better option.

A variable-length argument is specified by three periods (...). For example, here is how `vaTest()` is written using a vararg:

```java
static void vaTest(int ... v) {
    System.out.print("Number of args: "+v.length+
        " Contents: ");
    for(int x : v)
        System.out.print(x + " ");
    System.out.println();
}
```

In the program, the method `vaTest( )` is passed its arguments through the array `v`. This old-style approach to variable-length arguments does enable `vaTest( )` to take an arbitrary number of arguments. However, it requires that these arguments be manually packaged into an array prior to calling `vaTest( )`. Not only is it tedious to construct an array each time `vaTest( )` is called, it is potentially error-prone. The varargs feature offers a simpler, better option.

A variable-length argument is specified by three periods (...). For example, here is how `vaTest( )` is written using a vararg:

```java
static void vaTest(int ... v) {
    System.out.print("Number of args: "+v.length+
        " Contents: ");
    for(int x : v)
        System.out.print(x + " ");
    System.out.println();
}
```
This syntax tells the compiler that \texttt{vaTest()} can be called with zero or more arguments. As a result, \texttt{v} is implicitly declared as an array of type \texttt{int[ ]}. Thus, inside \texttt{vaTest()}, \texttt{v} is accessed using the normal array syntax. Here is the preceding program rewritten using a vararg:

```java
//@ Demonstrate variable-length arguments.
class VarArgs {

//@ vaTest() now uses a vararg.
static void vaTest(int ... v) {
   System.out.print("Number of args: "+ v.length +
   " Contents: ");

   for(int x : v)
      System.out.print(x + " ");

   System.out.println();
}

public static void main(String args[]) {
   // Notice how vaTest() can be called with a variable number of arguments.
   vaTest(10);       // 1 arg
   vaTest(1, 2, 3);  // 3 args
   vaTest();         // no args
}
```

The output from the program is the same as the original version.

There are two important things to notice about this program. First, as explained, inside \texttt{vaTest()}, \texttt{v} is operated on as an array. This is because \texttt{v} is an array. The ... syntax simply tells the compiler that a variable number of arguments will be used, and that these arguments will be stored in the array referred to by \texttt{v}. Second, in \texttt{main()}, \texttt{vaTest()} is called with different numbers of arguments, including no arguments at all. The arguments are automatically put in an array and passed to \texttt{v}. In the case of no arguments, the length of the array is zero.

A method can have “normal” parameters along with a variable-length parameter. However, the variable-length parameter must be the last parameter declared by the method. For example, this method declaration is perfectly acceptable:

```java
int doIt(int a, int b, double c, int ... vals) {
```

In this case, the first three arguments used in a call to \texttt{doIt()} are matched to the first three
parameters. Then, any remaining arguments are assumed to belong to `vals`.
Remember, the varargs parameter must be last. For example, the following declaration is incorrect:

```java
int doit(int a, int b, double c, int ... vals, boolean stopFlag) { // Error!
```

Here, there is an attempt to declare a regular parameter after the varargs parameter, which is illegal.

There is one more restriction to be aware of: there must be only one varargs parameter. For example, this declaration is also invalid:

```java
int doit(int a, int b, double c, int ... vals, double ... morevals) { // Error!
```

The attempt to declare the second varargs parameter is illegal.

Here is a reworked version of the `vaTest( )` method that takes a regular argument and a variable-length argument:

```java
// Use varargs with standard arguments.
class VarArgs2 {

    // Here, msg is a normal parameter and v is a varargs parameter.
    static void vaTest(String msg, int ... v) {
        System.out.print(msg + v.length + " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    public static void main(String args[]) {
        vaTest("One vararg: ", 10);
        vaTest("Three varargs: ", 1, 2, 3);
        vaTest("No varargs: ");
    }
}
```

The output from this program is shown here:
Overloading Vararg Methods
You can overload a method that takes a variable-length argument. For example, the following program overloads `vaTest()` three times:
// Varargs and overloading.
class VarArgs3 {

    static void vaTest(int ... v) {
        System.out.print("vaTest(int ...): ");
        System.out.print("Number of args: "+ v.length + 
                        " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    static void vaTest(boolean ... v) {
        System.out.print("vaTest(boolean ...): ");
        System.out.print("Number of args: "+ v.length + 
                        " Contents: ");

        for(boolean x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    static void vaTest(String msg, int ... v) {
        System.out.print("vaTest(String, int ...): ");
        System.out.print(msg + v.length + 
                        " Contents: ");

        for(int x : v)
            System.out.print(x + " ");

        System.out.println();
    }

    public static void main(String args[]) {
        vaTest(1, 2, 3);
        vaTest("Testing: ", 10, 20);
        vaTest(true, false, false);
    }
}

The output produced by this program is shown here:

vaTest(int ...): Number of args: 3 Contents: 1 2 3
vaTest(String, int ...): Testing: 2 Contents: 10 20
vaTest(boolean ...): Number of args: 3 Contents: true false false
This program illustrates both ways that a varargs method can be overloaded. First, the types of its vararg parameter can differ. This is the case for `vaTest(int ...)` and `vaTest(boolean ...)`). Remember, the ... causes the parameter to be treated as an array of the specified type. Therefore, just as you can overload methods by using different types of array parameters, you can overload vararg methods by using different types of varargs. In this case, Java uses the type difference to determine which overloaded method to call.

The second way to overload a varargs method is to add one or more normal parameters. This is what was done with `vaTest(String, int ...)`. In this case, Java uses both the number of arguments and the type of the arguments to determine which method to call.

NOTE A varargs method can also be overloaded by a non-varargs method. For example, `vaTest(int x)` is a valid overload of `vaTest()` in the foregoing program. This version is invoked only when one `int` argument is present. When two or more `int` arguments are passed, the varargs version `vaTest (int...v)` is used.

Varargs and Ambiguity

Somewhat unexpected errors can result when overloading a method that takes a variable-length argument. These errors involve ambiguity because it is possible to create an ambiguous call to an overloaded varargs method. For example, consider the following program:
In this program, the overloading of `vaTest()` is perfectly correct. However, this program will not compile because of the following call:

```
vaTest(); // Error: Ambiguous!
```

Because the vararg parameter can be empty, this call could be translated into a call to `vaTest(int ...)` or `vaTest(boolean ...)`. Both are equally valid. Thus, the call is inherently ambiguous.
Here is another example of ambiguity. The following overloaded versions of `vaTest()` are inherently ambiguous even though one takes a normal parameter:

```java
static void vaTest(int ... v) { // ...
static void vaTest(int n, int ... v) { // ...
```

Although the parameter lists of `vaTest()` differ, there is no way for the compiler to resolve the following call:

```java
vaTest(1)
```

Does this translate into a call to `vaTest(int ...)`, with one varargs argument, or into a call to `vaTest(int, int ...)` with no varargs arguments? There is no way for the compiler to answer this question. Thus, the situation is ambiguous.

Because of ambiguity errors like those just shown, sometimes you will need to forego overloading and simply use two different method names. Also, in some cases, ambiguity errors expose a conceptual flaw in your code, which you can remedy by more carefully crafting a solution.
Inheritance is one of the cornerstones of object-oriented programming because it allows the creation of hierarchical classifications. Using inheritance, you can create a general class that defines traits common to a set of related items. This class can then be inherited by other, more specific classes, each adding those things that are unique to it. In the terminology of Java, a class that is inherited is called a superclass. The class that does the inheriting is called a subclass. Therefore, a subclass is a specialized version of a superclass. It inherits all of the members defined by the superclass and adds its own, unique elements.

### Inheritance Basics

To inherit a class, you simply incorporate the definition of one class into another by using the **extends** keyword. To see how, let's begin with a short example. The following program creates a superclass called **A** and a subclass called **B**. Notice how the keyword **extends** is used to create a subclass of **A**.

```java
// A simple example of inheritance.

// Create a superclass.
class A {
  int i, j;

  void showij() {
    System.out.println("i and j: " + i + " " + j);
  }
}

// Create a subclass by extending class A.
class B extends A {
  int k;

  void showk() {
    System.out.println("k: " + k);
  }
}
```
The output from this program is shown here:

```
Contents of superOb:
i and j: 10 20

Contents of subOb:
i and j: 7 8
k: 9

Sum of i, j and k in subOb:
i+j+k: 24
```
As you can see, the subclass $B$ includes all of the members of its superclass, $A$. This is why
$subOb$ can access $i$ and $j$ and call $\text{showij()}$. Also, inside $\text{sum()}$, $i$ and $j$ can be referred to
directly, as if they were part of $B$.
Even though $A$ is a superclass for $B$, it is also a completely independent, stand-alone class.
Being a superclass for a subclass does not mean that the superclass cannot be used by itself.
Further, a subclass can be a superclass for another subclass.
The general form of a $\text{class}$ declaration that inherits a superclass is shown here:

```java
class subclass-name extends superclass-name {
    // body of class
}
```

You can only specify one superclass for any subclass that you create. Java does not support
the inheritance of multiple superclasses into a single subclass. You can, as stated, create a
hierarchy of inheritance in which a subclass becomes a superclass of another subclass.
However, no class can be a superclass of itself.

**Member Access and Inheritance**

Although a subclass includes all of the members of its superclass, it cannot access those
members of the superclass that have been declared as $\text{private}$. For example, consider the
following simple class hierarchy:
This program will not compile because the use of j inside the sum() method of B causes an access violation. Since j is declared as private, it is only accessible by other members of its own class. Subclasses have no access to it.

REMEMBER A class member that has been declared as private will
remain private to its class. It is not accessible by any code outside its class, including subclasses.

**A More Practical Example**

Let's look at a more practical example that will help illustrate the power of inheritance. Here, the final version of the **Box** class developed in the preceding chapter will be extended to include a fourth component called **weight**. Thus, the new class will contain a box's width, height, depth, and weight.
// This program uses inheritance to extend Box.
class Box {
    double width;
    double height;
    double depth;

    // construct clone of an object
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

// Here, Box is extended to include weight.
class BoxWeight extends Box {

BoxWeight inherits all of the characteristics of Box and adds to them the weight component. It is not necessary for BoxWeight to re-create all of the features found in Box. It can simply extend Box to meet its own purposes. A major advantage of inheritance is that once you have created a superclass that defines the attributes common to a set of objects, it can be used to create any number of more specific subclasses. Each subclass can precisely tailor its own classification. For example, the following class inherits Box and adds a color attribute:
Remember, once you have created a superclass that defines the general aspects of an object, that superclass can be inherited to form specialized classes. Each subclass simply adds its own unique attributes. This is the essence of inheritance.

**A Superclass Variable Can Reference a Subclass Object**
A reference variable of a superclass can be assigned a reference to any subclass derived from that superclass. You will find this aspect of inheritance quite useful in a variety of situations. For example, consider the following:

```java
// Here, Box is extended to include color.
class ColorBox extends Box {
    int color; // color of box
    ColorBox(double w, double h, double d, int c) {
        width = w;
        height = h;
        depth = d;
        color = c;
    }
}

class RefDemo {
    public static void main(String args[]) {
        BoxWeight weightbox = new BoxWeight(3, 5, 7, 8.37);
        Box plainbox = new Box();
        double vol;
        vol = weightbox.volume();
        System.out.println("Volume of weightbox is "+ vol);
        System.out.println("Weight of weightbox is "+ weightbox.weight);
        System.out.println();
        // assign BoxWeight reference to Box reference
        plainbox = weightbox;
        vol = plainbox.volume(); // OK, volume() defined in Box
        System.out.println("Volume of plainbox is "+ vol);
        // The following statement is invalid because plainbox does not define a weight member. */
        // System.out.println("Weight of plainbox is "+ plainbox.weight);
    }
}
```

Here, `weightbox` is a reference to `BoxWeight` objects, and `plainbox` is a reference to `Box` objects. Since `BoxWeight` is a subclass of `Box`, it is permissible to assign `plainbox` a reference to the `weightbox` object.
It is important to understand that it is the type of the reference variable—not the type of the object that it refers to—that determines what members can be accessed. That is, when a reference to a subclass object is assigned to a superclass reference variable, you will have access only to those parts of the object defined by the superclass. This is why plainbox can’t access weight even when it refers to a BoxWeight object. If you think about it, this makes sense, because the superclass has no knowledge of what a subclass adds to it. This is why the last line of code in the preceding fragment is commented out. It is not possible for a Box reference to access the weight field, because Box does not define one. Although the preceding may seem a bit esoteric, it has some important practical applications—two of which are discussed later in this chapter.

Using super
In the preceding examples, classes derived from Box were not implemented as efficiently or as robustly as they could have been. For example, the constructor for BoxWeight explicitly initializes the width, height, and depth fields of Box. Not only does this duplicate code found in its superclass, which is inefficient, but it implies that a subclass must be granted access to these members. However, there will be times when you will want to create a superclass that keeps the details of its implementation to itself (that is, that keeps its data members private). In this case, there would be no way for a subclass to directly access or initialize these variables on its own. Since encapsulation is a primary attribute of OOP, it is not surprising that Java provides a solution to this problem. Whenever a subclass needs to refer to its immediate superclass, it can do so by use of the keyword super. super has two general forms. The first calls the superclass’ constructor. The second is used to access a member of the superclass that has been hidden by a member of a subclass. Each use is examined here.

Using super to Call Superclass Constructors
A subclass can call a constructor defined by its superclass by use of the following form of super:

```java
super(arg-list);
```

Here, arg-list specifies any arguments needed by the constructor in the superclass. super() must always be the first statement executed inside a subclass’ constructor.

To see how super() is used, consider this improved version of the BoxWeight class:
Here, `BoxWeight()` calls `super()` with the arguments `w`, `h`, and `d`. This causes the `Box` constructor to be called, which initializes `width`, `height`, and `depth` using these values. `BoxWeight` no longer initializes these values itself. It only needs to initialize the value unique to it: `weight`. This leaves `Box` free to make these values private if desired.

In the preceding example, `super()` was called with three arguments. Since constructors can be overloaded, `super()` can be called using any form defined by the superclass. The constructor executed will be the one that matches the arguments. For example, here is a complete implementation of `BoxWeight` that provides constructors for the various ways that a box can be constructed. In each case, `super()` is called using the appropriate arguments. Notice that `width`, `height`, and `depth` have been made private within `Box`. 

```java
// BoxWeight now uses super to initialize its Box attributes.
class BoxWeight extends Box {
    double weight; // weight of box

    // initialize width, height, and depth using super()
    BoxWeight(double w, double h, double d, double m) {
        super(w, h, d); // call superclass constructor
        weight = m;
    }
}
```
// A complete implementation of BoxWeight.
class Box {
    private double width;
    private double height;
    private double depth;

    // construct clone of an object
    Box(Box ob) { // pass object to constructor
        width = ob.width;
        height = ob.height;
        depth = ob.depth;
    }

    // constructor used when all dimensions specified
    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    // constructor used when no dimensions specified
    Box() {
        width = -1; // use -1 to indicate
        height = -1; // an uninitialized
        depth = -1; // box
    }

    // constructor used when cube is created
    Box(double len) {
        width = height = depth = len;
    }

    // compute and return volume
    double volume() {
        return width * height * depth;
    }
}

// BoxWeight now fully implements all constructors.
class BoxWeight extends Box {
    double weight; // weight of box

    // construct clone of an object
    BoxWeight(BoxWeight ob) { // pass object to constructor
        super(ob);
        weight = ob.weight;
    }

    // constructor when all parameters are specified
    BoxWeight(double w, double h, double d, double m) {

This program generates the following output:
Pay special attention to this constructor in **BoxWeight**:

```java
// construct clone of an object
BoxWeight (BoxWeight ob) { // pass object to constructor
    super(ob);
    weight = ob.weight;
}
```

Notice that `super()` is passed an object of type **BoxWeight**—not of type **Box**. This still invokes the constructor `Box(Box ob)`. As mentioned earlier, a superclass variable can be used to reference any object derived from that class. Thus, we are able to pass a **BoxWeight** object to the **Box** constructor. Of course, **Box** only has knowledge of its own members.

Let’s review the key concepts behind `super()`. When a subclass calls `super()`, it is calling the constructor of its immediate superclass. Thus, `super()` always refers to the superclass immediately above the calling class. This is true even in a multileveled hierarchy. Also, `super()` must always be the first statement executed inside a subclass constructor.

**A Second Use for super**

The second form of `super` acts somewhat like `this`, except that it always refers to the superclass of the subclass in which it is used. This usage has the following general form:

```java
super.member
```

Here, `member` can be either a method or an instance variable.

This second form of `super` is most applicable to situations in which member names of a subclass hide members by the same name in the superclass. Consider this simple class hierarchy:
This program displays the following:

```
i in superclass: 1
i in subclass: 2
```

Although the instance variable i in B hides the i in A, super allows access to the i defined in the superclass. As you will see, super can also be used to call methods that are hidden by a subclass.

**Creating a Multilevel Hierarchy**

Up to this point, we have been using simple class hierarchies that consist of only a superclass and a subclass. However, you can build hierarchies that contain as many layers of inheritance as you like. As mentioned, it is perfectly acceptable to use a subclass as a superclass of another. For example, given three classes called A, B, and C, C can be a subclass of B, which is a subclass of A. When this type of situation occurs, each subclass inherits all of the traits found in all of its superclasses. In this case, C inherits all aspects of B and A. To see how a multilevel hierarchy can be useful, consider the following program.
In it, the subclass `BoxWeight` is used as a superclass to create the subclass called `Shipment`. `Shipment` inherits all of the traits of `BoxWeight` and `Box`, and adds a field called `cost`, which holds the cost of shipping such a parcel.

```java
// Extend BoxWeight to include shipping costs.

// Start with Box.
class Box {
    private double width;
    private double height;
    private double depth;
```
// construct clone of an object
Box(Box ob) { // pass object to constructor
    width = ob.width;
    height = ob.height;
    depth = ob.depth;
}

// constructor used when all dimensions specified
Box(double w, double h, double d) {
    width = w;
    height = h;
    depth = d;
}

// constructor used when no dimensions specified
Box() { // use -1 to indicate
    width = -1; // an uninitialized
    height = -1; // box
    depth = -1;
}

// constructor used when cube is created
Box(double len) {
    width = height = depth = len;
}

// compute and return volume
double volume() { // return width * height * depth;
    return width * height * depth;
}

// add weight.
class BoxWeight extends Box {
    double weight; // weight of box

    BoxWeight(BoxWeight ob) { // pass object to constructor
        super(ob);
        weight = ob.weight;
    }

    BoxWeight(double w, double h, double d, double m) {
        super(w, h, d); // call superclass constructor
        weight = m;
    }

    BoxWeight() {
        super();
        weight = -1;
    }
}
// constructor used when cube is created
BoxWeight(double len, double m) {
    super(len);
    weight = m;
}

// Add shipping costs.
class Shipment extends BoxWeight {
    double cost;

    // construct clone of an object.
    Shipment(Shipment ob) { // pass object to constructor
        super(ob); // pass object to superclass
        cost = ob.cost;
    }

    // constructor when all parameters are specified
    Shipment(double w, double h, double d,
             double n, double c) {
        super(w, h, d, m); // call superclass constructor
        cost = c;
    }

    // default constructor
    Shipment() {
        super();
        cost = -1;
    }

    // constructor used when cube is created
    Shipment(double len, double m, double c) {
        super(len, m);
        cost = c;
    }
}

class DemoShipment {
    public static void main(String args[]) {
        Shipment shipment1 =
                new Shipment(10, 20, 15, 10.34);
        Shipment shipment2 =
                new Shipment(2, 3, 4, 0.76, 1.28);

        double vol;
        vol = shipment1.volume();
        System.out.println("Volume of shipment1 is "+ vol);
        System.out.println("Weight of shipment1 is "+ shipment1.weight);
        System.out.println("Shipping cost: "+ shipment1.cost);
        System.out.println();
The output of this program is shown here:

```
Volume of shipment1 is 3000.0
Weight of shipment1 is 10.0
Shipping cost: $3.41

Volume of shipment2 is 24.0
Weight of shipment2 is 0.76
Shipping cost: $1.28
```

Because of inheritance, **Shipment** can make use of the previously defined classes of **Box** and **BoxWeight**, adding only the extra information it needs for its own, specific application. This is part of the value of inheritance; it allows the reuse of code.

This example illustrates one other important point: **super()** always refers to the constructor in the closest superclass. The **super()** in **Shipment** calls the constructor in **BoxWeight**. The **super()** in **BoxWeight** calls the constructor in **Box**. In a class hierarchy, if a superclass constructor requires parameters, then all subclasses must pass those parameters “up the line.” This is true whether or not a subclass needs parameters of its own.

---

**NOTE** In the preceding program, the entire class hierarchy, including **Box**, **BoxWeight**, and **Shipment**, is shown all in one file. This is for your convenience only. In Java, all three classes could have been placed into their own files and compiled separately. In fact, using separate files is the norm, not the exception, in creating class hierarchies.

**When Constructors Are Executed**

When a class hierarchy is created, in what order are the constructors for the classes that make up the hierarchy executed? For example, given a subclass called **B** and a superclass called **A**, is **A**’s constructor executed before **B**’s, or vice versa? The answer is that in a class
hierarchy, constructors complete their execution in order of derivation, from superclass to subclass. Further, since `super()` must be the first statement executed in a subclass’ constructor, this order is the same whether or not `super()` is used. If `super()` is not used, then the default or parameterless constructor of each superclass will be executed. The following program illustrates when constructors are executed:

```java
// Demonstrate when constructors are executed.

// Create a super class.
class A {
    A() {
        System.out.println("Inside A's constructor.");
    }
}

// Create a subclass by extending class A.
class B extends A {
    B() {
        System.out.println("Inside B's constructor.");
    }
}

// Create another subclass by extending B.
class C extends B {
    C() {
        System.out.println("Inside C's constructor.");
    }
}

class CallingCons {
    public static void main(String args[]) {
        C c = new C();
    }
}
```

The output from this program is shown here:

```
Inside A's constructor
Inside B's constructor
Inside C's constructor
```

As you can see, the constructors are executed in order of derivation. If you think about it, it makes sense that constructors complete their execution in order of derivation. Because a superclass has no knowledge of any subclass, any initialization it needs to perform is separate from and possibly prerequisite to any initialization performed
Method Overriding

In a class hierarchy, when a method in a subclass has the same name and type signature as a method in its superclass, then the method in the subclass is said to override the method in the superclass. When an overridden method is called from within its subclass, it will always refer to the version of that method defined by the subclass. The version of the method defined by the superclass will be hidden. Consider the following:

```java
// Method overriding.
class A {
    int i, j;
    A(int a, int b) {
        i = a;
        j = b;
    }

    // display i and j
    void show() {
        System.out.println("i and j: "+i+" "+j);
    }
}

class B extends A {
    int k;

    B(int a, int b, int c) {
        super(a, b);
        k = c;
    }

    // display k - this overrides show() in A
    void show() {
        System.out.println("k: "+k);
    }
}

class Override {
    public static void main(String args[]) {
        B subOb = new B(1, 2, 3);
        subOb.show(); // this calls show() in B
    }
}
```

The output produced by this program is shown here:
When `show()` is invoked on an object of type `B`, the version of `show()` defined within `B` is used. That is, the version of `show()` inside `B` overrides the version declared in `A`. If you wish to access the superclass version of an overridden method, you can do so by using `super`. For example, in this version of `B`, the superclass version of `show()` is invoked within the subclass' version. This allows all instance variables to be displayed.

```java
class B extends A {
    int k;

    B(int a, int b, int c) {
        super(a, b);
        k = c;
    }

    void show() {
        super.show(); // this calls A's show()
        System.out.println("k: " + k);
    }
}
```

If you substitute this version of `A` into the previous program, you will see the following output:

```plaintext
i and j: 1 2
k: 3
```

Here, `super.show()` calls the superclass version of `show()`.

Method overriding occurs only when the names and the type signatures of the two methods are identical. If they are not, then the two methods are simply overloaded. For example, consider this modified version of the preceding example:
Methods with differing type signatures are overloaded - not overridden.

```java
class A {
    int i, j;

    A(int a, int b) {
        i = a;
        j = b;
    }

    // display i and j
    void show() {
        System.out.println("i and j: "+i+" "+j);
    }
}

// Create a subclass by extending class A.
class B extends A {
    int k;

    B(int a, int b, int c) {
        super[a, b];
        k = c;
    }

    // overload show()
    void show(String msg) {
        System.out.println(msg+k);
    }
}

class Override {
    public static void main(String args[]) {
        B subBob = new B(1, 2, 3);

        subBob.show("This is k: "); // this calls show() in B
        subBob.show(); // this calls show() in A
    }
}
```

The output produced by this program is shown here:

```
This is k: 3
i and j: 1 2
```

The version of `show()` in **B** takes a string parameter. This makes its type signature different from the one in **A**, which takes no parameters. Therefore, no overriding (or name hiding) takes place. Instead, the version of `show()` in **B** simply overloads the version of `show()` in **A**.
Dynamic Method Dispatch

While the examples in the preceding section demonstrate the mechanics of method overriding, they do not show its power. Indeed, if there were nothing more to method overriding than a name space convention, then it would be, at best, an interesting curiosity, but of little real value. However, this is not the case. Method overriding forms the basis for one of Java’s most powerful concepts: dynamic method dispatch. Dynamic method dispatch is the mechanism by which a call to an overridden method is resolved at run time, rather than compile time. Dynamic method dispatch is important because this is how Java implements run-time polymorphism.

Let’s begin by restating an important principle: a superclass reference variable can refer to a subclass object. Java uses this fact to resolve calls to overridden methods at run time. Here is how. When an overridden method is called through a superclass reference, Java determines which version of that method to execute based upon the type of the object being referred to at the time the call occurs. Thus, this determination is made at run time. When different types of objects are referred to, different versions of an overridden method will be called. In other words, it is the type of the object being referred to (not the type of the reference variable) that determines which version of an overridden method will be executed. Therefore, if a superclass contains a method that is overridden by a subclass, then when different types of objects are referred to through a superclass reference variable, different versions of the method are executed. Here is an example that illustrates dynamic method dispatch:
// Dynamic Method Dispatch

class A {
    void callme() {
        System.out.println("Inside A's callme method");
    }
}

class B extends A {
    // override callme()
    void callme() {
        System.out.println("Inside B's callme method");
    }
}

class C extends A {
    // override callme()
    void callme() {
        System.out.println("Inside C's callme method");
    }
}

class dispatch {
    public static void main(String args[]) {
        A a = new A(); // object of type A
        B b = new B(); // object of type B
        C c = new C(); // object of type C
        A r; // obtain a reference of type A
        r = a; // r refers to an A object
        r.callme(); // calls A's version of callme
        r = b; // r refers to a B object
        r.callme(); // calls B's version of callme
        r = c; // r refers to a C object
        r.callme(); // calls C's version of callme
    }
}

The output from the program is shown here:

Inside A's callme method
Inside B's callme method
Inside C's callme method
This program creates one superclass called A and two subclasses of it, called B and C. Subclasses B and C override callme() declared in A. Inside the main() method, objects of type A, B, and C are declared. Also, a reference of type A, called r, is declared. The program then in turn assigns a reference to each type of object to r and uses that reference to invoke callme(). As the output shows, the version of callme() executed is determined by the type of object being referred to at the time of the call. Had it been determined by the type of the reference variable, r, you would see three calls to A’s callme() method.

NOTE Readers familiar with C++ or C# will recognize that overridden methods in Java are similar to virtual functions in those languages.

Why Overridden Methods?
As stated earlier, overridden methods allow Java to support run-time polymorphism. Polymorphism is essential to object-oriented programming for one reason: it allows a general class to specify methods that will be common to all of its derivatives, while allowing subclasses to define the specific implementation of some or all of those methods. Overridden methods are another way that Java implements the “one interface, multiple methods” aspect of polymorphism.
Part of the key to successfully applying polymorphism is understanding that the superclasses and subclasses form a hierarchy which moves from lesser to greater specialization. Used correctly, the superclass provides all elements that a subclass can use directly. It also defines those methods that the derived class must implement on its own. This allows the subclass the flexibility to define its own methods, yet still enforces a consistent interface. Thus, by combining inheritance with overridden methods, a superclass can define the general form of the methods that will be used by all of its subclasses.
Dynamic, run-time polymorphism is one of the most powerful mechanisms that object-oriented design brings to bear on code reuse and robustness. The ability of existing code libraries to call methods on instances of new classes without recompiling while maintaining a clean abstract interface is a profoundly powerful tool.

Applying Method Overriding
Let’s look at a more practical example that uses method overriding. The following program creates a superclass called Figure that stores the dimensions of a two-dimensional object. It also defines a method called area() that computes the area of an object. The program derives two subclasses from Figure. The first is Rectangle and the second is Triangle. Each of these subclasses overrides area() so that it returns the area of a rectangle and a triangle, respectively.
// Using run-time polymorphism:
class Figure {
    double dim1;
    double dim2;

    Figure(double a, double b) {
        dim1 = a;
        dim2 = b;
    }

    double area() {
        System.out.println("Area for Figure is undefined.");
        return 0;
    }
}

class Rectangle extends Figure {
    Rectangle(double a, double b) {
        super(a, b);
    }

    // override area for rectangle
    double area() {
        System.out.println("Inside Area for Rectangle.");
        return dim1 * dim2;
    }
}

class Triangle extends Figure {
    Triangle(double a, double b) {
        super(a, b);
    }

    // override area for right triangle
    double area() {
        System.out.println("Inside Area for Triangle.");
        return dim1 * dim2 / 2;
    }
}

class FindAreas {
    public static void main(String args[]) {
        Figure f = new Figure(10, 10);
        Rectangle r = new Rectangle(9, 5);
The output from the program is shown here:

```
Triangle t = new Triangle(10, 8);
Figure figref;

figref = r;
System.out.println("Area is " + figref.area());

figref = t;
System.out.println("Area is " + figref.area());

figref = f;
System.out.println("Area is " + figref.area());
```

Through the dual mechanisms of inheritance and run-time polymorphism, it is possible to
define one consistent interface that is used by several different, yet related, types of objects.
In this case, if an object is derived from `Figure`, then its area can be obtained by calling
`area()`. The interface to this operation is the same no matter what type of figure is being
used.

**Using Abstract Classes**

There are situations in which you will want to define a superclass that declares the structure
of a given abstraction without providing a complete implementation of every method. That
is, sometimes you will want to create a superclass that only defines a generalized form that
will be shared by all of its subclasses, leaving it to each subclass to fill in the details. Such a
class determines the nature of the methods that the subclasses must implement. One way
this situation can occur is when a superclass is unable to create a meaningful
implementation for a method. This is the case with the class `Figure` used in the preceding
example. The definition of `area()` is simply a placeholder. It will not compute and display
the area of any type of object.

As you will see as you create your own class libraries, it is not uncommon for a method to
have no meaningful definition in the context of its superclass. You can handle this situation
two ways. One way, as shown in the previous example, is to simply have it report a warning
message. While this approach can be useful in certain situations—such as debugging—it is not usually appropriate. You may have methods that must be overridden by the subclass in order for the subclass to have any meaning. Consider the class Triangle. It has no meaning if area( ) is not defined. In this case, you want some way to ensure that a subclass does, indeed, override all necessary methods. Java's solution to this problem is the abstract method.

You can require that certain methods be overridden by subclasses by specifying the abstract type modifier. These methods are sometimes referred to as subclasser responsibility because they have no implementation specified in the superclass. Thus, a subclass must override them—it cannot simply use the version defined in the superclass. To declare an abstract method, use this general form:

    abstract type name(parameter-list);

As you can see, no method body is present.

Any class that contains one or more abstract methods must also be declared abstract. To declare a class abstract, you simply use the abstract keyword in front of the class keyword at the beginning of the class declaration. There can be no objects of an abstract class. That is, an abstract class cannot be directly instantiated with the new operator. Such objects would be useless, because an abstract class is not fully defined. Also, you cannot declare abstract constructors, or abstract static methods. Any subclass of an abstract class must either implement all of the abstract methods in the superclass, or be declared abstract itself.

Here is a simple example of a class with an abstract method, followed by a class which implements that method:
Notice that no objects of class A are declared in the program. As mentioned, it is not possible to instantiate an abstract class. One other point: class A implements a concrete method called callmetoo(). This is perfectly acceptable. Abstract classes can include as much implementation as they see fit.

Although abstract classes cannot be used to instantiate objects, they can be used to create object references, because Java’s approach to run-time polymorphism is implemented through the use of superclass references. Thus, it must be possible to create a reference to an abstract class so that it can be used to point to a subclass object. You will see this feature put to use in the next example.

Using an abstract class, you can improve the Figure class shown earlier. Since there is no meaningful concept of area for an undefined two-dimensional figure, the following version of the program declares area() as abstract inside Figure. This, of course, means that all classes derived from Figure must override area().
As the comment inside `main()` indicates, it is no longer possible to declare objects of type `Figure`, since it is now abstract. And, all subclasses of `Figure` must override `area()`. To prove this to yourself, try creating a subclass that does not override `area()`. You will receive a compile-time error.

Although it is not possible to create an object of type `Figure`, you can create a reference
variable of type Figure. The variable figref is declared as a reference to Figure, which means that it can be used to refer to an object of any class derived from Figure. As explained, it is through superclass reference variables that overridden methods are resolved at run time.

**Using final with Inheritance**

The keyword final has three uses. First, it can be used to create the equivalent of a named constant. This use was described in the preceding chapter. The other two uses of final apply to inheritance. Both are examined here.

**Using final to Prevent Overriding**

While method overriding is one of Java’s most powerful features, there will be times when you will want to prevent it from occurring. To disallow a method from being overridden, specify final as a modifier at the start of its declaration. Methods declared as final cannot be overridden. The following fragment illustrates final:

```java
class A {
    final void meth() {
        System.out.println("This is a final method.");
    }
}
class B extends A {
    void meth() { // ERROR! Can't override.
        System.out.println("Illegal!");
    }
}
```

Because meth() is declared as final, it cannot be overridden in B. If you attempt to do so, a compile-time error will result.

Methods declared as final can sometimes provide a performance enhancement: The compiler is free to inline calls to them because it “knows” they will not be overridden by a subclass. When a small final method is called, often the Java compiler can copy the bytecode for the subroutine directly inline with the compiled code of the calling method, thus eliminating the costly overhead associated with a method call. Inlining is an option only with final methods. Normally, Java resolves calls to methods dynamically, at run time. This is called *late binding*. However, since final methods cannot be overridden, a call to one can be resolved at compile time. This is called *early binding*.

**Using final to Prevent Inheritance**

Sometimes you will want to prevent a class from being inherited. To do this, precede the class declaration with final. Declaring a class as final implicitly declares all of its methods
as **final**, too. As you might expect, it is illegal to declare a class as both **abstract** and **final** since an abstract class is incomplete by itself and relies upon its subclasses to provide complete implementations.

Here is an example of a **final** class:

```java
final class A {
   //...
}

// The following class is illegal.
class B extends A { // ERROR! Can't subclass A
   //...
}
```

As the comments imply, it is illegal for **B** to inherit **A** since **A** is declared as **final**.

**The Object Class**

There is one special class, **Object**, defined by Java. All other classes are subclasses of **Object**. That is, **Object** is a superclass of all other classes. This means that a reference variable of type **Object** can refer to an object of any other class. Also, since arrays are implemented as classes, a variable of type **Object** can also refer to any array.

**Object** defines the following methods, which means that they are available in every object.

<table>
<thead>
<tr>
<th>Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object clone( )</td>
<td>Creates a new object that is the same as the object being cloned.</td>
</tr>
<tr>
<td>boolean equals(Object object)</td>
<td>Determines whether one object is equal to another.</td>
</tr>
<tr>
<td>void finalize( )</td>
<td>Called before an unused object is recycled.</td>
</tr>
<tr>
<td>Class&lt;?&gt; getClass( )</td>
<td>Obtains the class of an object at run time.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td>void notify( )</td>
<td>Resumes execution of a thread waiting on the invoking object.</td>
</tr>
<tr>
<td>void notifyAll( )</td>
<td>Resumes execution of all threads waiting on the invoking object.</td>
</tr>
<tr>
<td>String toString( )</td>
<td>Returns a string that describes the object.</td>
</tr>
</tbody>
</table>
The methods `getClass()`, `notify()`, `notifyAll()`, and `wait()` are declared as `final`. You may override the others. These methods are described elsewhere in this book. However, notice two methods now: `equals()` and `toString()`. The `equals()` method compares two objects. It returns `true` if the objects are equal, and `false` otherwise. The precise definition of equality can vary, depending on the type of objects being compared. The `toString()` method returns a string that contains a description of the object on which it is called. Also, this method is automatically called when an object is output using `println()`. Many classes override this method. Doing so allows them to tailor a description specifically for the types of objects that they create.

One last point: Notice the unusual syntax in the return type for `getClass()`. This relates to Java’s `generics` feature, which is described in Chapter 14.
This chapter examines two of Java's most innovative features: packages and interfaces. Packages are containers for classes. They are used to keep the class name space compartmentalized. For example, a package allows you to create a class named `List`, which you can store in your own package without concern that it will collide with some other class named `List` stored elsewhere. Packages are stored in a hierarchical manner and are explicitly imported into new class definitions.

In previous chapters, you have seen how methods define the interface to the data in a class. Through the use of the `interface` keyword, Java allows you to fully abstract an interface from its implementation. Using `interface`, you can specify a set of methods that can be implemented by one or more classes. In its traditional form, the `interface`, itself, does not actually define any implementation. Although they are similar to abstract classes, `interfaces` have an additional capability: A class can implement more than one interface. By contrast, a class can only inherit a single superclass (abstract or otherwise).

### Packages

In the preceding chapters, the name of each example class was taken from the same name space. This means that a unique name had to be used for each class to avoid name collisions. After a while, without some way to manage the name space, you could run out of convenient, descriptive names for individual classes. You also need some way to be assured that the name you choose for a class will be reasonably unique and not collide with class names chosen by other programmers. (Imagine a small group of programmers fighting over who gets to use the name “Foobar” as a class name. Or, imagine the entire Internet community arguing over who first named a class “Espresso.”) Thankfully, Java provides a mechanism for partitioning the class name space into more manageable chunks. This mechanism is the package. The package is both a naming and a visibility control mechanism. You can define classes inside a package that are not accessible by code outside that package. You can also define class members that are exposed only to other members of the same package. This allows your classes to have intimate knowledge of each other, but not expose that knowledge to the rest of the world.
**Defining a Package**

To create a package is quite easy: simply include a **package** command as the first statement in a Java source file. Any classes declared within that file will belong to the specified package. The **package** statement defines a name space in which classes are stored. If you omit the **package** statement, the class names are put into the default package, which has no name. (This is why you haven’t had to worry about packages before now.) While the default package is fine for short, sample programs, it is inadequate for real applications. Most of the time, you will define a package for your code.

This is the general form of the **package** statement:

```java
package pkg;  
```

Here, `pkg` is the name of the package. For example, the following statement creates a package called **MyPackage**:

```java
package MyPackage;  
```

Java uses file system directories to store packages. For example, the **.class** files for any classes you declare to be part of **MyPackage** must be stored in a directory called **MyPackage**. Remember that case is significant, and the directory name must match the package name exactly.

More than one file can include the same **package** statement. The **package** statement simply specifies to which package the classes defined in a file belong. It does not exclude other classes in other files from being part of that same package. Most real-world packages are spread across many files.

You can create a hierarchy of packages. To do so, simply separate each package name from the one above it by use of a period. The general form of a multileveled package statement is shown here:

```java
package pkg1.pkg2.pkg3;  
```

A package hierarchy must be reflected in the file system of your Java development system. For example, a package declared as

```java
package java.awt.image;  
```

needs to be stored in **java\awt\image** in a Windows environment. Be sure to choose your package names carefully. You cannot rename a package without renaming the directory in which the classes are stored.

**Finding Packages and CLASSPATH**

As just explained, packages are mirrored by directories. This raises an important question: How does the Java run-time system know where to look for packages that you create? The answer has three parts. First, by default, the Java run-time system uses the current working
directory as its starting point. Thus, if your package is in a subdirectory of the current
directory, it will be found. Second, you can specify a directory path or paths by setting the
CLASSPATH environmental variable. Third, you can use the -classpath option with java
and javac to specify the path to your classes.
For example, consider the following package specification:

    package MyPack

In order for a program to find MyPack, one of three things must be true. Either the
program can be executed from a directory immediately above MyPack, or the
CLASSPATH must be set to include the path to MyPack, or the -classpath option must
specify the path to MyPack when the program is run via java.
When the second two options are used, the class path must not include MyPack, itself. It
must simply specify the path to MyPack. For example, in a Windows environment, if the
path to MyPack is

    C:\MyPrograms\Java\MyPack

then the class path to MyPack is

    C:\MyPrograms\Java

The easiest way to try the examples shown in this book is to simply create the package
directories below your current development directory, put the .class files into the
appropriate directories, and then execute the programs from the development directory.
This is the approach used in the following example.

A Short Package Example
Keeping the preceding discussion in mind, you can try this simple package:
Call this file AccountBalance.java and put it in a directory called MyPack.
Next, compile the file. Make sure that the resulting .class file is also in the MyPack directory. Then, try executing the AccountBalance class, using the following command line:

```
java MyPack.AccountBalance
```

Remember, you will need to be in the directory above MyPack when you execute this command. (Alternatively, you can use one of the other two options described in the preceding section to specify the path MyPack.)

As explained, AccountBalance is now part of the package MyPack. This means that it cannot be executed by itself. That is, you cannot use this command line:

```
java AccountBalance
```
AccountBalance must be qualified with its package name.

Access Protection
In the preceding chapters, you learned about various aspects of Java’s access control mechanism and its access modifiers. For example, you already know that access to a private member of a class is granted only to other members of that class. Packages add another dimension to access control. As you will see, Java provides many levels of protection to allow fine-grained control over the visibility of variables and methods within classes, subclasses, and packages.

Classes and packages are both means of encapsulating and containing the name space and scope of variables and methods. Packages act as containers for classes and other subordinate packages. Classes act as containers for data and code. The class is Java’s smallest unit of abstraction. Because of the interplay between classes and packages, Java addresses four categories of visibility for class members:

- Subclasses in the same package
- Non-subclasses in the same package
- Subclasses in different packages
- Classes that are neither in the same package nor subclasses

The three access modifiers, private, public, and protected, provide a variety of ways to produce the many levels of access required by these categories. Table 9-1 sums up the interactions.

<table>
<thead>
<tr>
<th>Class Member Access</th>
<th>Private</th>
<th>No Modifier</th>
<th>Protected</th>
<th>Public</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same class</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Same package subclass</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Same package non-subclass</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Different package subclass</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Different package non-subclass</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 9-1 Class Member Access

While Java’s access control mechanism may seem complicated, we can simplify it as follows. Anything declared public can be accessed from anywhere. Anything declared private cannot be seen outside of its class. When a member does not have an explicit access specification, it is visible to subclasses as well as to other classes in the same package. This is the default access. If you want to allow an element to be seen outside your current package, but only to classes that subclass your class directly, then declare that element protected.

Table 9-1 applies only to members of classes. A non-nested class has only two
possible access levels: default and public. When a class is declared as `public`, it is accessible by any other code. If a class has default access, then it can only be accessed by other code within its same package. When a class is public, it must be the only public class declared in the file, and the file must have the same name as the class.

**An Access Example**

The following example shows all combinations of the access control modifiers. This example has two packages and five classes. Remember that the classes for the two different packages need to be stored in directories named after their respective packages—in this case, `p1` and `p2`.

The source for the first package defines three classes: `Protection`, `Derived`, and `SamePackage`. The first class defines four `int` variables in each of the legal protection modes. The variable `n` is declared with the default protection, `n_pri` is `private`, `n_pro` is `protected`, and `n_pub` is `public`.

Each subsequent class in this example will try to access the variables in an instance of this class. The lines that will not compile due to access restrictions are commented out. Before each of these lines is a comment listing the places from which this level of protection would allow access.

The second class, `Derived`, is a subclass of `Protection` in the same package, `p1`. This grants `Derived` access to every variable in `Protection` except for `n_pri`, the `private` one. The third class, `SamePackage`, is not a subclass of `Protection`, but is in the same package and also has access to all but `n_pri`.

This is file `Protection.java`:

```java
package p1;

public class Protection {
    int n = 1;
    private int n_pri = 2;
    protected int n_pro = 3;
    public int n_pub = 4;

    public Protection() {
        System.out.println("base constructor");
        System.out.println("n = " + n);
        System.out.println("n_pri = " + n_pri);
        System.out.println("n_pro = " + n_pro);
        System.out.println("n_pub = " + n_pub);
    }
}
```

This is file `Derived.java`:
package p1;

class Derived extends Protection {
    Derived() {
        System.out.println("derived constructor");
        System.out.println("n = " + n);
        // class only
        // System.out.println("n_pri = " + n_pri);
        System.out.println("n_pro = " + n_pro);
        System.out.println("n_pub = " + n_pub);
    }
}

This is file SamePackage.java:

package p1;

class SamePackage {
    SamePackage() {
        Protection p = new Protection();
        System.out.println("same package constructor");
        System.out.println("n = " + p.n);
        // class only
        // System.out.println("n_pri = " + p.n_pri);
        System.out.println("n_pro = " + p.n_pro);
        System.out.println("n_pub = " + p.n_pub);
    }
}

Following is the source code for the other package, p2. The two classes defined in p2 cover the other two conditions that are affected by access control. The first class, Protection2, is a subclass of p1.Protection. This grants access to all of p1.Protection’s variables except for n_pri (because it is private) and n, the variable declared with the default protection. Remember, the default only allows access from within the class or the package, not extrapackage subclasses. Finally, the class OtherPackage has access to only one variable, n_pub, which was declared public.

This is file Protection2.java:
This is file **OtherPackage.java**:

```java
package p2;

class OtherPackage {
    OtherPackage() {
        p1.Protection p = new p1.Protection();
        System.out.println("other package constructor");

        // class or package only
        // System.out.println("n = " + p.n);

        // class only
        // System.out.println("n_pri = " + p.n_pri);

        // class, subclass or package only
        // System.out.println("n_pro = " + p.n_pro);
        System.out.println("n_pub = " + p.n_pub);
    }
}
```

If you want to try these two packages, here are two test files you can use. The one for package **p1** is shown here:
The test file for p2 is shown next:

```java
// Demo package p2.
package p2;

// Instantiate the various classes in p2.
public class Demo {
    public static void main(String args[]) {
        Protection ob1 = new Protection();
        Derived ob2 = new Derived();
        SamePackage ob3 = new SamePackage();
    }
}
```

Importing Packages

Given that packages exist and are a good mechanism for compartmentalizing diverse classes from each other, it is easy to see why all of the built-in Java classes are stored in packages. There are no core Java classes in the unnamed default package; all of the standard classes are stored in some named package. Since classes within packages must be fully qualified with their package name or names, it could become tedious to type in the long dot-separated package path name for every class you want to use. For this reason, Java includes the `import` statement to bring certain classes, or entire packages, into visibility. Once imported, a class can be referred to directly, using only its name. The `import` statement is a convenience to the programmer and is not technically needed to write a complete Java program. If you are going to refer to a few dozen classes in your application, however, the `import` statement will save a lot of typing.

In a Java source file, `import` statements occur immediately following the `package` statement (if it exists) and before any class definitions. This is the general form of the `import` statement:

```java
import pkg1.*; // Import all public classes and interfaces in the package
```

Here, `pkg1` is the name of a top-level package, and `pkg2` is the name of a
subordinate package inside the outer package separated by a dot (\.). There is no practical limit on the depth of a package hierarchy, except that imposed by the file system. Finally, you specify either an explicit \textit{classname} or a star (*), which indicates that the Java compiler should import the entire package. This code fragment shows both forms in use:

```java
import java.util.Date;
import java.io.*;
```

All of the standard Java classes included with Java are stored in a package called \textit{java}. The basic language functions are stored in a package inside of the \textit{java} package called \textit{java.lang}. Normally, you have to import every package or class that you want to use, but since Java is useless without much of the functionality in \textit{java.lang}, it is implicitly imported by the compiler for all programs. This is equivalent to the following line being at the top of all of your programs:

```java
import java.lang.*;
```

If a class with the same name exists in two different packages that you import using the star form, the compiler will remain silent, unless you try to use one of the classes. In that case, you will get a compile-time error and have to explicitly name the class specifying its package.

It must be emphasized that the \texttt{import} statement is optional. Any place you use a class name, you can use its \texttt{fully qualified name}, which includes its full package hierarchy. For example, this fragment uses an import statement:

```java
import java.util.*;
class MyDate extends Date {
}
```

The same example without the \texttt{import} statement looks like this:

```java
class MyDate extends java.util.Date {
}
```

In this version, \texttt{Date} is fully-qualified.

As shown in Table 9-1, when a package is imported, only those items within the package declared as \texttt{public} will be available to non-subclasses in the importing code. For example, if you want the \texttt{Balance} class of the package \texttt{MyPack} shown earlier to be available as a standalone class for general use outside of \texttt{MyPack}, then you will need to declare it as \texttt{public} and put it into its own file, as shown here:
package MyPack;

/* Now, the Balance class, its constructor, and its show() method are public. This means that they can be used by non-subclass code outside their package. */

public class Balance {
    String name;
    double bal;

    public Balance(String n, double b) {
        name = n;
        bal = b;
    }

    public void show() {
        if(bal<0)
            System.out.print("-> ");
        System.out.println(name + ": ": $" + bal);
    }
}

As you can see, the Balance class is now public. Also, its constructor and its show() method are public, too. This means that they can be accessed by any type of code outside the MyPack package. For example, here TestBalance imports MyPack and is then able to make use of the Balance class:

import MyPack.*;

class TestBalance {
    public static void main(String args[]) {
        /* Because Balance is public, you may use Balance class and call its constructor. */
        Balance test = new Balance("J. J. Jaspers", 99.99);
        test.show(); // you may also call show()
    }
}

As an experiment, remove the public specifier from the Balance class and then try compiling TestBalance. As explained, errors will result.

Interfaces
Using the keyword interface, you can fully abstract a class' interface from its
implementation. That is, using **interface**, you can specify what a class must do, but not how it does it. Interfaces are syntactically similar to classes, but they lack instance variables, and, as a general rule, their methods are declared without any body. In practice, this means that you can define interfaces that don’t make assumptions about how they are implemented. Once it is defined, any number of classes can implement an **interface**. Also, one class can implement any number of interfaces.

To implement an interface, a class must provide the complete set of methods required by the interface. However, each class is free to determine the details of its own implementation. By providing the **interface** keyword, Java allows you to fully utilize the “one interface, multiple methods” aspect of polymorphism.

Interfaces are designed to support dynamic method resolution at run time. Normally, in order for a method to be called from one class to another, both classes need to be present at compile time so the Java compiler can check to ensure that the method signatures are compatible. This requirement by itself makes for a static and nonextensible classing environment. Inevitably in a system like this, functionality gets pushed up higher and higher in the class hierarchy so that the mechanisms will be available to more and more subclasses. Interfaces are designed to avoid this problem. They disconnect the definition of a method or set of methods from the inheritance hierarchy. Since interfaces are in a different hierarchy from classes, it is possible for classes that are unrelated in terms of the class hierarchy to implement the same interface. This is where the real power of interfaces is realized.

### Defining an Interface

An interface is defined much like a class. This is a simplified general form of an interface:

```java
access interface name {
    return-type method-name1 (parameter-list);
    return-type method-name2 (parameter-list);

    type final-varname1 = value;
    type final-varname2 = value;
    // ...
    return-type method-nameN (parameter-list);
    type final-varnameN = value;
}
```

When no access modifier is included, then default access results, and the interface is only available to other members of the package in which it is declared. When it is declared as **public**, the interface can be used by any other code. In this case, the interface must be the only public interface declared in the file, and the file must have the same name as the
interface. *name* is the name of the interface, and can be any valid identifier. Notice that the methods that are declared have no bodies. They end with a semicolon after the parameter list. They are, essentially, abstract methods. Each class that includes such an interface must implement all of the methods.

Before continuing an important point needs to be made. JDK 8 added a feature to interface that makes a significant change to its capabilities. Prior to JDK 8, an interface could not define any implementation whatsoever. This is the type of interface that the preceding simplified form shows, in which no method declaration supplies a body. Thus, prior to JDK 8, an interface could define only “what,” but not “how.” JDK 8 changes this. Beginning with JDK 8, it is possible to add a *default implementation* to an interface method. Thus, it is now possible for interface to specify some behavior. However, default methods constitute what is, in essence, a special-use feature, and the original intent behind interface still remains. Therefore, as a general rule, you will still often create and use interfaces in which no default methods exist. For this reason, we will begin by discussing the interface in its traditional form. The default method is described at the end of this chapter. As the general form shows, variables can be declared inside of interface declarations. They are implicitly *final* and *static*, meaning they cannot be changed by the implementing class. They must also be initialized. All methods and variables are implicitly *public*.

Here is an example of an interface definition. It declares a simple interface that contains one method called *callback( )* that takes a single integer parameter.

```java
interface Callback {
    void callback(int param);
}
```

**Implementing Interfaces**

Once an interface has been defined, one or more classes can implement that interface. To implement an interface, include the *implements* clause in a class definition, and then create the methods required by the interface. The general form of a class that includes the *implements* clause looks like this:

```java
class classname [extends superclass] [implements interface [,interface...]] {
    // class-body
}
```

If a class implements more than one interface, the interfaces are separated with a comma. If a class implements two interfaces that declare the same method, then the same method will be used by clients of either interface. The methods that implement an interface must be declared *public*. Also, the type signature of the implementing method must match exactly
the type signature specified in the interface definition.
Here is a small example class that implements the Callback interface shown earlier:

```java
class Client implements Callback {
    // Implement Callback's interface
    public void callback(int p) {
        System.out.println("callback called with " + p);
    }
}
```

Notice that `callback()` is declared using the `public` access modifier.

---

**REMEMBER** When you implement an interface method, it must be declared as `public`.

It is both permissible and common for classes that implement interfaces to define additional members of their own. For example, the following version of Client implements `callback()` and adds the method `nonIfaceMeth()`:

```java
class Client implements Callback {
    // Implement Callback's interface
    public void callback(int p) {
        System.out.println("callback called with " + p);
    }

    void nonIfaceMeth() {
        System.out.println("Classes that implement interfaces " +
                        "may also define other members, too.");
    }
}
```

**Accessing Implementations Through Interface References**
You can declare variables as object references that use an interface rather than a class type. Any instance of any class that implements the declared interface can be referred to by such a variable. When you call a method through one of these references, the correct version will be called based on the actual instance of the interface being referred to. This is one of the key features of interfaces. The method to be executed is looked up dynamically at run time, allowing classes to be created later than the code which calls methods on them. The calling
code can dispatch through an interface without having to know anything about the “callee.” This process is similar to using a superclass reference to access a subclass object, as described in Chapter 8.

CAUTION Because dynamic lookup of a method at run time incurs a significant overhead when compared with the normal method invocation in Java, you should be careful not to use interfaces casually in performance-critical code.

The following example calls the `callback()` method via an interface reference variable:

```java
class TestInterface {
    public static void main(String args[]) {
        Callback c = new Client();
        c.callback(42);
    }
}
```

The output of this program is shown here:

```
callback called with 42
```

Notice that variable `c` is declared to be of the interface type `Callback`, yet it was assigned an instance of `Client`. Although `c` can be used to access the `callback()` method, it cannot access any other members of the `Client` class. An interface reference variable has knowledge only of the methods declared by its `interface` declaration. Thus, `c` could not be used to access `nonfaceMeth()` since it is defined by `Client` but not `Callback`. While the preceding example shows, mechanically, how an interface reference variable can access an implementation object, it does not demonstrate the polymorphic power of such a reference. To sample this usage, first create the second implementation of `Callback`, shown here:
Now, try the following class:

```java
class TestIface2 {
    public static void main(String args[]) {
        Callback c = new Client();
        AnotherClient ob = new AnotherClient();

        c.callback(42);

        c = ob; // c now refers to AnotherClient object
        c.callback(42);
    }
}
```

The output from this program is shown here:

```
callback called with 42
Another version of callback
p squared is 1764
```

As you can see, the version of `callback()` that is called is determined by the type of object that `c` refers to at run time. While this is a very simple example, you will see another, more practical one shortly.

**Partial Implementations**

If a class includes an interface but does not fully implement the methods required by that interface, then that class must be declared as `abstract`. For example:
abstract class Incomplete implements Callback {
    int a, b;
    void show() {
        System.out.println(a + " " + b);
    }
    //...
}

Here, the class Incomplete does not implement callback( ) and must be declared as abstract. Any class that inherits Incomplete must implement callback( ) or be declared abstract itself.

Nested Interfaces
An interface can be declared a member of a class or another interface. Such an interface is called a member interface or a nested interface. A nested interface can be declared as public, private, or protected. This differs from a top-level interface, which must either be declared as public or use the default access level, as previously described. When a nested interface is used outside of its enclosing scope, it must be qualified by the name of the class or interface of which it is a member. Thus, outside of the class or interface in which a nested interface is declared, its name must be fully qualified.
Here is an example that demonstrates a nested interface:

abstract class Incomplete implements Callback {
    int a, b;
    void show() {
        System.out.println(a + " " + b);
    }
    //...
}
Notice that A defines a member interface called NestedIF and that it is declared public. Next, B implements the nested interface by specifying

    implements A.NestedIF

Notice that the name is fully qualified by the enclosing class’ name. Inside the main() method, an A.NestedIF reference called nif is created, and it is assigned a reference to a B object. Because B implements A.NestedIF, this is legal.

Applying Interfaces
To understand the power of interfaces, let’s look at a more practical example. In earlier chapters, you developed a class called Stack that implemented a simple fixed-size stack. However, there are many ways to implement a stack. For example, the stack can be of a fixed size or it can be “growable.” The stack can also be held in an array, a linked list, a binary tree, and so on. No matter how the stack is implemented, the interface to the stack...
remains the same. That is, the methods `push()` and `pop()` define the interface to the stack independently of the details of the implementation. Because the interface to a stack is separate from its implementation, it is easy to define a stack interface, leaving it to each implementation to define the specifics. Let’s look at two examples.

First, here is the interface that defines an integer stack. Put this in a file called `IntStack.java`. This interface will be used by both stack implementations.

```java
// Define an integer stack interface.
interface IntStack {
    void push(int item); // store an item
    int pop(); // retrieve an item
}
```

The following program creates a class called `FixedStack` that implements a fixed-length version of an integer stack:

```java
// An implementation of IntStack that uses fixed storage.
class FixedStack implements IntStack {
    private int stk[];
    private int tos;

    // allocate and initialize stack
    FixedStack(int size) {
        stk = new int[size];
        tos = -1;
    }

    // Push an item onto the stack
    public void push(int item) {
        if(tos == stk.length-1) // use length member
            System.out.println("Stack is full.");
        else
            stk[++tos] = item;
    }
}
```
Following is another implementation of `IntStack` that creates a dynamic stack by use of the same `interface` definition. In this implementation, each stack is constructed with an initial length. If this initial length is exceeded, then the stack is increased in size. Each time more room is needed, the size of the stack is doubled.
// Implement a "growable" stack.
class DynStack implements IntStack {
    private int stk[];
    private int tos;

    // allocate and initialize stack
   DynStack(int size) {
        stk = new int[size];
        tos = -1;
    }

    // Push an item onto the stack
    public void push(int item) {
        // if stack is full, allocate a larger stack
        if(tos==stk.length-1) {
            int temp[] = new int[stk.length * 2]; // double size
            for(int i=0; i<stk.length; i++) temp[i] = stk[i];
        }
    }
The following class uses both the `FixedStack` and `DynStack` implementations. It does so through an interface reference. This means that calls to `push()` and `pop()` are resolved at run time rather than at compile time.
In this program, mystack is a reference to the IntStack interface. Thus, when it refers to ds, it uses the versions of push() and pop() defined by the DynStack implementation. When it refers to fs, it uses the versions of push() and pop() defined by FixedStack. As explained, these determinations are made at run time. Accessing multiple implementations of an interface through an interface reference variable is the most powerful way that Java achieves run-time polymorphism.

**Variables in Interfaces**

You can use interfaces to import shared constants into multiple classes by simply declaring an interface that contains variables that are initialized to the desired values. When you include that interface in a class (that is, when you “implement” the interface), all of those variable names will be in scope as constants. (This is similar to using a header file in C/C++ to create a large number of #defined constants or const declarations.) If an interface contains no methods, then any class that includes such an interface doesn’t actually implement anything. It is as if that class were importing the constant fields into the class name space as final variables. The next example uses this technique to implement an automated “decision maker”: 
import java.util.Random;

interface SharedConstants {
    int NO = 0;
    int YES = 1;
    int MAYBE = 2;
    int LATER = 3;
    int SOON = 4;
    int NEVER = 5;
}

class Question implements SharedConstants {
    Random rand = new Random();
    int ask() {
        int prob = (int) (100 * rand.nextDouble());
        if (prob < 30)
Notice that this program makes use of one of Java's standard classes: **Random**. This class provides pseudorandom numbers. It contains several methods that allow you to obtain random numbers in the form required by your program. In this example, the method **nextDouble()** is used. It returns random numbers in the range 0.0 to 1.0.

In this sample program, the two classes, **Question** and **AskMe**, both implement the
**SharedConstants** interface where **NO, YES, MAYBE, SOON, LATER, and NEVER** are defined. Inside each class, the code refers to these constants as if each class had defined or inherited them directly. Here is the output of a sample run of this program. Note that the results are different each time it is run.

```
Later
Soon
No
Yes
```

**NOTE** The technique of using an interface to define shared constants, as just described, is controversial. It is described here for completeness.

**Interfaces Can Be Extended**

One interface can inherit another by use of the keyword **extends**. The syntax is the same as for inheriting classes. When a class implements an interface that inherits another interface, it must provide implementations for all methods required by the interface inheritance chain. Following is an example:
As an experiment, you might want to try removing the implementation for `meth1()` in `MyClass`. This will cause a compile-time error. As stated earlier, any class that implements an interface must implement all methods required by that interface, including any that are inherited from other interfaces.

**Default Interface Methods**

As explained earlier, prior to JDK 8, an interface could not define any implementation whatsoever. This meant that for all previous versions of Java, the methods specified by an interface were abstract, containing no body. This is the traditional form of an interface and is the type of interface that the preceding discussions have used. The release of JDK 8 has
changed this by adding a new capability to **interface** called the **default method**. A default method lets you define a default implementation for an interface method. In other words, by use of a default method, it is now possible for an interface method to provide a body, rather than being abstract. During its development, the default method was also referred to as an **extension method**, and you will likely see both terms used.

A primary motivation for the default method was to provide a means by which interfaces could be expanded without breaking existing code. Recall that there must be implementations for all methods defined by an interface. In the past, if a new method were added to a popular, widely used interface, then the addition of that method would break existing code because no implementation would be found for that new method. The default method solves this problem by supplying an implementation that will be used if no other implementation is explicitly provided. Thus, the addition of a default method will not cause preexisting code to break.

Another motivation for the default method was the desire to specify methods in an interface that are, essentially, optional, depending on how the interface is used. For example, an interface might define a group of methods that act on a sequence of elements. One of these methods might be called **remove()**, and its purpose is to remove an element from the sequence. However, if the interface is intended to support both modifiable and nonmodifiable sequences, then **remove()** is essentially optional because it won’t be used by nonmodifiable sequences. In the past, a class that implemented a nonmodifiable sequence would have had to define an empty implementation of **remove()**, even though it was not needed. Today, a default implementation for **remove()** can be specified in the interface that does nothing (or throws an exception). Providing this default prevents a class used for nonmodifiable sequences from having to define its own, placeholder version of **remove()**. Thus, by providing a default, the interface makes the implementation of **remove()** by a class optional.

It is important to point out that the addition of default methods does not change a key aspect of **interface**: its inability to maintain state information. An interface still cannot have instance variables, for example. Thus, the defining difference between an interface and a class is that a class can maintain state information, but an interface cannot. Furthermore, it is still not possible to create an instance of an interface by itself. It must be implemented by a class. Therefore, even though, beginning with JDK 8, an interface can define default methods, the interface must still be implemented by a class if an instance is to be created.

One last point: As a general rule, default methods constitute a special-purpose feature. Interfaces that you create will still be used primarily to specify what and not how. However, the inclusion of the default method gives you added flexibility.

**Default Method Fundamentals**

An interface default method is defined similar to the way a method is defined by a **class**. The primary difference is that the declaration is preceded by the keyword **default**. For example, consider this simple interface:
MyIF declares two methods. The first, `getNumber()`, is a standard interface method declaration. It defines no implementation whatsoever. The second method is `getString()`, and it does include a default implementation. In this case, it simply returns the string "Default String". Pay special attention to the way `getString()` is declared. Its declaration is preceded by the `default` modifier. This syntax can be generalized. To define a default method, precede its declaration with `default`.

Because `getString()` includes a default implementation, it is not necessary for an implementing class to override it. In other words, if an implementing class does not provide its own implementation, the default is used. For example, the `MyIFImp` class shown next is perfectly valid:

```java
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getNumber();

    // This is a default method. Notice that it provides
    // a default implementation.
    default String getString() {
        return "Default String";
    }
}
```

The following code creates an instance of `MyIFImp` and uses it to call both `getNumber()` and `getString()`.
The output is shown here:

100
Default String

As you can see, the default implementation of `getString()` was automatically used. It was not necessary for `MyIFImp` to define it. Thus, for `getString()`, implementation by a class is optional. (Of course, its implementation by a class will be required if the class uses `getString()` for some purpose beyond that supported by its default.)

It is both possible and common for an implementing class to define its own implementation of a default method. For example, `MyIFImp2` overrides `getString()`:

```java
class MyIFImp2 implements MyIF {
    // Here, implementations for both getNumber() and getString() are provided.
    public int getNumber() {
        return 100;
    }

    public String getString() {
        return "This is a different string."
    }
}
```

Now, when `getString()` is called, a different string is returned.

**A More Practical Example**

Although the preceding shows the mechanics of using default methods, it doesn’t illustrate their usefulness in a more practical setting. To do this, let’s once again return to the `IntStack` interface shown earlier in this chapter. For the sake of discussion, assume that `IntStack` is widely used and many programs rely on it. Further assume that we now want to
add a method to `IntStack` that clears the stack, enabling the stack to be re-used. Thus, we want to evolve the `IntStack` interface so that it defines new functionality, but we don't want to break any preexisting code. In the past, this would be impossible, but with the inclusion of default methods, it is now easy to do. For example, the `IntStack` interface can be enhanced like this:

```java
interface IntStack {
    void push(int item); // store an item
    int pop(); // retrieve an Item

    // Because clear() has a default, it need not be
    // implemented by a preexisting class that uses IntStack.
    default void clear() {
        System.out.println("clear() not implemented.");
    }
}
```

Here, the default behavior of `clear()` simply displays a message indicating that it is not implemented. This is acceptable because no preexisting class that implements `IntStack` would ever call `clear()` because it was not defined by the earlier version of `IntStack`. However, `clear()` can be implemented by a new class that implements `IntStack`. Furthermore, `clear()` needs to be defined by a new implementation only if it is used. Thus, the default method gives you

- a way to gracefully evolve interfaces over time, and
- a way to provide optional functionality without requiring that a class provide a placeholder implementation when that functionality is not needed.

One other point: In real-world code, `clear()` would have thrown an exception, rather than displaying an error message. Exceptions are described in the next chapter. After working through that material, you might want to try modifying `clear()` so that its default implementation throws an `UnsupportedOperationException`.

### Multiple Inheritance Issues

As explained earlier in this book, Java does not support the multiple inheritance of classes. Now that an interface can include default methods, you might be wondering if an interface can provide a way around this restriction. The answer is, essentially, no. Recall that there is still a key difference between a class and an interface: a class can maintain state information (especially through the use of instance variables), but an interface cannot.

The preceding notwithstanding, default methods do offer a bit of what one would normally associate with the concept of multiple inheritance. For example, you might have a class that
implements two interfaces. If each of these interfaces provides default methods, then some behavior is inherited from both. Thus, to a limited extent, default methods do support multiple inheritance of behavior. As you might guess, in such a situation, it is possible that a name conflict will occur.

For example, assume that two interfaces called Alpha and Beta are implemented by a class called MyClass. What happens if both Alpha and Beta provide a method called reset() for which both declare a default implementation? Is the version by Alpha or the version by Beta used by MyClass? Or, consider a situation in which Beta extends Alpha. Which version of the default method is used? Or, what if MyClass provides its own implementation of the method? To handle these and other similar types of situations, Java defines a set of rules that resolves such conflicts.

First, in all cases, a class implementation takes priority over an interface default implementation. Thus, if MyClass provides an override of the reset() default method, MyClass’ version is used. This is the case even if MyClass implements both Alpha and Beta. In this case, both defaults are overridden by MyClass’ implementation.

Second, in cases in which a class implements two interfaces that both have the same default method, but the class does not override that method, then an error will result. Continuing with the example, if MyClass implements both Alpha and Beta, but does not override reset(), then an error will occur.

In cases in which one interface inherits another, with both defining a common default method, the inheriting interface’s version of the method takes precedence. Therefore, continuing the example, if Beta extends Alpha, then Beta’s version of reset() will be used.

It is possible to explicitly refer to a default implementation in an inherited interface by using a new form of super. Its general form is shown here:

\[ \text{InterfaceName.super.methodName( )} \]

For example, if Beta wants to refer to Alpha’s default for reset(), it can use this statement:

\[ \text{Alpha.super.reset();} \]

Use static Methods in an Interface
JDK 8 added another new capability to interface: the ability to define one or more static methods. Like static methods in a class, a static method defined by an interface can be called independently of any object. Thus, no implementation of the interface is necessary, and no instance of the interface is required, in order to call a static method. Instead, a static method is called by specifying the interface name, followed by a period, followed by the method name. Here is the general form:

\[ \text{InterfaceName.staticMethodName} \]
Notice that this is similar to the way that a static method in a class is called. The following shows an example of a static method in an interface by adding one to MyIF, shown in the previous section. The static method is `getDefaultNumber()`. It returns zero.

```java
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getNumber();

    // This is a default method. Notice that it provides
    // a default implementation.
    default String getString() {
        return "Default String";
    }

    // This is a static interface method.
    static int getDefaultNumber() {
        return 0;
    }
}
```

The `getDefaultNumber()` method can be called, as shown here:

```java
int defNum = MyIF.getDefaultNumber();
```

As mentioned, no implementation or instance of MyIF is required to call `getDefaultNumber()` because it is static.

One last point: static interface methods are not inherited by either an implementing class or a subinterface.

**Final Thoughts on Packages and Interfaces**

Although the examples we’ve included in this book do not make frequent use of packages or interfaces, both of these tools are an important part of the Java programming environment. Virtually all real programs that you write in Java will be contained within packages. A number will probably implement interfaces as well. It is important, therefore, that you be comfortable with their usage.
This chapter examines Java's exception-handling mechanism. An exception is an abnormal condition that arises in a code sequence at run time. In other words, an exception is a runtime error. In computer languages that do not support exception handling, errors must be checked and handled manually—typically through the use of error codes, and so on. This approach is as cumbersome as it is troublesome. Java's exception handling avoids these problems and, in the process, brings run-time error management into the object-oriented world.

**Exception-Handling Fundamentals**

A Java exception is an object that describes an exceptional (that is, error) condition that has occurred in a piece of code. When an exceptional condition arises, an object representing that exception is created and thrown in the method that caused the error. That method may choose to handle the exception itself, or pass it on. Either way, at some point, the exception is caught and processed. Exceptions can be generated by the Java run-time system, or they can be manually generated by your code. Exceptions thrown by Java relate to fundamental errors that violate the rules of the Java language or the constraints of the Java execution environment. Manually generated exceptions are typically used to report some error condition to the caller of a method.

Java exception handling is managed via five keywords: try, catch, throw, throws, and finally. Briefly, here is how they work. Program statements that you want to monitor for exceptions are contained within a try block. If an exception occurs within the try block, it is thrown. Your code can catch this exception (using catch) and handle it in some rational manner. System-generated exceptions are automatically thrown by the Java runtime system. To manually throw an exception, use the keyword throw. Any exception that is thrown out of a method must be specified as such by a throws clause. Any code that absolutely must be executed after a try block completes is put in a finally block. This is the general form of an exception-handling block:
Here, ExceptionType is the type of exception that has occurred. The remainder of this chapter describes how to apply this framework.

NOTE  Beginning with JDK 7, there is another form of the try statement that supports automatic resource management. This form of try, called try-with-resources, is described in Chapter 13 in the context of managing files because files are some of the most commonly used resources.

Exception Types
All exception types are subclasses of the built-in class Throwable. Thus, Throwable is at the top of the exception class hierarchy. Immediately below Throwable are two subclasses that partition exceptions into two distinct branches. One branch is headed by Exception. This class is used for exceptional conditions that user programs should catch. This is also the class that you will subclass to create your own custom exception types. There is an important subclass of Exception, called RuntimeException. Exceptions of this type are automatically defined for the programs that you write and include things such as division by zero and invalid array indexing.

The other branch is topped by Error, which defines exceptions that are not expected to be caught under normal circumstances by your program. Exceptions of type Error are used by the Java run-time system to indicate errors having to do with the run-time environment,
itself. Stack overflow is an example of such an error. This chapter will not be dealing with exceptions of type `Error`, because these are typically created in response to catastrophic failures that cannot usually be handled by your program.

The top-level exception hierarchy is shown here:

![Exception Hierarchy Diagram](image)

**Uncaught Exceptions**

Before you learn how to handle exceptions in your program, it is useful to see what happens when you don’t handle them. This small program includes an expression that intentionally causes a divide-by-zero error:

```java
class Exc0 {
    public static void main(String args[]) {
        int d = 0;
        int a = 42 / d;
    }
}
```

When the Java run-time system detects the attempt to divide by zero, it constructs a new exception object and then throws this exception. This causes the execution of `Exc0` to stop, because once an exception has been thrown, it must be caught by an exception handler and dealt with immediately. In this example, we haven’t supplied any exception handlers of our own, so the exception is caught by the default handler provided by the Java run-time system. Any exception that is not caught by your program will ultimately be processed by the default handler. The default handler displays a string describing the exception, prints a stack trace from the point at which the exception occurred, and terminates the program. Here is the exception generated when this example is executed:
Notice how the class name, `Exco`; the method name, `main`; the filename, `Exco.java`; and the line number, 4, are all included in the simple stack trace. Also, notice that the type of exception thrown is a subclass of `Exception` called `ArithmeticException`, which more specifically describes what type of error happened. As discussed later in this chapter, Java supplies several built-in exception types that match the various sorts of run-time errors that can be generated.

The stack trace will always show the sequence of method invocations that led up to the error. For example, here is another version of the preceding program that introduces the same error but in a method separate from `main()`:

```java
class Excl {
    static void subroutine() {
        int d = 0;
        int a = 10 / d;
    }
    public static void main(String args[]) {
        Excl.subroutine();
    }
}
```

The resulting stack trace from the default exception handler shows how the entire call stack is displayed:

```
java.lang.ArithmeticException: / by zero
    at Excl.subroutine(Excl.java:4)
    at Excl.main(Excl.java:7)
```

As you can see, the bottom of the stack is `main`’s line 7, which is the call to `subroutine()`, which caused the exception at line 4. The call stack is quite useful for debugging, because it pinpoints the precise sequence of steps that led to the error.

**Using try and catch**

Although the default exception handler provided by the Java run-time system is useful for debugging, you will usually want to handle an exception yourself. Doing so provides two benefits. First, it allows you to fix the error. Second, it prevents the program from automatically terminating. Most users would be confused (to say the least) if your program stopped running and printed a stack trace whenever an error occurred! Fortunately, it is quite easy to prevent this.
To guard against and handle a run-time error, simply enclose the code that you want to monitor inside a **try** block. Immediately following the **try** block, include a **catch** clause that specifies the exception type that you wish to catch. To illustrate how easily this can be done, the following program includes a **try** block and a **catch** clause that processes the **ArithmeticException** generated by the division-by-zero error:

```java
class Exc2 {
    public static void main(String args[]) {
        int d, a;
        try { // monitor a block of code.
            d = 0;
            a = 42 / d;
            System.out.println("This will not be printed.");
        } catch (ArithmeticException e) { // catch divide-by-zero error
            System.out.println("Division by zero.");
        }
        System.out.println("After catch statement.");
    }
}
```

This program generates the following output:

```
Division by zero.
After catch statement.
```

Notice that the call to **println()** inside the **try** block is never executed. Once an exception is thrown, program control transfers out of the **try** block into the **catch** block. Put differently, **catch** is not “called,” so execution never “returns” to the **try** block from a **catch**. Thus, the line "This will not be printed." is not displayed. Once the **catch** statement has executed, program control continues with the next line in the program following the entire **try / catch** mechanism.

A **try** and its **catch** statement form a unit. The scope of the **catch** clause is restricted to those statements specified by the immediately preceding **try** statement. A **catch** statement cannot catch an exception thrown by another **try** statement (except in the case of nested **try** statements, described shortly). The statements that are protected by **try** must be surrounded by curly braces. (That is, they must be within a block.) You cannot use **try** on a single statement.

The goal of most well-constructed **catch** clauses should be to resolve the exceptional condition and then continue on as if the error had never happened. For example, in the next program each iteration of the **for** loop obtains two random integers. Those two integers are divided by each other, and the result is used to divide the value 12345. The final result is put into **a**. If either division operation causes a divide-by-zero error, it is caught, the value of **a** is set to zero, and the program continues.
// Handle an exception and move on.
import java.util.Random;

class HandleError {
    public static void main(String args[]) {
        int a=0, b=0, c=0;
        Random r = new Random();

        for(int i=0; i<32000; i++) {
            try {
                b = r.nextInt();
                c = r.nextInt();
                a = 12345 / (b/c);
            } catch (ArithmeticException e) {
                System.out.println("Division by zero.");
                a = 0; // set a to zero and continue
            }
            System.out.println("a: " + a);
        }
    }
}

Displaying a Description of an Exception

Throwable overrides the toString() method (defined by Object) so that it returns a string containing a description of the exception. You can display this description in a println() statement by simply passing the exception as an argument. For example, the catch block in the preceding program can be rewritten like this:

```
catch (ArithmeticException e) {
    System.out.println("Exception: " + e);
    a = 0; // set a to zero and continue
}
```

When this version is substituted in the program, and the program is run, each divide-by-zero error displays the following message:

```
Exception: java.lang.ArithmeticException: / by zero
```

While it is of no particular value in this context, the ability to display a description of an exception is valuable in other circumstances—particularly when you are experimenting with exceptions or when you are debugging.

Multiple catch Clauses
In some cases, more than one exception could be raised by a single piece of code. To handle this type of situation, you can specify two or more `catch` clauses, each catching a different type of exception. When an exception is thrown, each `catch` statement is inspected in order, and the first one whose type matches that of the exception is executed. After one `catch` statement executes, the others are bypassed, and execution continues after the `try / catch` block. The following example traps two different exception types:

```java
// Demonstrate multiple catch statements.
class MultipleCatches {
    public static void main(String args[]) {
        try {
            int a = args.length;
            System.out.println("a = " + a);
            int b = 42 / a;
            int c[] = { 1 };
            c[42] = 99;
        } catch (ArithmeticException e) {
            System.out.println("Divide by 0: " + e);
        } catch (ArrayIndexOutOfBoundsException e) {
            System.out.println("Array index oob: " + e);
        }
        System.out.println("After try/catch blocks.");
    }
}
```

This program will cause a division-by-zero exception if it is started with no command-line arguments, since `a` will equal zero. It will survive the division if you provide a command-line argument, setting `a` to something larger than zero. But it will cause an `ArrayIndexOutOfBoundsException`, since the `int` array `c` has a length of 1, yet the program attempts to assign a value to `c[42]`.

Here is the output generated by running it both ways:

```
C:\>java MultipleCatches
a = 0
Divide by 0: java.lang.ArithmeticException: / by zero
After try/catch blocks.

C:\>java MultipleCatches TestArg
a = 1
Array index oob: java.lang.ArrayIndexOutOfBoundsException:42
After try/catch blocks.
```

When you use multiple `catch` statements, it is important to remember that exception subclasses must come before any of their superclasses. This is because a `catch` statement
that uses a superclass will catch exceptions of that type plus any of its subclasses. Thus, a subclass would never be reached if it came after its superclass. Further, in Java, unreachable code is an error. For example, consider the following program:

```java
/* This program contains an error.
 A subclass must come before its superclass in a series of catch statements. If not, unreachable code will be created and a compile-time error will result.
 */
class superSubCatch {
    public static void main(String args[]) {
        try {
            int a = 0;
            int b = 42 / a;
        } catch(Exception e) {
            System.out.println("Generic Exception catch.");
        }
        /* This catch is never reached because
         ArithmeticException is a subclass of Exception. */
        catch(ArithmeticException e) { // ERROR - unreachable
            System.out.println("This is never reached.");
        }
    }
}
```

If you try to compile this program, you will receive an error message stating that the second `catch` statement is unreachable because the exception has already been caught. Since `ArithmeticException` is a subclass of `Exception`, the first `catch` statement will handle all `Exception`-based errors, including `ArithmeticException`. This means that the second `catch` statement will never execute. To fix the problem, reverse the order of the `catch` statements.

**Nested try Statements**

The `try` statement can be nested. That is, a `try` statement can be inside the block of another `try`. Each time a `try` statement is entered, the context of that exception is pushed on the stack. If an inner `try` statement does not have a `catch` handler for a particular exception, the stack is unwound and the next `try` statement’s `catch` handlers are inspected for a match. This continues until one of the `catch` statements succeeds, or until all of the nested `try` statements are exhausted. If no `catch` statement matches, then the Java run-time system will handle the exception. Here is an example that uses nested `try` statements:
As you can see, this program nests one try block within another. The program works as follows. When you execute the program with no command-line arguments, a divide-by-zero exception is generated by the outer try block. Execution of the program with one command-line argument generates a divide-by-zero exception from within the nested try block. Since the inner block does not catch this exception, it is passed on to the outer try block, where it is handled. If you execute the program with two command-line arguments, an array boundary exception is generated from within the inner try block. Here are sample runs that illustrate each case:
Nesting of try statements can occur in less obvious ways when method calls are involved. For example, you can enclose a call to a method within a try block. Inside that method is another try statement. In this case, the try within the method is still nested inside the outer try block, which calls the method. Here is the previous program recoded so that the nested try block is moved inside the method nesttry():

```
C:\>java NestTry
Divide by 0: java.lang.ArithmeticException: / by zero

C:\>java NestTry One
a = 1
Divide by 0: java.lang.ArithmeticException: / by zero

C:\>java NestTry One Two
a = 2
Array index out-of-bounds:
java.lang.ArrayIndexOutOfBoundsException:42
```
The output of this program is identical to that of the preceding example.

**throw**

So far, you have only been catching exceptions that are thrown by the Java run-time system. However, it is possible for your program to throw an exception explicitly, using the **throw** statement. The general form of **throw** is shown here:

```java
throw ThrowableInstance;
```

Here, `ThrowableInstance` must be an object of type `Throwable` or a subclass of `Throwable`. Primitive types, such as `int` or `char`, as well as non-`Throwable` classes, such as `String` and `Object`, cannot be used as exceptions. There are two
ways you can obtain a Throwable object: using a parameter in a catch clause or creating one with the new operator.

The flow of execution stops immediately after the throw statement; any subsequent statements are not executed. The nearest enclosing try block is inspected to see if it has a catch statement that matches the type of exception. If it does find a match, control is transferred to that statement. If not, then the next enclosing try statement is inspected, and so on. If no matching catch is found, then the default exception handler halts the program and prints the stack trace.

Here is a sample program that creates and throws an exception. The handler that catches the exception rethrows it to the outer handler.

```java
// Demonstrate throw.
public class ThrowDemo {  
  static void demoproc() {  
    try {  
      throw new NullPointerException("demo");  
    } catch (NullPointerException e) {  
      System.out.println("Caught inside demoproc.");  
      throw e; // rethrow the exception  
    }  
  }

  public static void main(String args[]) {  
    try {  
      demoproc();  
    } catch (NullPointerException e) {  
      System.out.println("Recaught: " + e);  
    }  
  }
}
```

This program gets two chances to deal with the same error. First, main( ) sets up an exception context and then calls demoproc( ). The demoproc( ) method then sets up another exception-handling context and immediately throws a new instance of NullPointerException, which is caught on the next line. The exception is then rethrown.

Here is the resulting output:

```
Caught inside demoproc.
Recaught: java.lang.NullPointerException: demo
```

The program also illustrates how to create one of Java's standard exception objects. Pay close attention to this line:

```
throw new NullPointerException("demo");
```
Here, `new` is used to construct an instance of `NullPointerException`. Many of Java’s built-in run-time exceptions have at least two constructors: one with no parameter and one that takes a string parameter. When the second form is used, the argument specifies a string that describes the exception. This string is displayed when the object is used as an argument to `print()` or `println()`. It can also be obtained by a call to `getMessage()`, which is defined by `Throwable`.

```java
    throws
```

If a method is capable of causing an exception that it does not handle, it must specify this behavior so that callers of the method can guard themselves against that exception. You do this by including a `throws` clause in the method’s declaration. A `throws` clause lists the types of exceptions that a method might throw. This is necessary for all exceptions, except those of type `Error` or `RuntimeException`, or any of their subclasses. All other exceptions that a method can throw must be declared in the `throws` clause. If they are not, a compile-time error will result.

This is the general form of a method declaration that includes a `throws` clause:

```java
    type method-name(parameter-list) throws exception-list
    {
    // body of method
    }
```

Here, `exception-list` is a comma-separated list of the exceptions that a method can throw.

Following is an example of an incorrect program that tries to throw an exception that it does not catch. Because the program does not specify a `throws` clause to declare this fact, the program will not compile.

```java
// This program contains an error and will not compile.
class ThrowsDemo {
    static void throwOne() {
        System.out.println("Inside throwOne.");
        throw new IllegalAccessException("demo");
    }
    public static void main(String args[]) {
        throwOne();
    }
}
```

To make this example compile, you need to make two changes. First, you need to declare that `throwOne()` throws `IllegalAccessException`. Second, `main()` must define a `try` /
**catch** statement that catches this exception.
The corrected example is shown here:

```java
// This is now correct.
class ThrowsDemo {
    static void throwOne() throws IllegalAccessException {
        System.out.println("Inside throwOne.");
        throw new IllegalAccessException("demo");
    }
    public static void main(String args[]) {
        try {
            throwOne();
        } catch (IllegalAccessException e) {
            System.out.println("Caught "+ e);
        }
    }
}
```

Here is the output generated by running this example program:

```
inside throwOne
caught java.lang.IllegalArgumentException: demo
```

**finally**
When exceptions are thrown, execution in a method takes a rather abrupt, nonlinear path that alters the normal flow through the method. Depending upon how the method is coded, it is even possible for an exception to cause the method to return prematurely. This could be a problem in some methods. For example, if a method opens a file upon entry and closes it upon exit, then you will not want the code that closes the file to be bypassed by the exception-handling mechanism. The **finally** keyword is designed to address this contingency.

**finally** creates a block of code that will be executed after a **try / catch** block has completed and before the code following the **try/catch** block. The **finally** block will execute whether or not an exception is thrown. If an exception is thrown, the **finally** block will execute even if no **catch** statement matches the exception. Any time a method is about to return to the caller from inside a **try/catch** block, via an uncaught exception or an explicit return statement, the **finally** clause is also executed just before the method returns. This can be useful for closing file handles and freeing up any other resources that might have been allocated at the beginning of a method with the intent of disposing of them before returning. The **finally** clause is optional. However, each **try** statement requires at least one **catch** or a **finally** clause.

Here is an example program that shows three methods that exit in various ways, none without executing their **finally** clauses:
In this example, procA() prematurely breaks out of the try by throwing an exception. The finally clause is executed on the way out. procB()'s try statement is exited via a return statement. The finally clause is executed before procB() returns. In procC(), the try statement executes normally, without error. However, the finally block is still executed.
REMEMBER  If a finally block is associated with a try, the finally block will be executed upon conclusion of the try.

Here is the output generated by the preceding program:

```
inside procA
procA's finally
Exception caught
inside procB
procB's finally
inside procC
procC's finally
```

**Java’s Built-in Exceptions**

Inside the standard package `java.lang`, Java defines several exception classes. A few have been used by the preceding examples. The most general of these exceptions are subclasses of the standard type `RuntimeException`. As previously explained, these exceptions need not be included in any method’s `throws` list. In the language of Java, these are called **unchecked exceptions** because the compiler does not check to see if a method handles or throws these exceptions. The unchecked exceptions defined in `java.lang` are listed in Table 10-1. Table 10-2 lists those exceptions defined by `java.lang` that must be included in a method’s `throws` list if that method can generate one of these exceptions and does not handle it itself. These are called **checked exceptions**. In addition to the exceptions in `java.lang`, Java defines several more that relate to its other standard packages.
Creating Your Own Exception Subclasses

Although Java’s built-in exceptions handle most common errors, you will probably want to create your own exception types to handle situations specific to your applications. This is quite easy to do: just define a subclass of `Exception` (which is, of course, a subclass of `Throwable`). Your subclasses don’t need to actually implement anything—it is their existence in the type system that allows you to use them as exceptions. The `Exception` class does not define any methods of its own. It does, of course, inherit those methods provided by `Throwable`. Thus, all exceptions, including those that you

---

Table 10-1  Java’s Unchecked `RuntimeException` Subclasses Defined in `java.lang`

<table>
<thead>
<tr>
<th>Exception</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ArithmeticException</td>
<td>Arithmetic error, such as divide-by-zero.</td>
</tr>
<tr>
<td>ArrayIndexOutOfBoundsException</td>
<td>Array index is out-of-bounds.</td>
</tr>
<tr>
<td>ArrayStoreException</td>
<td>Assignment to an array element of an incompatible type.</td>
</tr>
<tr>
<td>ClassCastException</td>
<td>Invalid cast.</td>
</tr>
<tr>
<td>EnumConstantNotPresentException</td>
<td>An attempt is made to use an undefined enumeration value.</td>
</tr>
<tr>
<td>IllegalArgumentException</td>
<td>Illegal argument used to invoke a method.</td>
</tr>
<tr>
<td>IllegalMonitorStateException</td>
<td>Illegal monitor operation, such as waiting on an unlocked thread.</td>
</tr>
<tr>
<td>IllegalStateException</td>
<td>Environment or application is in incorrect state.</td>
</tr>
<tr>
<td>IllegalThreadStateException</td>
<td>Requested operation not compatible with current thread state.</td>
</tr>
<tr>
<td>IndexOutOfBoundsException</td>
<td>Some type of index is out-of-bounds.</td>
</tr>
<tr>
<td>NegativeArraySizeException</td>
<td>Array created with a negative size.</td>
</tr>
<tr>
<td>NullPointerException</td>
<td>Invalid use of a null reference.</td>
</tr>
<tr>
<td>NumberFormatException</td>
<td>Invalid conversion of a string to a numeric format.</td>
</tr>
<tr>
<td>SecurityException</td>
<td>Attempt to violate security.</td>
</tr>
<tr>
<td>StringIndexOutOfBoundsException</td>
<td>Attempt to index outside the bounds of a string.</td>
</tr>
<tr>
<td>TypeNotPresentException</td>
<td>Type not found.</td>
</tr>
<tr>
<td>UnsupportedOperationException</td>
<td>An unsupported operation was encountered.</td>
</tr>
</tbody>
</table>

Table 10-2  Java’s Checked Exceptions Defined in `java.lang`

<table>
<thead>
<tr>
<th>Exception</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClassCastException</td>
<td>Class not found.</td>
</tr>
<tr>
<td>CloneNotSupportedException</td>
<td>Attempt to clone an object that does not implement the <code>Cloneable</code> interface.</td>
</tr>
<tr>
<td>IllegalAccessException</td>
<td>Access to a class is denied.</td>
</tr>
<tr>
<td>InstantiationException</td>
<td>Attempt to create an object of an abstract class or interface.</td>
</tr>
<tr>
<td>InterruptedException</td>
<td>One thread has been interrupted by another thread.</td>
</tr>
<tr>
<td>NoSuchFieldException</td>
<td>A requested field does not exist.</td>
</tr>
<tr>
<td>NoSuchMethodException</td>
<td>A requested method does not exist.</td>
</tr>
<tr>
<td>ReflectiveOperationException</td>
<td>Subclass of reflection-related exceptions.</td>
</tr>
</tbody>
</table>
create, have the methods defined by `Throwable` available to them. They are shown in Table 10-3. You may also wish to override one or more of these methods in exception classes that you create.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>addSuppressed(Throwable ex)</code></td>
<td>Adds <code>ex</code> to the list of suppressed exceptions associated with the invoking exception. Primarily for use by the try-with-resources statement.</td>
</tr>
<tr>
<td><code>fillInStackTrace()</code></td>
<td>Returns a <code>Throwable</code> object that contains a completed stack trace. This object can be thrown.</td>
</tr>
<tr>
<td><code>getCause()</code></td>
<td>Returns the exception that underlies the current exception. If there is no underlying exception, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>getLocalizedMessage()</code></td>
<td>Returns a localized description of the exception.</td>
</tr>
<tr>
<td><code>getMessage()</code></td>
<td>Returns a description of the exception.</td>
</tr>
<tr>
<td><code>getStackTrace()</code></td>
<td>Returns an array that contains the stack trace of the exception and returns an array of <code>StackTraceElement</code>. The method at the top of the stack is the last method called before the exception was thrown. This method is found in the first element of the array. The <code>StackTraceElement</code> class gives your program access to information about each element in the stack trace, such as its method name.</td>
</tr>
<tr>
<td><code>getSuppressed()</code></td>
<td>Obtains the suppressed exceptions associated with the invoking exception and returns an array that contains the result. Suppressed exceptions are primarily generated by the try-with-resources statement.</td>
</tr>
<tr>
<td><code>initCause(Throwable cause)</code></td>
<td>Associates <code>cause</code> with the invoking exception as a cause of the invoking exception. Returns a reference to the exception.</td>
</tr>
<tr>
<td><code>printStackTrace()</code></td>
<td>Displays the stack trace.</td>
</tr>
<tr>
<td><code>printStackTrace(PrintStream stream)</code></td>
<td>Sends the stack trace to the specified stream.</td>
</tr>
<tr>
<td><code>printStackTrace(PrintWriter stream)</code></td>
<td>Sends the stack trace to the specified stream.</td>
</tr>
<tr>
<td><code>setStackTrace(StackTraceElement[] elements)</code></td>
<td>Sets the stack trace to the elements passed in <code>elements</code>. This method is for specialized applications, not normal use.</td>
</tr>
<tr>
<td><code>toString()</code></td>
<td>Returns a <code>String</code> object containing a description of the exception. This method is called by <code>printStackTrace()</code> when outputting a <code>Throwable</code> object.</td>
</tr>
</tbody>
</table>

**Table 10-3** The Methods Defined by `Throwable`

`Exception` defines four public constructors. Two support chained exceptions, described in the next section. The other two are shown here:

```
Exception()
Exception(String msg)
```

The first form creates an exception that has no description. The second form lets you specify a description of the exception.

Although specifying a description when an exception is created is often useful, sometimes it is better to override `toString()`. Here's why: The version of `toString()` defined by
**Throwable** (and inherited by **Exception**) first displays the name of the exception followed by a colon, which is then followed by your description. By overriding **toString()**, you can prevent the exception name and colon from being displayed. This makes for a cleaner output, which is desirable in some cases.

The following example declares a new subclass of **Exception** and then uses that subclass to signal an error condition in a method. It overrides the **toString()** method, allowing a carefully tailored description of the exception to be displayed.

```java
// This program creates a custom exception type.
class MyException extends Exception {
    private int detail;

    MyException(int a) {
        detail = a;
    }

    public String toString() {
        return "MyException[" + detail + "]";
    }
}

class ExceptionDemo {
    static void compute(int a) throws MyException {
        System.out.println("Called compute(" + a + ")");
        if (a > 10)
            throw new MyException(a);
        System.out.println("Normal exit");
    }

    public static void main(String args[]) {
        try {
            compute(1);
            compute(20);
        } catch (MyException e) {
            System.out.println("Caught " + e);
        }
    }
}
```

This example defines a subclass of **Exception** called **MyException**. This subclass is quite simple: It has only a constructor plus an overridden **toString()** method that displays the value of the exception. The **ExceptionDemo** class defines a method named **compute( )** that throws a **MyException** object. The exception is thrown when **compute( )**’s integer parameter is greater than 10. The **main( )** method sets up an exception handler for **MyException**, then calls **compute( )** with a legal value (less than 10) and an illegal one to
show both paths through the code. Here is the result:

<table>
<thead>
<tr>
<th>Called compute(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal exit</td>
</tr>
<tr>
<td>Called compute(20)</td>
</tr>
<tr>
<td>Caught MyException[20]</td>
</tr>
</tbody>
</table>

### Chained Exceptions

Beginning with JDK 1.4, a feature was incorporated into the exception subsystem: *chained exceptions*. The chained exception feature allows you to associate another exception with an exception. This second exception describes the cause of the first exception. For example, imagine a situation in which a method throws an `ArithmeticException` because of an attempt to divide by zero. However, the actual cause of the problem was that an I/O error occurred, which caused the divisor to be set improperly. Although the method must certainly throw an `ArithmeticException`, since that is the error that occurred, you might also want to let the calling code know that the underlying cause was an I/O error. Chained exceptions let you handle this, and any other situation in which layers of exceptions exist.

To allow chained exceptions, two constructors and two methods were added to `Throwable`. The constructors are shown here:

- `Throwable(Throwable causeExc)`
- `Throwable(String msg, Throwable causeExc)`

In the first form, `causeExc` is the exception that causes the current exception. That is, `causeExc` is the underlying reason that an exception occurred. The second form allows you to specify a description at the same time that you specify a cause exception. These two constructors have also been added to the `Error`, `Exception`, and `RuntimeException` classes.

The chained exception methods supported by `Throwable` are `getCause()` and `initCause()`. These methods are shown in Table 10-3 and are repeated here for the sake of discussion.

- `Throwable getCause()`
- `Throwable initCause(Throwable causeExc)`

The `getCause()` method returns the exception that underlies the current exception. If there is no underlying exception, `null` is returned. The `initCause()` method associates `causeExc` with the invoking exception and returns a reference to the exception. Thus, you can associate a cause with an exception after the exception has been created. However, the cause exception can be set only once. Thus, you can call `initCause()` only once for each exception object. Furthermore, if the cause exception was set by a constructor, then you can’t set it again using `initCause()`. In general, `initCause()` is used to set a cause for legacy exception
classes that don’t support the two additional constructors described earlier.

Here is an example that illustrates the mechanics of handling chained exceptions:

```java
// Demonstrate exception chaining.
class ChainExcDemo {
    static void demoproc() {
        // create an exception
        NullPointerException e =
            new NullPointerException("top layer");

        // add a cause
        e.initCause(new ArithmeticException("cause"));

        throw e;
    }

    public static void main(String args[]) {
        try {
            demoproc();
        } catch (NullPointerException e) {
            // display top level exception
            System.out.println("Caught: " + e);

            // display cause exception
            System.out.println("Original cause: " +
                e.getCause());
        }
    }
}
```

The output from the program is shown here:

Caught: java.lang.NullPointerException: top layer
Original cause: java.lang.ArithmeticException: cause

In this example, the top-level exception is `NullPointerException`. To it is added a cause exception, `ArithmeticException`. When the exception is thrown out of `demoproc()`, it is caught by `main()`. There, the top-level exception is displayed, followed by the underlying exception, which is obtained by calling `getCause()`.

Chained exceptions can be carried on to whatever depth is necessary. Thus, the cause exception can, itself, have a cause. Be aware that overly long chains of exceptions may indicate poor design.

Chained exceptions are not something that every program will need. However, in cases in which knowledge of an underlying cause is useful, they offer an elegant solution.
Three Recently Added Exception Features

Beginning with JDK 7, three interesting and useful features have been added to the exception system. The first automates the process of releasing a resource, such as a file, when it is no longer needed. It is based on an expanded form of the `try` statement called `try-with-resources`, and is described in Chapter 13 when files are introduced. The second feature is called `multi-catch`, and the third is sometimes referred to as `final rethrow` or `more precise rethrow`. These two features are described here.

The multi-catch feature allows two or more exceptions to be caught by the same `catch` clause. It is not uncommon for two or more exception handlers to use the same code sequence even though they respond to different exceptions. Instead of having to catch each exception type individually, you can use a single `catch` clause to handle all of the exceptions without code duplication.

To use a multi-catch, separate each exception type in the `catch` clause with the OR operator. Each multi-catch parameter is implicitly `final`. (You can explicitly specify `final`, if desired, but it is not necessary.) Because each multi-catch parameter is implicitly `final`, it can’t be assigned a new value.

Here is a `catch` statement that uses the multi-catch feature to catch both `ArithmeticException` and `ArrayIndexOutOfBoundsException`:

```java
try {
  int a=10, b=0;
  int vals[] = { 1, 2, 3 };

  try {
    int result = a / b; // generate an ArithmeticException
    vals[10] = 19; // generate an ArrayIndexOutOfBoundsException
  } catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
    // This catch clause catches both exceptions.
    System.out.println("Exception caught: "+ e);
  }

  System.out.println("After multi-catch.");
}
```

The following program shows the multi-catch feature in action:

The program will generate an `ArithmeticException` when the division by zero is attempted. If you comment out the division statement and remove the comment symbol from the next line, an `ArrayIndexOutOfBoundsException` is generated. Both
exceptions are caught by the single catch statement. The more precise rethrow feature restricts the type of exceptions that can be rethrown to only those checked exceptions that the associated try block throws, that are not handled by a preceding catch clause, and that are a subtype or supertype of the parameter. Although this capability might not be needed often, it is now available for use. For the more precise rethrow feature to be in force, the catch parameter must be either effectively final, which means that it must not be assigned a new value inside the catch block, or explicitly declared final.

**Using Exceptions**

Exception handling provides a powerful mechanism for controlling complex programs that have many dynamic run-time characteristics. It is important to think of try, throw, and catch as clean ways to handle errors and unusual boundary conditions in your program's logic. Unlike some other languages in which error return codes are used to indicate failure, Java uses exceptions. Thus, when a method can fail, have it throw an exception. This is a cleaner way to handle failure modes.

One last point: Java’s exception-handling statements should not be considered a general mechanism for nonlocal branching. If you do so, it will only confuse your code and make it hard to maintain.
Java provides built-in support for multithreaded programming. A multithreaded program contains two or more parts that can run concurrently. Each part of such a program is called a thread, and each thread defines a separate path of execution. Thus, multithreading is a specialized form of multitasking.

You are almost certainly acquainted with multitasking because it is supported by virtually all modern operating systems. However, there are two distinct types of multitasking: process-based and thread-based. It is important to understand the difference between the two. For many readers, process-based multitasking is the more familiar form. A process is, in essence, a program that is executing. Thus, process-based multitasking is the feature that allows your computer to run two or more programs concurrently. For example, process-based multitasking enables you to run the Java compiler at the same time that you are using a text editor or visiting a web site. In process-based multitasking, a program is the smallest unit of code that can be dispatched by the scheduler.

In a thread-based multitasking environment, the thread is the smallest unit of dispatchable code. This means that a single program can perform two or more tasks simultaneously. For instance, a text editor can format text at the same time that it is printing, as long as these two actions are being performed by two separate threads. Thus, process-based multitasking deals with the "big picture," and thread-based multitasking handles the details.

Multitasking threads require less overhead than multitasking processes. Processes are heavyweight tasks that require their own separate address spaces. Interprocess communication is expensive and limited. Context switching from one process to another is also costly. Threads, on the other hand, are lighter weight. They share the same address space and cooperatively share the same heavyweight process. Interthread communication is inexpensive, and context switching from one thread to the next is lower in cost. While Java programs make use of process-based multitasking environments, process-based multitasking is not under Java's control. However, multithreaded multitasking is.

Multithreading enables you to write efficient programs that make maximum use of the processing power available in the system. One important way multithreading achieves this is by keeping idle time to a minimum. This is especially important for the interactive,
networked environment in which Java operates because idle time is common. For example, the transmission rate of data over a network is much slower than the rate at which the computer can process it. Even local file system resources are read and written at a much slower pace than they can be processed by the CPU. And, of course, user input is much slower than the computer. In a single-threaded environment, your program has to wait for each of these tasks to finish before it can proceed to the next one—even though most of the time the program is idle, waiting for input. Multithreading helps you reduce this idle time because another thread can run when one is waiting.

If you have programmed for operating systems such as Windows, then you are already familiar with multithreaded programming. However, the fact that Java manages threads makes multithreading especially convenient because many of the details are handled for you.

**The Java Thread Model**

The Java run-time system depends on threads for many things, and all the class libraries are designed with multithreading in mind. In fact, Java uses threads to enable the entire environment to be asynchronous. This helps reduce inefficiency by preventing the waste of CPU cycles.

The value of a multithreaded environment is best understood in contrast to its counterpart. Single-threaded systems use an approach called an *event loop* with *polling*. In this model, a single thread of control runs in an infinite loop, polling a single event queue to decide what to do next. Once this polling mechanism returns with, say, a signal that a network file is ready to be read, then the event loop dispatches control to the appropriate event handler. Until this event handler returns, nothing else can happen in the program. This wastes CPU time. It can also result in one part of a program dominating the system and preventing any other events from being processed. In general, in a single-threaded environment, when a thread *blocks* (that is, suspends execution) because it is waiting for some resource, the entire program stops running.

The benefit of Java’s multithreading is that the main loop/polling mechanism is eliminated. One thread can pause without stopping other parts of your program. For example, the idle time created when a thread reads data from a network or waits for user input can be utilized elsewhere. Multithreading allows animation loops to sleep for a second between each frame without causing the whole system to pause. When a thread blocks in a Java program, only the single thread that is blocked pauses. All other threads continue to run.

As most readers know, over the past few years, multi-core systems have become commonplace. Of course, single-core systems are still in widespread use. It is important to understand that Java’s multithreading features work in both types of systems. In a single-core system, concurrently executing threads share the CPU, with each thread receiving a slice of CPU time. Therefore, in a single-core system, two or more threads do not actually run at the same time, but idle CPU time is utilized. However, in multi-core systems, it is possible for two or more threads to actually execute simultaneously. In many cases, this can
further improve program efficiency and increase the speed of certain operations.

**NOTE**  Recently, the Fork/Join Framework was added to Java. It provides a powerful means of creating multithreaded applications that automatically scale to make best use of multi-core environments. The Fork/Join Framework is part of Java's support for *parallel programming*, which is the name commonly given to the techniques that optimize some types of algorithms for parallel execution in systems that have more than one CPU. For a discussion of the Fork/Join Framework and other concurrency utilities, see Chapter 28. Java's traditional multithreading capabilities are described here.

Threads exist in several states. Here is a general description. A thread can be *running*. It can be *ready to run* as soon as it gets CPU time. A running thread can be *suspended*, which temporarily halts its activity. A suspended thread can then be *resumed*, allowing it to pick up where it left off. A thread can be *blocked* when waiting for a resource. At any time, a thread can be terminated, which halts its execution immediately. Once terminated, a thread cannot be resumed.

**Thread Priorities**
Java assigns to each thread a priority that determines how that thread should be treated with respect to the others. Thread priorities are integers that specify the relative priority of one thread to another. As an absolute value, a priority is meaningless; a higher-priority thread doesn’t run any faster than a lower-priority thread if it is the only thread running. Instead, a thread’s priority is used to decide when to switch from one running thread to the next. This is called a *context switch*. The rules that determine when a context switch takes place are simple:

- *A thread can voluntarily relinquish control*. This is done by explicitly yielding, sleeping, or blocking on pending I/O. In this scenario, all other threads are examined, and the highest-priority thread that is ready to run is given the CPU.
- *A thread can be preempted by a higher-priority thread*. In this case, a lower-priority thread that does not yield the processor is simply preempted—no matter what it is doing—by a higher-priority thread. Basically, as soon as a higher-priority thread wants to run, it does. This is called *preemptive multitasking*. 
In cases where two threads with the same priority are competing for CPU cycles, the situation is a bit complicated. For operating systems such as Windows, threads of equal priority are time-sliced automatically in round-robin fashion. For other types of operating systems, threads of equal priority must voluntarily yield control to their peers. If they don’t, the other threads will not run.

__CAUTION__ Portability problems can arise from the differences in the way that operating systems context-switch threads of equal priority.

**Synchronization**

Because multithreading introduces an asynchronous behavior to your programs, there must be a way for you to enforce synchronicity when you need it. For example, if you want two threads to communicate and share a complicated data structure, such as a linked list, you need some way to ensure that they don’t conflict with each other. That is, you must prevent one thread from writing data while another thread is in the middle of reading it. For this purpose, Java implements an elegant twist on an age-old model of interprocess synchronization: the *monitor*. The monitor is a control mechanism first defined by C.A.R. Hoare. You can think of a monitor as a very small box that can hold only one thread. Once a thread enters a monitor, all other threads must wait until that thread exits the monitor. In this way, a monitor can be used to protect a shared asset from being manipulated by more than one thread at a time.

In Java, there is no class “Monitor”; instead, each object has its own implicit monitor that is automatically entered when one of the object’s synchronized methods is called. Once a thread is inside a synchronized method, no other thread can call any other synchronized method on the same object. This enables you to write very clear and concise multithreaded code, because synchronization support is built into the language.

**Messaging**

After you divide your program into separate threads, you need to define how they will communicate with each other. When programming with some other languages, you must depend on the operating system to establish communication between threads. This, of course, adds overhead. By contrast, Java provides a clean, low-cost way for two or more threads to talk to each other, via calls to predefined methods that all objects have. Java’s messaging system allows a thread to enter a synchronized method on an object, and then wait there until some other thread explicitly notifies it to come out.

**The Thread Class and the Runnable Interface**
Java’s multithreading system is built upon the Thread class, its methods, and its companion interface, Runnable. Thread encapsulates a thread of execution. Since you can’t directly refer to the ethereal state of a running thread, you will deal with it through its proxy, the Thread instance that spawned it. To create a new thread, your program will either extend Thread or implement the Runnable interface.

The Thread class defines several methods that help manage threads. Several of those used in this chapter are shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>getName</td>
<td>Obtain a thread’s name.</td>
</tr>
<tr>
<td>getPriority</td>
<td>Obtain a thread’s priority.</td>
</tr>
<tr>
<td>isAlive</td>
<td>Determine if a thread is still running.</td>
</tr>
<tr>
<td>join</td>
<td>Wait for a thread to terminate.</td>
</tr>
<tr>
<td>run</td>
<td>Entry point for the thread.</td>
</tr>
<tr>
<td>sleep</td>
<td>Suspend a thread for a period of time.</td>
</tr>
<tr>
<td>start</td>
<td>Start a thread by calling its run method.</td>
</tr>
</tbody>
</table>

Thus far, all the examples in this book have used a single thread of execution. The remainder of this chapter explains how to use Thread and Runnable to create and manage threads, beginning with the one thread that all Java programs have: the main thread.

The Main Thread

When a Java program starts up, one thread begins running immediately. This is usually called the main thread of your program, because it is the one that is executed when your program begins. The main thread is important for two reasons:

- It is the thread from which other “child” threads will be spawned.
- Often, it must be the last thread to finish execution because it performs various shutdown actions.

Although the main thread is created automatically when your program is started, it can be controlled through a Thread object. To do so, you must obtain a reference to it by calling the method currentThread(), which is a public static member of Thread. Its general form is shown here:

```java
static Thread currentThread()
```

This method returns a reference to the thread in which it is called. Once you have a reference to the main thread, you can control it just like any other thread.
Let’s begin by reviewing the following example:

```java
// Controlling the main Thread.
class CurrentThreadDemo {
    public static void main(String args[]) {
        Thread t = Thread.currentThread();

        System.out.println("Current thread: " + t);

        // change the name of the thread
        t.setName("My Thread");
        System.out.println("After name change: " + t);

        try {
            for(int n = 5; n > 0; n--) {
                System.out.println(n);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println("Main thread interrupted");
        }
    }
}
```

In this program, a reference to the current thread (the main thread, in this case) is obtained by calling `currentThread()`, and this reference is stored in the local variable `t`. Next, the program displays information about the thread. The program then calls `setName()` to change the internal name of the thread. Information about the thread is then redisplayed.

Next, a loop counts down from five, pausing one second between each line. The pause is accomplished by the `sleep()` method. The argument to `sleep()` specifies the delay period in milliseconds. Notice the `try/catch` block around this loop. The `sleep()` method in `Thread` might throw an `InterruptedException`. This would happen if some other thread wanted to interrupt this sleeping one. This example just prints a message if it gets interrupted. In a real program, you would need to handle this differently. Here is the output generated by this program:

```
Current thread: Thread[main,5,main]
After name change: Thread[My Thread,5,main]
5
4
3
2
1
```
Notice the output produced when t is used as an argument to println(). This displays, in order: the name of the thread, its priority, and the name of its group. By default, the name of the main thread is **main**. Its priority is 5, which is the default value, and **main** is also the name of the group of threads to which this thread belongs. A thread group is a data structure that controls the state of a collection of threads as a whole. After the name of the thread is changed, t is again output. This time, the new name of the thread is displayed.

Let’s look more closely at the methods defined by **Thread** that are used in the program. The sleep() method causes the thread from which it is called to suspend execution for the specified period of milliseconds. Its general form is shown here:

```java
static void sleep(long milliseconds) throws InterruptedException
```

The number of milliseconds to suspend is specified in **milliseconds**. This method may throw an InterruptedException.

The sleep() method has a second form, shown next, which allows you to specify the period in terms of milliseconds and nanoseconds:

```java
static void sleep(long milliseconds, int nanoseconds) throws InterruptedException
```

This second form is useful only in environments that allow timing periods as short as nanoseconds.

As the preceding program shows, you can set the name of a thread by using setName().

You can obtain the name of a thread by calling getName() (but note that this is not shown in the program). These methods are members of the Thread class and are declared like this:

```java
final void setName(String threadName)
final String getName()
```

Here, **threadName** specifies the name of the thread.

**Creating a Thread**

In the most general sense, you create a thread by instantiating an object of type **Thread**.

Java defines two ways in which this can be accomplished:

- You can implement the **Runnable** interface.
- You can extend the **Thread** class, itself.

The following two sections look at each method, in turn.

**Implementing Runnable**

The easiest way to create a thread is to create a class that implements the **Runnable** interface. **Runnable** abstracts a unit of executable code. You can construct a thread on any object that implements **Runnable**. To implement **Runnable**, a class need only implement a single method called run(), which is declared like this:
public void run()

Inside run(), you will define the code that constitutes the new thread. It is important to understand that run() can call other methods, use other classes, and declare variables, just like the main thread can. The only difference is that run() establishes the entry point for another, concurrent thread of execution within your program. This thread will end when run() returns.

After you create a class that implements Runnable, you will instantiate an object of type Thread from within that class. Thread defines several constructors. The one that we will use is shown here:

Thread(Runnable threadOb, String threadName)

In this constructor, threadOb is an instance of a class that implements the Runnable interface. This defines where execution of the thread will begin. The name of the new thread is specified by threadName.

After the new thread is created, it will not start running until you call its start() method, which is declared within Thread. In essence, start() executes a call to run(). The start() method is shown here:

void start()

Here is an example that creates a new thread and starts it running:
Inside `NewThread`'s constructor, a new `Thread` object is created by the following statement:

```java
t = new Thread(this, "Demo Thread");
```
Passing `this` as the first argument indicates that you want the new thread to call the `run()` method on `this` object. Next, `start()` is called, which starts the thread of execution beginning at the `run()` method. This causes the child thread’s `for` loop to begin. After calling `start()`, `NewThread`’s constructor returns to `main()`. When the main thread resumes, it enters its `for` loop. Both threads continue running, sharing the CPU in single-core systems, until their loops finish. The output produced by this program is as follows.

(Your output may vary based upon the specific execution environment.)

```
Child thread: Thread[Demo Thread,5,main]
Main Thread: 5
Child Thread: 5
Child Thread: 4
Main Thread: 4
Child Thread: 3
Child Thread: 2
Main Thread: 3
Child Thread: 1
Exiting child thread.
Main Thread: 2
Main Thread: 1
Main thread exiting.
```

As mentioned earlier, in a multithreaded program, often the main thread must be the last thread to finish running. In fact, for some older JVMs, if the main thread finishes before a child thread has completed, then the Java run-time system may “hang.” The preceding program ensures that the main thread finishes last, because the main thread sleeps for 1,000 milliseconds between iterations, but the child thread sleeps for only 500 milliseconds. This causes the child thread to terminate earlier than the main thread. Shortly, you will see a better way to wait for a thread to finish.

**Extending Thread**

The second way to create a thread is to create a new class that extends `Thread`, and then to create an instance of that class. The extending class must override the `run()` method, which is the entry point for the new thread. It must also call `start()` to begin execution of the new thread. Here is the preceding program rewritten to extend `Thread`: 
This program generates the same output as the preceding version. As you can see, the child thread is created by instantiating an object of `NewThread`, which is derived from `Thread`. Notice the call to `super()` inside `NewThread`. This invokes the following form of the `Thread` constructor:

```java
public Thread(String threadName)
```
Here, *threadName* specifies the name of the thread.

**Choosing an Approach**

At this point, you might be wondering why Java has two ways to create child threads, and which approach is better. The answers to these questions turn on the same point. The *Thread* class defines several methods that can be overridden by a derived class. Of these methods, the only one that *must* be overridden is *run()* . This is, of course, the same method required when you implement *Runnable*. Many Java programmers feel that classes should be extended only when they are being enhanced or modified in some way. So, if you will not be overriding any of *Thread*’s other methods, it is probably best simply to implement *Runnable*. Also, by implementing *Runnable*, your thread class does not need to inherit *Thread*, making it free to inherit a different class. Ultimately, which approach to use is up to you. However, throughout the rest of this chapter, we will create threads by using classes that implement *Runnable*.

**Creating Multiple Threads**

So far, you have been using only two threads: the main thread and one child thread. However, your program can spawn as many threads as it needs. For example, the following program creates three child threads:
// Create multiple threads.
class NewThread implements Runnable {
    String name; // name of thread
    Thread t;

    NewThread(String threadname) {
        name = threadname;
        t = new Thread(this, name);
        System.out.println("New thread: "+t);
        t.start(); // Start the thread
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--)
            {
                System.out.println(name + ": "+i);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println(name + "Interrupted");
        }
        System.out.println(name + " exiting.");
    }
}

class MultiThreadDemo {
    public static void main(String args[]) {
        new NewThread("One"); // start threads
        new NewThread("Two");
        new NewThread("Three");

        try {
            // wait for other threads to end
            Thread.sleep(10000);
        } catch (InterruptedException e) {
            System.out.println("Main thread Interrupted");
        }
        System.out.println("Main thread exiting.");
    }
}

Sample output from this program is shown here. (Your output may vary based upon the specific execution environment.)
As you can see, once started, all three child threads share the CPU. Notice the call to `sleep(10000)` in `main()`. This causes the main thread to sleep for ten seconds and ensures that it will finish last.

**Using isAlive() and join()**

As mentioned, often you will want the main thread to finish last. In the preceding examples, this is accomplished by calling `sleep()` within `main()`, with a long enough delay to ensure that all child threads terminate prior to the main thread. However, this is hardly a satisfactory solution, and it also raises a larger question: How can one thread know when another thread has ended? Fortunately, `Thread` provides a means by which you can answer this question.

Two ways exist to determine whether a thread has finished. First, you can call `isAlive()` on the thread. This method is defined by `Thread`, and its general form is shown here:

```
final boolean isAlive()
```

The `isAlive()` method returns `true` if the thread upon which it is called is still running. It returns `false` otherwise.

While `isAlive()` is occasionally useful, the method that you will more commonly use to wait for a thread to finish is called `join()`, shown here:

```
final void join() throws InterruptedException
```
This method waits until the thread on which it is called terminates. Its name comes from the concept of the calling thread waiting until the specified thread joins it. Additional forms of `join()` allow you to specify a maximum amount of time that you want to wait for the specified thread to terminate.

Here is an improved version of the preceding example that uses `join()` to ensure that the main thread is the last to stop. It also demonstrates the `isAlive()` method.

```java
// Using join() to wait for threads to finish.
class NewThread implements Runnable {
    String name;    // name of thread
    Thread t;

    NewThread(String threadname) {
        name = threadname;
        t = new Thread(this, name);
        System.out.println("New thread: " + t);
        t.start();    // Start the thread
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--) {
                System.out.println(name + ": " + i);
                Thread.sleep(1000);
            }
        } catch (InterruptedException e) {
            System.out.println(name + " interrupted.");
        }
        System.out.println(name + " exiting.");
    }
}

class DemoJoin {
    public static void main(String args[]) {
        NewThread ob1 = new NewThread("One");
        NewThread ob2 = new NewThread("Two");
        NewThread ob3 = new NewThread("Three");
    }
}
```
Sample output from this program is shown here. (Your output may vary based upon the specific execution environment.)
As you can see, after the calls to `join()` return, the threads have stopped executing.

**Thread Priorities**

Thread priorities are used by the thread scheduler to decide when each thread should be allowed to run. In theory, over a given period of time, higher-priority threads get more CPU time than lower-priority threads. In practice, the amount of CPU time that a thread gets often depends on several factors besides its priority. (For example, how an operating system implements multitasking can affect the relative availability of CPU time.) A higher-priority thread can also preempt a lower-priority one. For instance, when a lower-priority thread is running and a higher-priority thread resumes (from sleeping or waiting on I/O, for example), it will preempt the lower-priority thread.

In theory, threads of equal priority should get equal access to the CPU. But you need to be careful. Remember, Java is designed to work in a wide range of environments. Some of those environments implement multitasking fundamentally differently than others. For
safety, threads that share the same priority should yield control once in a while. This ensures that all threads have a chance to run under a nonpreemptive operating system. In practice, even in nonpreemptive environments, most threads still get a chance to run, because most threads inevitably encounter some blocking situation, such as waiting for I/O. When this happens, the blocked thread is suspended and other threads can run. But, if you want smooth multithreaded execution, you are better off not relying on this. Also, some types of tasks are CPU-intensive. Such threads dominate the CPU. For these types of threads, you want to yield control occasionally so that other threads can run.

To set a thread’s priority, use the `setPriority()` method, which is a member of `Thread`. This is its general form:

```java
final void setPriority(int level)
```

Here, `level` specifies the new priority setting for the calling thread. The value of `level` must be within the range `MIN_PRIORITY` and `MAX_PRIORITY`. Currently, these values are 1 and 10, respectively. To return a thread to default priority, specify `NORM_PRIORITY`, which is currently 5. These priorities are defined as `static final` variables within `Thread`.

You can obtain the current priority setting by calling the `getPriority()` method of `Thread`, shown here:

```java
final int getPriority()
```

Implementations of Java may have radically different behavior when it comes to scheduling. Most of the inconsistencies arise when you have threads that are relying on preemptive behavior, instead of cooperatively giving up CPU time. The safest way to obtain predictable, cross-platform behavior with Java is to use threads that voluntarily give up control of the CPU.

**Synchronization**

When two or more threads need access to a shared resource, they need some way to ensure that the resource will be used by only one thread at a time. The process by which this is achieved is called synchronization. As you will see, Java provides unique, language-level support for it.

Key to synchronization is the concept of the monitor. A *monitor* is an object that is used as a mutually exclusive lock. Only one thread can *own* a monitor at a given time. When a thread acquires a lock, it is said to have *entered* the monitor. All other threads attempting to enter the locked monitor will be suspended until the first thread *exits* the monitor. These other threads are said to be *waiting* for the monitor. A thread that owns a monitor can reenter the same monitor if it so desires.

You can synchronize your code in either of two ways. Both involve the use of the `synchronized` keyword, and both are examined here.

**Using Synchronized Methods**
Synchronization is easy in Java, because all objects have their own implicit monitor associated with them. To enter an object’s monitor, just call a method that has been modified with the **synchronized** keyword. While a thread is inside a synchronized method, all other threads that try to call it (or any other synchronized method) on the same instance have to wait. To exit the monitor and relinquish control of the object to the next waiting thread, the owner of the monitor simply returns from the synchronized method.

To understand the need for synchronization, let’s begin with a simple example that does not use it—but should. The following program has three simple classes. The first one, **Callme**, has a single method named **call()**. The **call()** method takes a **String** parameter called **msg**. This method tries to print the **msg** string inside of square brackets. The interesting thing to notice is that after **call()** prints the opening bracket and the **msg** string, it calls **Thread.sleep(1000)**, which pauses the current thread for one second.

The constructor of the next class, **Caller**, takes a reference to an instance of the **Callme** class and a **String**, which are stored in **target** and **msg**, respectively. The constructor also creates a new thread that will call this object’s **run()** method. The thread is started immediately. The **run()** method of **Caller** calls the **call()** method on the **target** instance of **Callme**, passing in the **msg** string. Finally, the **Synch** class starts by creating a single instance of **Callme**, and three instances of **Caller**, each with a unique message string. The same instance of **Callme** is passed to each **Caller**.
// This program is not synchronized.
class Callme {
    void call(String msg) {
        System.out.println("[" + msg);
        try {
            Thread.sleep(1000);
        } catch (InterruptedException e) {
            System.out.println("Interrupted");
        }
        System.out.println("]");
    }
}

class Caller implements Runnable {
    String msg;
    Callme target;
    Thread t;

    public Caller(Callme targ, String s) {
        target = targ;
        msg = s;
        t = new Thread(this);
        t.start();
    }
    public void run() {
        target.call(msg);
    }
}

class Synch {
    public static void main(String args[]) {
        Callme target = new Callme();
        Caller obj1 = new Caller(target, "Hello");
        Caller obj2 = new Caller(target, "Synchronized");
        Caller obj3 = new Caller(target, "World");

        // wait for threads to end
        try {
            obj1.t.join();
            obj2.t.join();
            obj3.t.join();
        } catch (InterruptedException e) {
            System.out.println("Interrupted");
        }
    }
}

Here is the output produced by this program:

Hello[Synchronized[World;]
As you can see, by calling `sleep()` the `call()` method allows execution to switch to another thread. This results in the mixed-up output of the three message strings. In this program, nothing exists to stop all three threads from calling the same method, on the same object, at the same time. This is known as a race condition, because the three threads are racing each other to complete the method. This example used `sleep()` to make the effects repeatable and obvious. In most situations, a race condition is more subtle and less predictable, because you can’t be sure when the context switch will occur. This can cause a program to run right one time and wrong the next.

To fix the preceding program, you must serialize access to `call()`. That is, you must restrict its access to only one thread at a time. To do this, you simply need to precede `call()`’s definition with the keyword `synchronized`, as shown here:

```java
class Callme {
    synchronized void call(String msg) {
        ...
    }
}
```

This prevents other threads from entering `call()` while another thread is using it. After `synchronized` has been added to `call()`, the output of the program is as follows:

```
[Hello]
[Synchronized]
[World]
```

Any time that you have a method, or group of methods, that manipulates the internal state of an object in a multithreaded situation, you should use the `synchronized` keyword to guard the state from race conditions. Remember, once a thread enters any synchronized method on an instance, no other thread can enter any other synchronized method on the same instance. However, nonsynchronized methods on that instance will continue to be callable.

**The synchronized Statement**

While creating `synchronized` methods within classes that you create is an easy and effective means of achieving synchronization, it will not work in all cases. To understand why, consider the following. Imagine that you want to synchronize access to objects of a class that was not designed for multithreaded access. That is, the class does not use `synchronized` methods. Further, this class was not created by you, but by a third party, and you do not have access to the source code. Thus, you can’t add `synchronized` to the appropriate methods within the class. How can access to an object of this class be synchronized? Fortunately, the solution to this problem is quite easy: You simply put calls
to the methods defined by this class inside a **synchronized** block.

This is the general form of the **synchronized** statement:

```java
synchronized(objRef) {
    // statements to be synchronized
}
```

Here, `objRef` is a reference to the object being synchronized. A synchronized block ensures that a call to a synchronized method that is a member of `objRef`'s class occurs only after the current thread has successfully entered `objRef`'s monitor.

Here is an alternative version of the preceding example, using a synchronized block within the `run()` method:
Here, the `call()` method is not modified by `synchronized`. Instead, the `synchronized` statement is used inside `Caller`'s `run()` method. This causes the same correct output as the preceding example, because each thread waits for the prior one to finish before proceeding.

Interthread Communication
The preceding examples unconditionally blocked other threads from asynchronous access to certain methods. This use of the implicit monitors in Java objects is powerful, but you can achieve a more subtle level of control through interprocess communication. As you will see, this is especially easy in Java.

As discussed earlier, multithreading replaces event loop programming by dividing your tasks into discrete, logical units. Threads also provide a secondary benefit: they do away with polling. Polling is usually implemented by a loop that is used to check some condition repeatedly. Once the condition is true, appropriate action is taken. This wastes CPU time.

For example, consider the classic queuing problem, where one thread is producing some data and another is consuming it. To make the problem more interesting, suppose that the producer has to wait until the consumer is finished before it generates more data. In a polling system, the consumer would waste many CPU cycles while it waited for the producer to produce. Once the producer was finished, it would start polling, wasting more CPU cycles waiting for the consumer to finish, and so on. Clearly, this situation is undesirable.

To avoid polling, Java includes an elegant interprocess communication mechanism via the `wait()`, `notify()`, and `notifyAll()` methods. These methods are implemented as **final** methods in `Object`, so all classes have them. All three methods can be called only from within a **synchronized** context. Although conceptually advanced from a computer science perspective, the rules for using these methods are actually quite simple:

- **wait()** tells the calling thread to give up the monitor and go to sleep until some other thread enters the same monitor and calls `notify()` or `notifyAll()`.
- **notify()** wakes up a thread that called `wait()` on the same object.
- **notifyAll()** wakes up all the threads that called `wait()` on the same object. One of the threads will be granted access.

These methods are declared within `Object`, as shown here:

```java
final void wait( ) throws InterruptedException
final void notify( )
final void notifyAll( )
```

Additional forms of `wait()` exist that allow you to specify a period of time to wait. Before working through an example that illustrates interthread communication, an important point needs to be made. Although `wait()` normally waits until `notify()` or `notifyAll()` is called, there is a possibility that in very rare cases the waiting thread could be awakened due to a **spurious wakeup**. In this case, a waiting thread resumes without `notify()` or `notifyAll()` having been called. (In essence, the thread resumes for no apparent reason.) Because of this remote possibility, Oracle recommends that calls to `wait()` should take place within a loop that checks the condition on which the thread is waiting. The following example shows this technique.
Let’s now work through an example that uses `wait()` and `notify()`. To begin, consider the following sample program that incorrectly implements a simple form of the producer/consumer problem. It consists of four classes: `Q`, the queue that you’re trying to synchronize; `Producer`, the threaded object that is producing queue entries; `Consumer`, the threaded object that is consuming queue entries; and `PC`, the tiny class that creates the single `Q`, `Producer`, and `Consumer`. 
Although the `put()` and `get()` methods on `Q` are synchronized, nothing stops the producer from overrunning the consumer, nor will anything stop the consumer from consuming the same queue value twice. Thus, you get the erroneous output shown here (the exact output will vary with processor speed and task load):
As you can see, after the producer put 1, the consumer started and got the same 1 five times in a row. Then, the producer resumed and produced 2 through 7 without letting the consumer have a chance to consume them.

The proper way to write this program in Java is to use `wait()` and `notify()` to signal in both directions, as shown here:

```java
// A correct implementation of a producer and consumer.
class Q {
    int n;
    boolean valueSet = false;

    synchronized int get() {
        while(!valueSet)
            try {
                wait();
            } catch(InterruptedException e) {
                System.out.println("InterruptedException caught");
            }
        System.out.println("Got: " + n);
        valueSet = false;
        notify();
        return n;
    }

    synchronized void put(int n) {
```

Inside `get()`, `wait()` is called. This causes its execution to suspend until `Producer` notifies you that some data is ready. When this happens, execution inside `get()` resumes. After the data has been obtained, `get()` calls `notify()`. This tells `Producer` that it is okay to put more data in the queue. Inside `put()`, `wait()` suspends execution until `Consumer` has removed the item from the queue. When execution resumes, the next item of data is put
in the queue, and `notify()` is called. This tells `Consumer` that it should now remove it.

Here is some output from this program, which shows the clean synchronous behavior:

<table>
<thead>
<tr>
<th>Put:</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Got:</td>
<td>1</td>
</tr>
<tr>
<td>Put:</td>
<td>2</td>
</tr>
<tr>
<td>Got:</td>
<td>2</td>
</tr>
<tr>
<td>Put:</td>
<td>3</td>
</tr>
<tr>
<td>Got:</td>
<td>3</td>
</tr>
<tr>
<td>Put:</td>
<td>4</td>
</tr>
<tr>
<td>Got:</td>
<td>4</td>
</tr>
<tr>
<td>Put:</td>
<td>5</td>
</tr>
<tr>
<td>Got:</td>
<td>5</td>
</tr>
</tbody>
</table>

**Deadlock**

A special type of error that you need to avoid that relates specifically to multitasking is deadlock, which occurs when two threads have a circular dependency on a pair of synchronized objects. For example, suppose one thread enters the monitor on object X and another thread enters the monitor on object Y. If the thread in X tries to call any synchronized method on Y, it will block as expected. However, if the thread in Y, in turn, tries to call any synchronized method on X, the thread waits forever, because to access X, it would have to release its own lock on Y so that the first thread could complete. Deadlock is a difficult error to debug for two reasons:

- In general, it occurs only rarely, when the two threads time-slice in just the right way.
- It may involve more than two threads and two synchronized objects. (That is, deadlock can occur through a more convoluted sequence of events than just described.)

To understand deadlock fully, it is useful to see it in action. The next example creates two classes, A and B, with methods `foo()` and `bar()`, respectively, which pause briefly before trying to call a method in the other class. The main class, named `Deadlock`, creates an A and a B instance, and then starts a second thread to set up the deadlock condition. The `foo()` and `bar()` methods use `sleep()` as a way to force the deadlock condition to occur.
/ An example of deadlock.
   class A {
      synchronized void foo(B b) {
         String name = Thread.currentThread().getName();

         System.out.println(name + " entered A.foo");

         try {
            Thread.sleep(1000);
         } catch(Exception e) {
            System.out.println("A Interrupted");
         }
   }
When you run this program, you will see the output shown here:
Because the program has deadlocked, you need to press ctrl-c to end the program. You can see a full thread and monitor cache dump by pressing ctrl-break on a PC. You will see that RacingThread owns the monitor on b, while it is waiting for the monitor on a. At the same time, MainThread owns a and is waiting to get b. This program will never complete. As this example illustrates, if your multithreaded program locks up occasionally, deadlock is one of the first conditions that you should check for.

**Suspending, Resuming, and Stopping Threads**

Sometimes, suspending execution of a thread is useful. For example, a separate thread can be used to display the time of day. If the user doesn’t want a clock, then its thread can be suspended. Whatever the case, suspending a thread is a simple matter. Once suspended, restarting the thread is also a simple matter.

The mechanisms to suspend, stop, and resume threads differ between early versions of Java, such as Java 1.0, and modern versions, beginning with Java 2. Prior to Java 2, a program used `suspend()`, `resume()`, and `stop()`, which are methods defined by `Thread`, to pause, restart, and stop the execution of a thread. Although these methods seem to be a perfectly reasonable and convenient approach to managing the execution of threads, they must not be used for new Java programs. Here’s why. The `suspend()` method of the `Thread` class was deprecated by Java 2 several years ago. This was done because `suspend()` can sometimes cause serious system failures. Assume that a thread has obtained locks on critical data structures. If that thread is suspended at that point, those locks are not relinquished. Other threads that may be waiting for those resources can be deadlocked. The `resume()` method is also deprecated. It does not cause problems, but cannot be used without the `suspend()` method as its counterpart.

The `stop()` method of the `Thread` class, too, was deprecated by Java 2. This was done because this method can sometimes cause serious system failures. Assume that a thread is writing to a critically important data structure and has completed only part of its changes. If that thread is stopped at that point, that data structure might be left in a corrupted state. The trouble is that `stop()` causes any lock the calling thread holds to be released. Thus, the corrupted data might be used by another thread that is waiting on the same lock.

Because you can’t now use the `suspend()`, `resume()`, or `stop()` methods to control a thread, you might be thinking that no way exists to pause, restart, or terminate a thread. But, fortunately, this is not true. Instead, a thread must be designed so that the `run()` method periodically checks to determine whether that thread should suspend, resume, or stop its own execution. Typically, this is accomplished by establishing a flag variable that...
indicates the execution state of the thread. As long as this flag is set to “running,” the run() method must continue to let the thread execute. If this variable is set to “suspend,” the thread must pause. If it is set to “stop,” the thread must terminate. Of course, a variety of ways exist in which to write such code, but the central theme will be the same for all programs.

The following example illustrates how the wait() and notify() methods that are inherited from Object can be used to control the execution of a thread. Let us consider its operation. The NewThread class contains a boolean instance variable named suspendFlag, which is used to control the execution of the thread. It is initialized to false by the constructor. The run() method contains a synchronized statement block that checks suspendFlag. If that variable is true, the wait() method is invoked to suspend the execution of the thread. The mysuspend() method sets suspendFlag to true. The myresume() method sets suspendFlag to false and invokes notify() to wake up the thread. Finally, the main() method has been modified to invoke the mysuspend() and myresume() methods.
// Suspending and resuming a thread the modern way.
class NewThread implements Runnable {
    String name; // name of thread
    Thread t;
    boolean suspendFlag;

    NewThread(String threadname) {
        name = threadname;
        t = new Thread(this, name);
        System.out.println("New thread: " + t);
        suspendFlag = false;
        t.start(); // Start the thread
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 15; i > 0; i--) {
                System.out.println(name + ": "+ i);
                Thread.sleep(200);
                synchronized(this) {
                    while(suspendFlag) {
                        wait();
                    }
                }
            }
        } catch (InterruptedException e) {
            System.out.println(name + " interrupted.");
        }
        System.out.println(name + " exiting.");
        }

    synchronized void mysuspend() {
        suspendFlag = true;
    }

    synchronized void myresume() {
        suspendFlag = false;
        notify();
    }
}
When you run the program, you will see the threads suspend and resume. Later in this book, you will see more examples that use the modern mechanism of thread control. Although this mechanism isn’t as “clean” as the old way, nevertheless, it is the way required to ensure that run-time errors don’t occur. It is the approach that must be used for all new code.

### Obtaining A Thread’s State

As mentioned earlier in this chapter, a thread can exist in a number of different states. You can obtain the current state of a thread by calling the `getState()` method defined by `Thread`. It is shown here:

```java
Thread.State getState()
```

It returns a value of type `Thread.State` that indicates the state of the thread at the
time at which the call was made. **State** is an enumeration defined by **Thread**. (An enumeration is a list of named constants. It is discussed in detail in Chapter 12.)

Here are the values that can be returned by `getState()`:

<table>
<thead>
<tr>
<th>Value</th>
<th>State</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCKED</td>
<td>A thread that has suspended execution because it is waiting to acquire a lock.</td>
</tr>
<tr>
<td>NEW</td>
<td>A thread that has not begun execution.</td>
</tr>
<tr>
<td>Runnable</td>
<td>A thread that either is currently executing or will execute when it gains access to the CPU.</td>
</tr>
<tr>
<td>Terminated</td>
<td>A thread that has completed execution.</td>
</tr>
<tr>
<td>Timed_Waiting</td>
<td>A thread that has suspended execution for a specified period of time, such as when it has called <code>sleep()</code> . This state is also entered when a timeout version of <code>wait()</code> or <code>join()</code> is called.</td>
</tr>
<tr>
<td>Waiting</td>
<td>A thread that has suspended execution because it is waiting for some action to occur. For example, it is waiting because of a call to a non-timeout version of <code>wait()</code> or <code>join()</code>.</td>
</tr>
</tbody>
</table>

Figure 11-1 diagrams how the various thread states relate.
Given a `Thread` instance, you can use `getState()` to obtain the state of a thread. For example, the following sequence determines if a thread called `thrd` is in the `RUNNABLE` state at the time `getState()` is called:

```java
Thread.State ts = thrd.getState();
if(ts == Thread.State.RUNNABLE) // ...
```

It is important to understand that a thread’s state may change after the call to `getState()`. Thus, depending on the circumstances, the state obtained by calling `getState()` may not reflect the actual state of the thread only a moment later. For this (and other) reasons, `getState()` is not intended to provide a means of synchronizing threads. It’s primarily used for debugging or for profiling a thread’s run-time characteristics.

**Using Multithreading**

The key to utilizing Java’s multithreading features effectively is to think concurrently rather than serially. For example, when you have two subsystems within a program that can execute concurrently, make them individual threads. With the careful use of multithreading, you can create very efficient programs. A word of caution is in order, however: If you create too many threads, you can actually degrade the performance of your program rather than enhance it. Remember, some overhead is associated with context switching. If you create too many threads, more CPU time will be spent changing contexts than executing your program! One last point: To create compute-intensive applications that can automatically scale to make use of the available processors in a multi-core system, consider using the new Fork/Join Framework, which is described in Chapter 28.
This chapter examines three relatively recent additions to the Java language: enumerations, autoboxing, and annotations (also referred to as metadata). Each expands the power of the language by offering a streamlined approach to handling common programming tasks. This chapter also discusses Java’s type wrappers and introduces reflection.

**Enumerations**

Versions of Java prior to JDK 5 lacked one feature that many programmers felt was needed: enumerations. In its simplest form, an *enumeration* is a list of named constants. Although Java offered other features that provide somewhat similar functionality, such as *final* variables, many programmers still missed the conceptual purity of enumerations—especially because enumerations are supported by many other commonly used languages. Beginning with JDK 5, enumerations were added to the Java language, and they are now an integral and widely used part of Java.

In their simplest form, Java enumerations appear similar to enumerations in other languages. However, this similarity may be only skin deep because, in Java, an enumeration defines a class type. By making enumerations into classes, the capabilities of the enumeration are greatly expanded. For example, in Java, an enumeration can have constructors, methods, and instance variables. Therefore, although enumerations were several years in the making, Java’s rich implementation made them well worth the wait.

**Enumeration Fundamentals**

An enumeration is created using the *enum* keyword. For example, here is a simple enumeration that lists various apple varieties:

```java
// An enumeration of apple varieties.
enum Apple {
   Jonathan, GoldenDel, RedDel, Winesap, Cortland
}
```

The identifiers *Jonathan, GoldenDel*, and so on, are called *enumeration constants*. Each
is implicitly declared as a public, static final member of Apple. Furthermore, their type is the type of the enumeration in which they are declared, which is Apple in this case. Thus, in the language of Java, these constants are called *self-typed*, in which “self” refers to the enclosing enumeration.

Once you have defined an enumeration, you can create a variable of that type. However, even though enumerations define a class type, you do not instantiate an enum using new. Instead, you declare and use an enumeration variable in much the same way as you do one of the primitive types. For example, this declares `ap` as a variable of enumeration type Apple:

```java
Apple ap;
```

Because `ap` is of type Apple, the only values that it can be assigned (or can contain) are those defined by the enumeration. For example, this assigns `ap` the value RedDel:

```java
ap = Apple.RedDel;
```

Notice that the symbol RedDel is preceded by Apple.

Two enumeration constants can be compared for equality by using the `==` relational operator. For example, this statement compares the value in `ap` with the GoldenDel constant:

```java
if (ap == Apple.GoldenDel) // ...
```

An enumeration value can also be used to control a switch statement. Of course, all of the case statements must use constants from the same enum as that used by the switch expression. For example, this switch is perfectly valid:

```java
// Use an enum to control a switch statement.
switch (ap) {
    case Jonathan:
        // ...
    case Winesap:
        // ...
}
```

Notice that in the case statements, the names of the enumeration constants are used without being qualified by their enumeration type name. That is, Winesap, not Apple.Winesap, is used. This is because the type of the enumeration in the switch expression has already implicitly specified the enum type of the case constants. There is no need to qualify the constants in the case statements with their enum type name. In fact, attempting to do so will cause a compilation error.

When an enumeration constant is displayed, such as in a println() statement, its name is
output. For example, given this statement:

```java
System.out.println(Apple.Winesap);
```

the name \texttt{Winesap} is displayed. The following program puts together all of the pieces and demonstrates the \texttt{Apple} enumeration:
// An enumeration of apple varieties.
enum Apple {
    Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo {
    public static void main(String[] args) {
        Apple ap;
        ap = Apple.RedDel;
        // Output an enum value.
        System.out.println("Value of ap: " + ap);
        System.out.println();
        ap = Apple.GoldenDel;
        // Compare two enum values.
        if (ap == Apple.GoldenDel)
            System.out.println("ap contains GoldenDel.\n");
        // Use an enum to control a switch statement.
        switch (ap) {
            case Jonathan:
                System.out.println("Jonathan is red.");
                break;
            case GoldenDel:
                System.out.println("Golden Delicious is yellow.");
                break;
            case RedDel:
                System.out.println("Red Delicious is red.");
                break;
            case Winesap:
                System.out.println("Winesap is red.");
                break;
            case Cortland:
                System.out.println("Cortland is red.");
                break;
        }
    }
}

The output from the program is shown here:
The `values()` and `valueOf()` Methods

All enumerations automatically contain two predefined methods: `values()` and `valueOf()`. Their general forms are shown here:

```java
public static enum-type [] values()
public static enum-type valueOf(String str)
```

The `values()` method returns an array that contains a list of the enumeration constants. The `valueOf()` method returns the enumeration constant whose value corresponds to the string passed in `str`. In both cases, `enum-type` is the type of the enumeration. For example, in the case of the `Apple` enumeration shown earlier, the return type of `Apple.valueOf("Winesap")` is `Winesap`.

The following program demonstrates the `values()` and `valueOf()` methods:
// Use the built-in enumeration methods.

// An enumeration of apple varieties.
enum Apple {
    Jonathan, GoldenDel, RedDel, Winesap, Cortland
}

class EnumDemo2 {
    public static void main(String[] args) {
        Apple ap;
        System.out.println("Here are all Apple constants:");
        // use values()
        Apple allapples[] = Apple.values();
        for (Apple a : allapples) {
            System.out.println(a);
        }
        System.out.println();
        // use valueOf()
        ap = Apple.valueOf("Winesap");
        System.out.println("ap contains " + ap);
    }
}

The output from the program is shown here:

Here are all Apple constants:
Jonathan
GoldenDel
RedDel
Winesap
Cortland

ap contains Winesap

Notice that this program uses a for-each style for loop to cycle through the array of constants obtained by calling values(). For the sake of illustration, the variable allapples was created and assigned a reference to the enumeration array. However, this step is not necessary because the for could have been written as shown here, eliminating the need for the allapples variable:
Now, notice how the value corresponding to the name `Winesap` was obtained by calling `valueOf()`.

```java
    ap = Apple.valueOf("Winesap");
```

As explained, `valueOf()` returns the enumeration value associated with the name of the constant represented as a string.

**Java Enumerations Are Class Types**

As explained, a Java enumeration is a class type. Although you don't instantiate an `enum` using `new`, it otherwise has much the same capabilities as other classes. The fact that `enum` defines a class gives the Java enumeration extraordinary power. For example, you can give them constructors, add instance variables and methods, and even implement interfaces.

It is important to understand that each enumeration constant is an object of its enumeration type. Thus, when you define a constructor for an `enum`, the constructor is called when each enumeration constant is created. Also, each enumeration constant has its own copy of any instance variables defined by the enumeration. For example, consider the following version of `Apple`:
This version of Apple adds three things. The first is the instance variable price, which is used to hold the price of each variety of apple. The second is the Apple constructor, which is passed the price of an apple. The third is the method getPrice(), which returns the value of price.

When the variable ap is declared in main(), the constructor for Apple is called once for each constant that is specified. Notice how the arguments to the constructor are specified, by putting them inside parentheses after each constant, as shown here:

```
Winesap costs 15 cents.

All apple prices:
Jonathan costs 10 cents.
GoldenDel costs 9 cents.
RedDel costs 12 cents.
Winesap costs 15 cents.
Cortland costs 8 cents.
```
These values are passed to the \texttt{p} parameter of \texttt{Apple()}, which then assigns this value to \texttt{price}. Again, the constructor is called once for each constant.

Because each enumeration constant has its own copy of \texttt{price}, you can obtain the price of a specified type of apple by calling \texttt{getPrice()}. For example, in \texttt{main()} the price of a Winesap is obtained by the following call:

\begin{verbatim}
    Apple.Winesap.getPrice()
\end{verbatim}

The prices of all varieties are obtained by cycling through the enumeration using a \texttt{for} loop.

Because there is a copy of \texttt{price} for each enumeration constant, the value associated with one constant is separate and distinct from the value associated with another constant. This is a powerful concept, which is only available when enumerations are implemented as classes, as Java does.

Although the preceding example contains only one constructor, an \texttt{enum} can offer two or more overloaded forms, just as can any other class. For example, this version of \texttt{Apple} provides a default constructor that initializes the price to \texttt{-1}, to indicate that no price data is available:

\begin{verbatim}
// Use an enum constructor.
enum Apple {
    Jonathan(10), GoldenDel(9), RedDel, Winesap(15), Cortland(8);

    private int price; // price of each apple

    // Constructor
    Apple(int p) { price = p; }

    // Overloaded constructor
    Apple() { price = -1; }

    int getPrice() { return price; }
}
\end{verbatim}

Notice that in this version, \texttt{RedDel} is not given an argument. This means that the default constructor is called, and \texttt{RedDel}'s price variable is given the value \texttt{-1}.

Here are two restrictions that apply to enumerations. First, an enumeration can't inherit another class. Second, an \texttt{enum} cannot be a superclass. This means that an \texttt{enum} can't be extended. Otherwise, \texttt{enum} acts much like any other class type. The key is to remember that each of the enumeration constants is an object of the class in which it is defined.

\textbf{Enumerations Inherit Enum}

Although you can't inherit a superclass when declaring an \texttt{enum}, all enumerations
automatically inherit one: `java.lang.Enum`. This class defines several methods that are available for use by all enumerations. The `Enum` class is described in detail in Part II, but three of its methods warrant a discussion at this time.

You can obtain a value that indicates an enumeration constant’s position in the list of constants. This is called its `ordinal value`, and it is retrieved by calling the `ordinal()` method, shown here:

```java
final int ordinal()
```

It returns the ordinal value of the invoking constant. Ordinal values begin at zero. Thus, in the `Apple` enumeration, `Jonathan` has an ordinal value of zero, `GoldenDel` has an ordinal value of 1, `RedDel` has an ordinal value of 2, and so on.

You can compare the ordinal value of two constants of the same enumeration by using the `compareTo()` method. It has this general form:

```java
final int compareTo(enum-type e)
```

Here, `enum-type` is the type of the enumeration, and `e` is the constant being compared to the invoking constant. Remember, both the invoking constant and `e` must be of the same enumeration. If the invoking constant has an ordinal value less than `e`’s, then `compareTo()` returns a negative value. If the two ordinal values are the same, then zero is returned. If the invoking constant has an ordinal value greater than `e`’s, then a positive value is returned.

You can compare for equality an enumeration constant with any other object by using `equals()`, which overrides the `equals()` method defined by `Object`. Although `equals()` can compare an enumeration constant to any other object, those two objects will be equal only if they both refer to the same constant, within the same enumeration. Simply having ordinal values in common will not cause `equals()` to return `true` if the two constants are from different enumerations.

Remember, you can compare two enumeration references for equality by using `==`.

The following program demonstrates the `ordinal()`, `compareTo()`, and `equals()` methods:
The output from the program is shown here:
Another Enumeration Example

Before moving on, we will look at a different example that uses an `enum`. In Chapter 9, an automated “decision maker” program was created. In that version, variables called NO, YES, MAYBE, LATER, SOON, and NEVER were declared within an interface and used to represent the possible answers. While there is nothing technically wrong with that approach, the enumeration is a better choice. Here is an improved version of that program that uses an `enum` called Answers to define the answers. You should compare this version to the original in Chapter 9.
// An improved version of the "Decision Maker"
// program from Chapter 9. This version uses an
// enum, rather than interface variables, to
// represent the answers.

import java.util.Random;

// An enumeration of the possible answers.
enum Answers{
    NO, YES, MAYBE, LATER, SOON, NEVER
}

class Question{
    Random rand = new Random();
    Answers ask(){
        int prob = (int)(100 * rand.nextDouble());

        if (prob < 15)
            return Answers.MAYBE; // 15%
        else if (prob < 30)
            return Answers.NO;    // 15%
        else if (prob < 60)
            return Answers.YES;   // 30%
        else if (prob < 75)
            return Answers.LATER; // 15%
        else if (prob < 98)
            return Answers.SOON;  // 13%
        else
            return Answers.NEVER; // 2%
    }
}
Type Wrappers
As you know, Java uses primitive types (also called simple types), such as int or double, to hold the basic data types supported by the language. Primitive types, rather than objects, are used for these quantities for the sake of performance. Using objects for these values would add an unacceptable overhead to even the simplest of calculations. Thus, the primitive types are not part of the object hierarchy, and they do not inherit Object. Despite the performance benefit offered by the primitive types, there are times when you will need an object representation. For example, you can’t pass a primitive type by reference to a method. Also, many of the standard data structures implemented by Java operate on objects, which means that you can’t use these data structures to store primitive types. To handle these (and other) situations, Java provides type wrappers, which are classes that
encapsulate a primitive type within an object. The type wrapper classes are described in detail in Part II, but they are introduced here because they relate directly to Java’s autoboxing feature.

The type wrappers are **Double**, **Float**, **Long**, **Integer**, **Short**, **Byte**, **Character**, and **Boolean**. These classes offer a wide array of methods that allow you to fully integrate the primitive types into Java’s object hierarchy. Each is briefly examined next.

**Character**

**Character** is a wrapper around a `char`. The constructor for **Character** is

```java
Character(char ch)
```

Here, `ch` specifies the character that will be wrapped by the **Character** object being created.

To obtain the `char` value contained in a **Character** object, call `charValue()`, shown here:

```java
char charValue()
```

It returns the encapsulated character.

**Boolean**

**Boolean** is a wrapper around `boolean` values. It defines these constructors:

```java
Boolean(boolean boolValue)
Boolean(String boolString)
```

In the first version, `boolValue` must be either `true` or `false`. In the second version, if `boolString` contains the string "true" (in uppercase or lowercase), then the new **Boolean** object will be true. Otherwise, it will be false.

To obtain a `boolean` value from a **Boolean** object, use `booleanValue()`, shown here:

```java
boolean booleanValue()
```

It returns the `boolean` equivalent of the invoking object.

**The Numeric Type Wrappers**

By far, the most commonly used type wrappers are those that represent numeric values. These are **Byte**, **Short**, **Integer**, **Long**, **Float**, and **Double**. All of the numeric type wrappers inherit the abstract class **Number**. **Number** declares methods that return the value of an object in each of the different number formats. These methods are shown here:

```java
byte byteValue()
double doubleValue()
float floatValue()
int intValue()
long longValue()
short shortValue()
```
For example, `doubleValue()` returns the value of an object as a `double`, `floatValue()` returns the value as a `float`, and so on. These methods are implemented by each of the numeric type wrappers. All of the numeric type wrappers define constructors that allow an object to be constructed from a given value, or a string representation of that value. For example, here are the constructors defined for `Integer`:

```java
Integer(int num)
Integer(String str)
```

If `str` does not contain a valid numeric value, then a `NumberFormatException` is thrown. All of the type wrappers override `toString()`. It returns the human-readable form of the value contained within the wrapper. This allows you to output the value by passing a type wrapper object to `println()`, for example, without having to convert it into its primitive type.

The following program demonstrates how to use a numeric type wrapper to encapsulate a value and then extract that value.

```java
// Demonstrate a type wrapper.
class Wrap {
    public static void main(String args[]) {
        Integer iOb = new Integer(100);
        int i = iOb.intValue();
        System.out.println(i + " " + iOb); // displays 100 100
    }
}
```

This program wraps the integer value 100 inside an `Integer` object called `iOb`. The program then obtains this value by calling `intValue()` and stores the result in `i`. The process of encapsulating a value within an object is called **boxing**. Thus, in the program, this line boxes the value 100 into an `Integer`:

```java
Integer iOb = new Integer(100);
```

The process of extracting a value from a type wrapper is called **unboxing**. For example, the program unboxes the value in `iOb` with this statement:

```java
int i = iOb.intValue();
```

The same general procedure used by the preceding program to box and unbox values has
been employed since the original version of Java. However, since JDK 5, Java fundamentally improved on this through the addition of autoboxing, described next.

**Autoboxing**

Beginning with JDK 5, Java added two important features: *autoboxing* and *auto-unboxing*. Autoboxing is the process by which a primitive type is automatically encapsulated (boxed) into its equivalent type wrapper whenever an object of that type is needed. There is no need to explicitly construct an object. Auto-unboxing is the process by which the value of a boxed object is automatically extracted (unboxed) from a type wrapper when its value is needed. There is no need to call a method such as `intValue()` or `doubleValue()`.

The addition of autoboxing and auto-unboxing greatly streamlines the coding of several algorithms, removing the tedium of manually boxing and unboxing values. It also helps prevent errors. Moreover, it is very important to generics, which operate only on objects. Finally, autoboxing makes working with the Collections Framework (described in Part II) much easier.

With autoboxing, it is no longer necessary to manually construct an object in order to wrap a primitive type. You need only assign that value to a type-wrapper reference. Java automatically constructs the object for you. For example, here is the modern way to construct an `Integer` object that has the value 100:

```
Integer iOb = 100; // autobox an int
```

Notice that the object is not explicitly created through the use of `new`. Java handles this for you, automatically.

To unbox an object, simply assign that object reference to a primitive-type variable. For example, to unbox `iOb`, you can use this line:

```
int i = iOb; // auto-unbox
```

Java handles the details for you.

Here is the preceding program rewritten to use autoboxing/unboxing:

```java
// Demonstrate autoboxing/unboxing.
class Autobox {
    public static void main(String args[]) {
        Integer iOb = 100; // autobox an int
        int i = iOb; // auto-unbox
        System.out.println(i + " + " + iOb); // displays 100 100
    }
}
```
**Autoboxing and Methods**

In addition to the simple case of assignments, autoboxing automatically occurs whenever a primitive type must be converted into an object; auto-unboxing takes place whenever an object must be converted into a primitive type. Thus, autoboxing/unboxing might occur when an argument is passed to a method, or when a value is returned by a method. For example, consider this:

```java
// Autoboxing/unboxing takes place with
// method parameters and return values.

class AutoBox2 {
    // Take an Integer parameter and return
    // an int value;
    static int m(Integer v) {
        return v; // auto-unbox to int
    }

    public static void main(String args[]) {
        // Pass an int to m() and assign the return value
        // to an Integer. Here, the argument 100 is autoboxed
        // into an Integer. The return value is also autoboxed
        // into an Integer.
        Integer iOb = m(100);

        System.out.println(iOb);
    }
}
```

This program displays the following result:

```
100
```

In the program, notice that `m()` specifies an `Integer` parameter and returns an `int` result. Inside `main()`, `m()` is passed the value 100. Because `m()` is expecting an `Integer`, this value is automatically boxed. Then, `m()` returns the `int` equivalent of its argument. This causes `v` to be auto-unboxed. Next, this `int` value is assigned to `iOb` in `main()`, which causes the `int` return value to be autoboxed.

**Autoboxing/Unboxing Occurs in Expressions**

In general, autoboxing and unboxing take place whenever a conversion into an object or from an object is required. This applies to expressions. Within an expression, a numeric object is automatically unboxed. The outcome of the expression is reboxed, if necessary. For example, consider the following program:
The output is shown here:

<table>
<thead>
<tr>
<th>Original value of iOb: 100</th>
</tr>
</thead>
<tbody>
<tr>
<td>After ++iOb: 101</td>
</tr>
<tr>
<td>iOb2 after expression: 134</td>
</tr>
<tr>
<td>i after expression: 134</td>
</tr>
</tbody>
</table>

In the program, pay special attention to this line:

```java
++iOb;
```

This causes the value in `iOb` to be incremented. It works like this: `iOb` is unboxed, the value is incremented, and the result is reboxed. Auto-unboxing also allows you to mix different types of numeric objects in an expression.
Once the values are unboxed, the standard type promotions and conversions are applied. For example, the following program is perfectly valid:

```java
class AutoBox4 {
    public static void main(String args[]) {
        Integer iOb = 100;
        Double dOb = 98.6;

        dOb = dOb + iOb;
        System.out.println("dOb after expression: " + dOb);
    }
}
```

The output is shown here:

```
dOb after expression: 198.6
```

As you can see, both the `Double` object `dOb` and the `Integer` object `iOb` participated in the addition, and the result was reboxed and stored in `dOb`. Because of auto-unboxing, you can use `Integer` numeric objects to control a `switch` statement. For example, consider this fragment:

```java
Integer iOb = 2;

switch(iOb) {
    case 1: System.out.println("one");
            break;
    case 2: System.out.println("two");
            break;
    default: System.out.println("error");
}
```

When the `switch` expression is evaluated, `iOb` is unboxed and its `int` value is obtained. As the examples in the program show, because of autoboxing/unboxing, using numeric objects in an expression is both intuitive and easy. In the past, such code would have involved casts and calls to methods such as `intValue()`.

**Autoboxing/Unboxing Boolean and Character Values**

As described earlier, Java also supplies wrappers for `boolean` and `char`. These are `Boolean` and `Character`. Autoboxing/unboxing applies to these wrappers, too. For example, consider the following program:
The most important thing to notice about this program is the auto-unboxing of \texttt{b} inside the \texttt{if} conditional expression. As you should recall, the conditional expression that controls an \texttt{if} must evaluate to type \texttt{boolean}. Because of auto-unboxing, the \texttt{boolean} value contained within \texttt{b} is automatically unboxed when the conditional expression is evaluated. Thus, with the advent of autoboxing/unboxing, a \texttt{Boolean} object can be used to control an \texttt{if} statement.

Because of auto-unboxing, a \texttt{Boolean} object can now also be used to control any of Java’s loop statements. When a \texttt{Boolean} is used as the conditional expression of a \texttt{while}, \texttt{for}, or \texttt{do/while}, it is automatically unboxed into its \texttt{boolean} equivalent. For example, this is now perfectly valid code:

\begin{verbatim}
Boolean b;
// ...
while(b) { // ...
\end{verbatim}

\textbf{Autoboxing/Unboxing Helps Prevent Errors}

In addition to the convenience that it offers, autoboxing/unboxing can also help prevent errors. For example, consider the following program:

```
// Autoboxing/unboxing a Boolean and Character.

class AutoBox5 {
    public static void main(String args[]) {

        // Autobox/unbox a boolean.
        Boolean b = true;

        // Below, b is auto-unboxed when used in
        // a conditional expression, such as an if.
        if(b) System.out.println("b is true");

        // Autobox/unbox a char.
        Character ch = 'x'; // box a char
        char ch2 = ch; // unbox a char

        System.out.println("ch2 is " + ch2);
    }
}
```

The output is shown here:

\begin{verbatim}
b is true
ch2 is x
\end{verbatim}
This program displays not the expected value of 1000, but –24! The reason is that the value inside \texttt{iOb} is manually unboxed by calling \texttt{byteValue()}, which causes the truncation of the value stored in \texttt{iOb}, which is 1,000. This results in the garbage value of –24 being assigned to \texttt{i}. Auto-unboxing prevents this type of error because the value in \texttt{iOb} will always auto-unbox into a value compatible with \texttt{int}.

In general, because autoboxing always creates the proper object, and auto-unboxing always produces the proper value, there is no way for the process to produce the wrong type of object or value. In the rare instances where you want a type different than that produced by the automated process, you can still manually box and unbox values. Of course, the benefits of autoboxing/unboxing are lost. In general, new code should employ autoboxing/unboxing. It is the way that modern Java code is written.

\textbf{A Word of Warning}

Because of autoboxing and auto-unboxing, some might be tempted to use objects such as \texttt{Integer} or \texttt{Double} exclusively, abandoning primitives altogether. For example, with autoboxing/unboxing it is possible to write code like this:

```java
// A bad use of autoboxing/unboxing!
Double a, b, c;

a = 10.0;
b = 4.0;

c = Math.sqrt(a*a + b*b);
System.out.println("Hypotenuse is " + c);
```

In this example, objects of type \texttt{Double} hold values that are used to calculate the hypotenuse of a right triangle. Although this code is technically correct and does, in fact, work properly, it is a very bad use of autoboxing/unboxing. It is far less efficient than the equivalent code written using the primitive type \texttt{double}. The reason is that each autobox
and auto-unbox adds overhead that is not present if the primitive type is used.
In general, you should restrict your use of the type wrappers to only those cases in which an
object representation of a primitive type is required. Autoboxing/unboxing was not added to
Java as a “back door” way of eliminating the primitive types.

**Annotations (Metadata)**
Since JDK 5, Java has supported a feature that enables you to embed supplemental
information into a source file. This information, called an *annotation*, does not change the
actions of a program. Thus, an annotation leaves the semantics of a program unchanged.
However, this information can be used by various tools during both development and
deployment. For example, an annotation might be processed by a source-code generator.
The term *metadata* is also used to refer to this feature, but the term *annotation* is the most
descriptive and more commonly used.

**Annotation Basics**
An annotation is created through a mechanism based on the *interface*. Let’s begin with an
equation. Here is the declaration for an annotation called *MyAnno*:

```java
// A simple annotation type.
@interface MyAnno {
    String str();
    int val();
}
```

First, notice the @ that precedes the keyword *interface*. This tells the compiler that an
annotation type is being declared. Next, notice the two members *str()* and *val()*.
All annotations consist solely of method declarations. However, you don’t provide bodies for
these methods. Instead, Java implements these methods. Moreover, the methods act much
like fields, as you will see.

An annotation cannot include an *extends* clause. However, all annotation types
automatically extend the *Annotation* interface. Thus, *Annotation* is a super-interface of
all annotations. It is declared within the *java.lang.annotation* package. It overrides
*hashCode()*, *equals()*, and *toString()*, which are defined by *Object*. It also specifies
*annotationType()*, which returns a *Class* object that represents the invoking annotation.
Once you have declared an annotation, you can use it to annotate something. Prior to JDK
8, annotations could be used only on declarations, and that is where we will begin. (JDK 8
adds the ability to annotate type use, and this is described later in this chapter. However,
the same basic techniques apply to both kinds of annotations.) Any type of declaration can
have an annotation associated with it. For example, classes, methods, fields, parameters,
and *enum* constants can be annotated. Even an annotation can be annotated. In all cases,
the annotation precedes the rest of the declaration.
When you apply an annotation, you give values to its members. For example, here is an example of `MyAnno` being applied to a method declaration:

```java
// Annotate a method.
@MyAnno(str = "Annotation Example", val = 100)
public static void myMeth() {
    // ...
}
```

This annotation is linked with the method `myMeth()`. Look closely at the annotation syntax. The name of the annotation, preceded by an @, is followed by a parenthesized list of member initializations. To give a member a value, that member's name is assigned a value. Therefore, in the example, the string "Annotation Example" is assigned to the `str` member of `MyAnno`. Notice that no parentheses follow `str` in this assignment. When an annotation member is given a value, only its name is used. Thus, annotation members look like fields in this context.

**Specifying a Retention Policy**

Before exploring annotations further, it is necessary to discuss annotation retention policies. A retention policy determines at what point an annotation is discarded. Java defines three such policies, which are encapsulated within the `java.lang.annotation.RetentionPolicy` enumeration. They are `SOURCE`, `CLASS`, and `RUNTIME`.

An annotation with a retention policy of `SOURCE` is retained only in the source file and is discarded during compilation.

An annotation with a retention policy of `CLASS` is stored in the `.class` file during compilation. However, it is not available through the JVM during run time.

An annotation with a retention policy of `RUNTIME` is stored in the `.class` file during compilation and is available through the JVM during run time. Thus, `RUNTIME` retention offers the greatest annotation persistence.

---

**NOTE** An annotation on a local variable declaration is not retained in the `.class` file.

A retention policy is specified for an annotation by using one of Java's built-in annotations: `@Retention`. Its general form is shown here:

```java
@Retention(retention-policy)
```

Here, `retention-policy` must be one of the previously discussed enumeration
constants. If no retention policy is specified for an annotation, then the default policy of CLASS is used.
The following version of MyAnno uses @Retention to specify the RUNTIME retention policy. Thus, MyAnno will be available to the JVM during program execution.

```java
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}
```

**Obtaining Annotations at Run Time by Use of Reflection**

Although annotations are designed mostly for use by other development or deployment tools, if they specify a retention policy of RUNTIME, then they can be queried at run time by any Java program through the use of reflection. Reflection is the feature that enables information about a class to be obtained at run time. The reflection API is contained in the java.lang.reflect package. There are a number of ways to use reflection, and we won’t examine them all here. We will, however, walk through a few examples that apply to annotations.

The first step to using reflection is to obtain a Class object that represents the class whose annotations you want to obtain. Class is one of Java’s built-in classes and is defined in java.lang. It is described in detail in Part II. There are various ways to obtain a Class object. One of the easiest is to call getClass(), which is a method defined by Object. Its general form is shown here:

```java
final Class<?> getClass()
```

It returns the Class object that represents the invoking object.

---

**NOTE** Notice the <?> that follows Class in the declaration of getClass() just shown. This is related to Java’s generics feature. getClass() and several other reflection-related methods discussed in this chapter make use of generics. Generics are described in Chapter 14. However, an understanding of generics is not needed to grasp the fundamental principles of reflection.

After you have obtained a Class object, you can use its methods to obtain information about the various items declared by the class, including its annotations. If you want to
obtain the annotations associated with a specific item declared within a class, you must first obtain an object that represents that item. For example, Class supplies (among others) the getMethod(), getfield(), and getConstructor() methods, which obtain information about a method, field, and constructor, respectively. These methods return objects of type Method, Field, and Constructor.

To understand the process, let's work through an example that obtains the annotations associated with a method. To do this, you first obtain a Class object that represents the class, and then call getMethod() on that Class object, specifying the name of the method. getMethod() has this general form:

Method getMethod(String methName, Class<?> … paramTypes)

The name of the method is passed in methName. If the method has arguments, then Class objects representing those types must also be specified by paramTypes. Notice that paramTypes is a varargs parameter. This means that you can specify as many parameter types as needed, including zero. getMethod() returns a Method object that represents the method. If the method can’t be found, NoSuchMethodException is thrown.

From a Class, Method, Field, or Constructor object, you can obtain a specific annotation associated with that object by calling getAnnotation(). Its general form is shown here:

<A extends Annotation> getAnnotation(Class<A> annoType)

Here, annoType is a Class object that represents the annotation in which you are interested. The method returns a reference to the annotation. Using this reference, you can obtain the values associated with the annotation’s members. The method returns null if the annotation is not found, which will be the case if the annotation does not have RUNTIME retention.

Here is a program that assembles all of the pieces shown earlier and uses reflection to display the annotation associated with a method:
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}

class Meta {

    // Annotate a method.
    @MyAnno(str = "Annotation Example", val = 100)
    public static void myMeth() {
        Meta ob = new Meta();

        // Obtain the annotation for this method
        // and display the values of the members.
        try {
            // First, get a Class object that represents
            // this class.
            Class<?> c = ob.getClass();

            // Now, get a Method object that represents
            // this method.
            Method m = c.getMethod("myMeth");

            // Next, get the annotation for this class.
            MyAnno anno = m.getAnnotation(MyAnno.class);

            // Finally, display the values.
            System.out.println(anno.str() + " " + anno.val());
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }
    }

    public static void main(String args[]) {
        myMeth();
    }
}

The output from the program is shown here:

Annotation Example 100

This program uses reflection as described to obtain and display the values of \texttt{str} and \texttt{val} in
the MyAnno annotation associated with \texttt{myMeth()} in the Meta class. There are two things to pay special attention to. First, in this line

\begin{verbatim}
  MyAnno anno = m.getAnnotation(MyAnno.class);
\end{verbatim}

notice the expression \texttt{MyAnno.class}. This expression evaluates to a Class object of type \texttt{MyAnno}, the annotation. This construct is called a \textit{class literal}. You can use this type of expression whenever a Class object of a known class is needed. For example, this statement could have been used to obtain the Class object for Meta:

\begin{verbatim}
  Class<?> c = Meta.class;
\end{verbatim}

Of course, this approach only works when you know the class name of an object in advance, which might not always be the case. In general, you can obtain a class literal for classes, interfaces, primitive types, and arrays. (Remember, the \texttt{<?>} syntax relates to Java's generics feature. It is described in Chapter 14.)

The second point of interest is the way the values associated with \texttt{str} and \texttt{val} are obtained when they are output by the following line:

\begin{verbatim}
  System.out.println(anno.str() + " " + anno.val());
\end{verbatim}

Notice that they are invoked using the method-call syntax. This same approach is used whenever the value of an annotation member is required.

\textbf{A Second Reflection Example}

In the preceding example, \texttt{myMeth()} has no parameters. Thus, when \texttt{getMethod()} was called, only the name \texttt{myMeth} was passed. However, to obtain a method that has parameters, you must specify class objects representing the types of those parameters as arguments to \texttt{getMethod()}. For example, here is a slightly different version of the preceding program:
The output from this version is shown here:

Two Parameters

In this version, `myMeth()` takes a `String` and an `int` parameter. To obtain information about this method, `getMethod()` must be called as shown here:

```java
Method m = c.getMethod("myMeth", String.class, int.class);
```

Here, the `Class` objects representing `String` and `int` are passed as additional arguments.

**Obtaining All Annotations**

You can obtain all annotations that have `RUNTIME` retention that are associated with an item by calling `getAnnotations()` on that item. It has this general form:
Annotation[] getAnnotations()

It returns an array of the annotations. getAnnotations() can be called on objects of type Class, Method, Constructor, and Field, among others. Here is another reflection example that shows how to obtain all annotations associated with a class and with a method. It declares two annotations. It then uses those annotations to annotate a class and a method.

```java
// Show all annotations for a class and a method.
import java.lang.annotation.*;
import java.lang.reflect.*;

@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str();
    int val();
}

@Retention(RetentionPolicy.RUNTIME)
@interface What {
    String description();
}

@What(description = "An annotation test class")
@MyAnno(str = "Meta2", val = 99)
class Meta2 {
    @What(description = "An annotation test method")
    @MyAnno(str = "Testing", val = 100)
    public static void myMeth() {
        Meta2 ob = new Meta2();
        try {
            Annotation annos[] = ob.getClass().getAnnotations();
            // Display all annotations for Meta2.
            System.out.println("All annotations for Meta2:");
            for(Annotation a : annos)
                System.out.println(a);
            System.out.println();
            // Display all annotations for myMeth.
        }
    }
}
```
The program uses `getAnnotations()` to obtain an array of all annotations associated with the `Meta2` class and with the `myMeth()` method. As explained, `getAnnotations()` returns an array of `Annotation` objects. Recall that `Annotation` is a super-interface of all annotation interfaces and that it overrides `toString()` in `Object`. Thus, when a reference to an `Annotation` is output, its `toString()` method is called to generate a string that describes the annotation, as the preceding output shows.

The AnnotatedElement Interface
The methods `getAnnotation()` and `getAnnotations()` used by the preceding examples are defined by the `AnnotatedElement` interface, which is defined in `java.lang.reflect`. This interface supports reflection for annotations and is implemented by the classes `Method`, `Field`, `Constructor`, `Class`, and `Package`, among others.

In addition to `getAnnotation()` and `getAnnotations()`, `AnnotatedElement` defines several other methods. Two have been available since JDK 5. The first is `getDeclaredAnnotations()`, which has this general form:

```java
Annotation[] getDeclaredAnnotations()
```

The output is shown here:

```
All annotations for Meta2:
@What(description=An annotation test class)
@MyAnno(str=Meta2, val=99)

All annotations for myMeth:
@What(description=An annotation test method)
@MyAnno(str=Testing, val=100)
```
It returns all non-inherited annotations present in the invoking object. The second is `isAnnotationPresent()`, which has this general form:

```java
boolean isAnnotationPresent(Class<? extends Annotation> annoType)
```

It returns `true` if the annotation specified by `annoType` is associated with the invoking object. It returns `false` otherwise. To these, JDK 8 adds `getDeclaredAnnotation()`, `getAnnotationsByType()`, and `getDeclaredAnnotationsByType()`. Of these, the last two automatically work with a repeated annotation. (Repeated annotations are discussed at the end of this chapter.)

### Using Default Values

You can give annotation members default values that will be used if no value is specified when the annotation is applied. A default value is specified by adding a `default` clause to a member’s declaration. It has this general form:

```java
type member() default value;
```

Here, `value` must be of a type compatible with `type`.

Here is `@MyAnno` rewritten to include default values:

```java
// An annotation type declaration that includes defaults.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str() default "Testing";
    int val() default 9000;
}
```

This declaration gives a default value of "Testing" to `str` and 9000 to `val`. This means that neither value needs to be specified when `@MyAnno` is used. However, either or both can be given values if desired. Therefore, following are the four ways that `@MyAnno` can be used:

```java
@MyAnno()  // both str and val default
@MyAnno(str = "some string")  // val defaults
@MyAnno(val = 100)  // str defaults
@MyAnno(str = "Testing", val = 100)  // no defaults
```

The following program demonstrates the use of default values in an annotation.
import java.lang.annotation.*;
import java.lang.reflect.*;

// An annotation type declaration that includes defaults.
@Retention(RetentionPolicy.RUNTIME)
@interface MyAnno {
    String str() default "Testing";
    int val() default 9000;
}

class Meta3 {
    // Annotate a method using the default values.
    @MyAnno()
    public static void myMeth() {
        Meta3 ob = new Meta3();

        // Obtain the annotation for this method
        // and display the values of the members.
        try {
            Class<?> c = ob.getClass();
            Method m = c.getMethod("myMeth");
            MyAnno anno = m.getAnnotation(MyAnno.class);

            System.out.println(anno.str() + " " + anno.val());
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }
    }

    public static void main(String args[]) {
        myMeth();
    }
}

The output is shown here:

Testing 9000

**Marker Annotations**

A *marker* annotation is a special kind of annotation that contains no members. Its sole purpose is to mark an item. Thus, its presence as an annotation is sufficient. The best way to determine if a marker annotation is present is to use the method `isAnnotationPresent( )`, which is defined by the `AnnotatedElement` interface.
Here is an example that uses a marker annotation. Because a marker interface contains no members, simply determining whether it is present or absent is sufficient.

```java
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyMarker {}

class Marker {

    // Annotate a method using a marker.
    // Notice that no () is needed.
    @MyMarker
    public static void myMeth() {
        Marker ob = new Marker();

        try {
            Method m = ob.getClass().getMethod("myMeth");

            // Determine if the annotation is present.
            if (m.isAnnotationPresent(MyMarker.class))
                System.out.println("MyMarker is present.");
        }
        catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }

        public static void main(String args[]) {
            myMeth();
        }
    }
}
```

The output, shown here, confirms that `@MyMarker` is present:

```
MyMarker is present.
```

In the program, notice that you do not need to follow `@MyMarker` with parentheses when it is applied. Thus, `@MyMarker` is applied simply by using its name, like this:

```
@MyMarker
```

It is not wrong to supply an empty set of parentheses, but they are not needed.

**Single-Member Annotations**
A single-member annotation contains only one member. It works like a normal annotation except that it allows a shorthand form of specifying the value of the member. When only one member is present, you can simply specify the value for that member when the annotation is applied—you don’t need to specify the name of the member. However, in order to use this shorthand, the name of the member must be **value**.

Here is an example that creates and uses a single-member annotation:

```java
import java.lang.annotation.*;
import java.lang.reflect.*;

// A single-member annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MySingle {
    int value(); // this variable name must be value
}

class Single {

    // Annotate a method using a single-member annotation.
    @MySingle(100)
    public static void myMeth() {
        Single ob = new Single();
        try {
            Method m = ob.getClass().getMethod("myMeth");
            MySingle anno = m.getAnnotation(MySingle.class);
            System.out.println(anno.value()); // displays 100
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }
    }

    public static void main(String args[]) {
        myMeth();
    }
}
```

As expected, this program displays the value 100. In the program, `@MySingle` is used to annotate `myMeth()`, as shown here:

```java
@MySingle(100)
```

Notice that **value** = need not be specified.
You can use the single-value syntax when applying an annotation that has other members, but those other members must all have default values. For example, here the value \texttt{xyz} is added, with a default value of zero:

```java
@interface SomeAnno {
    int value();
    int xyz() default 0;
}
```

In cases in which you want to use the default for \texttt{xyz}, you can apply \texttt{@SomeAnno}, as shown next, by simply specifying the value of \texttt{value} by using the single-member syntax.

```java
@SomeAnno (88)
```

In this case, \texttt{xyz} defaults to zero, and \texttt{value} gets the value 88. Of course, to specify a different value for \texttt{xyz} requires that both members be explicitly named, as shown here:

```java
@SomeAnno (value = 88, xyz = 99)
```

Remember, whenever you are using a single-member annotation, the name of that member must be \texttt{value}.

\textbf{The Built-In Annotations}

Java defines many built-in annotations. Most are specialized, but nine are general purpose. Of these, four are imported from \texttt{java.lang.annotation}: \texttt{@Retention}, \texttt{@Documented}, \texttt{@Target}, and \texttt{@Inherited}. Five—\texttt{@Override}, \texttt{@Deprecated}, \texttt{@FunctionalInterface}, \texttt{@SafeVarargs}, and \texttt{@SuppressWarnings}—are included in \texttt{java.lang}. Each is described here.

---

\textbf{NOTE} To \texttt{java.lang.annotation}, JDK 8 adds the annotations \texttt{Repeatable} and \texttt{Native}. \texttt{Repeatable} supports repeatable annotations, as described later in this chapter. \texttt{Native} annotates a field that can be accessed by native code.

\texttt{@Retention} \texttt{@Retention} is designed to be used only as an annotation to another annotation. It specifies the retention policy as described earlier in this chapter.
@Documented
The @Documented annotation is a marker interface that tells a tool that an annotation is to be documented. It is designed to be used only as an annotation to an annotation declaration.

@Target
The @Target annotation specifies the types of items to which an annotation can be applied. It is designed to be used only as an annotation to another annotation. @Target takes one argument, which is an array of constants of the ElementType enumeration. This argument specifies the types of declarations to which the annotation can be applied. The constants are shown here along with the type of declaration to which they correspond:

<table>
<thead>
<tr>
<th>Target Constant</th>
<th>Annotation Can Be Applied To</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANNOTATION_TYPE</td>
<td>Another annotation</td>
</tr>
<tr>
<td>CONSTRUCTOR</td>
<td>Constructor</td>
</tr>
<tr>
<td>FIELD</td>
<td>Field</td>
</tr>
<tr>
<td>LOCAL_VARIABLE</td>
<td>Local variable</td>
</tr>
<tr>
<td>METHOD</td>
<td>Method</td>
</tr>
<tr>
<td>PACKAGE</td>
<td>Package</td>
</tr>
<tr>
<td>PARAMETER</td>
<td>Parameter</td>
</tr>
<tr>
<td>TYPE</td>
<td>Class, interface, or enumeration</td>
</tr>
<tr>
<td>TYPE_PARAMETER</td>
<td>Type parameter (Added by JDK 8.)</td>
</tr>
<tr>
<td>TYPE_USE</td>
<td>Type use (Added by JDK 8.)</td>
</tr>
</tbody>
</table>

You can specify one or more of these values in a @Target annotation. To specify multiple values, you must specify them within a braces-delimited list. For example, to specify that an annotation applies only to fields and local variables, you can use this @Target annotation:

```java
@Target( { ElementType.FIELD, ElementType.LOCAL_VARIABLE } )
```

If you don’t use @Target, then, except for type parameters, the annotation can be used on any declaration. For this reason, it is often a good idea to explicitly specify the target or targets so as to clearly indicate the intended uses of an annotation.

@Inherited
@Inherited is a marker annotation that can be used only on another annotation declaration. Furthermore, it affects only annotations that will be used on class declarations. @Inherited causes the annotation for a superclass to be inherited by a subclass. Therefore, when a request for a specific annotation is made to the subclass, if that annotation is not
present in the subclass, then its superclass is checked. If that annotation is present in the superclass, and if it is annotated with @Inherited, then that annotation will be returned.

@Override
@Override is a marker annotation that can be used only on methods. A method annotated with @Override must override a method from a superclass. If it doesn’t, a compile-time error will result. It is used to ensure that a superclass method is actually overridden, and not simply overloaded.

@Deprecated
@Deprecated is a marker annotation. It indicates that a declaration is obsolete and has been replaced by a newer form.

@FunctionalInterface
@FunctionalInterface is a marker annotation added by JDK 8 and designed for use on interfaces. It indicates that the annotated interface is a functional interface. A functional interface is an interface that contains one and only one abstract method. Functional interfaces are used by lambda expressions. (See Chapter 15 for details on functional interfaces and lambda expressions.) If the annotated interface is not a functional interface, a compilation error will be reported. It is important to understand that @FunctionalInterface is not needed to create a functional interface. Any interface with exactly one abstract method is, by definition, a functional interface. Thus, @FunctionalInterface is purely informational.

@SafeVarargs
@SafeVarargs is a marker annotation that can be applied to methods and constructors. It indicates that no unsafe actions related to a varargs parameter occur. It is used to suppress unchecked warnings on otherwise safe code as it relates to non-reifiable vararg types and parameterized array instantiation. (A non-reifiable type is, essentially, a generic type. Generics are described in Chapter 14.) It must be applied only to vararg methods or constructors that are static or final.

@SuppressWarnings
@SuppressWarnings specifies that one or more warnings that might be issued by the compiler are to be suppressed. The warnings to suppress are specified by name, in string form.

Type Annotations
Beginning with JDK 8, the places in which annotations can be used has been expanded. As mentioned earlier, annotations were originally allowed only on declarations. However, with the advent of JDK 8, annotations can also be specified in most cases in which a type is used. This expanded aspect of annotations is called type annotation. For example, you can annotate the return type of a method, the type of this within a method, a cast, array levels,
an inherited class, and a `throws` clause. You can also annotate generic types, including
generic type parameter bounds and generic type arguments. (See Chapter 14 for a discussion
of generics.)

Type annotations are important because they enable tools to perform additional checks on
code to help prevent errors. Understand that, as a general rule, `javac` will not perform these
checks, itself. A separate tool is used for this purpose, although such a tool might operate as
a compiler plug-in.

A type annotation must include `ElementType.TYPE_USE` as a target. (Recall that valid
annotation targets are specified using the `@Target` annotation, as previously described.) A
type annotation applies to the type that the annotation precedes. For example, assuming
some type annotation called `@TypeAnno`, the following is legal:

```java
    void myMeth() throws @TypeAnno NullPointerException { // ...
```

Here, `@TypeAnno` annotates `NullPointerException` in the `throws` clause.

You can also annotate the type of `this` (called the `receiver`). As you know, `this` is an implicit
argument to all instance methods and it refers to the invoking object. To annotate its type
requires the use of another new JDK 8 feature. Beginning with JDK 8, you can explicitly
declare `this` as the first parameter to a method. In this declaration, the type of `this` must be
the type of its class; for example:

```java
    class SomeClass {
        int myMeth(SomeClass this, int i, int j) { // ...
```

Here, because `myMeth()` is a method defined by `SomeClass`, the type of `this` is
`SomeClass`. Using this declaration, you can now annotate the type of `this`. For example,
again assuming that `@TypeAnno` is a type annotation, the following is legal:

```java
    int myMeth(@TypeAnno SomeClass this, int i, int j) { // ...
```

It is important to understand that it is not necessary to declare `this` unless you are
annotating it. (If `this` is not declared, it is still implicitly passed. JDK 8 does not change this
fact.) Also, explicitly declaring `this` does not change any aspect of the method's signature
because `this` is implicitly declared, by default. Again, you will declare `this` only if you want
to apply a type annotation to it. If you do declare `this`, it must be the first parameter.

The following program shows a number of the places that a type annotation can be used. It
defines several annotations, of which several are for type annotation. The names and targets
of the annotations are shown here:

<table>
<thead>
<tr>
<th>Annotation</th>
<th>Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>@TypeAnno</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>Annotation</td>
<td>ElementType</td>
</tr>
<tr>
<td>-------------</td>
<td>----------------------</td>
</tr>
<tr>
<td>@MaxLen</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@NotZeroLen</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@Unique</td>
<td>ElementType.TYPE_USE</td>
</tr>
<tr>
<td>@What</td>
<td>ElementType.TYPE_PARAMETER</td>
</tr>
<tr>
<td>@EmptyOK</td>
<td>ElementType.FIELD</td>
</tr>
<tr>
<td>@Recommended</td>
<td>ElementType.METHOD</td>
</tr>
</tbody>
</table>

Notice that `@EmptyOK`, `@Recommended`, and `@What` are not type annotations. They are included for comparison purposes. Of special interest is `@What`, which is used to annotate a generic type parameter declaration and is another new annotation feature added by JDK 8. The comments in the program describe each use.
// Demonstrate several type annotations.
import java.lang.annotation.*;
import java.lang.reflect.*;

// A marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface TypeAnno {
}

// Another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface NotZeroLen {
}

// Still another marker annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface Unique {
}

// A parameterized annotation that can be applied to a type.
@Target(ElementType.TYPE_USE)
@interface MaxLen {
    int value();
}

// An annotation that can be applied to a type parameter.
@Target(ElementType.TYPE_PARAMETER)
@interface What {
    String description();
}

// An annotation that can be applied to a field declaration.
@Target(ElementType.FIELD)
@interface EmptyOK {
}

// An annotation that can be applied to a method declaration.
@Target(ElementType.METHOD)
@interface Recommended {
}

// Use an annotation on a type parameter.
class TypeAnnoDemo<?@What(description = "Generic data type") T> {

    // Use a type annotation on a constructor.
    public @Unique TypeAnnoDemo() {}

    // Annotate the type (in this case String), not the field.
    @TypeAnno String str;
Although what most of the annotations in the preceding program refer to is clear, four uses require a bit of discussion. The first is the annotation of a method return type versus the annotation of a method declaration. In the program, pay special attention to these two method declarations:
Notice that in both cases, an annotation precedes the method's return type (which is \texttt{Integer}). However, the two annotations annotate two different things. In the first case, the \texttt{@TypeAnno} annotation annotates \texttt{f2()}’s return type. This is because \texttt{@TypeAnno} has its target specified as \texttt{ElementType.TYPE\_USE}, which means that it can be used to annotate type uses. In the second case, \texttt{@Recommended} annotates the method declaration, itself. This is because \texttt{@Recommended} has its target specified as \texttt{ElementType.METHOD}. As a result, \texttt{@Recommended} applies to the declaration, not the return type. Therefore, the target specification is used to eliminate what, at first glance, appears to be ambiguity between the annotation of a method declaration and the annotation of the method’s return type.

One other thing about annotating a method return type: You cannot annotate a return type of \texttt{void}.

The second point of interest are the field annotations, shown here:

\begin{verbatim}
// Annotate the type (in this case String), not the field.
@TypeAnno String str;

// This annotates the field test.
@EmptyOK String test;
\end{verbatim}

Here, \texttt{@TypeAnno} annotates the type \texttt{String}, but \texttt{@EmptyOK} annotates the field \texttt{test}. Even though both annotations precede the entire declaration, their targets are different, based on the target element type. If the annotation has the \texttt{ElementType\_USE} target, then the type is annotated. If it has \texttt{ElementType\_FIELD} as a target, then the field is annotated. Thus, the situation is similar to that just described for methods, and no ambiguity exists. The same mechanism also disambiguates annotations on local variables.

Next, notice how \texttt{this} (the receiver) is annotated here:

\begin{verbatim}
public int f(@TypeAnno TypeAnnoDemo\langle T\rangle this, int x) {
\end{verbatim}

Here, \texttt{this} is specified as the first parameter and is of type \texttt{TypeAnnoDemo} (which is the
class of which \( f() \) is a member). As explained, beginning with JDK 8, an instance method declaration can explicitly specify the \texttt{this} parameter for the sake of applying a type annotation.

Finally, look at how array levels are annotated by the following statement:

```java
String @MaxLen(10) [] @NotZeroLen [] w;
```

In this declaration, \texttt{@MaxLen} annotates the type of the first level and \texttt{@NotZeroLen} annotates the type of the second level. In this declaration

```java
@TypeAnno Integer[] vec;
```

the element type \texttt{Integer} is annotated.

**Repeating Annotations**

Another new JDK 8 annotation feature enables an annotation to be repeated on the same element. This is called \textit{repeating annotations}. For an annotation to be repeatable, it must be annotated with the \texttt{@Repeatable} annotation, defined in \texttt{java.lang.annotation}. Its \texttt{value} field specifies the \texttt{container} type for the repeatable annotation. The container is specified as an annotation for which the \texttt{value} field is an array of the repeatable annotation type. Thus, to create a repeatable annotation, you must create a container annotation and then specify that annotation type as an argument to the \texttt{@Repeatable} annotation.

To access the repeated annotations using a method such as \texttt{getAnnotation( )}, you will use the container annotation, not the repeatable annotation. The following program shows this approach. It converts the version of \texttt{MyAnno} shown previously into a repeatable annotation and demonstrates its use.
// Demonstrate a repeated annotation.

import java.lang.annotation.*;
import java.lang.reflect.*;

// Make MyAnno repeatable.
@Retention(RetentionPolicy.RUNTIME)
@Repeatable(MyRepeatedAnnos.class)
@interface MyAnno {
    String str() default "Testing";
    int val() default 9000;
}

// This is the container annotation.
@Retention(RetentionPolicy.RUNTIME)
@interface MyRepeatedAnnos {
    MyAnno[] value();
}

class RepeatAnno {

    // Repeat MyAnno on myMeth().
    @MyAnno(str = "First annotation", val = -1)
    @MyAnno(str = "Second annotation", val = 100)
    public static void myMeth(String str, int i)

    { RepeatAnno ob = new RepeatAnno();

        try {
            Class<?> c = ob.getClass();
            // Obtain the annotations for myMeth().
            Method m = c.getMethod("myMeth", String.class, int.class);
            // Display the repeated MyAnno annotations.
            Annotation anno = m.getAnnotation(MyRepeatedAnnos.class);
            System.out.println(anno);
        } catch (NoSuchMethodException exc) {
            System.out.println("Method Not Found.");
        }

        public static void main(String args[]) {
            myMeth("test", 10);
        }
    }
}
As explained, in order for MyAnno to be repeatable, it must be annotated with the @Repeatable annotation, which specifies its container annotation. The container annotation is called MyRepeatedAnnos. The program accesses the repeated annotations by calling getAnnotation(), passing in the class of the container annotation, not the repeatable annotation, itself. As the output shows, the repeated annotations are separated by a comma. They are not returned individually.

Another way to obtain the repeated annotations is to use one of the new methods added to AnnotatedElement by JDK 8, which can operate directly on a repeated annotation. These are getAnnotationsByType() and getDeclaredAnnotationsByType(). Here, we will use the former. It is shown here:

```
<T extends Annotation> T[] getAnnotationsByType(Class<T> annoType)
```

It returns an array of the annotations of annoType associated with the invoking object. If no annotations are present, the array will be of zero length. Here is an example. Assuming the preceding program, the following sequence uses getAnnotationsByType() to obtain the repeated MyAnno annotations:

```
Annotation[] annos = m.getAnnotationsByType(MyAnno.class);
for(Annotation a : annos)
    System.out.println(a);
```

Here, the repeated annotation type, which is MyAnno, is passed to getAnnotationsByType(). The returned array contains all of the instances of MyAnno associated with myMeth(), which, in this example, is two. Each repeated annotation can be accessed via its index in the array. In this case, each MyAnno annotation is displayed via a for-each loop.

**Some Restrictions**

There are a number of restrictions that apply to annotation declarations. First, no annotation can inherit another. Second, all methods declared by an annotation must be without parameters. Furthermore, they must return one of the following:

- A primitive type, such as int or double
- An object of type String or Class
- An enum type
Annotations cannot be generic. In other words, they cannot take type parameters. (Generics are described in Chapter 14.) Finally, annotation methods cannot specify a `throws` clause.
This chapter introduces two of Java’s most important packages: `io` and `applet`. The `io` package supports Java’s basic I/O (input/output) system, including file I/O. The `applet` package supports applets. Support for both I/O and applets comes from Java’s core API libraries, not from language keywords. For this reason, an in-depth discussion of these topics is found in Part II of this book, which examines Java’s API classes. This chapter discusses the foundation of these two subsystems so that you can see how they are integrated into the Java language and how they fit into the larger context of the Java programming and execution environment. This chapter also examines the `try-with-resources` statement and the last of Java’s keywords: `transient`, `volatile`, `instanceof`, `native`, `strictfp`, and `assert`. It concludes by discussing static import, describing another use for the `this` keyword, and introducing compact profiles (a feature added by JDK 8).

**I/O Basics**

As you may have noticed while reading the preceding 12 chapters, not much use has been made of I/O in the example programs. In fact, aside from `print()` and `println()`, none of the I/O methods have been used significantly. The reason is simple: most real applications of Java are not text-based, console programs. Rather, they are either graphically oriented programs that rely on one of Java’s graphical user interface (GUI) frameworks, such as Swing, the AWT, or JavaFX, for user interaction, or they are Web applications. Although text-based, console programs are excellent as teaching examples, they do not constitute an important use for Java in the real world. Also, Java’s support for console I/O is limited and somewhat awkward to use—even in simple example programs. Text-based console I/O is just not that useful in real-world Java programming.

The preceding paragraph notwithstanding, Java does provide strong, flexible support for I/O as it relates to files and networks. Java’s I/O system is cohesive and consistent. In fact, once you understand its fundamentals, the rest of the I/O system is easy to master. A general overview of I/O is presented here. A detailed description is found in Chapters 20 and 21.

**Streams**
Java programs perform I/O through streams. A stream is an abstraction that either produces or consumes information. A stream is linked to a physical device by the Java I/O system. All streams behave in the same manner, even if the actual physical devices to which they are linked differ. Thus, the same I/O classes and methods can be applied to different types of devices. This means that an input stream can abstract many different kinds of input: from a disk file, a keyboard, or a network socket. Likewise, an output stream may refer to the console, a disk file, or a network connection. Streams are a clean way to deal with input/ output without having every part of your code understand the difference between a keyboard and a network, for example. Java implements streams within class hierarchies defined in the java.io package.

NOTE In addition to the stream-based I/O defined in java.io, Java also provides buffer- and channel-based I/O, which is defined in java.nio and its subpackages. They are described in Chapter 21.

Byte Streams and Character Streams
Java defines two types of streams: byte and character. Byte streams provide a convenient means for handling input and output of bytes. Byte streams are used, for example, when reading or writing binary data. Character streams provide a convenient means for handling input and output of characters. They use Unicode and, therefore, can be internationalized. Also, in some cases, character streams are more efficient than byte streams. The original version of Java (Java 1.0) did not include character streams and, thus, all I/O was byte-oriented. Character streams were added by Java 1.1, and certain byte-oriented classes and methods were deprecated. Although old code that doesn’t use character streams is becoming increasingly rare, it may still be encountered from time to time. As a general rule, old code should be updated to take advantage of character streams where appropriate. One other point: at the lowest level, all I/O is still byte-oriented. The character-based streams simply provide a convenient and efficient means for handling characters. An overview of both byte-oriented streams and character-oriented streams is presented in the following sections.

The Byte Stream Classes
Byte streams are defined by using two class hierarchies. At the top are two abstract classes: InputStream and OutputStream. Each of these abstract classes has several concrete subclasses that handle the differences among various devices, such as disk files, network connections, and even memory buffers. The byte stream classes in java.io are shown in Table 13-1. A few of these classes are discussed later in this section. Others are described in
Part II of this book. Remember, to use the stream classes, you must import `java.io`.

<table>
<thead>
<tr>
<th>Stream Class</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedReader</td>
<td>Buffered input stream</td>
</tr>
<tr>
<td>BufferedWriter</td>
<td>Buffered output stream</td>
</tr>
<tr>
<td>ByteArrayInputStream</td>
<td>Input stream that reads from a byte array</td>
</tr>
<tr>
<td>ByteArrayOutputStream</td>
<td>Output stream that writes to a byte array</td>
</tr>
<tr>
<td>DataInputStream</td>
<td>An input stream that contains methods for reading the Java standard data types</td>
</tr>
<tr>
<td>DataOutputStream</td>
<td>An output stream that contains methods for writing the Java standard data types</td>
</tr>
<tr>
<td>FileInputStream</td>
<td>Input stream that reads from a file</td>
</tr>
<tr>
<td>FileOutputStream</td>
<td>Output stream that writes to a file</td>
</tr>
<tr>
<td>FilterInputStream</td>
<td>Implements InputStream</td>
</tr>
<tr>
<td>FilterOutputStream</td>
<td>Implements OutputStream</td>
</tr>
<tr>
<td>InputStream</td>
<td>Abstract class that describes stream input</td>
</tr>
<tr>
<td>ObjectInputStream</td>
<td>Input stream for objects</td>
</tr>
<tr>
<td>ObjectOutputStream</td>
<td>Output stream for objects</td>
</tr>
<tr>
<td>OutputStream</td>
<td>Abstract class that describes stream output</td>
</tr>
<tr>
<td>PipedInputStream</td>
<td>Input pipe</td>
</tr>
<tr>
<td>PipedOutputStream</td>
<td>Output pipe</td>
</tr>
<tr>
<td>PrintStream</td>
<td>OutputStream that contains print() and println()</td>
</tr>
<tr>
<td>PushbackInputStream</td>
<td>Input stream that supports one-byte “unget,” which returns a byte to the input stream</td>
</tr>
<tr>
<td>SequenceInputStream</td>
<td>Input stream that is a combination of two or more input streams that will be read sequentially, one after the other</td>
</tr>
</tbody>
</table>

**Table 13-1** The Byte Stream Classes in `java.io`

The abstract classes `InputStream` and `OutputStream` define several key methods that the other stream classes implement. Two of the most important are `read()` and `write()`, which, respectively, read and write bytes of data. Each has a form that is abstract and must be overridden by derived stream classes.

**The Character Stream Classes**

Character streams are defined by using two class hierarchies. At the top are two abstract classes: `Reader` and `Writer`. These abstract classes handle Unicode character streams. Java has several concrete subclasses of each of these. The character stream classes in `java.io` are shown in Table 13-2.
Table 13-2 The Character Stream I/O Classes in java.io

<table>
<thead>
<tr>
<th>Stream Class</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedReader</td>
<td>Buffered input character stream</td>
</tr>
<tr>
<td>BufferedWriter</td>
<td>Buffered output character stream</td>
</tr>
<tr>
<td>CharArrayReader</td>
<td>Input stream that reads from a character array</td>
</tr>
<tr>
<td>CharArrayWriter</td>
<td>Output stream that writes to a character array</td>
</tr>
<tr>
<td>FileReader</td>
<td>Input stream that reads from a file</td>
</tr>
<tr>
<td>FileWriter</td>
<td>Output stream that writes to a file</td>
</tr>
<tr>
<td>FilterReader</td>
<td>Filtered reader</td>
</tr>
<tr>
<td>FilterWriter</td>
<td>Filtered writer</td>
</tr>
<tr>
<td>InputStreamReader</td>
<td>Input stream that translates bytes to characters</td>
</tr>
<tr>
<td>LineNumberReader</td>
<td>Input stream that counts lines</td>
</tr>
<tr>
<td>OutputStreamWriter</td>
<td>Output stream that translates characters to bytes</td>
</tr>
<tr>
<td>PipedReader</td>
<td>Input pipe</td>
</tr>
<tr>
<td>PipedWriter</td>
<td>Output pipe</td>
</tr>
<tr>
<td>PrintStream</td>
<td>Output stream that contains print() and println()</td>
</tr>
<tr>
<td>PushbackReader</td>
<td>Input stream that allows character to be returned to the input stream</td>
</tr>
<tr>
<td>Reader</td>
<td>Abstract class that describes character stream input</td>
</tr>
<tr>
<td>StringReader</td>
<td>Input stream that reads from a string</td>
</tr>
<tr>
<td>StringWriter</td>
<td>Output stream that writes to a string</td>
</tr>
<tr>
<td>Writer</td>
<td>Abstract class that describes character stream output</td>
</tr>
</tbody>
</table>

The abstract classes Reader and Writer define several key methods that the other stream classes implement. Two of the most important methods are `read()` and `write()`, which read and write characters of data, respectively. Each has a form that is abstract and must be overridden by derived stream classes.

**The Predefined Streams**

As you know, all Java programs automatically import the java.lang package. This package defines a class called System, which encapsulates several aspects of the run-time environment. For example, using some of its methods, you can obtain the current time and the settings of various properties associated with the system. System also contains three predefined stream variables: `in`, `out`, and `err`. These fields are declared as public, static, and final within System. This means that they can be used by any other part of your program and without reference to a specific System object.

System.out refers to the standard output stream. By default, this is the console. System.in refers to standard input, which is the keyboard by default. System.err refers to the standard error stream, which also is the console by default. However, these streams may be redirected to any compatible I/O device.

System.in is an object of type InputStream; System.out and System.err are objects of type PrintStream. These are byte streams, even though they are typically used to read and write characters from and to the console. As you will see, you can wrap these within character-based streams, if desired.
The preceding chapters have been using `System.out` in their examples. You can use `System.err` in much the same way. As explained in the next section, use of `System.in` is a little more complicated.

### Reading Console Input

In Java 1.0, the only way to perform console input was to use a byte stream. Today, using a byte stream to read console input is still acceptable. However, for commercial applications, the preferred method of reading console input is to use a character-oriented stream. This makes your program easier to internationalize and maintain.

In Java, console input is accomplished by reading from `System.in`. To obtain a character-based stream that is attached to the console, wrap `System.in` in a `BufferedReader` object. `BufferedReader` supports a buffered input stream. A commonly used constructor is shown here:

```java
BufferedReader(Reader inputReader)
```

Here, `inputReader` is the stream that is linked to the instance of `BufferedReader` that is being created. `Reader` is an abstract class. One of its concrete subclasses is `InputStreamReader`, which converts bytes to characters. To obtain an `InputStreamReader` object that is linked to `System.in`, use the following constructor:

```java
InputStreamReader(InputStream inputStream)
```

Because `System.in` refers to an object of type `InputStream`, it can be used for `inputStream`. Putting it all together, the following line of code creates a `BufferedReader` that is connected to the keyboard:

```java
BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
```

After this statement executes, `br` is a character-based stream that is linked to the console through `System.in`.

### Reading Characters

To read a character from a `BufferedReader`, use `read()`. The version of `read()` that we will be using is

```java
int read() throws IOException
```

Each time that `read()` is called, it reads a character from the input stream and returns it as an integer value. It returns –1 when the end of the stream is encountered. As you can see, it can throw an `IOException`.

The following program demonstrates `read()` by reading characters from the console until the user types a “q.” Notice that any I/O exceptions that might be generated are simply thrown out of `main()`. Such an approach is common when reading from the console in
simple example programs such as those shown in this book, but in more sophisticated applications, you can handle the exceptions explicitly.

```java
// Use a BufferedReader to read characters from the console.
import java.io.*;

class BRRead {
    public static void main(String args[]) throws IOException
    {
        char c;
        BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
        System.out.println("Enter characters, 'q' to quit.");
        // read characters
        do {
            c = (char) br.read();
            System.out.println(c);
        } while(c != 'q');
    }
}
```

Here is a sample run:

```
Enter characters, 'q' to quit.
123abcq
1
2
3
a
b
c
q
```

This output may look a little different from what you expected because **System.in** is line buffered, by default. This means that no input is actually passed to the program until you press ENTER. As you can guess, this does not make `read()` particularly valuable for interactive console input.

**Reading Strings**

To read a string from the keyboard, use the version of `readLine()` that is a member of the `BufferedReader` class. Its general form is shown here:

```java
String readLine() throws IOException
```

As you can see, it returns a **String** object.

The following program demonstrates **BufferedReader** and the **readLine()** method; the
program reads and displays lines of text until you enter the word "stop":

```java
// Read a string from console using a BufferedReader.
import java.io.*;
class BRReadLines {
    public static void main(String args[]) throws IOException {
        // create a BufferedReader using System.in
        BufferedReader br = new BufferedReader(new InputStreamReader(System.in));
        String str;
        System.out.println("Enter lines of text.");
        System.out.println("Enter 'stop' to quit.");
        do {
            str = br.readLine();
            System.out.println(str);
        } while(!str.equals("stop"));
    }
}
```

The next example creates a tiny text editor. It creates an array of String objects and then reads in lines of text, storing each line in the array. It will read up to 100 lines or until you enter "stop." It uses a BufferedReader to read from the console.
Here is a sample run:

```
Enter lines of text.
Enter 'stop' to quit.
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.
stop
Here is your file:
This is line one.
This is line two.
Java makes working with strings easy.
Just create String objects.
```

**Writing Console Output**

Console output is most easily accomplished with `print()` and `println()`, described earlier, which are used in most of the examples in this book. These methods are defined by the class `PrintStream` (which is the type of object referenced by `System.out`). Even though `System.out` is a byte stream, using it for simple program output is still acceptable. However, a character-based alternative is described in the next section.
Because **PrintStream** is an output stream derived from **OutputStream**, it also implements the low-level method **write()**. Thus, **write()** can be used to write to the console. The simplest form of **write()** defined by **PrintStream** is shown here:

```java
void write(int byteval)
```

This method writes the byte specified by **byteval**. Although **byteval** is declared as an integer, only the low-order eight bits are written. Here is a short example that uses **write()** to output the character "A" followed by a newline to the screen:

```java
// Demonstrate System.out.write[].
class WriteDemo {
    public static void main(String args[]) {
        int b;

        b = 'A';
        System.out.write(b);
        System.out.write('\n');
    }
}
```

You will not often use **write()** to perform console output (although doing so might be useful in some situations) because **print()** and **println()** are substantially easier to use.

**The PrintWriter Class**

Although using **System.out** to write to the console is acceptable, its use is probably best for debugging purposes or for sample programs, such as those found in this book. For real-world programs, the recommended method of writing to the console when using Java is through a **PrintWriter** stream. **PrintWriter** is one of the character-based classes. Using a character-based class for console output makes internationalizing your program easier. **PrintWriter** defines several constructors. The one we will use is shown here:

```java
PrintWriter(OutputStream outputStream, boolean flushingOn)
```

Here, **outputStream** is an object of type **OutputStream**, and **flushingOn** controls whether Java flushes the output stream every time a **println()** method (among others) is called. If **flushingOn** is **true**, flushing automatically takes place. If **false**, flushing is not automatic. 

**PrintWriter** supports the **print()** and **println()** methods. Thus, you can use these methods in the same way as you used them with **System.out**. If an argument is not a simple type, the **PrintWriter** methods call the object's **toString()** method and then display the result.

To write to the console by using a **PrintWriter**, specify **System.out** for the output stream and automatic flushing. For example, this line of code creates a **PrintWriter** that is
The following application illustrates using a PrintWriter to handle console output:

```java
// Demonstrate PrintWriter
import java.io.*;

public class PrintWriterDemo {
    public static void main(String args[]) {
        PrintWriter pw = new PrintWriter(System.out, true);
        pw.println("This is a string");
        int i = -7;
        pw.println(i);
        double d = 4.5e-7;
        pw.println(d);
    }
}
```

The output from this program is shown here:

```
This is a string
-7
4.5E-7
```

Remember, there is nothing wrong with using System.out to write simple text output to the console when you are learning Java or debugging your programs. However, using a PrintWriter makes your real-world applications easier to internationalize. Because no advantage is gained by using a PrintWriter in the sample programs shown in this book, we will continue to use System.out to write to the console.

### Reading and Writing Files

Java provides a number of classes and methods that allow you to read and write files. Before we begin, it is important to state that the topic of file I/O is quite large and file I/O is examined in detail in Part II. The purpose of this section is to introduce the basic techniques that read from and write to a file. Although bytes streams are used, these techniques can be adapted to the character-based streams.

Two of the most often-used stream classes are FileInputStream and FileOutputStream, which create byte streams linked to files. To open a file, you simply create an object of one of these classes, specifying the name of the file as an argument to the constructor. Although both classes support additional constructors, the following are the
forms that we will be using:

FileInputStream(String fileName) throws FileNotFoundException
FileOutputStream(String fileName) throws FileNotFoundException

Here, fileName specifies the name of the file that you want to open. When you create an input stream, if the file does not exist, then FileNotFoundException is thrown. For output streams, if the file cannot be opened or created, then FileNotFoundException is thrown. FileNotFoundException is a subclass of IOException. When an output file is opened, any preexisting file by the same name is destroyed.

NOTE In situations in which a security manager is present, several of the file classes, including FileInputStream and FileOutputStream, will throw a SecurityException if a security violation occurs when attempting to open a file. By default, applications run via java do not use a security manager. For that reason, the I/O examples in this book do not need to watch for a possible SecurityException. However, other types of applications (such as applets) will use the security manager, and file I/O performed by such an application could generate a SecurityException. In that case, you will need to appropriately handle this exception.

When you are done with a file, you must close it. This is done by calling the close() method, which is implemented by both FileInputStream and FileOutputStream. It is shown here:

void close() throws IOException

Closing a file releases the system resources allocated to the file, allowing them to be used by another file. Failure to close a file can result in “memory leaks” because of unused resources remaining allocated.

NOTE Beginning with JDK 7, the close( ) method is specified by the AutoCloseable interface in java.lang. AutoCloseable is inherited by the Closeable interface in java.io. Both interfaces are implemented by the stream classes, including FileInputStream and
Before moving on, it is important to point out that there are two basic approaches that you can use to close a file when you are done with it. The first is the traditional approach, in which `close()` is called explicitly when the file is no longer needed. This is the approach used by all versions of Java prior to JDK 7 and is, therefore, found in all pre-JDK 7 legacy code. The second is to use the `try-with-resources` statement added by JDK 7, which automatically closes a file when it is no longer needed. In this approach, no explicit call to `close()` is executed. Since there is a large amount of pre-JDK 7 legacy code that is still being used and maintained, it is important that you know and understand the traditional approach. Therefore, we will begin with it. The new automated approach is described in the following section.

To read from a file, you can use a version of `read()` that is defined within `FileInputStream`. The one that we will use is shown here:

```java
    int read() throws IOException
```

Each time that it is called, it reads a single byte from the file and returns the byte as an integer value. `read()` returns –1 when the end of the file is encountered. It can throw an `IOException`.

The following program uses `read()` to input and display the contents of a file that contains ASCII text. The name of the file is specified as a command-line argument.
In the program, notice the try/catch blocks that handle the I/O errors that might occur. Each I/O operation is monitored for exceptions, and if an exception occurs, it is handled. Be aware that in simple programs or example code, it is common to see I/O exceptions simply thrown out of main(), as was done in the earlier console I/O examples. Also, in some real-world code, it can be helpful to let an exception propagate to a calling routine to let the
caller know that an I/O operation failed. However, most of the file I/O examples in this book handle all I/O exceptions explicitly, as shown, for the sake of illustration. Although the preceding example closes the file stream after the file is read, there is a variation that is often useful. The variation is to call close( ) within a finally block. In this approach, all of the methods that access the file are contained within a try block, and the finally block is used to close the file. This way, no matter how the try block terminates, the file is closed. Assuming the preceding example, here is how the try block that reads the file can be recoded:

```java
try {
    do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
    } while(i != -1);
    catch(InterruptedException e) {
        System.out.println("Error Reading File");
    }
    finally {
        // Close file on the way out of the try block.
        try {
            fin.close();
        } catch(IOException e) {
            System.out.println("Error Closing File");
        }
    }
}
```

Although not an issue in this case, one advantage to this approach in general is that if the code that accesses a file terminates because of some non-I/O related exception, the file is still closed by the finally block.
Sometimes it’s easier to wrap the portions of a program that open the file and access the file within a single try block (rather than separating the two) and then use a finally block to close the file. For example, here is another way to write the ShowFile program:
In this approach, notice that `fin` is initialized to `null`. Then, in the `finally` block, the file is closed only if `fin` is not `null`. This works because `fin` will be non-null only if the file is successfully opened. Thus, `close()` is not called if an exception occurs while opening the file.

It is possible to make the `try/catch` sequence in the preceding example a bit more compact.
Because `FileNotFoundException` is a subclass of `IOException`, it need not be caught separately. For example, here is the sequence recoded to eliminate catching `FileNotFoundException`. In this case, the standard exception message, which describes the error, is displayed.

```java
try {
    fin = new FileInputStream(args[0]);

    do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
    } while(i != -1);

    } catch(Exception e) {
        System.out.println("I/O Error: " + e);
    } finally {
        // Close file in all cases.
        try {
            if(fin != null) fin.close();
        } catch(Exception e) {
            System.out.println("Error Closing File");
        }
    }
}
```

In this approach, any error, including an error opening the file, is simply handled by the single `catch` statement. Because of its compactness, this approach is used by many of the I/O examples in this book. Be aware, however, that this approach is not appropriate in cases in which you want to deal separately with a failure to open a file, such as might be caused if a user mistypes a filename. In such a situation, you might want to prompt for the correct name, for example, before entering a `try` block that accesses the file.

To write to a file, you can use the `write()` method defined by `FileOutputStream`. Its simplest form is shown here:

```java
void write(int byteval) throws IOException
```

This method writes the byte specified by `byteval` to the file. Although `byteval` is declared as an integer, only the low-order eight bits are written to the file. If an error occurs during writing, an `IOException` is thrown. The next example uses `write()` to copy a file:
In the program, notice that two separate try blocks are used when closing the files. This ensures that both files are closed, even if the call to fin.close() throws an exception.

In general, notice that all potential I/O errors are handled in the preceding two programs by the use of exceptions. This differs from some computer languages that use error codes to report file errors. Not only do exceptions make file handling cleaner, but they also enable
Java to easily differentiate the end-of-file condition from file errors when input is being performed.

**Automatically Closing a File**

In the preceding section, the example programs have made explicit calls to `close()` to close a file once it is no longer needed. As mentioned, this is the way files were closed when using versions of Java prior to JDK 7. Although this approach is still valid and useful, JDK 7 added a new feature that offers another way to manage resources, such as file streams, by automating the closing process. This feature, sometimes referred to as automatic resource management, or ARM for short, is based on an expanded version of the `try` statement. The principal advantage of automatic resource management is that it prevents situations in which a file (or other resource) is inadvertently not released after it is no longer needed. As explained, forgetting to close a file can result in memory leaks, and could lead to other problems.

Automatic resource management is based on an expanded form of the `try` statement. Here is its general form:

```
try (resource-specification) {
  // use the resource
}
```

Here, `resource-specification` is a statement that declares and initializes a resource, such as a file stream. It consists of a variable declaration in which the variable is initialized with a reference to the object being managed. When the `try` block ends, the resource is automatically released. In the case of a file, this means that the file is automatically closed. (Thus, there is no need to call `close()` explicitly.) Of course, this form of `try` can also include `catch` and `finally` clauses. This new form of `try` is called the `try-with-resources` statement.

The `try-with-resources` statement can be used only with those resources that implement the `AutoCloseable` interface defined by `java.lang`. This interface defines the `close()` method. `AutoCloseable` is inherited by the `Closeable` interface in `java.io`. Both interfaces are implemented by the stream classes. Thus, `try-with-resources` can be used when working with streams, including file streams.

As a first example of automatically closing a file, here is a reworked version of the `ShowFile` program that uses it:
In the program, pay special attention to how the file is opened within the `try` statement:

```java
try(FileInputStream fin = new FileInputStream(args[0]));
```

Notice how the resource-specification portion of the `try` declares a `FileInputStream` called `fin`, which is then assigned a reference to the file opened by its constructor. Thus, in this version of the program, the variable `fin` is local to the `try` block, being created when the `try` is entered. When the `try` is left, the stream associated with `fin` is automatically closed by an implicit call to `close()`. You don’t need to call `close()` explicitly, which means that you can’t forget to close the file. This is a key advantage of using `try-with-resources.

It is important to understand that the resource declared in the `try` statement is implicitly `final`. This means that you can’t assign to the resource after it has been created. Also, the scope of the resource is limited to the `try-with-resources` statement.

You can manage more than one resource within a single `try` statement. To do so, simply separate each resource specification with a semicolon. The following program shows an example. It reworks the `CopyFile` program shown earlier so that it uses a single `try-with-
resources statement to manage both **fin** and **fout**.

```java
/* A version of CopyFile that uses try-with-resources. It demonstrates two resources (in this case files) being managed by a single try statement. */
import java.io.*;

class CopyFile {
    public static void main(String args[]) throws IOException {
        int i;

        // First, confirm that both files have been specified.
        if(args.length != 2) {
            System.out.println("Usage: CopyFile from to");
            return;
        }

        // Open and manage two files via the try statement.
        try (FileInputStream fin = new FileInputStream(args[0]);
             FileOutputStream fout = new FileOutputStream(args[1])) {
            do {
                i = fin.read();
                if(i != -1) fout.write(i);
            } while(i != -1);
            catch( IOException e ) {
                System.out.println("I/O Error: " + e);
            }
        }
    }
}
```

In this program, notice how the input and output files are opened within the **try** block:

```java
try (FileInputStream fin = new FileInputStream(args[0]);
     FileOutputStream fout = new FileOutputStream(args[1])) {
    // ...
}
```

After this **try** block ends, both **fin** and **fout** will have been closed. If you compare this version of the program to the previous version, you will see that it is much shorter. The ability to streamline source code is a side-benefit of automatic resource management. There is one other aspect to **try**-with-resources that needs to be mentioned. In general, when a **try** block executes, it is possible that an exception inside the **try** block will lead to another exception that occurs when the resource is closed in a **finally** clause. In the case of
a “normal” try statement, the original exception is lost, being preempted by the second exception. However, when using try-with-resources, the second exception is suppressed. It is not, however, lost. Instead, it is added to the list of suppressed exceptions associated with the first exception. The list of suppressed exceptions can be obtained by using the `getSuppressed()` method defined by Throwable. Because of the benefits that the try-with-resources statement offers, it will be used by many, but not all, of the example programs in this edition of this book. Some of the examples will still use the traditional approach to closing a resource. There are several reasons for this. First, there is legacy code that still relies on the traditional approach. It is important that all Java programmers be fully versed in, and comfortable with, the traditional approach when maintaining this older code. Second, because not all project development will immediately switch to a new version of the JDK, it is likely that some programmers will continue to work in a pre-JDK 7 environment for a period of time. In such situations, the expanded form of try is not available. Finally, there may be cases in which explicitly closing a resource is more appropriate than the automated approach. For these reasons, some of the examples in this book will continue to use the traditional approach, explicitly calling close(). In addition to illustrating the traditional technique, these examples can also be compiled and run by all readers in all environments.

```
REMEMBER  A few examples in this book use the traditional approach to closing files as a means of illustrating this technique, which is widely used in legacy code. However, for new code, you will usually want to use the new automated approach supported by the try-with-resources statement just described.
```

### Applet Fundamentals

All of the preceding examples in this book have been Java console-based applications. However, these types of applications constitute only one class of Java programs. Another type of program is the applet. As mentioned in Chapter 1, applets are small applications that are accessed on an Internet server, transported over the Internet, automatically installed, and run as part of a web document. After an applet arrives on the client, it has limited access to resources so that it can produce a graphical user interface and run various computations without introducing the risk of viruses or breaching data integrity. Many of the issues connected with the creation and use of applets are found in Part II, when the applet package is examined, and also when Swing is described in Part III. However, the fundamentals connected to the creation of an applet are presented here, because applets are
not structured in the same way as the programs that have been used thus far. As you will see, applets differ from console-based applications in several key areas. Let's begin with the simple applet shown here:

```java
import java.awt.*;
import java.applet.*;

public class SimpleApplet extends Applet {
    public void paint(Graphics g) {
        g.drawString("A Simple Applet", 20, 20);
    }
}
```

This applet begins with two `import` statements. The first imports the Abstract Window Toolkit (AWT) classes. Applets interact with the user through a GUI framework, not through the console-based I/O classes. One of these frameworks is the AWT, and that is the framework used here to introduce applet programming. The AWT contains very basic support for a window-based, graphical user interface. As you might expect, the AWT is quite large, and a detailed discussion of it is found in Part II of this book. Fortunately, this simple applet makes very limited use of the AWT. (Another commonly used GUI for applets is Swing, but this approach is described later in this book.) The second `import` statement imports the `applet` package, which contains the class `Applet`. Every AWT-based applet that you create must be a subclass (either directly or indirectly) of `Applet`.

The next line in the program declares the class `SimpleApplet`. This class must be declared as `public`, because it will be accessed by code that is outside the program.

Inside `SimpleApplet`, `paint( )` is declared. This method is defined by the AWT and must be overridden by the applet. `paint( )` is called each time that the applet must redisplay its output. This situation can occur for several reasons. For example, the window in which the applet is running can be overwritten by another window and then uncovered. Or, the applet window can be minimized and then restored. `paint( )` is also called when the applet begins execution. Whatever the cause, whenever the applet must redraw its output, `paint( )` is called. The `paint( )` method has one parameter of type `Graphics`. This parameter contains the graphics context, which describes the graphics environment in which the applet is running. This context is used whenever output to the applet is required.

Inside `paint( )` is a call to `drawString( )`, which is a member of the `Graphics` class. This method outputs a string beginning at the specified X,Y location. It has the following general form:

```java
void drawString(String message, int x, int y)
```

Here, `message` is the string to be output beginning at `x,y`. In a Java window, the upper-left corner is location 0,0. The call to `drawString( )` in the applet causes
Notice that the applet does not have a `main()` method. Unlike Java programs, applets do not begin execution at `main()`. In fact, most applets don’t even have a `main()` method. Instead, an applet begins execution when the name of its class is passed to an applet viewer or to a network browser.

After you enter the source code for `SimpleApplet`, compile in the same way that you have been compiling programs. However, running `SimpleApplet` involves a different process. In fact, there are two ways in which you can run an applet:

- Executing the applet within a Java-compatible web browser.
- Using an applet viewer, such as the standard tool, `appletviewer`. An applet viewer executes your applet in a window. This is generally the fastest and easiest way to test your applet.

Each of these methods is described next.

One way to execute an applet in a web browser is to write a short HTML text file that contains a tag that loads the applet. At the time of this writing, Oracle recommends using the APPLET tag for this purpose. (The OBJECT tag can also be used. See Chapter 23 for further information regarding applet deployment strategies.) Using APPLET, here is the HTML file that executes `SimpleApplet`:

```html
<applet code="SimpleApplet" width=200 height=60>
</applet>
```

The `width` and `height` statements specify the dimensions of the display area used by the applet. (The APPLET tag contains several other options that are examined more closely in Part II.) After you create this file, you can use it to execute the applet.

---

**NOTE** Beginning with the release of Java 7, update 21, Java applets must be signed to prevent security warnings when run in a browser. In fact, in some cases, the applet may be prevented from running. Applets stored in the local file system, such as you would create when compiling the examples in this book, are especially sensitive to this change. You may need to adjust the security settings in the Java Control Panel to run a local applet in a browser. At the time of this writing, Oracle recommends against the use of local applets, recommending instead that applets be executed through a web server. Furthermore, it is expected that unsigned local applets will be blocked from execution in the future. In general, for applets that will be distributed via the Internet, such as commercial
applications, signing is a virtual necessity. The concepts and techniques required to sign applets (and other types of Java programs) are beyond the scope of this book. However, extensive information is found on Oracle’s website. Finally, as mentioned, the easiest way to try the applet examples is to use appletviewer.

To execute SimpleApplet with an applet viewer, you may also execute the HTML file shown earlier. For example, if the preceding HTML file is called RunApp.html, then the following command line will run SimpleApplet:

C:\>appletviewer RunApp.html

However, a more convenient method exists that you can use to speed up testing. Simply include a comment at the head of your Java source code file that contains the APPLET tag. By doing so, your code is documented with a prototype of the necessary HTML statements, and you can test your compiled applet merely by starting the applet viewer with your Java source code file. If you use this method, the SimpleApplet source file looks like this:

```java
import java.awt.*;
import java.applet.*;
/
<applet code="SimpleApplet" width=200 height=60>
</applet>
*/

public class SimpleApplet extends Applet {
    public void paint(Graphics g) {
        g.drawString("A Simple Applet", 20, 20);
    }
}
```

With this approach, you can quickly iterate through applet development by using these three steps:

1. Edit a Java source file.
2. Compile your program.
3. Execute the applet viewer, specifying the name of your applet’s source file. The applet viewer will encounter the APPLET tag within the comment and execute your applet.

The window produced by SimpleApplet, as displayed by the applet viewer, is
shown in the following illustration. Of course, the precise appearance of the applet viewer frame may differ based on your environment. For this reason, the screen captures in this book reflect a number of different environments.

While the subject of applets is more fully discussed later in this book, here are the key points that you should remember now:

- Applets do not need a `main()` method.
- Applets must be run under an applet viewer or a Java-compatible browser.
- User I/O is not accomplished with Java's stream I/O classes. Instead, applets use the interface provided by a GUI framework.

**The transient and volatile Modifiers**

Java defines two interesting type modifiers: transient and volatile. These modifiers are used to handle somewhat specialized situations.

When an instance variable is declared as transient, then its value need not persist when an object is stored. For example:

```java
class T {
    transient int a; // will not persist
    int b; // will persist
}
```

Here, if an object of type T is written to a persistent storage area, the contents of a would not be saved, but the contents of b would.

The volatile modifier tells the compiler that the variable modified by volatile can be changed unexpectedly by other parts of your program. One of these situations involves multithreaded programs. In a multithreaded program, sometimes two or more threads share the same variable. For efficiency considerations, each thread can keep its own, private copy of such a shared variable. The real (or master) copy of the variable is updated at
various times, such as when a **synchronized** method is entered. While this approach works fine, it may be inefficient at times. In some cases, all that really matters is that the master copy of a variable always reflects its current state. To ensure this, simply specify the variable as **volatile**, which tells the compiler that it must always use the master copy of a **volatile** variable (or, at least, always keep any private copies up-to-date with the master copy, and vice versa). Also, accesses to the master variable must be executed in the precise order in which they are executed on any private copy.

### Using instanceof

Sometimes, knowing the type of an object during run time is useful. For example, you might have one thread of execution that generates various types of objects, and another thread that processes these objects. In this situation, it might be useful for the processing thread to know the type of each object when it receives it. Another situation in which knowledge of an object’s type at run time is important involves casting. In Java, an invalid cast causes a run-time error. Many invalid casts can be caught at compile time. However, casts involving class hierarchies can produce invalid casts that can be detected only at run time. For example, a superclass called A can produce two subclasses, called B and C. Thus, casting a B object into type A or casting a C object into type A is legal, but casting a B object into type C (or vice versa) isn’t legal. Because an object of type A can refer to objects of either B or C, how can you know, at run time, what type of object is actually being referred to before attempting the cast to type C? It could be an object of type A, B, or C. If it is an object of type B, a run-time exception will be thrown. Java provides the run-time operator **instanceof** to answer this question.

The **instanceof** operator has this general form:

```
objref instanceof type
```

Here, `objref` is a reference to an instance of a class, and `type` is a class type. If `objref` is of the specified type or can be cast into the specified type, then the **instanceof** operator evaluates to **true**. Otherwise, its result is **false**. Thus, **instanceof** is the means by which your program can obtain run-time type information about an object.

The following program demonstrates **instanceof**: 
// Demonstrate instanceof operator.
class A {
    int i, j;
}

class B {
    int i, j;
}

class C extends A {
    int k;
}

class D extends A {
    int k;
}

class InstanceOf {
    public static void main(String args[]) {
        A a = new A();
        B b = new B();
        C c = new C();
        D d = new D();
        if(a instanceof A)
            System.out.println("a is instance of A");
        if(b instanceof B)
            System.out.println("b is instance of B");
        if(c instanceof C)
            System.out.println("c is instance of C");
        if(c instanceof A)
            System.out.println("c can be cast to A");
        if(a instanceof C)
            System.out.println("a can be cast to C");
        System.out.println();
        // compare types of derived types
        A ob;
        ob = d; // A reference to d
        System.out.println("ob now refers to d");
        if(ob instanceof D)
            System.out.println("ob is instance of D");
        System.out.println();
        ob = c; // A reference to c
        System.out.println("ob now refers to c");
        if(ob instanceof D)
            System.out.println("ob can be cast to D");
        else
            System.out.println("ob cannot be cast to D");
        if(ob instanceof A)
            System.out.println("ob can be cast to A");
        System.out.println();
The output from this program is shown here:

```java
// all objects can be cast to Object
if (a instanceof Object)
    System.out.println("a may be cast to Object");
if (b instanceof Object)
    System.out.println("b may be cast to Object");
if (c instanceof Object)
    System.out.println("c may be cast to Object");
if (d instanceof Object)
    System.out.println("d may be cast to Object");
```

The `instanceof` operator isn't needed by most programs, because, generally, you know the type of object with which you are working. However, it can be very useful when you’re writing generalized routines that operate on objects of a complex class hierarchy.

**strictfp**

With the creation of Java 2, the floating-point computation model was relaxed slightly. Specifically, the new model does not require the truncation of certain intermediate values that occur during a computation. This prevents overflow or underflow in some cases. By modifying a class, a method, or interface with `strictfp`, you ensure that floating-point calculations (and thus all truncations) take place precisely as they did in earlier versions of Java. When a class is modified by `strictfp`, all the methods in the class are also modified by `strictfp` automatically.

For example, the following fragment tells Java to use the original floating-point model for
calculations in all methods defined within **MyClass**:

```
strictfp class MyClass { //...
```

Frankly, most programmers never need to use `strictfp`, because it affects only a very small class of problems.

**Native Methods**

Although it is rare, occasionally you may want to call a subroutine that is written in a language other than Java. Typically, such a subroutine exists as executable code for the CPU and environment in which you are working—that is, native code. For example, you may want to call a native code subroutine to achieve faster execution time. Or, you may want to use a specialized, third-party library, such as a statistical package. However, because Java programs are compiled to bytecode, which is then interpreted (or compiled on-the-fly) by the Java run-time system, it would seem impossible to call a native code subroutine from within your Java program. Fortunately, this conclusion is false. Java provides the `native` keyword, which is used to declare native code methods. Once declared, these methods can be called from inside your Java program just as you call any other Java method.

To declare a native method, precede the method with the `native` modifier, but do not define any body for the method. For example:

```
public native int method();
```

After you declare a native method, you must write the native method and follow a rather complex series of steps to link it with your Java code.

Most native methods are written in C. The mechanism used to integrate C code with a Java program is called the **Java Native Interface (JNI)**. A detailed description of the JNI is beyond the scope of this book, but the approach described here provides sufficient information for simple applications.

---

**NOTE** The precise steps that you need to follow will vary between different Java environments. They also depend on the language that you are using to implement the native method. The following discussion assumes a Windows environment. The language used to implement the native method is C. Also, the approach shown here uses a dynamically linked library, but beginning with JDK 8, it is possible to create a statically linked library.
The easiest way to understand the process is to work through an example. To begin, enter the following short program, which uses a **native** method called **test()**:

```java
// A simple example that uses a native method.
public class NativeDemo {
    int i;
    public static void main(String args[]) {
        NativeDemo ob = new NativeDemo();

        ob.i = 10;
        System.out.println("This is ob.i before the native method:" + ob.i);
        ob.test(); // call a native method
        System.out.println("This is ob.i after the native method:" + ob.i);
    }

    // declare native method
    public native void test();

    // load DLL that contains static method
    static {
        System.loadLibrary("NativeDemo");
    }
}
```

Notice that the **test()** method is declared as **native** and has no body. This is the method that we will implement in C shortly. Also notice the **static** block. As explained earlier in this book, a **static** block is executed only once, when your program begins execution (or, more precisely, when its class is first loaded). In this case, it is used to load the dynamic link library that contains the native implementation of **test()**. (You will see how to create this library soon.)

The library is loaded by the **loadLibrary()** method, which is part of the **System** class. This is its general form:

```java
static void loadLibrary(String filename)
```

Here, **filename** is a string that specifies the name of the file that holds the library.

For the Windows environment, this file is assumed to have the .DLL extension.

After you enter the program, compile it to produce **NativeDemo.class**. Next, you must use **javah.exe** to produce one file: **NativeDemo.h**. (**javah.exe** is included in the JDK.) You will include **NativeDemo.h** in your implementation of **test()**. To produce **NativeDemo.h**, use the following command:

```bash
javah -jni NativeDemo
```

This command produces a header file called **NativeDemo.h**. This file must be included in the C file that implements **test()**. The output produced by this
Pay special attention to the following line, which defines the prototype for the `test( )`
function that you will create:

```
JNIENTRPORT void JNICALL Java_NativeDemo_test
        (JNIEnv *, jobject);
```

Notice that the name of the function is `Java_NativeDemo_test()`. You must use this as
the name of the native function that you implement. That is, instead of creating a C function
called `test( )`, you will create one called `Java_NativeDemo_test()`. The `NativeDemo`
component of the prefix is added because it identifies the `test( )` method as being part of
the `NativeDemo` class. Remember, another class may define its own native `test( )` method
that is completely different from the one declared by `NativeDemo`. Including the class
name in the prefix provides a way to differentiate between differing versions. As a general
rule, native functions will be given a name whose prefix includes the name of the class in
which they are declared.

After producing the necessary header file, you can write your implementation of `test( )` and
store it in a file named `NativeDemo.c`:  

```c
/* DO NOT EDIT THIS FILE - it is machine generated */
#include <jni.h>
/* Header for class NativeDemo */

#ifdef _Included_NativeDemo
#define _Included_NativeDemo
#ifdef _cplusplus
extern "C" {
#endif
/*
 * Class: NativeDemo
 * Method: test
 * Signature: ()V
 */
JNIEXPORT void JNICALL Java_NativeDemo_test
        (JNIEnv *, jobject);

#ifdef _cplusplus
}
#endif
#endif
```
Notice that this file includes `jni.h`, which contains interfacing information. This file is provided by your Java compiler. The header file `NativeDemo.h` was created by `javah` earlier.

In this function, the `GetObjectClass()` method is used to obtain a C structure that has information about the class `NativeDemo`. The `GetFieldID()` method returns a C structure with information about the field named "i" for the class. `GetIntField()` retrieves the original value of that field. `SetIntField()` stores an updated value in that field. (See the file `jni.h` for additional methods that handle other types of data.)

After creating `NativeDemo.c`, you must compile it and create a DLL. To do this by using the Microsoft C/C++ compiler, use the following command line. (You might need to specify the path to `jni.h` and its subordinate file `jni_md.h`.)

```plaintext
Cl /LD NativeDemo.c
```

This produces a file called `NativeDemo.dll`. Once this is done, you can execute the Java program, which will produce the following output:
**Problems with Native Methods**

Native methods seem to offer great promise, because they enable you to gain access to an existing base of library routines, and they offer the possibility of faster run-time execution. But native methods also introduce two significant problems:

- **Potential security risk**  
  Because a native method executes actual machine code, it can gain access to any part of the host system. That is, native code is not confined to the Java execution environment. This could allow a virus infection, for example. For this reason, unsigned applets cannot use native methods. Also, the loading of DLLs can be restricted, and their loading is subject to the approval of the security manager.

- **Loss of portability**  
  Because the native code is contained in a DLL, it must be present on the machine that is executing the Java program. Further, because each native method is CPU- and operating system-dependent, each DLL is inherently nonportable. Thus, a Java application that uses native methods will be able to run only on a machine for which a compatible DLL has been installed.

The use of native methods should be restricted, because they render your Java programs nonportable and pose significant security risks.

**Using assert**

Another relatively new addition to Java is the keyword **assert**. It is used during program development to create an **assertion**, which is a condition that should be true during the execution of the program. For example, you might have a method that should always return a positive integer value. You might test this by asserting that the return value is greater than zero using an **assert** statement. At run time, if the condition is true, no other action takes place. However, if the condition is false, then an **AssertionError** is thrown. Assertions are often used during testing to verify that some expected condition is actually met. They are not usually used for released code.

The **assert** keyword has two forms. The first is shown here:

```
assert condition;
```

Here, **condition** is an expression that must evaluate to a Boolean result. If the result is true, then the assertion is true and no other action takes place. If the
condition is false, then the assertion fails and a default `AssertionError` object is thrown.

The second form of `assert` is shown here:

```java
assert condition: expr;
```

In this version, `expr` is a value that is passed to the `AssertionError` constructor. This value is converted to its string format and displayed if an assertion fails. Typically, you will specify a string for `expr`, but any non-`void` expression is allowed as long as it defines a reasonable string conversion.

Here is an example that uses `assert`. It verifies that the return value of `getnum()` is positive.

```java
// Demonstrate assert.
class AssertDemo {
    static int val = 3;

    // Return an integer.
    static int getnum() {
        return val--;
    }

    public static void main(String args[]) {
        int n;
        for(int i=0; i < 10; i++) {
            n = getnum();

            assert n > 0; // will fail when n is 0
            System.out.println("n is " + n);
        }
    }
}
```

To enable assertion checking at run time, you must specify the `-ea` option. For example, to enable assertions for `AssertDemo`, execute it using this line:

```
java -ea AssertDemo
```

After compiling and running as just described, the program creates the following output:
In `main()`, repeated calls are made to the method `getnum()`, which returns an integer value. The return value of `getnum()` is assigned to `n` and then tested using this `assert` statement:

```
assert n > 0;  // will fail when n is 0
```

This statement will fail when `n` equals 0, which it will after the fourth call. When this happens, an exception is thrown.

As explained, you can specify the message displayed when an assertion fails. For example, if you substitute

```
assert n > 0 : "n is negative!";
```

for the assertion in the preceding program, then the following output will be generated:

```
Exception in thread "main" java.lang.AssertionError: n is negative!
at AssertDemo.main(AssertDemo.java:17)
```

One important point to understand about assertions is that you must not rely on them to perform any action actually required by the program. The reason is that normally, released code will be run with assertions disabled. For example, consider this variation of the preceding program:
In this version of the program, the call to `getnum()` is moved inside the `assert` statement. Although this works fine if assertions are enabled, it will cause a malfunction when assertions are disabled, because the call to `getnum()` will never be executed! In fact, `n` must now be initialized, because the compiler will recognize that it might not be assigned a value by the `assert` statement.

Assertions are a good addition to Java because they streamline the type of error checking that is common during development. For example, prior to `assert`, if you wanted to verify that `n` was positive in the preceding program, you had to use a sequence of code similar to this:

```java
if(n < 0) {
    System.out.println("n is negative!");
    return; // or throw an exception
}
```

With `assert`, you need only one line of code. Furthermore, you don’t have to remove the `assert` statements from your released code.

**Assertion Enabling and Disabling Options**

When executing code, you can disable all assertions by using the `-da` option. You can enable or disable a specific package (and all of its subpackages) by specifying its name followed by
three periods after the -ea or -da option. For example, to enable assertions in a package called MyPack, use

    -ea:MyPack...

To disable assertions in MyPack, use

    -da:MyPack...

You can also specify a class with the -ea or -da option. For example, this enables AssertDemo individually:

    -ea:AssertDemo

**Static Import**
Java includes a feature called *static import* that expands the capabilities of the import keyword. By following import with the keyword static, an import statement can be used to import the static members of a class or interface. When using static import, it is possible to refer to static members directly by their names, without having to qualify them with the name of their class. This simplifies and shortens the syntax required to use a static member.

To understand the usefulness of static import, let’s begin with an example that does not use it. The following program computes the hypotenuse of a right triangle. It uses two static methods from Java’s built-in math class Math, which is part of java.lang. The first is Math.pow( ), which returns a value raised to a specified power. The second is Math.sqrt( ), which returns the square root of its argument.
Because `pow()` and `sqrt()` are static methods, they must be called through the use of their class’ name, `Math`. This results in a somewhat unwieldy hypotenuse calculation:

```java
hypot = Math.sqrt(Math.pow(side1, 2) + Math.pow(side2, 2));
```

As this simple example illustrates, having to specify the class name each time `pow()` or `sqrt()` (or any of Java’s other math methods, such as `sin()`, `cos()`, and `tan()`) is used can grow tedious.

You can eliminate the tedium of specifying the class name through the use of static import, as shown in the following version of the preceding program:
// Use static import to bring sqrt() and pow() into view.
import static java.lang.Math.sqrt;
import static java.lang.Math.pow;

// Compute the hypotenuse of a right triangle.
class Hypot {
   public static void main(String args[]) {
      double side1, side2;
      double hypot;

      side1 = 3.0;
      side2 = 4.0;

      // Here, sqrt() and pow() can be called by themselves,
      // without their class name.
      hypot = sqrt(pow(side1, 2) + pow(side2, 2));

      System.out.println("Given sides of lengths "+
                     side1 + " and " + side2 +
                     " the hypotenuse is " +
                     hypot);
   }
}

In this version, the names sqrt and pow are brought into view by these static import statements:

   import static java.lang.Math.sqrt;
   import static java.lang.Math.pow;

After these statements, it is no longer necessary to qualify sqrt() or pow() with their class name. Therefore, the hypotenuse calculation can more conveniently be specified, as shown here:

   hypot = sqrt(pow(side1, 2) + pow(side2, 2));

As you can see, this form is considerably more readable.
There are two general forms of the import static statement. The first, which is used by the preceding example, brings into view a single name. Its general form is shown here:

   import static pkg.type-name.static-member-name;

Here, type-name is the name of a class or interface that contains the desired static member. Its full package name is specified by pkg. The name of the member is specified by static-member-name.
The second form of static import imports all static members of a given class or interface. Its
general form is shown here:

```java
import static pkg.type-name.*;
```

If you will be using many static methods or fields defined by a class, then this form lets you bring them into view without having to specify each individually. Therefore, the preceding program could have used this single `import` statement to bring both `pow()` and `sqrt()` (and all other static members of `Math`) into view:

```java
import static java.lang.Math.*;
```

Of course, static import is not limited just to the `Math` class or just to methods. For example, this brings the static field `System.out` into view:

```java
import static java.lang.System.out;
```

After this statement, you can output to the console without having to qualify `out` with `System`, as shown here:

```java
out.println("After importing System.out, you can use out directly.");
```

Whether importing `System.out` as just shown is a good idea is subject to debate. Although it does shorten the statement, it is no longer instantly clear to anyone reading the program that the `out` being referred to is `System.out`.

One other point: in addition to importing the static members of classes and interfaces defined by the Java API, you can also use static import to import the static members of classes and interfaces that you create.

As convenient as static import can be, it is important not to abuse it. Remember, the reason that Java organizes its libraries into packages is to avoid namespace collisions. When you import static members, you are bringing those members into the global namespace. Thus, you are increasing the potential for namespace conflicts and for the inadvertent hiding of other names. If you are using a static member once or twice in the program, it’s best not to import it. Also, some static names, such as `System.out`, are so recognizable that you might not want to import them. Static import is designed for those situations in which you are using a static member repeatedly, such as when performing a series of mathematical computations. In essence, you should use, but not abuse, this feature.

**Invoking Overloaded Constructors Through this( )**

When working with overloaded constructors, it is sometimes useful for one constructor to invoke another. In Java, this is accomplished by using another form of the `this` keyword. The general form is shown here:

```java
this(arg-list)
```
When `this()` is executed, the overloaded constructor that matches the parameter list specified by `arg-list` is executed first. Then, if there are any statements inside the original constructor, they are executed. The call to `this()` must be the first statement within the constructor.

To understand how `this()` can be used, let's work through a short example. First, consider the following class that does not use `this()`:

```java
class MyClass {
    int a;
    int b;

    // initialize a and b individually
    MyClass(int i, int j) {
        a = i;
        b = j;
    }

    // initialize a and b to the same value
    MyClass(int i) {
        a = i;
        b = i;
    }

    // give a and b default values of 0
    MyClass() {
        a = 0;
        b = 0;
    }
}
```

This class contains three constructors, each of which initializes the values of `a` and `b`. The first is passed individual values for `a` and `b`. The second is passed just one value, which is assigned to both `a` and `b`. The third gives `a` and `b` default values of zero.

By using `this()`, it is possible to rewrite `MyClass` as shown here:
In this version of MyClass, the only constructor that actually assigns values to the a and b fields is MyClass(int, int). The other two constructors simply invoke that constructor (either directly or indirectly) through this(). For example, consider what happens when this statement executes:

```java
class MyClass {
    int a;
    int b;

    // initialize a and b individually
    MyClass(int i, int j) {
        a = i;
        b = j;
    }

    // initialize a and b to the same value
    MyClass(int i) {
        this(i, i); // invokes MyClass(i, i)
    }

    // give a and b default values of 0
    MyClass() {
        this(0); // invokes MyClass(0)
    }
}
```

In this case, MyClass mc = new MyClass(8); causes this(8, 8) to be executed, which translates into a call to MyClass(8, 8), because this is the version of the MyClass constructor whose parameter list matches the arguments passed via this(). Now, consider the following statement, which uses the default constructor:

```java
MyClass mc2 = new MyClass();
```

In this case, this(0) is called. This causes MyClass(0) to be invoked because it is the constructor with the matching parameter list. Of course, MyClass(0) then calls MyClass(0,0) as just described.

One reason why invoking overloaded constructors through this() can be useful is that it can prevent the unnecessary duplication of code. In many cases, reducing duplicate code decreases the time it takes to load your class because often the object code is smaller. This is especially important for programs delivered via the Internet in which load times are an issue. Using this() can also help structure your code when constructors contain a large
amount of duplicate code. However, you need to be careful. Constructors that call \texttt{this( )} will execute a bit slower than those that contain all of their initialization code inline. This is because the call and return mechanism used when the second constructor is invoked adds overhead. If your class will be used to create only a handful of objects, or if the constructors in the class that call \texttt{this( )} will be seldom used, then this decrease in run-time performance is probably insignificant. However, if your class will be used to create a large number of objects (on the order of thousands) during program execution, then the negative impact of the increased overhead could be meaningful. Because object creation affects all users of your class, there will be cases in which you must carefully weigh the benefits of faster load time against the increased time it takes to create an object.

Here is another consideration: for very short constructors, such as those used by \texttt{MyClass}, there is often little difference in the size of the object code whether \texttt{this( )} is used or not. (Actually, there are cases in which no reduction in the size of the object code is achieved.) This is because the bytecode that sets up and returns from the call to \texttt{this( )} adds instructions to the object file. Therefore, in these types of situations, even though duplicate code is eliminated, using \texttt{this( )} will not obtain significant savings in terms of load time. However, the added cost in terms of overhead to each object’s construction will still be incurred. Therefore, \texttt{this( )} is most applicable to constructors that contain large amounts of initialization code, not those that simply set the value of a handful of fields.

There are two restrictions you need to keep in mind when using \texttt{this( )}. First, you cannot use any instance variable of the constructor’s class in a call to \texttt{this( )}. Second, you cannot use \texttt{super( )} and \texttt{this( )} in the same constructor because each must be the first statement in the constructor.

\textbf{Compact API Profiles}

JDK 8 adds a feature that organizes subsets of the API library into what are called \textit{compact profiles}. These are called \texttt{compact1}, \texttt{compact2}, and \texttt{compact3}. Each profile contains a subset of the library. Furthermore, \texttt{compact2} includes all of \texttt{compact1}, and \texttt{compact3} includes all of \texttt{compact2}. Thus, each profile builds on the previous one. The advantage of the compact profiles is that an application that does not require the full library need not download it. Using a compact profile reduces the size of the library, thus enabling some types of Java applications to run on devices that could not otherwise support the entire Java API. The use of a compact profile can also reduce the time it takes to load a program. The Java API documentation indicates to which (if any) profile each API element belongs. When compiling a program, you can determine if a program uses only APIs defined by a compact profile by using the \texttt{-profile} option. Here is its general form:

\texttt{javac -profile profileName programName}

Here, \texttt{profileName} specifies the profile, which must be \texttt{compact1}, \texttt{compact2}, or \texttt{compact3}. For example:
javac -profile compact2 Test.java

Here, the **compact2** profile is specified. If **Test.java** contains an API that is not part of **compact2**, then a compilation error will result.
Since the original 1.0 release in 1995, many new features have been added to Java. One that has had a profound impact is generics. Introduced by JDK 5, generics changed Java in two important ways. First, it added a new syntactical element to the language. Second, it caused changes to many of the classes and methods in the core API. Today, generics are an integral part of Java programming, and a solid understanding of this important feature is required. It is examined here in detail.

Through the use of generics, it is possible to create classes, interfaces, and methods that will work in a type-safe manner with various kinds of data. Many algorithms are logically the same no matter what type of data they are being applied to. For example, the mechanism that supports a stack is the same whether that stack is storing items of type `Integer`, `String`, `Object`, or `Thread`. With generics, you can define an algorithm once, independently of any specific type of data, and then apply that algorithm to a wide variety of data types without any additional effort. The expressive power generics added to the language fundamentally changed the way that Java code is written.

Perhaps the one feature of Java that has been most significantly affected by generics is the Collections Framework. The Collections Framework is part of the Java API and is described in detail in Chapter 18, but a brief mention is useful now. A `collection` is a group of objects. The Collections Framework defines several classes, such as lists and maps, that manage collections. The collection classes have always been able to work with any type of object. The benefit that generics added is that the collection classes can now be used with complete type safety. Thus, in addition to being a powerful language element on its own, generics also enabled an existing feature to be substantially improved. This is another reason why generics were such an important addition to Java.

This chapter describes the syntax, theory, and use of generics. It also shows how generics provide type safety for some previously difficult cases. Once you have completed this chapter, you will want to examine Chapter 18, which covers the Collections Framework. There you will find many examples of generics at work.

**What Are Generics?**
At its core, the term `generics` means parameterized types. Parameterized types are
important because they enable you to create classes, interfaces, and methods in which the
type of data upon which they operate is specified as a parameter. Using generics, it is
possible to create a single class, for example, that automatically works with different types
of data. A class, interface, or method that operates on a parameterized type is called
generic, as in generic class or generic method.
It is important to understand that Java has always given you the ability to create generalized
classes, interfaces, and methods by operating through references of type Object. Because
Object is the superclass of all other classes, an Object reference can refer to any type
object. Thus, in pre-generics code, generalized classes, interfaces, and methods used Object
references to operate on various types of objects. The problem was that they could not do so
with type safety.
Generics added the type safety that was lacking. They also streamlined the process, because
it is no longer necessary to explicitly employ casts to translate between Object and the type
of data that is actually being operated upon. With generics, all casts are automatic and
implicit. Thus, generics expanded your ability to reuse code and let you do so safely and
easily.

NOTE A Warning to C++ Programmers: Although generics are similar to
templates in C++, they are not the same. There are some fundamental
differences between the two approaches to generic types. If you have a
background in C++, it is important not to jump to conclusions about how
generics work in Java.

A Simple Generics Example
Let’s begin with a simple example of a generic class. The following program defines two
classes. The first is the generic class Gen, and the second is GenDemo, which uses Gen.
// A simple generic class.
// Here, T is a type parameter that
// will be replaced by a real type
// when an object of type Gen is created.
class Gen<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getOb() {
        return ob;
    }

    // Show type of T.
    void showType() {
        System.out.println("Type of T is " + ob.getClass().getName());
    }
}

// Demonstrate the generic class.
class GenDemo {
    public static void main(String args[]) {
        // Create a Gen reference for integers.
        Gen<Integer> iob;

        // Create a Gen<Integer> object and assign its
        // reference to iob. Notice the use of autoboxing
        // to encapsulate the value 99 within an Integer object.
        iob = new Gen<Integer>(99);

        // Show the type of data used by iob.
        iob.showType();

        // Get the value in iob. Notice that
        // no cast is needed.
        int v = iob.getOb();
        System.out.println("value: " + v);
        System.out.println();

        // Create a Gen object for Strings.
        Gen<String> strOb = new Gen<String> ("Generics Test");

        // Show the type of data used by strOb.
        strOb.showType();

        // Get the value of strOb. Again, notice
        // that no cast is needed.
        String str = strOb.getOb();
        System.out.println("value: " + str);
    }
}
Let's examine this program carefully. First, notice how `Gen` is declared by the following line:

```java
class Gen<T> {}
```

Here, `T` is the name of a **type parameter**. This name is used as a placeholder for the actual type that will be passed to `Gen` when an object is created. Thus, `T` is used within `Gen` whenever the type parameter is needed. Notice that `T` is contained within `< >`. This syntax can be generalized. Whenever a type parameter is being declared, it is specified within angle brackets. Because `Gen` uses a type parameter, `Gen` is a generic class, which is also called a **parameterized type**.

Next, `T` is used to declare an object called `ob`, as shown here:

```java
T ob; // declare an object of type T
```

As explained, `T` is a placeholder for the actual type that will be specified when a `Gen` object is created. Thus, `ob` will be an object of the type passed to `T`. For example, if type `String` is passed to `T`, then in that instance, `ob` will be of type `String`.

Now consider `Gen`'s constructor:

```java
Gen(T o) {
    ob = o;
}
```

Notice that its parameter, `o`, is of type `T`. This means that the actual type of `o` is determined by the type passed to `T` when a `Gen` object is created. Also, because both the parameter `o` and the member variable `ob` are of type `T`, they will both be of the same actual type when a `Gen` object is created.

The type parameter `T` can also be used to specify the return type of a method, as is the case with the `getob()` method, shown here:

```java
T getob() {
    return ob;
}
```
Because `ob` is also of type `T`, its type is compatible with the return type specified by `getob()`.

The `showType()` method displays the type of `T` by calling `getName()` on the `Class` object returned by the call to `getClass()` on `ob`. The `getClass()` method is defined by `Object` and is thus a member of all class types. It returns a `Class` object that corresponds to the type of the class of the object on which it is called. `Class` defines the `getName()` method, which returns a string representation of the class name.

The `GenDemo` class demonstrates the generic `Gen` class. It first creates a version of `Gen` for integers, as shown here:

```
Gen<Integer> iOb;
```

Look closely at this declaration. First, notice that the type `Integer` is specified within the angle brackets after `Gen`. In this case, `Integer` is a type argument that is passed to `Gen`’s type parameter, `T`. This effectively creates a version of `Gen` in which all references to `T` are translated into references to `Integer`. Thus, for this declaration, `ob` is of type `Integer`, and the return type of `getob()` is of type `Integer`.

Before moving on, it’s necessary to state that the Java compiler does not actually create different versions of `Gen`, or of any other generic class. Although it’s helpful to think in these terms, it is not what actually happens. Instead, the compiler removes all generic type information, substituting the necessary casts, to make your code behave as if a specific version of `Gen` were created. Thus, there is really only one version of `Gen` that actually exists in your program. The process of removing generic type information is called erasure, and we will return to this topic later in this chapter.

The next line assigns to `iOb` a reference to an instance of an `Integer` version of the `Gen` class:

```
iOb = new Gen<Integer>(88);
```

Notice that when the `Gen` constructor is called, the type argument `Integer` is also specified. This is because the type of the object (in this case `iOb`) to which the reference is being assigned is of type `Gen<Integer>`. Thus, the reference returned by `new` must also be of type `Gen<Integer>`. If it isn’t, a compile-time error will result. For example, the following assignment will cause a compile-time error:

```
iOb = new Gen<Double>(88.0); // Error
```

Because `iOb` is of type `Gen<Integer>`, it can’t be used to refer to an object of `Gen[Double]`. This type checking is one of the main benefits of generics because it ensures type safety.
NOTE As you will see later in this chapter, beginning with JDK 7, it is possible to shorten the syntax used to create an instance of a generic class. In the interest of clarity, we will use the full syntax at this time.

As the comments in the program state, the assignment

```java
iOb = new Gen<Integer>(88);
```

makes use of autoboxing to encapsulate the value 88, which is an `int`, into an `Integer`. This works because `Gen<Integer>` creates a constructor that takes an `Integer` argument. Because an `Integer` is expected, Java will automatically box 88 inside one. Of course, the assignment could also have been written explicitly, like this:

```java
iOb = new Gen<Integer>(new Integer(88));
```

However, there would be no benefit to using this version.

The program then displays the type of `ob` within `iOb`, which is `Integer`. Next, the program obtains the value of `ob` by use of the following line:

```java
int v = iOb.getob();
```

Because the return type of `getob()` is `T`, which was replaced by `Integer` when `iOb` was declared, the return type of `getob()` is also `Integer`, which unboxes into `int` when assigned to `v` (which is an `int`). Thus, there is no need to cast the return type of `getob()` to `Integer`.

Of course, it’s not necessary to use the auto-unboxing feature. The preceding line could have been written like this, too:

```java
int v = iOb.getob().intValue();
```

However, the auto-unboxing feature makes the code more compact.

Next, `GenDemo` declares an object of type `Gen<String>`:

```java
Gen<String> strOb = new Gen<String>("Generics Test");
```

Because the type argument is `String`, `String` is substituted for `T` inside `Gen`. This creates (conceptually) a `String` version of `Gen`, as the remaining lines in the program demonstrate.

**Generics Work Only with Reference Types**

When declaring an instance of a generic type, the type argument passed to the type
parameter must be a reference type. You cannot use a primitive type, such as `int` or `char`.

For example, with `Gen`, it is possible to pass any class type to `T`, but you cannot pass a primitive type to a type parameter. Therefore, the following declaration is illegal:

```java
Gen<int> intOb = new Gen<int>{53}; // Error, can't use primitive type
```

Of course, not being able to specify a primitive type is not a serious restriction because you can use the type wrappers (as the preceding example did) to encapsulate a primitive type. Further, Java's autoboxing and auto-unboxing mechanism makes the use of the type wrapper transparent.

**Generic Types Differ Based on Their Type Arguments**

A key point to understand about generic types is that a reference of one specific version of a generic type is not type compatible with another version of the same generic type. For example, assuming the program just shown, the following line of code is in error and will not compile:

```java
iOb = strOb; // Wrong!
```

Even though both `iOb` and `strOb` are of type `Gen<T>`, they are references to different types because their type parameters differ. This is part of the way that generics add type safety and prevent errors.

**How Generics Improve Type Safety**

At this point, you might be asking yourself the following question: Given that the same functionality found in the generic `Gen` class can be achieved without generics, by simply specifying `Object` as the data type and employing the proper casts, what is the benefit of making `Gen` generic? The answer is that generics automatically ensure the type safety of all operations involving `Gen`. In the process, they eliminate the need for you to enter casts and to type-check code by hand.

To understand the benefits of generics, first consider the following program that creates a non-generic equivalent of `Gen`:
// NonGen is functionally equivalent to Gen
// but does not use generics.
class NonGen {
  Object ob; // ob is now of type Object

  // Pass the constructor a reference to
  // an object of type Object
  NonGen(Object o) {
    ob = o;
  }

  // Return type Object.
  Object getOb() {
    return ob;
  }

  // Show type of ob.
  void showType() {
    System.out.println("Type of ob is: " + ob.getClass().getName());
  }
}

// Demonstrate the non-generic class.
class NonGenDemo {
  public static void main(String args[]) {
    NonGen iOb;

    // Create NonGen Object and store
    // an Integer in it. Autoboxing still occurs.
    iOb = new NonGen(88);

    // Show the type of data used by iOb.
    iOb.showType();

    // Get the value of iOb.
    // This time, a cast is necessary.
    int v = (Integer) iOb.getOb();
    System.out.println("Value: \" + v + \"\n\n\n    system.out.println();

    // Create another NonGen object and
    // store a String in it.
    NonGen strOb = new NonGen("Non-Generics Test");

    // Show the type of data used by strOb.
    strOb.showType();

    // Get the value of strOb.
    // Again, notice that a cast is necessary.
There are several things of interest in this version. First, notice that NonGen replaces all uses of T with Object. This makes NonGen able to store any type of object, as can the generic version. However, it also prevents the Java compiler from having any real knowledge about the type of data actually stored in NonGen, which is bad for two reasons. First, explicit casts must be employed to retrieve the stored data. Second, many kinds of type mismatch errors cannot be found until run time. Let's look closely at each problem. Notice this line:

```java
String str = (String) strOb.getob();
System.out.println("value: " + str);

// This compiles, but is conceptually wrong!
iOb = strOb;
v = (Integer) iOb.getob(); // run-time error;
```

There are several things of interest in this version. First, notice that NonGen replaces all uses of T with Object. This makes NonGen able to store any type of object, as can the generic version. However, it also prevents the Java compiler from having any real knowledge about the type of data actually stored in NonGen, which is bad for two reasons. First, explicit casts must be employed to retrieve the stored data. Second, many kinds of type mismatch errors cannot be found until run time. Let’s look closely at each problem. Notice this line:

```java
int v = (Integer) iOb.getob();
```

Because the return type of getob() is Object, the cast to Integer is necessary to enable that value to be auto-unboxed and stored in v. If you remove the cast, the program will not compile. With the generic version, this cast was implicit. In the non-generic version, the cast must be explicit. This is not only an inconvenience, but also a potential source of error. Now, consider the following sequence from near the end of the program:

```java
// This compiles, but is conceptually wrong!
iOb = strOb;
v = (Integer) iOb.getob(); // run-time error!
```

Here, strOb is assigned to iOb. However, strOb refers to an object that contains a string, not an integer. This assignment is syntactically valid because all NonGen references are the same, and any NonGen reference can refer to any other NonGen object. However, the statement is semantically wrong, as the next line shows. Here, the return type of getob() is cast to Integer, and then an attempt is made to assign this value to v. The trouble is that iOb now refers to an object that stores a String, not an Integer. Unfortunately, without the use of generics, the Java compiler has no way to know this. Instead, a run-time exception occurs when the cast to Integer is attempted. As you know, it is extremely bad to have run-time exceptions occur in your code!

The preceding sequence can’t occur when generics are used. If this sequence were attempted in the generic version of the program, the compiler would catch it and report an error, thus preventing a serious bug that results in a run-time exception. The ability to create type-safe
code in which type-mismatch errors are caught at compile time is a key advantage of generics. Although using `Object` references to create “generic” code has always been possible, that code was not type safe, and its misuse could result in run-time exceptions. Generics prevent this from occurring. In essence, through generics, run-time errors are converted into compile-time errors. This is a major advantage.

**A Generic Class with Two Type Parameters**

You can declare more than one type parameter in a generic type. To specify two or more type parameters, simply use a comma-separated list. For example, the following `TwoGen` class is a variation of the `Gen` class that has two type parameters:
// A simple generic class with two type
// parameters: T and V.
class TwoGen<T, V> {
    T ob1;
    V ob2;

    // Pass the constructor a reference to
    // an object of type T and an object of type V.
    TwoGen(T o1, V o2) {
        ob1 = o1;
        ob2 = o2;
    }

    // Show types of T and V.
    void showTypes() {
        System.out.println("Type of T is "+
                         ob1.getClass().getName());
        System.out.println("Type of V is "+
                         ob2.getClass().getName());
    }

    T getOb1() {
        return ob1;
    }

    V getOb2() {
        return ob2;
    }
}

// Demonstrate TwoGen.
class SimpGen {
    public static void main(String args[]) {
        TwoGen<Integer, String> tgObj =
            new TwoGen<Integer, String>(88, "Generics");

        // Show the types.
        tgObj.showTypes();

        // Obtain and show values.
        int v = tgObj.getOb1();
        System.out.println("value: "+v);
        System.out.println("value: "+v);
        String str = tgObj.getOb2();
        System.out.println("value: "+str);
    }
}

The output from this program is shown here:
Notice how **TwoGen** is declared:

```java
class TwoGen<T, V> {

It specifies two type parameters: `T` and `V`, separated by a comma. Because it has two type parameters, two type arguments must be passed to **TwoGen** when an object is created, as shown next:

```java
TwoGen<Integer, String> tgObj =
    new TwoGen<Integer, String>(88, "Generics");
```

In this case, `Integer` is substituted for `T`, and `String` is substituted for `V`.

Although the two type arguments differ in this example, it is possible for both types to be the same. For example, the following line of code is valid:

```java
TwoGen<String, String> x = new TwoGen<String, String> ("A", "B");
```

In this case, both `T` and `V` would be of type `String`. Of course, if the type arguments were always the same, then two type parameters would be unnecessary.

**The General Form of a Generic Class**
The generics syntax shown in the preceding examples can be generalized. Here is the syntax for declaring a generic class:

```java
class class-name<type-param-list> { // ...
```

Here is the full syntax for declaring a reference to a generic class and instance creation:

```java
class-name<type-arg-list> var-name =
    new class-name<type-arg-list>(cons-arg-list);
```

**Bounded Types**
In the preceding examples, the type parameters could be replaced by any class type. This is fine for many purposes, but sometimes it is useful to limit the types that can be passed to a type parameter. For example, assume that you want to create a generic class that contains a method that returns the average of an array of numbers. Furthermore, you want to use the class to obtain the average of an array of any type of number, including integers, floats, and doubles. Thus, you want to specify the type of the numbers generically, using a type
parameter. To create such a class, you might try something like this:

```java
// Stats attempts (unsuccessfully) to
create a generic class that can compute
the average of an array of numbers of
any given type.

// The class contains an error!
<

class Stats<T> {
    T[] nums; // nums is an array of type T

    // Pass the constructor a reference to
    // an array of type T.
    Stats(T[] o) {
        nums = o;
    }

    // Return type double in all cases.
    double average() {
        double sum = 0.0;
        for(int i=0; i < nums.length; i++)
            sum += nums[i].doubleValue(); // Error!!!

        return sum / nums.length;
    }
}
```

In Stats, the `average()` method attempts to obtain the **double** version of each number in the `nums` array by calling `doubleValue()`. Because all numeric classes, such as `Integer` and `Double`, are subclasses of `Number`, and `Number` defines the `doubleValue()` method, this method is available to all numeric wrapper classes. The trouble is that the compiler has no way to know that you are intending to create `Stats` objects using only numeric types. Thus, when you try to compile `Stats`, an error is reported that indicates that the `doubleValue()` method is unknown. To solve this problem, you need some way to tell the compiler that you intend to pass only numeric types to `T`. Furthermore, you need some way to **ensure** that only numeric types are actually passed.

To handle such situations, Java provides **bounded types**. When specifying a type parameter, you can create an upper bound that declares the superclass from which all type arguments must be derived. This is accomplished through the use of an **extends** clause when specifying the type parameter, as shown here:

```java
<T extends superclass>
```

This specifies that `T` can only be replaced by `superclass`, or subclasses of `superclass`. Thus, `superclass` defines an inclusive, upper limit.
You can use an upper bound to fix the **Stats** class shown earlier by specifying **Number** as an upper bound, as shown here:

```java
// In this version of Stats, the type argument for
// T must be either Number, or a class derived
// from Number.
class Stats<T extends Number> {
    T[] nums; // array of Number or subclass
    // Pass the constructor a reference to
    // an array of type Number or subclass.
    Stats(T[] o) {
        nums = o;
    }

    // Return type double in all cases.
    double average() {
        double sum = 0.0;
        for(int i=0; i < nums.length; i++)
            sum += nums[i].doubleValue();
        return sum / nums.length;
    }

    // Demonstrate Stats.
    class BoundsDemo {
        public static void main(String args[]) {
            Integer inums[] = { 1, 2, 3, 4, 5 };
            Stats<Integer> iobj = new Stats<Integer>(inums);
            double v = iobj.average();
            System.out.println("iobj average is " + v);

            Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };
            Stats<Double> dobj = new Stats<Double>(dnums);
            double w = dobj.average();
            System.out.println("dobj average is " + w);

            // This won't compile because String is not a
            // subclass of Number.
            String strs[] = { "1", "2", "3", "4", "5" };
            Stats<String> strob = new Stats<String>(strs);
            double x = strob.average();
            System.out.println("strob average is " + x);
        }
    }
}
```

The output is shown here:
Notice how `Stats` is now declared by this line:

```java
class Stats<T extends Number> {
```

Because the type `T` is now bounded by `Number`, the Java compiler knows that all objects of type `T` can call `doubleValue` because it is a method declared by `Number`. This is, by itself, a major advantage. However, as an added bonus, the bounding of `T` also prevents nonnumeric `Stats` objects from being created. For example, if you try removing the comments from the lines at the end of the program, and then try recompiling, you will receive compile-time errors because `String` is not a subclass of `Number`.

In addition to using a class type as a bound, you can also use an interface type. In fact, you can specify multiple interfaces as bounds. Furthermore, a bound can include both a class type and one or more interfaces. In this case, the class type must be specified first. When a bound includes an interface type, only type arguments that implement that interface are legal. When specifying a bound that has a class and an interface, or multiple interfaces, use the `&` operator to connect them. For example,

```java
class Gen<T extends MyClass & MyInterface> { // ...
```

Here, `T` is bounded by a class called `MyClass` and an interface called `MyInterface`. Thus, any type argument passed to `T` must be a subclass of `MyClass` and implement `MyInterface`.

### Using Wildcard Arguments

As useful as type safety is, sometimes it can get in the way of perfectly acceptable constructs. For example, given the `Stats` class shown at the end of the preceding section, assume that you want to add a method called `sameAvg()` that determines if two `Stats` objects contain arrays that yield the same average, no matter what type of numeric data each object holds. For example, if one object contains the `double` values `1.0`, `2.0`, and `3.0`, and the other object contains the integer values `2`, `1`, and `3`, then the averages will be the same. One way to implement `sameAvg()` is to pass it a `Stats` argument, and then compare the average of that argument against the invoking object, returning true only if the averages are the same.

For example, you want to be able to call `sameAvg()`, as shown here:
At first, creating `sameAvg()` seems like an easy problem. Because `Stats` is generic and its `average()` method can work on any type of `Stats` object, it seems that creating `sameAvg()` would be straightforward. Unfortunately, trouble starts as soon as you try to declare a parameter of type `Stats`. Because `Stats` is a parameterized type, what do you specify for `Stats`' type parameter when you declare a parameter of that type?

At first, you might think of a solution like this, in which `T` is used as the type parameter:

```java
Integer inums[] = { 1, 2, 3, 4, 5 };
Double dnums[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };
Stats<Integer> iob = new Stats<Integer>(inums);
Stats<Double> dob = new Stats<Double>(dnums);
if(iob.sameAvg(dob))
    System.out.println("Averages are the same.");
else
    System.out.println("Averages differ.");
```

The trouble with this attempt is that it will work only with other `Stats` objects whose type is the same as the invoking object. For example, if the invoking object is of type `Stats<Integer>`, then the parameter `ob` must also be of type `Stats<Integer>`. It can’t be used to compare the average of an object of type `Stats<Double>` with the average of an object of type `Stats<Short>`, for example. Therefore, this approach won’t work except in a very narrow context and does not yield a general (that is, generic) solution.

To create a generic `sameAvg()` method, you must use another feature of Java generics: the wildcard argument. The wildcard argument is specified by the `?`, and it represents an unknown type. Using a wildcard, here is one way to write the `sameAvg()` method:

```java
// This won't work!
// Determine if two averages are the same.
boolean sameAvg(Stats<T> ob) {
    if(average() == ob.average())
        return true;
    return false;
}
```
Here, Stats<?> matches any Stats object, allowing any two Stats objects to have their averages compared. The following program demonstrates this:

```java
// Use a wildcard.
class Stats<T extends Number> {
    T[] nums; // array of Number or subclass

    // Pass the constructor a reference to
    // an array of type Number or subclass.
    Stats(T[] o) {
        nums = o;
    }

    // Return type double in all cases.
    double average() {
        double sum = 0.0;

        for(int i=0; i < nums.length; i++)
            sum += nums[i].doubleValue();
```
public static void main(String args[]) {
    Integer inums[] = {1, 2, 3, 4, 5};
    Stats<Integer> iob = new Stats<Integer>(inums);
    double v = iob.average();
    System.out.println("iob average is " + v);

    Double dnums[] = {1.1, 2.2, 3.3, 4.4, 5.5};
    Stats<Double> dob = new Stats<Double>(dnums);
    double w = dob.average();
    System.out.println("dob average is " + w);

    Float fnums[] = {1.6F, 2.0F, 3.0F, 4.0F, 5.0F};
    Stats<Float> fob = new Stats<Float>(fnums);
    double x = fob.average();
    System.out.println("fob average is " + x);

    // See which arrays have same average.
    System.out.print("Averages of iob and dob ");
    if(iob.sameAvg(dob))
        System.out.println("are the same.");
    else
        System.out.println("differ.");

    System.out.print("Averages of iob and fob ");
    if(iob.sameAvg(fob))
        System.out.println("are the same.");
    else
        System.out.println("differ.");
}
One last point: It is important to understand that the wildcard does not affect what type of \texttt{Stats} objects can be created. This is governed by the \texttt{extends} clause in the \texttt{Stats} declaration. The wildcard simply matches any valid \texttt{Stats} object.

\textbf{Bounded Wildcards}

Wildcard arguments can be bounded in much the same way that a type parameter can be bounded. A bounded wildcard is especially important when you are creating a generic type that will operate on a class hierarchy. To understand why, let’s work through an example.

Consider the following hierarchy of classes that encapsulate coordinates:

```java
// Two-dimensional coordinates.
class TwoD {
    int x, y;

    TwoD(int a, int b) {
        x = a;
        y = b;
    }
}

// Three-dimensional coordinates.
class ThreeD extends TwoD {
    int z;

    ThreeD(int a, int b, int c) {
        super(a, b);
        z = c;
    }
}

// Four-dimensional coordinates.
class FourD extends ThreeD {
    int t;

    FourD(int a, int b, int c, int d) {
        super(a, b, c);
        t = d;
    }
}
```
At the top of the hierarchy is **TwoD**, which encapsulates a two-dimensional, XY coordinate. **TwoD** is inherited by **ThreeD**, which adds a third dimension, creating an XYZ coordinate. **ThreeD** is inherited by **FourD**, which adds a fourth dimension (time), yielding a four-dimensional coordinate.

Shown next is a generic class called **Coords**, which stores an array of coordinates:

```java
// This class holds an array of coordinate objects.
class Coords<T extends TwoD> {
    T[] coords;

    Coords(T[] c) { coords = c; }
}
```

Notice that **Coords** specifies a type parameter bounded by **TwoD**. This means that any array stored in a **Coords** object will contain objects of type **TwoD** or one of its subclasses.

Now, assume that you want to write a method that displays the X and Y coordinates for each element in the **coords** array of a **Coords** object. Because all types of **Coords** objects have at least two coordinates (X and Y), this is easy to do using a wildcard, as shown here:

```java
static void showXY(Coords<?> c) {
    System.out.println("X Y Coordinates:");
    for(int i=0; i < c.coords.length; i++)
        System.out.println(c.coords[i].x + " " + c.coords[i].y);
    System.out.println();
}
```

Because **Coords** is a bounded generic type that specifies **TwoD** as an upper bound, all objects that can be used to create a **Coords** object will be arrays of type **TwoD**, or of classes derived from **TwoD**. Thus, **showXY()** can display the contents of any **Coords** object.

However, what if you want to create a method that displays the X, Y, and Z coordinates of a **ThreeD** or **FourD** object? The trouble is that not all **Coords** objects will have three coordinates, because a **Coords<TwoD>** object will only have X and Y. Therefore, how do you write a method that displays the X, Y, and Z coordinates for **Coords<ThreeD>** and **Coords<FourD>** objects, while preventing that method from being used with **Coords<TwoD>** objects? The answer is the **bounded wildcard argument**.

A bounded wildcard specifies either an upper bound or a lower bound for the type argument. This enables you to restrict the types of objects upon which a method will operate. The most common bounded wildcard is the upper bound, which is created using an
extends clause in much the same way it is used to create a bounded type.
Using a bounded wildcard, it is easy to create a method that displays the X, Y, and Z
coordinates of a Coords object, if that object actually has those three coordinates. For
example, the following showXYZ( ) method shows the X, Y, and Z coordinates of the
elements stored in a Coords object, if those elements are actually of type ThreeD (or are
derived from ThreeD):

```
static void showXYZ(Coords<? extends ThreeD> c) {
    System.out.println("X Y Z Coordinates: ");
    for(int i=0; i < c.coords.length; i++)
        System.out.println(c.coords[i].x + " "+
                            c.coords[i].y + " "+
                            c.coords[i].z);
    System.out.println();
}
```

Notice that an extends clause has been added to the wildcard in the declaration of
parameter c. It states that the ? can match any type as long as it is ThreeD, or a class
derived from ThreeD. Thus, the extends clause establishes an upper bound that the ? can
match. Because of this bound, showXYZ( ) can be called with references to objects of type
Coords<ThreeD> or Coords<FourD>, but not with a reference of type
Coords<TwoD>. Attempting to call showXYZ( ) with a Coords<TwoD> reference
results in a compile-time error, thus ensuring type safety.

Here is an entire program that demonstrates the actions of a bounded wildcard argument:
// Bounded Wildcard arguments.

// Two-dimensional coordinates.
class TwoD {
    int x, y;

    TwoD(int a, int b) {
        x = a;
        y = b;
    }
}

// Three-dimensional coordinates.
class ThreeD extends TwoD {
    int z;

    ThreeD(int a, int b, int c) {
        super(a, b);
        z = c;
    }
}

// Four-dimensional coordinates.
class FourD extends ThreeD {
    int t;

    FourD(int a, int b, int c, int d) {
        super(a, b, c);
        t = d;
    }
}

// This class holds an array of coordinate objects.
class Coords<? extends TwoD> {
    T[] coords;

    Coords(T[] o) { coords = o; }
}

// Demonstrate a bounded wildcard.
class BoundedWildcard {
    static void showXY(Coords<? extends TwoD> c) {
        System.out.println("X Y Coordinates:");
        for(int i=0; i < c.coords.length; i++)
            System.out.println(c.coords[i].x + " " + c.coords[i].y);
        System.out.println();
    }

    static void showXYZ(Coords<? extends ThreeD> c) {
        System.out.println("X Y Z Coordinates:");
        for(int i=0; i < c.coords.length; i++)
            System.out.println(c.coords[i].x + " " + c.coords[i].y + " " + c.coords[i].z);
        System.out.println();
    }
}
The output from the program is shown here:
Notice these commented-out lines:

```java
// showXYZ(tdlocs); // Error, not a ThreeD
// showAll(tdlocs); // Error, not a FourD
```

Because `tdlocs` is a `Coords(TwoD)` object, it cannot be used to call `showXYZ()` or `showAll()` because bounded wildcard arguments in their declarations prevent it. To prove this to yourself, try removing the comment symbols, and then attempt to compile the program. You will receive compilation errors because of the type mismatches.

In general, to establish an upper bound for a wildcard, use the following type of wildcard expression:

```java
<? extends superclass>
```

where `superclass` is the name of the class that serves as the upper bound.

Remember, this is an inclusive clause because the class forming the upper bound (that is, specified by `superclass`) is also within bounds.

You can also specify a lower bound for a wildcard by adding a `super` clause to a wildcard declaration. Here is its general form:
<? super subclass>

In this case, only classes that are superclasses of subclass are acceptable arguments. This is an inclusive clause.

Creating a Generic Method
As the preceding examples have shown, methods inside a generic class can make use of a class’ type parameter and are, therefore, automatically generic relative to the type parameter. However, it is possible to declare a generic method that uses one or more type parameters of its own. Furthermore, it is possible to create a generic method that is enclosed within a non-generic class.

Let’s begin with an example. The following program declares a non-generic class called GenMethDemo and a static generic method within that class called isIn(). The isIn() method determines if an object is a member of an array. It can be used with any type of object and array as long as the array contains objects that are compatible with the type of the object being sought.
The output from the program is shown here:

```
2 is in nums
7 is not in nums
two is in strs
seven is not in strs
```

Let’s examine `isIn()` closely. First, notice how it is declared by this line:

```
static <T extends Comparable<T>, V extends T> boolean isIn(T x, V[] y) {
```

The type parameters are declared before the return type of the method. Also note that `T` extends `Comparable<T>`. `Comparable` is an interface declared in `java.lang`. A class that implements `Comparable` defines objects that can be ordered. Thus, requiring an upper
bound of Comparable ensures that isIn() can be used only with objects that are capable of being compared. Comparable is generic, and its type parameter specifies the type of objects that it compares. (Shortly, you will see how to create a generic interface.) Next, notice that the type V is upper-bounded by T. Thus, V must either be the same as type T, or a subclass of T. This relationship enforces that isIn() can be called only with arguments that are compatible with each other. Also notice that isIn() is static, enabling it to be called independently of any object. Understand, though, that generic methods can be either static or non-static. There is no restriction in this regard.

Now, notice how isIn() is called within main() by use of the normal call syntax, without the need to specify type arguments. This is because the types of the arguments are automatically discerned, and the types of T and V are adjusted accordingly. For example, in the first call:

```java
if(isIn(2, nums))
```

the type of the first argument is Integer (due to autoboxing), which causes Integer to be substituted for T. The base type of the second argument is also Integer, which makes Integer a substitute for V, too. In the second call, String types are used, and the types of T and V are replaced by String.

Although type inference will be sufficient for most generic method calls, you can explicitly specify the type argument if needed. For example, here is how the first call to isIn() looks when the type arguments are specified:

```java
GenMathDemo.<Integer, Integer>isIn(2, nums)
```

Of course, in this case, there is nothing gained by specifying the type arguments. Furthermore, JDK 8 has improved type inference as it relates to methods. As a result, there are fewer cases in which explicit type arguments are needed.

Now, notice the commented-out code, shown here:

```java
// if(isIn("two", nums))
// System.out.println("two is in strs");
```

If you remove the comments and then try to compile the program, you will receive an error. The reason is that the type parameter V is bounded by T in the extends clause in V's declaration. This means that V must be either type T, or a subclass of T. In this case, the first argument is of type String, making T into String, but the second argument is of type Integer, which is not a subclass of String. This causes a compile-time type-mismatch error. This ability to enforce type safety is one of the most important advantages of generic methods.

The syntax used to create isIn() can be generalized. Here is the syntax for a generic method:
In all cases, \textit{type-param-list} is a comma-separated list of type parameters. Notice that for a generic method, the type parameter list precedes the return type.

\textbf{Generic Constructors}

It is possible for constructors to be generic, even if their class is not. For example, consider the following short program:

```java
// Use a generic constructor.
class GenCons {
    private double val;

    \textit{<T extends Number>} GenCons(T arg) {
        val = arg.doubleValue();
    }

    void showval() {
        System.out.println("val: "+ val);
    }
}

class GenConsDemo {
    public static void main(String args[]) {
        GenCons test = new GenCons(100);
        GenCons test2 = new GenCons(123.5F);

        test.showval();
        test2.showval();
    }
}
```

The output is shown here:

```
val: 100.0
val: 123.5
```

Because \texttt{GenCons( )} specifies a parameter of a generic type, which must be a subclass of \texttt{Number}, \texttt{GenCons( )} can be called with any numeric type, including \texttt{Integer}, \texttt{Float}, or \texttt{Double}. Therefore, even though \texttt{GenCons} is not a generic class, its constructor is generic.

\textbf{Generic Interfaces}

In addition to generic classes and methods, you can also have generic interfaces. Generic
interfaces are specified just like generic classes. Here is an example. It creates an interface called MinMax that declares the methods min() and max(), which are expected to return the minimum and maximum value of some set of objects.

```java
// A generic interface example.

// A Min/Max interface.
interface MinMax<T> { // T min();
   T min();
   T max();
}

// Now, implement MinMax
class MyClass<T> implements MinMax<T> { // T[] vals;
   MyClass(T[] o) { vals = o; }
   // Return the minimum value in vals.
   public T min() {
      T v = vals[0];
      for(int i=1; i < vals.length; i++)
         if(vals[i].compareTo(v) < 0) v = vals[i];
      return v;
   }
   // Return the maximum value in vals.
   public T max() {
      T v = vals[0];
      for(int i=1; i < vals.length; i++)
         if(vals[i].compareTo(v) > 0) v = vals[i];
      return v;
   }
}

class GenIFDemo {
   public static void main(String args[]) {
      Integer inums[] = {3, 6, 2, 0, 5};
      Character chs[] = {'b', 'r', 'p', 'w'};
      MyClass<Integer> iob = new MyClass<Integer>(inums);
      MyClass<Character> cob = new MyClass<Character>(chs);
      System.out.println("Max value in inums: " + iob.max());
      System.out.println("Min value in inums: " + iob.min());
      System.out.println("Max value in chs: " + cob.max());
      System.out.println("Min value in chs: " + cob.min());
   }
}
```

The output is shown here:
Although most aspects of this program should be easy to understand, a couple of key points need to be made. First, notice that MinMax is declared like this:

```java
interface MinMax<T extends Comparable<T>> {
```

In general, a generic interface is declared in the same way as is a generic class. In this case, the type parameter is `T`, and its upper bound is `Comparable`. As explained earlier, `Comparable` is an interface defined by `java.lang` that specifies how objects are compared. Its type parameter specifies the type of the objects being compared.

Next, MinMax is implemented by MyClass. Notice the declaration of MyClass, shown here:

```java
class MyClass<T extends Comparable<T>> implements MinMax<T> {
```

Pay special attention to the way that the type parameter `T` is declared by MyClass and then passed to MinMax. Because MinMax requires a type that implements Comparable, the implementing class (MyClass in this case) must specify the same bound. Furthermore, once this bound has been established, there is no need to specify it again in the implements clause. In fact, it would be wrong to do so. For example, this line is incorrect and won’t compile:

```java
// This is wrong!
class MyClass<T extends Comparable<T>>
    implements MinMax<T extends Comparable<T>> {
```

Once the type parameter has been established, it is simply passed to the interface without further modification.

In general, if a class implements a generic interface, then that class must also be generic, at least to the extent that it takes a type parameter that is passed to the interface. For example, the following attempt to declare MyClass is in error:

```java
class MyClass implements MinMax<T> { // Wrong!
```

Because MyClass does not declare a type parameter, there is no way to pass one to MinMax. In this case, the identifier `T` is simply unknown, and the compiler reports an error. Of course, if a class implements a specific type of generic interface, such as shown
then the implementing class does not need to be generic. The generic interface offers two benefits. First, it can be implemented for different types of data. Second, it allows you to put constraints (that is, bounds) on the types of data for which the interface can be implemented. In the MinMax example, only types that implement the Comparable interface can be passed to T.

Here is the generalized syntax for a generic interface:

```
interface interface-name<type-param-list> { // ...
```

Here, type-param-list is a comma-separated list of type parameters. When a generic interface is implemented, you must specify the type arguments, as shown here:

```
class class-name<type-param-list>
    implements interface-name<type-arg-list> { ...
```

### Raw Types and Legacy Code

Because support for generics did not exist prior to JDK 5, it was necessary to provide some transition path from old, pre-generics code. At the time of this writing, there is still pre-generics legacy code that must remain both functional and compatible with generics. Pre-generics code must be able to work with generics, and generic code must be able to work with pre-generics code.

To handle the transition to generics, Java allows a generic class to be used without any type arguments. This creates a raw type for the class. This raw type is compatible with legacy code, which has no knowledge of generics. The main drawback to using the raw type is that the type safety of generics is lost.

Here is an example that shows a raw type in action:

```
class MyClass implements MinMax<Integer> { // OK
```
This program contains several interesting things. First, a raw type of the generic `Gen` class is created by the following declaration:

```java
Gen raw = new Gen(new Double(98.6));
```
Notice that no type arguments are specified. In essence, this creates a `Gen` object whose type `T` is replaced by `Object`.

A raw type is not type safe. Thus, a variable of a raw type can be assigned a reference to any type of `Gen` object. The reverse is also allowed; a variable of a specific `Gen` type can be assigned a reference to a raw `Gen` object. However, both operations are potentially unsafe because the type checking mechanism of generics is circumvented.

This lack of type safety is illustrated by the commented-out lines at the end of the program. Let’s examine each case. First, consider the following situation:

```java
//   int i = (Integer) raw.getOb();  // run-time error
```

In this statement, the value of `ob` inside `raw` is obtained, and this value is cast to `Integer`. The trouble is that `raw` contains a `Double` value, not an integer value. However, this cannot be detected at compile time because the type of `raw` is unknown. Thus, this statement fails at run time.

The next sequence assigns to a `strOb` (a reference of type `Gen<String>`) a reference to a raw `Gen` object:

```java
strOb = raw;  // OK, but potentially wrong
// String str = strOb.getOb();  // run-time error
```

The assignment, itself, is syntactically correct, but questionable. Because `strOb` is of type `Gen<String>`, it is assumed to contain a `String`. However, after the assignment, the object referred to by `strOb` contains a `Double`. Thus, at run time, when an attempt is made to assign the contents of `strOb` to `str`, a run-time error results because `strOb` now contains a `Double`. Thus, the assignment of a raw reference to a generic reference bypasses the type-safety mechanism.

The following sequence inverts the preceding case:

```java
raw = iOb;  // OK, but potentially wrong
// d = (Double) raw.getOb();  // run-time error
```

Here, a generic reference is assigned to a raw reference variable. Although this is syntactically correct, it can lead to problems, as illustrated by the second line. In this case, `raw` now refers to an object that contains an `Integer` object, but the cast assumes that it contains a `Double`. This error cannot be prevented at compile time. Rather, it causes a run-time error.

Because of the potential for danger inherent in raw types, `javac` displays `unchecked warnings` when a raw type is used in a way that might jeopardize type safety. In the preceding program, these lines generate unchecked warnings:
In the first line, it is the call to the `Gen` constructor without a type argument that causes the warning. In the second line, it is the assignment of a raw reference to a generic variable that generates the warning.

At first, you might think that this line should also generate an unchecked warning, but it does not:

```java
raw = iOb; // OK, but potentially wrong
```

No compiler warning is issued because the assignment does not cause any further loss of type safety than had already occurred when `raw` was created.

One final point: You should limit the use of raw types to those cases in which you must mix legacy code with newer, generic code. Raw types are simply a transitional feature and not something that should be used for new code.

**Generic Class Hierarchies**

Generic classes can be part of a class hierarchy in just the same way as a non-generic class. Thus, a generic class can act as a superclass or be a subclass. The key difference between generic and non-generic hierarchies is that in a generic hierarchy, any type arguments needed by a generic superclass must be passed up the hierarchy by all subclasses. This is similar to the way that constructor arguments must be passed up a hierarchy.

**Using a Generic Superclass**

Here is a simple example of a hierarchy that uses a generic superclass:
In this hierarchy, **Gen2** extends the generic class **Gen**. Notice how **Gen2** is declared by the following line:

```java
class Gen2<T> extends Gen<T> {
    // A simple generic class hierarchy.
    class Gen<T> {
        T ob;
        Gen(T o) {
            ob = o;
        }
        // Return ob.
        T getob() {
            return ob;
        }
    }
    // A subclass of Gen.
    class Gen2<T> extends Gen<T> {
        Gen2(T o) {
            super(o);
        }
    }
}
```

The type parameter **T** is specified by **Gen2** and is also passed to **Gen** in the `extends` clause. This means that whatever type is passed to **Gen2** will also be passed to **Gen**. For example, this declaration,

```java
Gen2<Integer> num = new Gen2<Integer>(100);
```

passes **Integer** as the type parameter to **Gen**. Thus, the `ob` inside the **Gen** portion of **Gen2** will be of type **Integer**.

Notice also that **Gen2** does not use the type parameter **T** except to support the **Gen** superclass. Thus, even if a subclass of a generic superclass would otherwise not need to be generic, it still must specify the type parameter(s) required by its generic superclass.

Of course, a subclass is free to add its own type parameters, if needed. For example, here is a variation on the preceding hierarchy in which **Gen2** adds a type parameter of its own:
// A subclass can add its own type parameters.
class Gen2<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getob() {
        return ob;
    }
}

// A subclass of Gen that defines a second
// type parameter, called V.
class Gen2<T, V> extends Gen<T> {
    V ob2;

    Gen2(T o, V o2) {
        super(o);
        ob2 = o2;
    }

    V getob2() {
        return ob2;
    }
}

// Create an object of type Gen2.
class HierDemo {
    public static void main(String args[]) {
        // Create a Gen2 object for String and Integer.
        Gen2<String, Integer> x =
            new Gen2<String, Integer>("Value is: ", 99);
        System.out.print(x.getob());
        System.out.println(x.getob2());
    }
}

Notice the declaration of this version of Gen2, which is shown here:

    class Gen2<T, V> extends Gen<T> {

Here, T is the type passed to Gen, and V is the type that is specific to Gen2. V is used to
declare an object called ob2, and as a return type for the method getob2(). In main(), a
Gen2 object is created in which type parameter T is String, and type parameter V is
Integer. The program displays the following, expected, result:

Value is: 99

A Generic Subclass
It is perfectly acceptable for a non-generic class to be the superclass of a generic subclass.
For example, consider this program:
The output from the program is shown here:

```
Hello 47
```

In the program, notice how `Gen` inherits `NonGen` in the following declaration:
Because `NonGen` is not generic, no type argument is specified. Thus, even though `Gen` declares the type parameter `T`, it is not needed by (nor can it be used by) `NonGen`. Thus, `NonGen` is inherited by `Gen` in the normal way. No special conditions apply.

**Run-Time Type Comparisons Within a Generic Hierarchy**

Recall the run-time type information operator `instanceof` that was described in Chapter 13. As explained, `instanceof` determines if an object is an instance of a class. It returns true if an object is of the specified type or can be cast to the specified type. The `instanceof` operator can be applied to objects of generic classes. The following class demonstrates some of the type compatibility implications of a generic hierarchy:

```java
class Gen<T> extends NonGen {
    T ob;
    Gen(T o) {
        ob = o;
    }
    // Return ob.
    T getOb() {
        return ob;
    }
}

// A subclass of Gen.
class Gen2<T> extends Gen<T> {
    Gen2(T o) {
        super(o);
    }
}

// Demonstrate run-time type ID implications of generic // class hierarchy.
class HierDemo3 {
    public static void main(String args[]) {
        // Create a Gen object for Integers.
        Gen<Integer> 10b = new Gen<Integer>(88);
        // Create a Gen2 object for Integers.
        Gen2<Integer> 10b2 = new Gen2<Integer>(99);
    }
}
```
The output from the program is shown here:

```
// Create a Gen2 object for Strings.
Gen2<String> strOb2 = new Gen2<String>("Generics Test");

// See if iOb2 is some form of Gen2.
if(iOb2 instanceof Gen2<?, ?>)
    System.out.println("iOb2 is instance of Gen2");

// See if iOb2 is some form of Gen.
if(iOb2 instanceof Gen<?, ?>)
    System.out.println("iOb2 is instance of Gen");;
System.out.println();

// See if strOb2 is a Gen2.
if(strOb2 instanceof Gen2<?, ?>)
    System.out.println("strOb2 is instance of Gen2");;

// See if strOb2 is a Gen.
if(strOb2 instanceof Gen<?, ?>)
    System.out.println("strOb2 is instance of Gen");;
System.out.println();

// See if iOb is an instance of Gen2, which it is not.
if(iOb instanceof Gen2<?, ?>)
    System.out.println("iOb is instance of Gen2");;

// See if iOb is an instance of Gen, which it is.
if(iOb instanceof Gen<?, ?>)
    System.out.println("iOb is instance of Gen");;

// The following can't be compiled because
generic type info does not exist at run time.
// if(iOb2 instanceof Gen2<Integer>)
//    System.out.println("iOb2 is instance of Gen2<Integer>");
}
```

The output from the program is shown here:

```
  iOb2 is instance of Gen2
  iOb2 is instance of Gen

  strOb2 is instance of Gen2
  strOb2 is instance of Gen

  iOb is instance of Gen
```

In this program, `Gen2` is a subclass of `Gen`, which is generic on type parameter `T`. In `main()`, three objects are created. The first is `iOb`, which is an object of type
**Gen<Integer>**. The second is **iOb2**, which is an instance of **Gen2<Integer>**. Finally, **strOb2** is an object of type **Gen2<String>**.

Then, the program performs these **instanceof** tests on the type of **iOb2**:

```java
// See if iOb2 is some form of Gen2.
if (iOb2 instanceof Gen2<?>)
    System.out.println("iOb2 is instance of Gen2");

// See if iOb2 is some form of Gen.
if (iOb2 instanceof Gen<?>)
    System.out.println("iOb2 is instance of Gen");
```

As the output shows, both succeed. In the first test, **iOb2** is checked against **Gen2<?]**. This test succeeds because it simply confirms that **iOb2** is an object of some type of **Gen2** object. The use of the wildcard enables **instanceof** to determine if **iOb2** is an object of any type of **Gen2**. Next, **iOb2** is tested against **Gen<?]**, the superclass type. This is also true because **iOb2** is some form of **Gen**, the superclass. The next few lines in **main()** show the same sequence (and same results) for **strOb2**.

Next, **iOb**, which is an instance of **Gen<Integer>** (the superclass), is tested by these lines:

```java
// See if iOb is an instance of Gen2, which it is not.
if (iOb instanceof Gen2<?>)
    System.out.println("iOb is instance of Gen2");

// See if iOb is an instance of Gen, which it is.
if (iOb instanceof Gen<?>)
    System.out.println("iOb is instance of Gen");
```

The first **if** fails because **iOb** is not some type of **Gen2** object. The second test succeeds because **iOb** is some type of **Gen** object.

Now, look closely at these commented-out lines:

```java
// The following can't be compiled because
// generic type info does not exist at run time.
// if (iOb2 instanceof Gen2<Integer>)
// System.out.println("iOb2 is instance of Gen2<Integer>");
```

As the comments indicate, these lines can’t be compiled because they attempt to compare **iOb2** with a specific type of **Gen2**, in this case, **Gen2<Integer>**. Remember, there is no generic type information available at run time. Therefore, there is no way for **instanceof** to know if **iOb2** is an instance of **Gen2<Integer>** or not.
Casting
You can cast one instance of a generic class into another only if the two are otherwise compatible and their type arguments are the same. For example, assuming the foregoing program, this cast is legal:

```
(Gen<Integer>) iOb2 // legal
```
because `iOb2` includes an instance of `Gen<Integer>`. But, this cast:

```
(Gen<Long>) iOb2 // illegal
```
is not legal because `iOb2` is not an instance of `Gen<Long>`.

Overriding Methods in a Generic Class
A method in a generic class can be overridden just like any other method. For example, consider this program in which the method `getOb()` is overridden:
// Overriding a generic method in a generic class.
class Gen<T> {
    T ob; // declare an object of type T

    // Pass the constructor a reference to
    // an object of type T.
    Gen(T o) {
        ob = o;
    }

    // Return ob.
    T getOb() {
        System.out.print("Gen's getOb(): ", ob);
        return ob;
    }
}

// A subclass of Gen that overrides getOb().
class Gen2<T> extends Gen<T> {

    Gen2(T o) {
        super(o);
    }

    // Override getOb().
    T getOb() {
        System.out.print("Gen2's getOb(): ", ob);
        return ob;
    }
}

// Demonstrate generic method override.
class OverrideDemo {
    public static void main(String args[]) {

        // Create a Gen object for Integers.
        Gen<Integer> iOb = new Gen<Integer>(88);

        // Create a Gen2 object for Integers.
        Gen2<Integer> iOb2 = new Gen2<Integer>(99);

        // Create a Gen2 object for Strings.
        Gen2<String> strOb2 = new Gen2<String>("Generics Test");

        System.out.println(iOb.getOb());
        System.out.println(iOb2.getOb());
        System.out.println(strOb2.getOb());
    }
}

The output is shown here:

Gen's getOb(): 88
Gen2's getOb(): 99
Gen2's getOb(): Generics Test
As the output confirms, the overridden version of `getob()` is called for objects of type `Gen2`, but the superclass version is called for objects of type `Gen`.

**Type Inference with Generics**
Beginning with JDK 7, it is possible to shorten the syntax used to create an instance of a generic type. To begin, consider the following generic class:

```java
class MyClass<T, V> {
    T ob1;
    V ob2;

    MyClass(T o1, V o2) {
        ob1 = o1;
        ob2 = o2;
    }

    // ...
}
```

Prior to JDK 7, to create an instance of `MyClass`, you would have needed to use a statement similar to the following:

```java
MyClass<Integer, String> mcOb =
    new MyClass<Integer, String>(98, "A String");
```

Here, the type arguments (which are `Integer` and `String`) are specified twice: first, when `mcOb` is declared, and second, when a `MyClass` instance is created via `new`. Since generics were introduced by JDK 5, this is the form required by all versions of Java prior to JDK 7. Although there is nothing wrong, per se, with this form, it is a bit more verbose than it needs to be. In the `new` clause, the type of the type arguments can be readily inferred from the type of `mcOb`; therefore, there is really no reason that they need to be specified a second time. To address this situation, JDK 7 added a syntactic element that lets you avoid the second specification.

Today the preceding declaration can be rewritten as shown here:

```java
MyClass<Integer, String> mcOb = new MyClass<>(98, "A String");
```

Notice that the instance creation portion simply uses `< >`, which is an empty type argument list. This is referred to as the `diamond` operator. It tells the compiler to infer the type arguments needed by the constructor in the `new` expression. The principal advantage of this type-inference syntax is that it shortens what are sometimes quite long declaration statements.
The preceding can be generalized. When type inference is used, the declaration syntax for a
generic reference and instance creation has this general form:

\[
\text{class-name<type-arg-list> var-name = new class-name <>)(cons-arg-list);} \\
\]

Here, the type argument list of the constructor in the \textbf{new} clause is empty.
Type inference can also be applied to parameter passing. For example, if the following
method is added to \textbf{MyClass},

```java
boolean isSame(MyClass<T, V> o) {
    if (ob1 == o.ob1 && ob2 == o.ob2) return true;
    else return false;
}
```

then the following call is legal:

```java
if (mcOb.isSame(new MyClass<>[1, "test"])) System.out.println("Same");
```

In this case, the type arguments for the argument passed to \textbf{isSame()} can be inferred from
the parameter’s type.
Because the type-inference syntax was added by JDK 7 and won’t work with older
compilers, most of the examples in this book will continue to use the full syntax when
declaring instances of generic classes. This way, the examples will work with any Java
compiler that supports generics. Using the full-length syntax also makes it very clear
precisely what is being created, which is important in example code shown in a book.
However, in your own code, the use of the type-inference syntax will streamline your
declarations.

\textbf{Erasure}

Usually, it is not necessary to know the details about how the Java compiler transforms your
source code into object code. However, in the case of generics, some general understanding
of the process is important because it explains why the generic features work as they do—
and why their behavior is sometimes a bit surprising. For this reason, a brief discussion of
how generics are implemented in Java is in order.
An important constraint that governed the way that generics were added to Java was the
need for compatibility with previous versions of Java. Simply put, generic code had to be
compatible with preexisting, non-generic code. Thus, any changes to the syntax of the Java
language, or to the JVM, had to avoid breaking older code. The way Java implements
generics while satisfying this constraint is through the use of \textbf{erasure}.
In general, here is how erasure works. When your Java code is compiled, all generic type
information is removed (erased). This means replacing type parameters with their bound
type, which is \textbf{Object} if no explicit bound is specified, and then applying the appropriate
casts (as determined by the type arguments) to maintain type compatibility with the types specified by the type arguments. The compiler also enforces this type compatibility. This approach to generics means that no type parameters exist at run time. They are simply a source-code mechanism.

**Bridge Methods**

Occasionally, the compiler will need to add a *bridge method* to a class to handle situations in which the type erasure of an overriding method in a subclass does not produce the same erasure as the method in the superclass. In this case, a method is generated that uses the type erasure of the superclass, and this method calls the method that has the type erasure specified by the subclass. Of course, bridge methods only occur at the bytecode level, are not seen by you, and are not available for your use.

Although bridge methods are not something that you will normally need to be concerned with, it is still instructive to see a situation in which one is generated. Consider the following program:
In the program, the subclass `Gen2` extends `Gen`, but does so using a `String`-specific version of `Gen`, as its declaration shows:

```java
class Gen2 extends Gen<String> {
    Gen2(String o) {
        super(o);
    }

    // A String-specific override of getob().
    String getob() {
        System.out.print("You called String getob(): ");
        return ob;
    }
}
```

Furthermore, inside `Gen2`, `getob()` is overridden with `String` specified as the return type:
All of this is perfectly acceptable. The only trouble is that because of type erasure, the expected form of `getob()` will be

```java
Object getob() { // ...
}
```

To handle this problem, the compiler generates a bridge method with the preceding signature that calls the `String` version. Thus, if you examine the class file for `Gen2` by using `javap`, you will see the following methods:

```java
class Gen2 extends Gen<java.lang.String> {
    Gen2(java.lang.String);
    java.lang.String getob();
    java.lang.Object getob(); // bridge method
}
```

As you can see, the bridge method has been included. (The comment was added by the author and not by `javap`, and the precise output you see may vary based on the version of Java that you are using.)

There is one last point to make about this example. Notice that the only difference between the two `getob()` methods is their return type. Normally, this would cause an error, but because this does not occur in your source code, it does not cause a problem and is handled correctly by the JVM.

**Ambiguity Errors**

The inclusion of generics gives rise to a new type of error that you must guard against: ambiguity. Ambiguity errors occur when erasure causes two seemingly distinct generic declarations to resolve to the same erased type, causing a conflict. Here is an example that involves method overloading:
// Ambiguity caused by erasure on overloaded methods.
class MyGenClass<T, V> {
    T ob1;
    V ob2;

    // ...
    // These two overloaded methods are ambiguous
    // and will not compile.
    void set(T o) {
        ob1 = o;
    }

    void set(V o) {
        ob2 = o;
    }
}

Notice that MyGenClass declares two generic types: T and V. Inside MyGenClass, an attempt is made to overload set( ) based on parameters of type T and V. This looks reasonable because T and V appear to be different types. However, there are two ambiguity problems here.
First, as MyGenClass is written, there is no requirement that T and V actually be different types. For example, it is perfectly correct (in principle) to construct a MyGenClass object as shown here:

    MyGenClass<String, String> obj = new MyGenClass<String, String>();

In this case, both T and V will be replaced by String. This makes both versions of set( ) identical, which is, of course, an error.
The second and more fundamental problem is that the type erasure of set( ) reduces both versions to the following:

    void set(Object o) { // ...

Thus, the overloading of set( ) as attempted in MyGenClass is inherently ambiguous. Ambiguity errors can be tricky to fix. For example, if you know that V will always be some type of Number, you might try to fix MyGenClass by rewriting its declaration as shown here:

    class MyGenClass<T, V extends Number> { // almost OK

This change causes MyGenClass to compile, and you can even instantiate objects like the
This works because Java can accurately determine which method to call. However, ambiguity returns when you try this line:

```
MyGenClass<Number, Number> x = new MyGenClass<Number, Number>();
```

In this case, since both `T` and `V` are `Number`, which version of `set()` is to be called? The call to `set()` is now ambiguous. Frankly, in the preceding example, it would be much better to use two separate method names, rather than trying to overload `set()`. Often, the solution to ambiguity involves the restructuring of the code, because ambiguity frequently means that you have a conceptual error in your design.

**Some Generic Restrictions**

There are a few restrictions that you need to keep in mind when using generics. They involve creating objects of a type parameter, static members, exceptions, and arrays. Each is examined here.

**Type Parameters Can’t Be Instantiated**

It is not possible to create an instance of a type parameter. For example, consider this class:

```java
// Can't create an instance of T.
class Gen<T> {
    T ob;

    Gen() {
        ob = new T(); // Illegal!!!
    }
}
```

Here, it is illegal to attempt to create an instance of `T`. The reason should be easy to understand: the compiler does not know what type of object to create. `T` is simply a placeholder.

**Restrictions on Static Members**

No `static` member can use a type parameter declared by the enclosing class. For example, both of the `static` members of this class are illegal:
Although you can’t declare `static` members that use a type parameter declared by the enclosing class, you can declare `static` generic methods, which define their own type parameters, as was done earlier in this chapter.

**Generic Array Restrictions**

There are two important generics restrictions that apply to arrays. First, you cannot instantiate an array whose element type is a type parameter. Second, you cannot create an array of type-specific generic references. The following short program shows both situations:

```java
class Wrong<T> {
    // Wrong, no static variables of type T.
    static T ob;

    // Wrong, no static method can use T.
    static T getob() {
        return ob;
    }
}
```

```java
// Generics and arrays.
class Gen<T extends Number> {
    T ob;
    T vals[]; // OK

    Gen(T o, T[] nums) {
        ob = o;

        // This statement is illegal.
        // vals = new T[10]; // can't create an array of T

        // But, this statement is OK.
        vals = nums; // OK to assign reference to existent array
    }
}

class GenArrays {
    public static void main(String args[]) {
        Integer n[] = { 1, 2, 3, 4, 5 };

        Gen<Integer> iob = new Gen<Integer>(50, n);

        // Can't create an array of type-specific generic references.
        // Gen<Integer> gens[] = new Gen<Integer>[10]; // Wrong!

        // This is OK.
        Gen<?> gens[] = new Gen<?>[10]; // OK
    }
}
```
As the program shows, it's valid to declare a reference to an array of type \( T \), as this line does:

\[
T \ \text{vals}[]; \quad // \ \text{OK}
\]

But, you cannot instantiate an array of \( T \), as this commented-out line attempts:

\[
// \ \text{vals} = \text{new T}[10]; \quad // \ \text{can't create an array of T}
\]

The reason you can't create an array of \( T \) is that there is no way for the compiler to know what type of array to actually create.
However, you can pass a reference to a type-compatible array to \( \text{Gen}() \) when an object is created and assign that reference to \( \text{vals} \), as the program does in this line:

\[
\text{vals} = \text{nums}; \quad // \ \text{OK to assign reference to existent array}
\]

This works because the array passed to \( \text{Gen}() \) has a known type, which will be the same type as \( T \) at the time of object creation.
Inside \( \text{main}() \), notice that you can't declare an array of references to a specific generic type. That is, this line

\[
// \ \text{Gen<Integer>} \ \text{gens}[] = \text{new Gen<Integer>}[10]; \quad // \ \text{Wrong!}
\]

won't compile.
You can create an array of references to a generic type if you use a wildcard, however, as shown here:

\[
\text{Gen<?>} \ \text{gens}[] = \text{new Gen<?>}[10]; \quad // \ \text{OK}
\]

This approach is better than using an array of raw types, because at least some type checking will still be enforced.

**Generic Exception Restriction**
A generic class cannot extend \( \text{Throwable} \). This means that you cannot create generic exception classes.
During Java's ongoing development and evolution, many features have been added since its original 1.0 release. However, two stand out because they have profoundly reshaped the language, fundamentally changing the way that code is written. The first was the addition of generics, added by JDK 5. (See Chapter 14.) The second is the lambda expression, which is the subject of this chapter.

Added by JDK 8, lambda expressions (and their related features) significantly enhance Java because of two primary reasons. First, they add new syntax elements that increase the expressive power of the language. In the process, they streamline the way that certain common constructs are implemented. Second, the addition of lambda expressions resulted in new capabilities being incorporated into the API library. Among these new capabilities are the ability to more easily take advantage of the parallel processing capabilities of multi-core environments, especially as it relates to the handling of for-each style operations, and the new stream API, which supports pipeline operations on data. The addition of lambda expressions also provided the catalyst for other new Java features, including the default method (described in Chapter 9), which lets you define default behavior for an interface method, and the method reference (described here), which lets you refer to a method without executing it.

Beyond the benefits that lambda expressions bring to the language, there is another reason why they constitute an important addition to Java. Over the past few years, lambda expressions have become a major focus of computer language design. For example, they have been added to languages such as C# and C++. Their inclusion in JDK 8 helps Java remain the vibrant, innovative language that programmers have come to expect.

In the final analysis, in much the same way that generics reshaped Java several years ago, lambda expressions are reshaping Java today. Simply put, lambda expressions will impact virtually all Java programmers. They truly are that important.

**Introducing Lambda Expressions**

Key to understanding Java’s implementation of lambda expressions are two constructs. The first is the lambda expression, itself. The second is the functional interface. Let’s begin with a simple definition of each.
A lambda expression is, essentially, an anonymous (that is, unnamed) method. However, this method is not executed on its own. Instead, it is used to implement a method defined by a functional interface. Thus, a lambda expression results in a form of anonymous class. Lambda expressions are also commonly referred to as closures.

A functional interface is an interface that contains one and only one abstract method. Normally, this method specifies the intended purpose of the interface. Thus, a functional interface typically represents a single action. For example, the standard interface Runnable is a functional interface because it defines only one method: run(). Therefore, run() defines the action of Runnable. Furthermore, a functional interface defines the target type of a lambda expression. Here is a key point: a lambda expression can be used only in a context in which its target type is specified. One other thing: a functional interface is sometimes referred to as a SAM type, where SAM stands for Single Abstract Method.

NOTE  A functional interface may specify any public method defined by Object, such as equals(), without affecting its “functional interface” status. The public Object methods are considered implicit members of a functional interface because they are automatically implemented by an instance of a functional interface.

Let’s now look more closely at both lambda expressions and functional interfaces.

Lambda Expression Fundamentals

The lambda expression introduces a new syntax element and operator into the Java language. The new operator, sometimes referred to as the lambda operator or the arrow operator, is \( \rightarrow \). It divides a lambda expression into two parts. The left side specifies any parameters required by the lambda expression. (If no parameters are needed, an empty parameter list is used.) On the right side is the lambda body, which specifies the actions of the lambda expression. The \( \rightarrow \) can be verbalized as “becomes” or “goes to.” Java defines two types of lambda bodies. One consists of a single expression, and the other type consists of a block of code. We will begin with lambdas that define a single expression. Lambdas with block bodies are discussed later in this chapter.

At this point, it will be helpful to look a few examples of lambda expressions before continuing. Let’s begin with what is probably the simplest type of lambda expression you can write. It evaluates to a constant value and is shown here:

\[
() \rightarrow 123.45
\]
This lambda expression takes no parameters, thus the parameter list is empty. It returns the constant value 123.45. Therefore, it is similar to the following method:

```java
double myMethod() { return 123.45; }
```

Of course, the method defined by a lambda expression does not have a name.

A slightly more interesting lambda expression is shown here:

```java
() -> Math.random() * 100
```

This lambda expression obtains a pseudo-random value from `Math.random()`, multiplies it by 100, and returns the result. It, too, does not require a parameter.

When a lambda expression requires a parameter, it is specified in the parameter list on the left side of the lambda operator. Here is a simple example:

```java
(n) -> (n % 2) == 0
```

This lambda expression returns `true` if the value of parameter `n` is even. Although it is possible to explicitly specify the type of a parameter, such as `n` in this case, often you won’t need to do so because in many cases its type can be inferred. Like a named method, a lambda expression can specify as many parameters as needed.

### Functional Interfaces

As stated, a functional interface is an interface that specifies only one abstract method. If you have been programming in Java for some time, you might at first think that all interface methods are implicitly abstract. Although this was true prior to JDK 8, the situation has changed. As explained in Chapter 9, beginning with JDK 8, it is possible to specify default behavior for a method declared in an interface. This is called a default method. Today, an interface method is abstract only if it does not specify a default implementation. Because nondefault interface methods are implicitly abstract, there is no need to use the `abstract` modifier (although you can specify it, if you like).

Here is an example of a functional interface:

```java
interface MyNumber {
    double getValue();
}
```

In this case, the method `getValue()` is implicitly abstract, and it is the only method defined by `MyNumber`. Thus, `MyNumber` is a functional interface, and its function is defined by `getValue()`.

As mentioned earlier, a lambda expression is not executed on its own. Rather, it forms the implementation of the abstract method defined by the functional interface that specifies its
target type. As a result, a lambda expression can be specified only in a context in which a
target type is defined. One of these contexts is created when a lambda expression is
assigned to a functional interface reference. Other target type contexts include variable
initialization, return statements, and method arguments, to name a few.
Let's work through an example that shows how a lambda expression can be used in an
assignment context. First, a reference to the functional interface MyNumber is declared:

```java
// Create a reference to a MyNumber instance.
MyNumber myNum;
```

Next, a lambda expression is assigned to that interface reference:

```java
// Use a lambda in an assignment context.
myNum = () -> 123.45;
```

When a lambda expression occurs in a target type context, an instance of a class is
automatically created that implements the functional interface, with the lambda expression
defining the behavior of the abstract method declared by the functional interface. When that
method is called through the target, the lambda expression is executed. Thus, a lambda
expression gives us a way to transform a code segment into an object.
In the preceding example, the lambda expression becomes the implementation for the
getValue( ) method. As a result, the following displays the value 123.45:

```java
// Call getValue(), which is implemented by the previously assigned
// lambda expression.
System.out.println("myNum.getValue()");
```

Because the lambda expression assigned to myNum returns the value 123.45, that is the
value obtained when getValue( ) is called.
In order for a lambda expression to be used in a target type context, the type of the abstract
method and the type of the lambda expression must be compatible. For example, if the
abstract method specifies two int parameters, then the lambda must specify two parameters
whose type either is explicitly int or can be implicitly inferred as int by the context. In
general, the type and number of the lambda expression’s parameters must be compatible
with the method’s parameters; the return types must be compatible; and any exceptions
thrown by the lambda expression must be acceptable to the method.

### Some Lambda Expression Examples

With the preceding discussion in mind, let’s look at some simple examples that illustrate the
basic lambda expression concepts. The first example puts together the pieces shown in the
foregoing section.
Sample output from the program is shown here:

```
A fixed value: 123.45
A random value: 88.90663650412304
Another random value: 53.00582701784129
```

As mentioned, the lambda expression must be compatible with the abstract method that it is intended to implement. For this reason, the commented-out line at the end of the preceding program is illegal because a value of type `String` is not compatible with `double`, which is the return type required by `getValue()`. The next example shows the use of a parameter with a lambda expression:
The output from this program is shown here:

```
10 is even
9 is not even
1 is non-negative
-1 is negative
```

This program demonstrates a key fact about lambda expressions that warrants close examination. Pay special attention to the lambda expression that performs the test for evenness. It is shown again here:

```
(n) -> (n % 2) == 0
```

Notice that the type of `n` is not specified. Rather, its type is inferred from the context. In this case, its type is inferred from the parameter type of `test()` as defined by the `NumericTest` interface, which is `int`. It is also possible to explicitly specify the type of a parameter in a lambda expression. For example, this is also a valid way to write the preceding:

```
(int n) -> (n % 2) == 0
```

Here, `n` is explicitly specified as `int`. Usually it is not necessary to explicitly specify the type,
but you can in those situations that require it.

This program demonstrates another important point about lambda expressions: A functional interface reference can be used to execute any lambda expression that is compatible with it. Notice that the program defines two different lambda expressions that are compatible with the `test()` method of the functional interface `NumericTest`. The first, called `isEven`, determines if a value is even. The second, called `isNonNeg`, checks if a value is non-negative. In each case, the value of the parameter `n` is tested. Because each lambda expression is compatible with `test()`, each can be executed through a `NumericTest` reference.

One other point before moving on. When a lambda expression has only one parameter, it is not necessary to surround the parameter name with parentheses when it is specified on the left side of the lambda operator. For example, this is also a valid way to write the lambda expression used in the program:

\[
\text{n} \rightarrow (n \& 2) == 0
\]

For consistency, this book will surround all lambda expression parameter lists with parentheses, even those containing only one parameter. Of course, you are free to adopt a different style.

The next program demonstrates a lambda expression that takes two parameters. In this case, the lambda expression tests if one number is a factor of another.

```java
// Demonstrate a lambda expression that takes two parameters.

interface NumericTest2 {
    boolean test(int n, int d);
}

class LambdaDemo3 {
    public static void main(String args[]) {
        // This lambda expression determines if one number is a factor of another.
        NumericTest2 isFactor = (n, d) -> (n % d) == 0;
        
        if(isFactor.test(10, 2))
            System.out.println("2 is a factor of 10");
        if(!isFactor.test(10, 3))
            System.out.println("3 is not a factor of 10");
    }
}
```

The output is shown here:
In this program, the functional interface `NumericTest2` defines the `test()` method:

```java
    boolean test(int n, int d);
```

In this version, `test()` specifies two parameters. Thus, for a lambda expression to be compatible with `test()`, the lambda expression must also specify two parameters. Notice how they are specified:

```java
    (n, d) -> (n % d) == 0
```

The two parameters, `n` and `d`, are specified in the parameter list, separated by commas. This example can be generalized. Whenever more than one parameter is required, the parameters are specified, separated by commas, in a parenthesized list on the left side of the lambda operator.

Here is an important point about multiple parameters in a lambda expression: If you need to explicitly declare the type of a parameter, then all of the parameters must have declared types. For example, this is legal:

```java
    (int n, int d) -> (n % d) == 0
```

But this is not:

```java
    (int n, d) -> (n % d) == 0
```

### Block Lambda Expressions

The body of the lambdas shown in the preceding examples consist of a single expression. These types of lambda bodies are referred to as **expression bodies**, and lambdas that have expression bodies are sometimes called **expression lambdas**. In an expression body, the code on the right side of the lambda operator must consist of a single expression. While expression lambdas are quite useful, sometimes the situation will require more than a single expression. To handle such cases, Java supports a second type of lambda expression in which the code on the right side of the lambda operator consists of a block of code that can contain more than one statement. This type of lambda body is called a **block body**. Lambdas that have block bodies are sometimes referred to as **block lambdas**.

A block lambda expands the types of operations that can be handled within a lambda expression because it allows the body of the lambda to contain multiple statements. For example, in a block lambda you can declare variables, use loops, specify **if** and **switch** statements, create nested blocks, and so on. A block lambda is easy to create. Simply enclose the body within braces as you would any other block of statements.
Aside from allowing multiple statements, block lambdas are used much like the expression lambdas just discussed. One key difference, however, is that you must explicitly use a **return** statement to return a value. This is necessary because a block lambda body does not represent a single expression.

Here is an example that uses a block lambda to compute and return the factorial of an **int** value:

```java
// A block lambda that computes the factorial of an int value.
interface NumericFunc {
    int func(int n);
}

class BlockLambdaDemo {
    public static void main(String args[]) {
        // This block lambda computes the factorial of an int value.
        NumericFunc factorial = (n) -> {
            int result = 1;
            for (int i=1; i <= n; i++)
                result = i * result;
            return result;
        };

        System.out.println("The factorial of 3 is " + factorial.func(3));
        System.out.println("The factorial of 5 is " + factorial.func(5));
    }
}
```

The output is shown here:

```
The factorial of 3 is 6
The factorial of 5 is 120
```

In the program, notice that the block lambda declares a variable called **result**, uses a **for** loop, and has a **return** statement. These are legal inside a block lambda body. In essence, the block body of a lambda is similar to a method body. One other point. When a **return** statement occurs within a lambda expression, it simply causes a return from the lambda. It does not cause an enclosing method to return.

Another example of a block lambda is shown in the following program. It reverses the characters in a string.
In this example, the functional interface `StringFunc` declares the `func()` method. This method takes a parameter of type `String` and has a return type of `String`. Thus, in the reverse lambda expression, the type of `str` is inferred to be `String`. Notice that the `charAt()` method is called on `str`. This is legal because of the inference that `str` is of type `String`.

### Generic Functional Interfaces

A lambda expression, itself, cannot specify type parameters. Thus, a lambda expression cannot be generic. (Of course, because of type inference, all lambda expressions exhibit some “generic-like” qualities.) However, the functional interface associated with a lambda expression can be generic. In this case, the target type of the lambda expression is determined, in part, by the type argument or arguments specified when a functional interface reference is declared.
To understand the value of generic functional interfaces, consider this. The two examples in the previous section used two different functional interfaces, one called `NumericFunc` and the other called `StringFunc`. However, both defined a method called `func()` that took one parameter and returned a result. In the first case, the type of the parameter and return type was `int`. In the second case, the parameter and return type was `String`. Thus, the only difference between the two methods was the type of data they required. Instead of having two functional interfaces whose methods differ only in their data types, it is possible to declare one generic interface that can be used to handle both circumstances. The following program shows this approach:

```java
// Use a generic functional interface with lambda expressions.

// A generic functional interface.
interface SomeFunc<T> {
    T func(T t);
}

class GenericFunctionalInterfaceDemo {
    public static void main(String args[]) {

        // Use a String-based version of SomeFunc.
        SomeFunc<String> reverse = (str) -> {
            String result = "";
            int i;
            for (i = str.length() - 1; i >= 0; i--)
                result += str.charAt(i);
            return result;
        };
        System.out.println("Lambda reversed is "+
                            reverse.func("Lambda"));
        System.out.println("Expression reversed is "+
                            reverse.func("Expression"));

        // Now, use an Integer-based version of SomeFunc.
        SomeFunc<Integer> factorial = (n) -> {
            int result = 1;
            for (int i = 1; i <= n; i++)
                result *= result;
            return result;
        };
        System.out.println("The factorial of 3 is "+factorial.func(3));
        System.out.println("The factorial of 5 is "+factorial.func(5));
    }
}
```
In the program, the generic functional interface `SomeFunc` is declared as shown here:

```
interface SomeFunc<T> {
    T func(T t);
}
```

Here, `T` specifies both the return type and the parameter type of `func()`. This means that it is compatible with any lambda expression that takes one parameter and returns a value of the same type.

The `SomeFunc` interface is used to provide a reference to two different types of lambdas. The first uses type `String`, and the second uses type `Integer`. Thus, the same functional interface can be used to refer to the `reverse` lambda and the `factorial` lambda. Only the type argument passed to `SomeFunc` differs.

**Passing Lambda Expressions as Arguments**

As explained earlier, a lambda expression can be used in any context that provides a target type. One of these is when a lambda expression is passed as an argument. In fact, passing a lambda expression as an argument is a common use of lambdas. Moreover, it is a very powerful use because it gives you a way to pass executable code as an argument to a method. This greatly enhances the expressive power of Java.

To pass a lambda expression as an argument, the type of the parameter receiving the lambda expression argument must be of a functional interface type compatible with the lambda. Although using a lambda expression as an argument is straightforward, it is still helpful to see it in action. The following program demonstrates the process:

```
Lambda reversed is adbmaL
Expression reversed is noisserpxE
The factorial of 3 is 6
The factorial of 5 is 120
```
// Use lambda expressions as an argument to a method.

interface StringFunc {
    String func(String n);
}

class LambdasAsArgumentsDemo {

    // This method has a functional interface as the type of
    // its first parameter. Thus, it can be passed a reference to
    // any instance of that interface, including the instance created
    // by a lambda expression.
    // The second parameter specifies the string to operate on.
    static String stringOp(StringFunc sf, String s) {
        return sf.func(s);
    }

    public static void main(String args[])
```java
{  
    String inStr = "Lambdas add power to Java";
    String outStr;
    System.out.println("Here is input string: " + inStr);

    // Here, a simple expression lambda that uppercases a string
    // is passed to stringOp().
    outStr = stringOp(str) -> str.toUpperCase().
    System.out.println("The string in uppercase: " + outStr);

    // This passes a block lambda that removes spaces.
    outStr = stringOp((str) -> {
        String result = "";
        int i;
        for(i = 0; i < str.length(); i++)
            if(str.charAt(i) == ' ')
                result += str.charAt(i);
            return result;
    }, inStr);
    System.out.println("The string with spaces removed: " + outStr);

    // Of course, it is also possible to pass a StringFunc instance
    // created by an earlier lambda expression. For example,
    // after this declaration executes, reverse refers to an
    // instance of StringFunc.
    StringFunc reverse = (str) -> {
        String result = "";
        int i;
        for(i = str.length()-1; i > 0; i--)
            result += str.charAt(i);
        return result;
    };

    // Now, reverse can be passed as the first parameter to stringOp()
    // since it refers to a StringFunc object.
    System.out.println("The string reversed: " +
        stringOp(reverse, inStr));
}
```

The output is shown here:

Here is input string: Lambdas add power to Java
The string in uppercase: LAMBDAS ADD POWER TO JAVA
The string with spaces removed: LambdasaddpowerToJava
The string reversed: avaj ot rewop dda sadbmaL
In the program, first notice the `stringOp()` method. It has two parameters. The first is of type `StringFunc`, which is a functional interface. Thus, this parameter can receive a reference to any instance of `StringFunc`, including one created by a lambda expression. The second argument of `stringOp()` is of type `String`, and this is the string operated on.

Next, notice the first call to `stringOp()`, shown again here:

```java
outStr = stringOp((str) -> str.toUpperCase(), inStr);
```

Here, a simple expression lambda is passed as an argument. When this occurs, an instance of the functional interface `StringFunc` is created and a reference to that object is passed to the first parameter of `stringOp()`. Thus, the lambda code, embedded in a class instance, is passed to the method. The target type context is determined by the type of parameter. Because the lambda expression is compatible with that type, the call is valid. Embedding simple lambdas, such as the one just shown, inside a method call is often a convenient technique—especially when the lambda expression is intended for a single use.

Next, the program passes a block lambda to `stringOp()`. This lambda removes spaces from a string. It is shown again here:

```java
outStr = stringOp((str) -> {
    String result = "";
    int i;
    for(i = 0; i < str.length(); i++)
        if(str.charAt(i) != ' ')
            result += str.charAt(i);
    return result;
}, inStr);
```

Although this uses a block lambda, the process of passing the lambda expression is the same as just described for the simple expression lambda. In this case, however, some programmers will find the syntax a bit awkward.

When a block lambda seems overly long to embed in a method call, it is an easy matter to assign that lambda to a functional interface variable, as the previous examples have done. Then, you can simply pass that reference to the method. This technique is shown at the end of the program. There, a block lambda is defined that reverses a string. This lambda is assigned to `reverse`, which is a reference to a `StringFunc` instance. Thus, `reverse` can be used as an argument to the first parameter of `stringOp()`. The program then calls `stringOp()`, passing in `reverse` and the string on which to operate. Because the instance obtained by the evaluation of each lambda expression is an implementation of `StringFunc`, each can be used as the first parameter to `stringOp()`.

One last point: In addition to variable initialization, assignment, and argument passing, the
Lambda Expressions and Exceptions

A lambda expression can throw an exception. However, if it throws a checked exception, then that exception must be compatible with the exception(s) listed in the `throws` clause of the abstract method in the functional interface. Here is an example that illustrates this fact. It computes the average of an array of `double` values. If a zero-length array is passed, however, it throws the custom exception `EmptyArrayException`. As the example shows, this exception is listed in the `throws` clause of `func()` declared inside the `DoubleNumericArrayFunc` functional interface.

```java
// Throw an exception from a lambda expression.
interface DoubleNumericArrayFunc {
    double func(double[] n) throws EmptyArrayException;
}

class EmptyArrayException extends Exception {
    EmptyArrayException() {
        super("Array Empty");
    }
}

class LambdaExceptionDemo {
    public static void main(String args[]) throws EmptyArrayException {
        double[] values = {1.0, 2.0, 3.0, 4.0};

        // This block lambda computes the average of an array of doubles.
        DoubleNumericArrayFunc average = (n) -> {
            double sum = 0;
            if(n.length == 0)
                throw new EmptyArrayException();
            for(int i=0; i < n.length; i++)
                sum += n[i];
            return sum / n.length;
        };

        System.out.println("The average is " + average.func(values));
        // This causes an exception to be thrown.
        System.out.println("The average is " + average.func(new double[0]));
    }
}
```

The first call to `average.func()` returns the value 2.5. The second call, which passes a zero-length array, causes an `EmptyArrayException` to be thrown. Remember, the inclusion of the `throws` clause in `func()` is necessary. Without it, the program will not
Because the lambda expression will no longer be compatible with `func()`. This example demonstrates another important point about lambda expressions. Notice that the parameter specified by `func()` in the functional interface `DoubleNumericArrayFunc` is an array. However, the parameter to the lambda expression is simply `n`, rather than `n[ ]`. Remember, the type of a lambda expression parameter will be inferred from the target context. In this case, the target context is `double[ ]`, thus the type of `n` will be `double[ ]`. It is not necessary (or legal) to specify it as `n[ ]`. It would be legal to explicitly declare it as `double[ ] n`, but doing so gains nothing in this case.

**Lambda Expressions and Variable Capture**

Variables defined by the enclosing scope of a lambda expression are accessible within the lambda expression. For example, a lambda expression can use an instance or static variable defined by its enclosing class. A lambda expression also has access to this (both explicitly and implicitly), which refers to the invoking instance of the lambda expression’s enclosing class. Thus, a lambda expression can obtain or set the value of an instance or static variable and call a method defined by its enclosing class.

However, when a lambda expression uses a local variable from its enclosing scope, a special situation is created that is referred to as a variable capture. In this case, a lambda expression may only use local variables that are effectively final. An effectively final variable is one whose value does not change after it is first assigned. There is no need to explicitly declare such a variable as final, although doing so would not be an error. (The this parameter of an enclosing scope is automatically effectively final, and lambda expressions do not have a this of their own.)

It is important to understand that a local variable of the enclosing scope cannot be modified by the lambda expression. Doing so would remove its effectively final status, thus rendering it illegal for capture.

The following program illustrates the difference between effectively final and mutable local variables:
As the comments indicate, `num` is effectively final and can, therefore, be used inside `myLambda`. However, if `num` were to be modified, either inside the lambda or outside of it, `num` would lose its effectively final status. This would cause an error, and the program would not compile.

It is important to emphasize that a lambda expression can use and modify an instance variable from its invoking class. It just can’t use a local variable of its enclosing scope unless that variable is effectively final.

**Method References**

There is an important feature related to lambda expressions called the *method reference*. A method reference provides a way to refer to a method without executing it. It relates to lambda expressions because it, too, requires a target type context that consists of a compatible functional interface. When evaluated, a method reference also creates an instance of the functional interface.

There are different types of method references. We will begin with method references to static methods.

**Method References to static Methods**

To create a static method reference, use this general syntax:

```
ClassName::methodName
```
Notice that the class name is separated from the method name by a double colon. The :: is a new separator that has been added to Java by JDK 8 expressly for this purpose. This method reference can be used anywhere in which it is compatible with its target type.

The following program demonstrates a **static** method reference:

```java
// Demonstrate a method reference for a static method.

// A functional interface for string operations.
interface StringFunc {
  String func(String n);
}

// This class defines a static method called strReverse().
class MyStringOps {
  // A static method that reverses a string.
  static String strReverse(String str) {
    String result = "";

    int i;
    for(i = str.length() - 1; i >= 0; i--)
      result += str.charAt(i);
    return result;
  }
}

class MethodRefDemo {
  // This method has a functional interface as the type of
  // its first parameter. Thus, it can be passed any instance
  // of that interface, including a method reference.
  static String stringOp(StringFunc sf, String s) {
    return sf.func(s);
  }

  public static void main(String args[]) 
  {
    String inStr = "Lambdas add power to Java";
    String outStr;

    // Here, a method reference to strReverse is passed to stringOp().
    outStr = stringOp(MyStringOps::strReverse, inStr);
    System.out.println("Original string: " + inStr);
    System.out.println("String reversed: " + outStr);
  }
}
```

The output is shown here:
In the program, pay special attention to this line:

```java
outStr = stringOp(MyStringOps::strReverse, inStr);
```

Here, a reference to the `static` method `strReverse`, declared inside `MyStringOps`, is passed as the first argument to `stringOp()`. This works because `strReverse` is compatible with the `StringFunc` functional interface. Thus, the expression `MyStringOps::strReverse` evaluates to a reference to an object in which `strReverse` provides the implementation of `func()` in `StringFunc`.

**Method References to Instance Methods**

To pass a reference to an instance method on a specific object, use this basic syntax:

```java
objRef::methodName
```

As you can see, the syntax is similar to that used for a `static` method, except that an object reference is used instead of a class name. Here is the previous program rewritten to use an instance method reference:
This program produces the same output as the previous version. In the program, notice that `strReverse()` is now an instance method of `MyStringOps`. Inside `main()`, an instance of `MyStringOps` called `strOps` is created. This instance is used to create the method reference to `strReverse` in the call to `stringOp`, as shown again, here:

```java
outStr = stringOp(strOps::strReverse, inStr);
```
In this example, `strReverse()` is called on the `strOps` object. It is also possible to handle a situation in which you want to specify an instance method that can be used with any object of a given class—not just a specified object. In this case, you will create a method reference as shown here:

```
ClassName::instanceMethodName
```

Here, the name of the class is used instead of a specific object, even though an instance method is specified. With this form, the first parameter of the functional interface matches the invoking object and the second parameter matches the parameter specified by the method. Here is an example. It defines a method called `counter()` that counts the number of objects in an array that satisfy the condition defined by the `func()` method of the `MyFunc` functional interface. In this case, it counts instances of the `HighTemp` class.

```java
// Use an instance method reference with different objects.
// A functional interface that takes two reference arguments
// and returns a boolean result.
interface MyFunc<T> {
    boolean func(T v1, T v2);
}

// A class that stores the temperature high for a day.
class HighTemp {
    private int hTemp;
    HighTemp(int ht) { hTemp = ht; }
    // Return true if the invoking HighTemp object has the same
    // temperature as ht2.
    boolean sameTemp(HighTemp ht2) {
        return hTemp == ht2.hTemp;
    }
    // Return true if the invoking HighTemp object has a temperature
    // that is less than ht2.
    boolean lessThanTemp(HighTemp ht2) {
        return hTemp < ht2.hTemp;
    }
}

class InstanceMethodWithObjectRefDemo {

    // A method that returns the number of occurrences
    // of an object for which some criteria, as specified by
    // the MyFunc parameter, is true.
    static <T> int counter(T[] vals, MyFunc<T> f, T v) {
```
```java
int count = 0;

for(int i=0; i < vals.length; i++)
    if(f.func(vals[i], v)) count++;

return count;
}

public static void main(String args[])
{
    int count;

    // Create an array of HighTemp objects.
    HighTemp[] weekDayHighs = { new HighTemp(89), new HighTemp(92),
                                new HighTemp(90), new HighTemp(89),
                                new HighTemp(89), new HighTemp(91),
                                new HighTemp(84), new HighTemp(92) };

    // Use counter() with arrays of the class HighTemp.
    // Notice that a reference to the instance method
    // sameTemp() is passed as the second argument.
    count = counter(weekDayHighs, HighTemp::sameTemp,
                    new HighTemp(89));
    System.out.println(count + " days had a high of 89");

    // Now, create and use another array of HighTemp objects.
    HighTemp[] weekDayHighs2 = { new HighTemp(32), new HighTemp(12),
                                new HighTemp(24), new HighTemp(19),
                                new HighTemp(18), new HighTemp(12),
                                new HighTemp(-1), new HighTemp(13) };

    count = counter(weekDayHighs2, HighTemp::sameTemp,
                    new HighTemp(12));
    System.out.println(count + " days had a high of 12");

    // Now, use lessThanTemp() to find days when temperature was less
    // than a specified value.
    count = counter(weekDayHighs, HighTemp::lessThanTemp,
                    new HighTemp(89));
    System.out.println(count + " days had a high less than 89");

    count = counter(weekDayHighs2, HighTemp::lessThanTemp,
                    new HighTemp(19));
    System.out.println(count + " days had a high of less than 19");
}
```

The output is shown here:

3 days had a high of 89
2 days had a high of 12
3 days had a high less than 89
5 days had a high of less than 19
In the program, notice that \texttt{HighTemp} has two instance methods: \texttt{sameTemp()} and \texttt{lessThanTemp()}. The first returns \texttt{true} if two \texttt{HighTemp} objects contain the same temperature. The second returns \texttt{true} if the temperature of the invoking object is less than that of the passed object. Each method has a parameter of type \texttt{HighTemp} and each method returns a \texttt{boolean} result. Thus, each is compatible with the \texttt{MyFunc} functional interface because the invoking object type can be mapped to the first parameter of \texttt{func()} and the argument mapped to \texttt{func()}'s second parameter. Thus, when the expression

\begin{verbatim}
    HighTemp::sameTemp
\end{verbatim}

is passed to the \texttt{counter()} method, an instance of the functional interface \texttt{MyFunc} is created in which the parameter type of the first parameter is that of the invoking object of the instance method, which is \texttt{HighTemp}. The type of the second parameter is also \texttt{HighTemp} because that is the type of the parameter to \texttt{sameTemp()} . The same is true for the \texttt{lessThanTemp()} method.

One other point: you can refer to the superclass version of a method by use of \texttt{super}, as shown here:

\begin{verbatim}
    super::name
\end{verbatim}

The name of the method is specified by \texttt{name}.

\textbf{Method References with Generics}

You can use method references with generic classes and/or generic methods. For example, consider the following program:
// Demonstrate a method reference to a generic method
// declared inside a non-generic class.

// A functional interface that operates on an array
// and a value, and returns an int result.
interface MyFunc<T> {
    int func(T[] vals, T v);
}

// This class defines a method called countMatching() that
// returns the number of items in an array that are equal
// to a specified value. Notice that countMatching()
// is generic, but MyArrayOps is not.
class MyArrayOps {
    static <T> int countMatching(T[] vals, T v) {
        int count = 0;

        for(int i=0; i < vals.length; i++)
            if(vals[i] == v) count++;

        return count;
    }
}

class GenericMethodRefDemo {
    // This method has the MyFunc functional interface as the
    // type of its first parameter. The other two parameters
    // receive an array and a value, both of type T.
    static <T> int myOp(MyFunc<T> f, T[] vals, T v) {
        return f.func(vals, v);
    }

    public static void main(String args[]) {
        Integer[] vals = { 1, 2, 3, 4, 2, 3, 4, 4, 5 };  
        String[] strs = { "One", "Two", "Three", "Two" }; 
        int count;

        count = myOp(MyArrayOps::countMatching, vals, 4);  
        System.out.println("vals contains " + count + " 4s");

        count = myOp(MyArrayOps::countMatching, strs, "Two");  
        System.out.println("strs contains " + count + " Twos");
    }
}
In the program, `MyArrayOps` is a non-generic class that contains a generic method called `countMatching()`. The method returns a count of the elements in an array that match a specified value. Notice how the generic type argument is specified. For example, its first call in `main()`, shown here:

```java
   count = myOp(MyArrayOps::<Integer>countMatching, vals, 4);
```

passes the type argument `Integer`. Notice that it occurs after the `::`. This syntax can be generalized: When a generic method is specified as a method reference, its type argument comes after the `::` and before the method name. It is important to point out, however, that explicitly specifying the type argument is not required in this situation (and many others) because the type argument would have been automatically inferred. In cases in which a generic class is specified, the type argument follows the class name and precedes the `::`.

Although the preceding examples show the mechanics of using method references, they don’t show their real benefits. One place method references can be quite useful is in conjunction with the Collections Framework, which is described later in Chapter 18.

However, for completeness, a short, but effective, example that uses a method reference to help determine the largest element in a collection is included here. (If you are unfamiliar with the Collections Framework, return to this example after you have worked through Chapter 18.)

One way to find the largest element in a collection is to use the `max()` method defined by the `Collections` class. For the version of `max()` used here, you must pass a reference to the collection and an instance of an object that implements the `Comparator<T>` interface. This interface specifies how two objects are compared. It defines only one abstract method, called `compare()`, that takes two arguments, each the type of the objects being compared. It must return greater than zero if the first argument is greater than the second, zero if the two arguments are equal, and less than zero if the first object is less than the second.

In the past, to use `max()` with user-defined objects, an instance of `Comparator<T>` had to be obtained by first explicitly implementing it by a class, and then creating an instance of that class. This instance was then passed as the comparator to `max()`. With JDK 8, it is now possible to simply pass a reference to a comparison method to `max()` because doing so automatically implements the comparator. The following simple example shows the process by creating an `ArrayList` of `MyClass` objects and then finding the one in the list that has the highest value (as defined by the comparison method).
In the program, notice that MyClass neither defines any comparison method of its own, nor does it implement Comparator. However, the maximum value of a list of MyClass items can still be obtained by calling max() because UseMethodRef defines the static method compareMC(), which is compatible with the compare() method defined by Comparator. Therefore, there is no need to explicitly implement and create an instance of Comparator.

Constructor References
Similar to the way that you can create references to methods, you can create references to constructors. Here is the general form of the syntax that you will use:

classname::new

This reference can be assigned to any functional interface reference that defines a
method compatible with the constructor. Here is a simple example:

```java
// Demonstrate a Constructor reference.

// MyFunc is a functional interface whose method returns
// a MyClass reference.
interface MyFunc {
    MyClass func(int n);
}

class MyClass {
    private int val;

    // This constructor takes an argument.
    MyClass(int v) { val = v; }

    // This is the default constructor.
    MyClass() { val = 0; }

    // ...

    int getVal() { return val; }
}

class ConstructorRefDemo {
    public static void main(String args[]) {
        // Create a reference to the MyClass constructor.
        // Because func( ) in MyFunc takes an argument, new
        // refers to the parameterized constructor in MyClass,
        // not the default constructor.
        MyFunc myClassCons = MyClass::new;

        // Create an instance of MyClass via that constructor reference.
        MyClass mc = myClassCons.func(100);

        // Use the instance of MyClass just created.
        System.out.println("val in mc is " + mc.getVal( ));
    }
}
```

The output is shown here:

```
val in mc is 100
```

In the program, notice that the `func( )` method of `MyFunc` returns a reference of type `MyClass` and has an `int` parameter. Next, notice that `MyClass` defines two constructors. The first specifies a parameter of type `int`. The second is the default, parameterless constructor. Now, examine the following line:

```
MyFunc myClassCons = MyClass::new;
```
Here, the expression `MyClass::new` creates a constructor reference to a `MyClass` constructor. In this case, because `MyFunc`'s `func()` method takes an `int` parameter, the constructor being referred to is `MyClass(int v)` because it is the one that matches. Also notice that the reference to this constructor is assigned to a `MyFunc` reference called `myClassCons`. After this statement executes, `myClassCons` can be used to create an instance of `MyClass`, as this line shows:

```
MyClass mc = myClassCons.func(100);
```

In essence, `myClassCons` has become another way to call `MyClass(int v)`. Constructor references to generic classes are created in the same fashion. The only difference is that the type argument can be specified. This works the same as it does for using a generic class to create a method reference: simply specify the type argument after the class name. The following illustrates this by modifying the previous example so that `MyFunc` and `MyClass` are generic.

```java
// Demonstrate a constructor reference with a generic class.

// MyFunc is now a generic functional interface.
interface MyFunc<T> {
    MyClass<T> func(T n);
}

class MyClass<T> {
    private T val;
    // A constructor that takes an argument.
    MyClass(T v) { val = v; }
    // This is the default constructor.
    MyClass() { val = null; }
    // ...
    T getVal() { return val; }
}

class ConstructorRefDemo2 {
    public static void main(String args[])
    {
        // Create a reference to the MyClass<T> constructor.
        MyFunc<Integer> myClassCons = MyClass<Integer>::new;
        // Create an instance of MyClass<T> via that constructor referer
        MyClass<Integer> mc = myClassCons.func(100);
        // Use the instance of MyClass<T> just created.
        System.out.println("val in mc is "+mc.getVal());
    }
}
```
This program produces the same output as the previous version. The difference is that now both `MyFunc` and `MyClass` are generic. Thus, the sequence that creates a constructor reference can include a type argument (although one is not always needed), as shown here:

```
MyFunc<Integer> myClassCons = MyClass<Integer>::new;
```

Because the type argument `Integer` has already been specified when `myClassCons` is created, it can be used to create a `MyClass<Integer>` object, as the next line shows:

```
MyClass<Integer> mc = myClassCons.func(100);
```

Although the preceding examples demonstrate the mechanics of using a constructor reference, no one would use a constructor reference as just shown because nothing is gained. Furthermore, having what amounts to two names for the same constructor creates a confusing situation (to say the least). However, to give you the flavor of a more practical usage, the following program uses a static method, called `myClassFactory()`, that is a factory for objects of any type of `MyFunc` objects. It can be used to create any type of object that has a constructor compatible with its first parameter.
// The default constructor. This constructor
// is NOT used by this program.
MyClass() { val = null; }
// ...

T两个维护() { return val; }
}

// A simple, non-generic class.
class MyClass2 {
  String str;

  // A constructor that takes an argument.
  MyClass2(String s) { str = s; }

  // The default constructor. This constructor is NOT used by this program.
  MyClass2() { str = ""; }
  // ...

  String两个维护() { return str; }
}

class ConstructorRefDemo3 {

  // A factory method for class objects. The class must
  // have a constructor that takes one parameter of type T.
  // R specifies the type of object being created.
  static <R,T> R myClassFactory(MyFunc<R, T> cons, T v) {
      return cons.func(v);
  }

  public static void main(String args[])
  {
      // Create a reference to a MyClass constructor.
      // In this case, new refers to the constructor that
      // takes an argument.
      MyFunc<MyClass<Double>, Double> myClassCons = MyClass<Double>::new;

      // Create an instance of MyClass by use of the factory method.
      MyClass<Double> mc = myClassFactory(myClassCons, 100.1);

      // Use the instance of MyClass just created.
      System.out.println("val in mc is " + mc.两个维护());

      // Now, create a different class by use of myClassFactory().
      MyFunc<MyClass2, String> myClassCons2 = MyClass2::new;

      // Create an instance of MyClass2 by use of the factory method.
      MyClass2 mc2 = myClassFactory(myClassCons2, "Lambda");

      // Use the instance of MyClass just created.
      System.out.println("str in mc2 is " + mc2.两个维护());
  }
}
The output is shown here:

    val in mc is 100.1
    str in mc2 is Lambda

As you can see, `myClassFactory()` is used to create objects of type `MyClass<Double>` and `MyClass2`. Although both classes differ, for example `MyClass` is generic and `MyClass2` is not, both can be created by `myClassFactory()` because they both have constructors that are compatible with `func()` in `MyFunc`. This works because `myClassFactory()` is passed the constructor for the object that it builds. You might want to experiment with this program a bit, trying different classes that you create. Also try creating instances of different types of `MyClass` objects. As you will see, `myClassFactory()` can create any type of object whose class has a constructor that is compatible with `func()` in `MyFunc`. Although this example is quite simple, it hints at the power that constructor references bring to Java.

Before moving on, it is important to mention a second form of the constructor reference syntax that is used for arrays. To create a constructor reference for an array, use this construct:

```
type[]::new
```

Here, `type` specifies the type of object being created. For example, assuming the form of `MyClass` as shown in the first constructor reference example (ConstructorRefDemo) and given the `MyArrayCreator` interface shown here:

```
interface MyArrayCreator<T> {
    T func(int n);
}
```

the following creates a two-element array of `MyClass` objects and gives each element an initial value:

```
MyArrayCreator<MyClass[]> mcArrayCons = MyClass[]::new;
MyClass[] a = mcArrayCons.func(2);
a[0] = new MyClass(1);
a[1] = new MyClass(2);
```

Here, the call to `func(2)` causes a two-element array to be created. In general, a functional interface must contain a method that takes a single `int` parameter if it is to be used to refer to an array constructor.

**Predefined Functional Interfaces**
Up to this point, the examples in this chapter have defined their own functional interfaces so that the fundamental concepts behind lambda expressions and functional interfaces could be clearly illustrated. However, in many cases, you won’t need to define your own functional interface because JDK 8 adds a new package called `java.util.function` that provides several predefined ones. Although we will look at them more closely in Part II, here is a sampling:

<table>
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<tr>
<th>Interface</th>
<th>Purpose</th>
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</thead>
<tbody>
<tr>
<td>UnaryOperator&lt;T&gt;</td>
<td>Apply a unary operation to an object of type T and return the result, which is also of type T. Its method is called apply().</td>
</tr>
<tr>
<td>BinaryOperator&lt;T&gt;</td>
<td>Apply an operation to two objects of type T and return the result, which is also of type T. Its method is called apply().</td>
</tr>
<tr>
<td>Consumer&lt;T&gt;</td>
<td>Apply an operation on an object of type T. Its method is called accept().</td>
</tr>
<tr>
<td>Supplier&lt;T&gt;</td>
<td>Return an object of type T. Its method is called get().</td>
</tr>
<tr>
<td>Function&lt;T, R&gt;</td>
<td>Apply an operation to an object of type T and return the result as an object of type R. Its method is called apply().</td>
</tr>
<tr>
<td>Predicate&lt;T&gt;</td>
<td>Determine if an object of type T fulfills some constraint. Return a boolean value that indicates the outcome. Its method is called test().</td>
</tr>
</tbody>
</table>

The following program shows the `Function` interface in action by using it to rework the earlier example called `BlockLambdaDemo` that demonstrated block lambdas by implementing a factorial example. That example created its own functional interface called `NumericFunc`, but the built-in `Function` interface could have been used, as this version of the program illustrates:
// Use the Function built-in functional interface.

// Import the Function interface.
import java.util.function.Function;

class UseFunctionInterfaceDemo {
    public static void main(String args[]) {

        // This block lambda computes the factorial of an int value.
        // This time, Function is the functional interface.
        Function<Integer, Integer> factorial = (n) -> {
            int result = 1;
            for(int i=1; i <= n; i++)
                result = i * result;
            return result;
        };

        System.out.println("The factorial of 3 is " + factorial.apply(3));
        System.out.println("The factorial of 5 is " + factorial.apply(5));
    }
}
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<td>CHAPTER 24</td>
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</tbody>
</table>
A brief overview of Java’s string handling was presented in Chapter 7. In this chapter, it is described in detail. As is the case in most other programming languages, in Java a string is a sequence of characters. But, unlike some other languages that implement strings as character arrays, Java implements strings as objects of type `String`. Implementing strings as built-in objects allows Java to provide a full complement of features that make string handling convenient. For example, Java has methods to compare two strings, search for a substring, concatenate two strings, and change the case of letters within a string. Also, `String` objects can be constructed a number of ways, making it easy to obtain a string when needed.

Somewhat unexpectedly, when you create a `String` object, you are creating a string that cannot be changed. That is, once a `String` object has been created, you cannot change the characters that comprise that string. At first, this may seem to be a serious restriction. However, such is not the case. You can still perform all types of string operations. The difference is that each time you need an altered version of an existing string, a new `String` object is created that contains the modifications. The original string is left unchanged. This approach is used because fixed, immutable strings can be implemented more efficiently than changeable ones. For those cases in which a modifiable string is desired, Java provides two options: `StringBuffer` and `StringBuilder`. Both hold strings that can be modified after they are created.

The `String`, `StringBuffer`, and `StringBuilder` classes are defined in `java.lang`. Thus, they are available to all programs automatically. All are declared `final`, which means that none of these classes may be subclassed. This allows certain optimizations that increase performance to take place on common string operations. All three implement the `CharSequence` interface.

One last point: To say that the strings within objects of type `String` are unchangeable means that the contents of the `String` instance cannot be changed after it has been created. However, a variable declared as a `String` reference can be changed to point at some other `String` object at any time.

### The String Constructors
The `String` class supports several constructors. To create an empty `String`, call the default constructor. For example,

```java
String s = new String();
```

will create an instance of `String` with no characters in it.

Frequently, you will want to create strings that have initial values. The `String` class provides a variety of constructors to handle this. To create a `String` initialized by an array of characters, use the constructor shown here:

```java
String(char chars[])
```

Here is an example:

```java
char chars[] = { 'a', 'b', 'c' };
String s = new String(chars);
```

This constructor initializes `s` with the string "abc".

You can specify a subrange of a character array as an initializer using the following constructor:

```java
String(char chars[], int startIndex, int numChars)
```

Here, `startIndex` specifies the index at which the subrange begins, and `numChars` specifies the number of characters to use. Here is an example:

```java
char chars[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
String s = new String(chars, 2, 3);
```

This initializes `s` with the characters `cde`.

You can construct a `String` object that contains the same character sequence as another `String` object using this constructor:

```java
String(String strObj)
```

Here, `strObj` is a `String` object. Consider this example:
The output from this program is as follows:

Java
Java

As you can see, \texttt{s1} and \texttt{s2} contain the same string.

Even though Java’s \texttt{char} type uses 16 bits to represent the basic Unicode character set, the typical format for strings on the Internet uses arrays of 8-bit bytes constructed from the ASCII character set. Because 8-bit ASCII strings are common, the \texttt{String} class provides constructors that initialize a string when given a \texttt{byte} array. Two forms are shown here:

\begin{verbatim}
String(byte \texttt{chrs}[ ])
String(byte \texttt{chrs}[ ], int \texttt{startIndex}, int \texttt{numChars})
\end{verbatim}

Here, \texttt{chrs} specifies the array of bytes. The second form allows you to specify a subrange. In each of these constructors, the byte-to-character conversion is done by using the default character encoding of the platform. The following program illustrates these constructors:

```
// Construct string from subset of char array.
class SubStrCons {
    public static void main(String args[]) {
        byte ascii[] = {65, 66, 67, 68, 69, 70 };

        String s1 = new String(ascii);
        System.out.println(s1);

        String s2 = new String(ascii, 2, 3);
        System.out.println(s2);
    }
}
```

This program generates the following output:
Extended versions of the byte-to-string constructors are also defined in which you can specify the character encoding that determines how bytes are converted to characters. However, you will often want to use the default encoding provided by the platform.

**NOTE** The contents of the array are copied whenever you create a String object from an array. If you modify the contents of the array after you have created the string, the String will be unchanged.

You can construct a String from a StringBuffer by using the constructor shown here:

```java
String(StringBuffer strBufObj)
```

You can construct a String from a StringBuilder by using this constructor:

```java
String(StringBuilder strBuildObj)
```

The following constructor supports the extended Unicode character set:

```java
String(int codePoints[], int startIndex, int numChars)
```

Here, codePoints is an array that contains Unicode code points. The resulting string is constructed from the range that begins at startIndex and runs for numChars.

There are also constructors that let you specify a Charset.

**NOTE** A discussion of Unicode code points and how they are handled by Java is found in Chapter 17.

**String Length**

The length of a string is the number of characters that it contains. To obtain this value, call the `length()` method, shown here:

```java
int length()
```

The following fragment prints "3", since there are three characters in the string s:
Special String Operations
Because strings are a common and important part of programming, Java has added special support for several string operations within the syntax of the language. These operations include the automatic creation of new String instances from string literals, concatenation of multiple String objects by use of the + operator, and the conversion of other data types to a string representation. There are explicit methods available to perform all of these functions, but Java does them automatically as a convenience for the programmer and to add clarity.

String Literals
The earlier examples showed how to explicitly create a String instance from an array of characters by using the new operator. However, there is an easier way to do this using a string literal. For each string literal in your program, Java automatically constructs a String object. Thus, you can use a string literal to initialize a String object. For example, the following code fragment creates two equivalent strings:

```java
char chars[] = { 'a', 'b', 'c' };
String s = new String(chars);
System.out.println(s.length());
```

Because a String object is created for every string literal, you can use a string literal any place you can use a String object. For example, you can call methods directly on a quoted string as if it were an object reference, as the following statement shows. It calls the length() method on the string "abc". As expected, it prints "3".

```java
System.out.println("abc".length());
```

String Concatenation
In general, Java does not allow operators to be applied to String objects. The one exception to this rule is the + operator, which concatenates two strings, producing a String object as the result. This allows you to chain together a series of + operations. For example, the following fragment concatenates three strings:

```java
String age = "9";
String s = "He is " + age + " years old."
System.out.println(s);
```
This displays the string "He is 9 years old."
One practical use of string concatenation is found when you are creating very long strings.
Instead of letting long strings wrap around within your source code, you can break them
into smaller pieces, using the + to concatenate them. Here is an example:

```java
// Using concatenation to prevent long lines.
class ConCat {
    public static void main(String args[]) {
        String longStr = "This could have been " +
                         "a very long line that would have " +
                         "wrapped around. But string concatenation " +
                         "prevents this."
                        
        System.out.println(longStr);
    }
}
```

**String Concatenation with Other Data Types**
You can concatenate strings with other types of data. For example, consider this slightly
different version of the earlier example:

```java
int age = 9;
String s = "He is " + age + " years old."
System.out.println(s);
```

In this case, `age` is an `int` rather than another `String`, but the output produced is the same
as before. This is because the `int` value in `age` is automatically converted into its string
representation within a `String` object. This string is then concatenated as before. The
compiler will convert an operand to its string equivalent whenever the other operand of the
+ is an instance of `String`.

Be careful when you mix other types of operations with string concatenation expressions,
however. You might get surprising results. Consider the following:

```java
String s = "four: " + 2 + 2;
System.out.println(s);
```

This fragment displays

```
four: 22
```

rather than the
that you probably expected. Here’s why. Operator precedence causes the concatenation of “four” with the string equivalent of 2 to take place first. This result is then concatenated with the string equivalent of 2 a second time. To complete the integer addition first, you must use parentheses, like this:

```
String s = "four: " + (2 + 2);
```

Now `s` contains the string "four: 4".

**String Conversion and `toString()`**

When Java converts data into its string representation during concatenation, it does so by calling one of the overloaded versions of the string conversion method `valueOf()` defined by `String`. `valueOf()` is overloaded for all the primitive types and for type `Object`. For the primitive types, `valueOf()` returns a string that contains the human-readable equivalent of the value with which it is called. For objects, `valueOf()` calls the `toString()` method on the object. We will look more closely at `valueOf()` later in this chapter. Here, let’s examine the `toString()` method, because it is the means by which you can determine the string representation for objects of classes that you create.

Every class implements `toString()` because it is defined by `Object`. However, the default implementation of `toString()` is seldom sufficient. For most important classes that you create, you will want to override `toString()` and provide your own string representations. Fortunately, this is easy to do. The `toString()` method has this general form:

```
String toString()
```

To implement `toString()`, simply return a `String` object that contains the human-readable string that appropriately describes an object of your class. By overriding `toString()` for classes that you create, you allow them to be fully integrated into Java’s programming environment. For example, they can be used in `print()` and `println()` statements and in concatenation expressions. The following program demonstrates this by overriding `toString()` for the `Box` class:
// Override toString() for Box class.
class Box {
    double width;
    double height;
    double depth;

    Box(double w, double h, double d) {
        width = w;
        height = h;
        depth = d;
    }

    public String toString() {
        return "Dimensions are " + width + " by " +
                depth + " by " + height + ".";
    }
}

class toStringDemo {
    public static void main(String args[]) {
        Box b = new Box(10.0, 12.0, 14.0);
        String s = "Box b: " + b; // concatenate Box object

        System.out.println(b); // convert Box to string
        System.out.println(s);
    }
}

The output of this program is shown here:

Dimensions are 10.0 by 14.0 by 12.0
Box b: Dimensions are 10.0 by 14.0 by 12.0

As you can see, Box's toString() method is automatically invoked when a Box object is used in a concatenation expression or in a call to println().

Character Extraction
The String class provides a number of ways in which characters can be extracted from a String object. Several are examined here. Although the characters that comprise a string within a String object cannot be indexed as if they were a character array, many of the String methods employ an index (or offset) into the string for their operation. Like arrays, the string indexes begin at zero.

charAt()
To extract a single character from a String, you can refer directly to an individual character
via the `charAt()` method. It has this general form:

```java
char charAt(int where)
```

Here, `where` is the index of the character that you want to obtain. The value of `where` must be nonnegative and specify a location within the string. `charAt()` returns the character at the specified location. For example,

```java
char ch;
ch = "abc".charAt(1);
```

assigns the value `b` to `ch`.

### getChars()

If you need to extract more than one character at a time, you can use the `getChars()` method. It has this general form:

```java
void getChars(int sourceStart, int sourceEnd, char target[], int targetStart)
```

Here, `sourceStart` specifies the index of the beginning of the substring, and `sourceEnd` specifies an index that is one past the end of the desired substring. Thus, the substring contains the characters from `sourceStart` through `sourceEnd - 1`. The array that will receive the characters is specified by `target`. The index within `target` at which the substring will be copied is passed in `targetStart`. Care must be taken to assure that the `target` array is large enough to hold the number of characters in the specified substring.

The following program demonstrates `getChars()`:

```java
class getCharsDemo {
    public static void main(String args[]) {
        String s = "This is a demo of the getChars method.";
        int start = 10;
        int end = 14;
        char buf[] = new char[end - start];
        s.getChars(start, end, buf, 0);
        System.out.println(buf);
    }
}
```

Here is the output of this program:

```
demo
```

`getBytes()`
There is an alternative to `getChars()` that stores the characters in an array of bytes. This method is called `getBytes()`, and it uses the default character-to-byte conversions provided by the platform. Here is its simplest form:

```java
byte[ ] getBytes()
```

Other forms of `getBytes()` are also available. `getBytes()` is most useful when you are exporting a `String` value into an environment that does not support 16-bit Unicode characters. For example, most Internet protocols and text file formats use 8-bit ASCII for all text interchange.

`toCharArray()`

If you want to convert all the characters in a `String` object into a character array, the easiest way is to call `toCharArray()`. It returns an array of characters for the entire string. It has this general form:

```java
char[ ] toCharArray()
```

This function is provided as a convenience, since it is possible to use `getChars()` to achieve the same result.

**String Comparison**

The `String` class includes a number of methods that compare strings or substrings within strings. Several are examined here.

`equals()` and `equalsIgnoreCase()`

To compare two strings for equality, use `equals()`. It has this general form:

```java
boolean equals(Object str)
```

Here, `str` is the `String` object being compared with the invoking `String` object. It returns `true` if the strings contain the same characters in the same order, and `false` otherwise. The comparison is case-sensitive.

To perform a comparison that ignores case differences, call `equalsIgnoreCase()`. When it compares two strings, it considers `A-Z` to be the same as `a-z`. It has this general form:

```java
boolean equalsIgnoreCase(String str)
```

Here, `str` is the `String` object being compared with the invoking `String` object. It, too, returns `true` if the strings contain the same characters in the same order, and `false` otherwise.

Here is an example that demonstrates `equals()` and `equalsIgnoreCase()`:
The output from the program is shown here:

<table>
<thead>
<tr>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hello equals Hello -&gt; true</td>
</tr>
<tr>
<td>Hello equals Good-bye -&gt; false</td>
</tr>
<tr>
<td>Hello equals HELLO -&gt; false</td>
</tr>
<tr>
<td>Hello equalsIgnoreCase HELLO -&gt; true</td>
</tr>
</tbody>
</table>

**regionMatches()**

The `regionMatches()` method compares a specific region inside a string with another specific region in another string. There is an overloaded form that allows you to ignore case in such comparisons. Here are the general forms for these two methods:

```java
boolean regionMatches(int startIndex, String str2, int str2StartIndex, int numChars)
```

```java
boolean regionMatches(boolean ignoreCase, int startIndex, String str2, int str2StartIndex, int numChars)
```

For both versions, `startIndex` specifies the index at which the region begins within the invoking `String` object. The `String` being compared is specified by `str2`. The index at which the comparison will start within `str2` is specified by `str2StartIndex`. The length of the substring being compared is passed in `numChars`. In the second version, if `ignoreCase` is `true`, the case of the characters is ignored. Otherwise, case is significant.

**startsWith() and endsWith()**
String defines two methods that are, more or less, specialized forms of `regionMatches()`.
The `startsWith()` method determines whether a given String begins with a specified string. Conversely, `endsWith()` determines whether the String in question ends with a specified string. They have the following general forms:

```java
boolean startsWith(String str)
boolean endsWith(String str)
```

Here, `str` is the String being tested. If the string matches, `true` is returned. Otherwise, `false` is returned. For example,

```
"Foobar".endsWith("bar")
```

and

```
"Foobar".startsWith("Foo")
```

are both `true`.

A second form of `startsWith()` shown here, lets you specify a starting point:

```java
boolean startsWith(String str, int startIndex)
```

Here, `startIndex` specifies the index into the invoking string at which point the search will begin. For example,

```
"Foobar".startsWith("bar", 3)
```

returns `true`.

**equals() Versus ==**

It is important to understand that the `equals()` method and the `==` operator perform two different operations. As just explained, the `equals()` method compares the characters inside a `String` object. The `==` operator compares two object references to see whether they refer to the same instance. The following program shows how two different `String` objects can contain the same characters, but references to these objects will not compare as equal:

```
// equals() vs ==
class EqualsNotEqualTo {
    public static void main(String args[]) {
        String s1 = "Hello";
        String s2 = new String(s1);
        System.out.println("s1 equals s2" + " " + (s1.equals(s2)));
        System.out.println("s1 -- " + s2 + " -> " + (s1 == s2));
    }
}
```
The variable \texttt{s1} refers to the \texttt{String} instance created by "Hello". The object referred to by \texttt{s2} is created with \texttt{s1} as an initializer. Thus, the contents of the two \texttt{String} objects are identical, but they are distinct objects. This means that \texttt{s1} and \texttt{s2} do not refer to the same objects and are, therefore, not ==, as is shown here by the output of the preceding example:

\begin{verbatim}
Hello equals Hello -> true
Hello == Hello -> false
\end{verbatim}

\textbf{compareTo( )}

Often, it is not enough to simply know whether two strings are identical. For sorting applications, you need to know which is \textit{less than}, \textit{equal to}, or \textit{greater than} the next. A string is less than another if it comes before the other in dictionary order. A string is greater than another if it comes after the other in dictionary order. The method \texttt{compareTo( )} serves this purpose. It is specified by the \texttt{Comparable<T>} interface, which \texttt{String} implements. It has this general form:

\begin{verbatim}
int compareTo(String \texttt{str})
\end{verbatim}

Here, \texttt{str} is the \texttt{String} being compared with the invoking \texttt{String}. The result of the comparison is returned and is interpreted as shown here:

\begin{table}[h]
\centering
\begin{tabular}{|c|c|}
\hline
\textbf{Value} & \textbf{Meaning} \\
\hline
Less than zero & The invoking string is less than \texttt{str}. \\
\hline
Greater than zero & The invoking string is greater than \texttt{str}. \\
\hline
Zero & The two strings are equal. \\
\hline
\end{tabular}
\end{table}

Here is a sample program that sorts an array of strings. The program uses \texttt{compareTo( )} to determine sort ordering for a bubble sort:
The output of this program is the list of words:

```
  Now
  aid
  all
  come
  country
  for
  good
  is
  men
  of
  the
  the
  their
  time
  to
  to
```

As you can see from the output of this example, `compareTo()` takes into account uppercase and lowercase letters. The word "Now" came out before all the others because it begins with an uppercase letter, which means it has a lower value in the ASCII character set.

If you want to ignore case differences when comparing two strings, use `compareToIgnoreCase()`, as shown here:

```
  int compareToIgnoreCase(String str)
```
This method returns the same results as `compareTo()`, except that case differences are ignored. You might want to try substituting it into the previous program. After doing so, "Now" will no longer be first.

**Searching Strings**
The `String` class provides two methods that allow you to search a string for a specified character or substring:

- `indexOf()`: Searches for the first occurrence of a character or substring.
- `lastIndexOf()`: Searches for the last occurrence of a character or substring.

These two methods are overloaded in several different ways. In all cases, the methods return the index at which the character or substring was found, or -1 on failure.

To search for the first occurrence of a character, use

```
int indexOf(int ch)
```

To search for the last occurrence of a character, use

```
int lastIndexOf(int ch)
```

Here, `ch` is the character being sought.

To search for the first or last occurrence of a substring, use

```
int indexOf(String str)
int lastIndexOf(String str)
```

Here, `str` specifies the substring.

You can specify a starting point for the search using these forms:

```
int indexOf(int ch, int startIndex)
int lastIndexOf(int ch, int startIndex)
int indexOf(String str, int startIndex)
int lastIndexOf(String str, int startIndex)
```

Here, `startIndex` specifies the index at which point the search begins. For

`indexOf()`, the search runs from `startIndex` to the end of the string. For

`lastIndexOf()`, the search runs from `startIndex` to zero.

The following example shows how to use the various index methods to search inside of a `String`:
Here is the output of this program:

```
Now is the time for all good men to come to the aid of their country.
indexOf(t) = 7
indexOf(the) = 7
indexOf(t, 10) = 11
indexOf(t, 60) = 65
indexOf(the, 10) = 44
indexOf(the, 60) = 55
```

**Modifying a String**

Because `String` objects are immutable, whenever you want to modify a `String`, you must either copy it into a `StringBuilder` or `StringBuffer`, or use a `String` method that constructs a new copy of the string with your modifications complete. A sampling of these methods are described here.

**substring( )**

You can extract a substring using `substring( )`. It has two forms. The first is
String substring(int startIndex)

Here, startIndex specifies the index at which the substring will begin. This form returns a copy of the substring that begins at startIndex and runs to the end of the invoking string.

The second form of substring( ) allows you to specify both the beginning and ending index of the substring:

String substring(int startIndex, int endIndex)

Here, startIndex specifies the beginning index, and endIndex specifies the stopping point. The string returned contains all the characters from the beginning index, up to, but not including, the ending index.

The following program uses substring( ) to replace all instances of one substring with another within a string:

```java
// Substring replacement.
class StringReplace {
    public static void main(String args[]) {
        String org = "This is a test. This is, too.";
        String search = "is";
        String sub = "was";
        String result = "";
        int i;

        do { // replace all matching substrings
            System.out.println(org);
            i = org.indexOf(search);
            if(i != -1) {
                result = org.substring(0, i);
                result = result + sub;
                result = result + org.substring(i + search.length());
                org = result;
            }
        } while(i != -1);
    }
}
```

The output from this program is shown here:

```
This is a test. This is, too.
This is a test. This is, too.
Thwas was a test. Thwas is, too.
Thwas was a test. Thwas is, too.
```

Thwas was a test. Thwas was, too.
concat() 
You can concatenate two strings using `concat()`, shown here:

```java
String concat(String str)
```

This method creates a new object that contains the invoking string with the contents of `str` appended to the end. `concat()` performs the same function as `+`. For example,

```java
String s1 = "one";
String s2 = s1.concat("two");
```

puts the string "onetwo" into `s2`. It generates the same result as the following sequence:

```java
String s1 = "one";
String s2 = s1 + "two";
```

replace() 
The `replace()` method has two forms. The first replaces all occurrences of one character in the invoking string with another character. It has the following general form:

```java
String replace(char original, char replacement)
```

Here, `original` specifies the character to be replaced by the character specified by `replacement`. The resulting string is returned. For example,

```java
String s = "Hewwo".replace('l', 'w');
```

puts the string "Hewwo" into `s`. The second form of `replace()` replaces one character sequence with another. It has this general form:

```java
String replace(CharSequence original, CharSequence replacement)
```

trim() 
The `trim()` method returns a copy of the invoking string from which any leading and trailing whitespace has been removed. It has this general form:

```java
String trim()
```

Here is an example:

```java
String s = " Hello World ".trim();
```

This puts the string "Hello World" into `s`. The `trim()` method is quite useful when you process user commands. For example, the following program prompts the user for the name of a state and then displays that state's
capital. It uses `trim()` to remove any leading or trailing whitespace that may have inadvertently been entered by the user.

```java
// Using trim() to process commands.
import java.io.*;

class UseTrim {
    public static void main(String args[])
        throws IOException {
        // create a BufferedReader using System.in
        BufferedReader br = new
            BufferedReader(new InputStreamReader(System.in));
        String str;

        System.out.println("Enter 'stop' to quit.");
        System.out.println("Enter State: ");
        do {
            str = br.readLine();
            str = str.trim(); // remove whitespace

            if(str.equals("Illinois"))
                System.out.println("Capital is Springfield.");
            else if(str.equals("Missouri"))
                System.out.println("Capital is Jefferson City.");
            else if(str.equals("California"))
                System.out.println("Capital is Sacramento.");
            else if(str.equals("Washington"))
                System.out.println("Capital is Olympia.");
            // ...
        } while(!str.equals("stop");
    }
}
```

**Data Conversion Using `valueOf()`**
The `valueOf()` method converts data from its internal format into a human-readable form. It is a static method that is overloaded within `String` for all of Java’s built-in types so that each type can be converted properly into a string. `valueOf()` is also overloaded for type `Object`, so an object of any class type you create can also be used as an argument. (Recall that `Object` is a superclass for all classes.) Here are a few of its forms:

- static String valueOf(double `num`)
- static String valueOf(long `num`)
- static String valueOf(Object `ob`)
- static String valueOf(char `chars[ ]`)
As discussed earlier, `valueOf()` is called when a string representation of some other type of data is needed—for example, during concatenation operations. You can call this method directly with any data type and get a reasonable `String` representation. All of the simple types are converted to their common `String` representation. Any object that you pass to `valueOf()` will return the result of a call to the object’s `toString()` method. In fact, you could just call `toString()` directly and get the same result.

For most arrays, `valueOf()` returns a rather cryptic string, which indicates that it is an array of some type. For arrays of `char`, however, a `String` object is created that contains the characters in the `char` array. There is a special version of `valueOf()` that allows you to specify a subset of a `char` array. It has this general form:

```
static String valueOf(char chars[ ], int startIndex, int numChars)
```

Here, `chars` is the array that holds the characters, `startIndex` is the index into the array of characters at which the desired substring begins, and `numChars` specifies the length of the substring.

### Changing the Case of Characters Within a String

The method `toLowerCase()` converts all the characters in a string from uppercase to lowercase. The `toUpperCase()` method converts all the characters in a string from lowercase to uppercase. Nonalphabetical characters, such as digits, are unaffected. Here are the simplest forms of these methods:

- `String toLowerCase()`
- `String toUpperCase()`

Both methods return a `String` object that contains the uppercase or lowercase equivalent of the invoking `String`. The default locale governs the conversion in both cases.

Here is an example that uses `toLowerCase()` and `toUpperCase()`:
The output produced by the program is shown here:

```
Original: This is a test.
Uppercase: THIS IS A TEST.
Lowercase: this is a test.
```

One other point: Overloaded versions of `toLowerCase()` and `toUpperCase()` that let you specify a `Locale` object to govern the conversion are also supplied. Specifying the locale can be quite important in some cases and can help internationalize your application.

### Joining Strings

JDK 8 adds a new method to `String` called `join()`. It is used to concatenate two or more strings, separating each string with a delimiter, such as a space or a comma. It has two forms. Its first is shown here:

```
static String join(CharSequence delim, CharSequence ... strs)
```

Here, `delim` specifies the delimiter used to separate the character sequences specified by `strs`. Because `String` implements the `CharSequence` interface, `strs` can be a list of strings. (See Chapter 17 for information on `CharSequence`.) The following program demonstrates this version of `join()`:
In the first call to `join()`, a space is inserted between each string. In the second call, the delimiter is a comma followed by a space. This illustrates that the delimiter need not be just a single character.

The second form of `join()` lets you join a list of strings obtained from an object that implements the `Iterable` interface. `Iterable` is implemented by the Collections Framework classes described in Chapter 18, among others. See Chapter 17 for information on `Iterable`.

**Additional String Methods**

In addition to those methods discussed earlier, `String` has many other methods, including those summarized in the following table:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int codePointAt(int i)</td>
<td>Returns the Unicode code point at the location specified by <code>i</code>.</td>
</tr>
<tr>
<td>int codePointBefore(int i)</td>
<td>Returns the Unicode code point at the location that precedes that specified by <code>i</code>.</td>
</tr>
<tr>
<td>int codePointCount(int start, int end)</td>
<td>Returns the number of code points in the portion of the invoking <code>String</code> that are between <code>start</code> and <code>end−1</code>.</td>
</tr>
<tr>
<td>boolean contains(CharSequence str)</td>
<td>Returns <code>true</code> if the invoking object contains the string specified by <code>str</code>. Returns <code>false</code> otherwise.</td>
</tr>
<tr>
<td>boolean contentEquals(CharSequence str)</td>
<td>Returns <code>true</code> if the invoking string contains the same string as <code>str</code>. Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td>boolean contentEquals(StringBuffer str)</td>
<td>Returns <code>true</code> if the invoking string contains the same string as <code>str</code>. Otherwise, returns <code>false</code>.</td>
</tr>
</tbody>
</table>
static String format(String fmtstr, Object ... args)

Returns a string formatted as specified by fmtstr. (See Chapter 19 for details on formatting.)

static String format(Locale loc, String fmtstr, Object ... args)

Returns a string formatted as specified by fmtstr. Formatting is governed by the locale specified by loc. (See Chapter 19 for details on formatting.)

boolean isEmpty()

Returns true if the invoking string contains no characters and has a length of zero.

boolean matches(String regExp)

Returns true if the invoking string matches the regular expression passed in regExp. Otherwise, returns false.

int offsetByCodePoints(int start, int num)

Returns the index within the invoking string that is num code points beyond the starting index specified by start.

String replaceFirst(String regExp, String newStr)

Returns a string in which the first substring that matches the regular expression specified by regExp is replaced by newStr.

String replaceAll(String regExp, String newStr)

Returns a string in which all substrings that match the regular expression specified by regExp are replaced by newStr.

String[] split(String regExp)

Decomposes the invoking string into parts and returns an array that contains the result. Each part is delimited by the regular expression passed in regExp.

String[] split(String regExp, int max)

Decomposes the invoking string into parts and returns an array that contains the result. Each part is delimited by the regular expression passed in regExp. The number of pieces is specified by max. If max is negative, then the invoking string is fully decomposed. Otherwise, if max contains a nonzero value, the last entry in the returned array contains the remainder of the invoking string. If max is zero, the invoking string is fully decomposed, but no trailing empty strings will be included.

CharSequence subSequence(int startIndex, int stopIndex)

Returns a substring of the invoking string, beginning at startIndex and stopping at stopIndex. This method is required by the CharSequence interface, which is implemented by String.

Notice that several of these methods work with regular expressions. Regular expressions are
described in Chapter 30.

**StringBuffer**

`StringBuffer` supports a modifiable string. As you know, `String` represents fixed-length, immutable character sequences. In contrast, `StringBuffer` represents growable and writable character sequences. `StringBuffer` may have characters and substrings inserted in the middle or appended to the end. `StringBuffer` will automatically grow to make room for such additions and often has more characters preallocated than are actually needed, to allow room for growth.

**StringBuffer Constructors**

`StringBuffer` defines these four constructors:

- `StringBuffer()`
- `StringBuffer(int size)`
- `StringBuffer(String str)`
- `StringBuffer(CharSequence chars)`

The default constructor (the one with no parameters) reserves room for 16 characters without reallocation. The second version accepts an integer argument that explicitly sets the size of the buffer. The third version accepts a `String` argument that sets the initial contents of the `StringBuffer` object and reserves room for 16 more characters without reallocation. `StringBuffer` allocates room for 16 additional characters when no specific buffer length is requested, because reallocation is a costly process in terms of time. Also, frequent reallocations can fragment memory. By allocating room for a few extra characters, `StringBuffer` reduces the number of reallocations that take place. The fourth constructor creates an object that contains the character sequence contained in `chars` and reserves room for 16 more characters.

**length() and capacity()**

The current length of a `StringBuffer` can be found via the `length()` method, while the total allocated capacity can be found through the `capacity()` method. They have the following general forms:

- `int length()`
- `int capacity()`

Here is an example:
Here is the output of this program, which shows how StringBuffer reserves extra space for additional manipulations:

```
buffer = Hello
length = 5
capacity = 21
```

Since `sb` is initialized with the string "Hello" when it is created, its length is 5. Its capacity is 21 because room for 16 additional characters is automatically added.

**ensureCapacity( )**

If you want to preallocate room for a certain number of characters after a StringBuffer has been constructed, you can use `ensureCapacity( )` to set the size of the buffer. This is useful if you know in advance that you will be appending a large number of small strings to a StringBuffer. `ensureCapacity( )` has this general form:

```java
void ensureCapacity(int minCapacity)
```

Here, `minCapacity` specifies the minimum size of the buffer. (A buffer larger than `minCapacity` may be allocated for reasons of efficiency.)

**setLength( )**

To set the length of the string within a StringBuffer object, use `setLength( )`. Its general form is shown here:

```java
void setLength(int len)
```

Here, `len` specifies the length of the string. This value must be nonnegative. When you increase the size of the string, null characters are added to the end. If you call `setLength( )` with a value less than the current value returned by `length( )`, then the characters stored beyond the new length will be lost. The `setCharAtDemo` sample program in the following section uses `setLength( )` to shorten a StringBuffer.

`charAt( )` and `setCharAt( )`
The value of a single character can be obtained from a `StringBuffer` via the `charAt()` method. You can set the value of a character within a `StringBuffer` using `setCharAt()`. Their general forms are shown here:

```
char charAt(int where)
void setCharAt(int where, char ch)
```

For `charAt()`, `where` specifies the index of the character being obtained. For `setCharAt()`, `where` specifies the index of the character being set, and `ch` specifies the new value of that character. For both methods, `where` must be nonnegative and must not specify a location beyond the end of the string.

The following example demonstrates `charAt()` and `setCharAt()`:

```java
// Demonstrate charAt() and setCharAt().
class setCharAtDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("Hello");
        System.out.println("buffer before = " + sb);
        System.out.println("charAt(1) before = " + sb.charAt(1));

        sb.setCharAt(1, 'i');
        sb.setLength(2);
        System.out.println("buffer after = " + sb);
        System.out.println("charAt(1) after = " + sb.charAt(1));
    }
}
```

Here is the output generated by this program:

```
buffer before = Hello
charAt(1) before = e
buffer after = Hi
charAt(1) after = i
```

`getChars()`

To copy a substring of a `StringBuffer` into an array, use the `getChars()` method. It has this general form:

```
void getChars(int sourceStart, int sourceEnd, char target[ ], int targetStart)
```

Here, `sourceStart` specifies the index of the beginning of the substring, and `sourceEnd` specifies an index that is one past the end of the desired substring. This means that the substring contains the characters from `sourceStart` through `sourceEnd-1`. The array that will receive the characters is specified by `target`. The index within `target` at which the substring will be copied is passed in `targetStart`. 
Care must be taken to assure that the target array is large enough to hold the number of characters in the specified substring.

**append()**
The **append()** method concatenates the string representation of any other type of data to the end of the invoking **StringBuffer** object. It has several overloaded versions. Here are a few of its forms:

```java
StringBuffer append(String str)
StringBuffer append(int num)
StringBuffer append(Object obj)
```

The string representation of each parameter is obtained, often by calling **String.valueOf()**. The result is appended to the current **StringBuffer** object. The buffer itself is returned by each version of **append()**. This allows subsequent calls to be chained together, as shown in the following example:

```java
// Demonstrate append().
class appendDemo {
    public static void main(String args[]) {
        String s;
        int a = 42;
        StringBuffer sb = new StringBuffer("0");
        s = sb.append("a = ").append(a).append("!").toString();
        System.out.println(s);
    }
}
```

The output of this example is shown here:

```
a = 42.
```

**insert()**
The **insert()** method inserts one string into another. It is overloaded to accept values of all the primitive types, plus **Strings**, **Objects**, and **CharSequences**. Like **append()**, it obtains the string representation of the value it is called with. This string is then inserted into the invoking **StringBuffer** object. These are a few of its forms:

```java
StringBuffer insert(int index, String str)
StringBuffer insert(int index, char ch)
StringBuffer insert(int index, Object obj)
```

Here, **index** specifies the index at which point the string will be inserted into the invoking **StringBuffer** object.
The following sample program inserts "like" between "I" and "Java":

```java
// Demonstrate insert().
class InsertDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("I Java");
        sb.insert(2, "like ");
        System.out.println(sb);
    }
}
```

The output of this example is shown here:

```
I like Java:
```

reverse( )
You can reverse the characters within a `StringBuffer` object using `reverse()`, shown here:

```
StringBuffer reverse( )
```

This method returns the reverse of the object on which it was called. The following program demonstrates `reverse()`:  

```java
// Using reverse() to reverse a StringBuffer.
class ReverseDemo {
    public static void main(String args[]) {
        StringBuffer s = new StringBuffer("abcdef");

        System.out.println(s);
        s.reverse();
        System.out.println(s);
    }
}
```

Here is the output produced by the program:

```
abcdef
fedcba
```

delete( ) and deleteCharAt( )
You can delete characters within a `StringBuffer` by using the methods `delete( )` and `deleteCharAt( )`. These methods are shown here:

```java
StringBuffer delete(int startIndex, int endIndex)
```
StringBuffer deleteCharAt(int loc)

The **delete( )** method deletes a sequence of characters from the invoking object. Here, `startIndex` specifies the index of the first character to remove, and `endIndex` specifies an index one past the last character to remove. Thus, the substring deleted runs from `startIndex` to `endIndex–1`. The resulting **StringBuffer** object is returned.

The **deleteCharAt( )** method deletes the character at the index specified by `loc`. It returns the resulting **StringBuffer** object.

Here is a program that demonstrates the **delete( )** and **deleteCharAt( )** methods:

```java
// Demonstrate delete() and deleteCharAt()
class deleteDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("This is a test.");
        sb.delete(4, 7);
        System.out.println("After delete: " + sb);
        sb.deleteCharAt(0);
        System.out.println("After deleteCharAt: " + sb);
    }
}
```

The following output is produced:

```
After delete: This a test.
After deleteCharAt: his a test.
```

**replace( )**

You can replace one set of characters with another set inside a **StringBuffer** object by calling **replace( )**. Its signature is shown here:

```
StringBuffer replace(int startIndex, int endIndex, String str)
```

The substring being replaced is specified by the indexes `startIndex` and `endIndex`. Thus, the substring at `startIndex` through `endIndex–1` is replaced. The replacement string is passed in `str`. The resulting **StringBuffer** object is returned.

The following program demonstrates **replace( )**:
Here is the output:

After replace: This was a test.

**substring( )**

You can obtain a portion of a *StringBuffer* by calling `substring( )`. It has the following two forms:

- `String substring(int startIndex)`
- `String substring(int startIndex, int endIndex)`

The first form returns the substring that starts at `startIndex` and runs to the end of the invoking *StringBuffer* object. The second form returns the substring that starts at `startIndex` and runs through `endIndex`–1. These methods work just like those defined for *String* that were described earlier.

**Additional StringBuffer Methods**

In addition to those methods just described, *StringBuffer* supplies several others, including those summarized in the following table:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>StringBuffer appendCodePoint(int ch)</code></td>
<td>Appends a Unicode code point to the end of the invoking object. A reference to the object is returned.</td>
</tr>
<tr>
<td><code>int codePointAt(int i)</code></td>
<td>Returns the Unicode code point at the location specified by <code>i</code>.</td>
</tr>
<tr>
<td><code>int codePointBefore(int i)</code></td>
<td>Returns the Unicode code point at the location that precedes that specified by <code>i</code>.</td>
</tr>
<tr>
<td><code>int codePointCount(int start, int end)</code></td>
<td>Returns the number of code points in the portion of the invoking <em>String</em> that are between <code>start</code> and <code>end</code>–1.</td>
</tr>
<tr>
<td><code>int indexOf(String str)</code></td>
<td>Searches the invoking <em>StringBuffer</em> for the first occurrence of <code>str</code>. Returns the index of the match, or –1 if no match is found.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>int indexOf(String str, int startIndex)</code></td>
<td>Searches the invoking <code>StringBuffer</code> for the first occurrence of <code>str</code>, beginning at <code>startIndex</code>. Returns the index of the match, or -1 if no match is found.</td>
</tr>
<tr>
<td><code>int lastIndexOf(String str)</code></td>
<td>Searches the invoking <code>StringBuffer</code> for the last occurrence of <code>str</code>. Returns the index of the match, or -1 if no match is found.</td>
</tr>
<tr>
<td><code>int lastIndexOf(String str, int startIndex)</code></td>
<td>Searches the invoking <code>StringBuffer</code> for the last occurrence of <code>str</code>, beginning at <code>startIndex</code>. Returns the index of the match, or -1 if no match is found.</td>
</tr>
<tr>
<td><code>int offsetByCodePoints(int start, int num)</code></td>
<td>Returns the index within the invoking string that is <code>num</code> code points beyond the starting index specified by <code>start</code>.</td>
</tr>
<tr>
<td><code>CharSequence subSequence(int startIndex, int stopIndex)</code></td>
<td>Returns a substring of the invoking string, beginning at <code>startIndex</code> and stopping at <code>stopIndex</code>. This method is required by the <code>CharSequence</code> interface, which is implemented by <code>StringBuffer</code>.</td>
</tr>
<tr>
<td><code>void trimToSize()</code></td>
<td>Requests that the size of the character buffer for the invoking object be reduced to better fit the current contents.</td>
</tr>
</tbody>
</table>

The following program demonstrates `indexOf()` and `lastIndexOf()`:

```java
class IndexOfDemo {
    public static void main(String args[]) {
        StringBuffer sb = new StringBuffer("one two one");
        int i;

        i = sb.indexOf("one");
        System.out.println("First index: " + i);

        i = sb.lastIndexOf("one");
        System.out.println("Last index: " + i);
    }
}
```

The output is shown here:

```
First index: 0
Last index: 8
```

**StringBuilder**

Introduced by JDK 5, **StringBuilder** is a relatively recent addition to Java’s string
handling capabilities. **StringBuilder** is similar to **StringBuffer** except for one important difference: it is not synchronized, which means that it is not thread-safe. The advantage of **StringBuilder** is faster performance. However, in cases in which a mutable string will be accessed by multiple threads, and no external synchronization is employed, you must use **StringBuffer** rather than **StringBuilder**.
This chapter discusses those classes and interfaces defined by `java.lang`. As you know, `java.lang` is automatically imported into all programs. It contains classes and interfaces that are fundamental to virtually all of Java programming. It is Java’s most widely used package.

`java.lang` includes the following classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Class</th>
<th>Class</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boolean</td>
<td>Enum</td>
<td>Process</td>
<td>String</td>
</tr>
<tr>
<td>Byte</td>
<td>Float</td>
<td>ProcessBuilder</td>
<td>StringBuffer</td>
</tr>
<tr>
<td>Character</td>
<td>Inheretable</td>
<td>ProcessBuilder.Redirect</td>
<td>StringBuilder</td>
</tr>
<tr>
<td>Character Subset</td>
<td>Integer</td>
<td>Runtime</td>
<td>System</td>
</tr>
<tr>
<td>Character.UnicodeBlock</td>
<td>Long</td>
<td>Runtime.Permission</td>
<td>Thread</td>
</tr>
<tr>
<td>Class</td>
<td>Math</td>
<td>SecurityManager</td>
<td>ThreadGroup</td>
</tr>
<tr>
<td>ClassLoader</td>
<td>Number</td>
<td>Start</td>
<td>ThreadLocal</td>
</tr>
<tr>
<td>ClassValue</td>
<td>Object</td>
<td>StackTraceElement</td>
<td>Throwable</td>
</tr>
<tr>
<td>Compiler</td>
<td>Package</td>
<td>StrictMath</td>
<td>Void</td>
</tr>
<tr>
<td>Double</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

`java.lang` defines the following interfaces:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Interface</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Appendable</td>
<td>Cloneable</td>
<td>Serializable</td>
</tr>
<tr>
<td>AutoCloseable</td>
<td>Comparable</td>
<td>Runnable</td>
</tr>
<tr>
<td>CharSequence</td>
<td>Iterable</td>
<td>Throwable.UncaughtExceptionHandler</td>
</tr>
</tbody>
</table>

Several of the classes contained in `java.lang` contain deprecated methods, most dating back to Java 1.0. These deprecated methods are still provided by Java to support an ever-shrinking pool of legacy code and are not recommended for new code. Because of this, the deprecated methods are not discussed here.

**Primitive Type Wrappers**

As mentioned in Part I of this book, Java uses primitive types, such as `int` and `char`, for performance reasons. These data types are not part of the object hierarchy. They are passed
by value to methods and cannot be directly passed by reference. Also, there is no way for
two methods to refer to the same instance of an int. At times, you will need to create an
object representation for one of these primitive types. For example, there are collection
classes discussed in Chapter 18 that deal only with objects; to store a primitive type in one
of these classes, you need to create an instance of a class. To address this need, Java
provides classes that correspond to each of the primitive types. In essence, these classes
encapsulate, or wrap, the primitive types within a class. Thus, they are commonly referred
to as type wrappers. The type wrappers were introduced in Chapter 12. They are examined
in detail here.

**Number**
The abstract class **Number** defines a superclass that is implemented by the classes that
wrap the numeric types byte, short, int, long, float, and double. **Number** has abstract
methods that return the value of the object in each of the different number formats. For
example, **doubleValue( )** returns the value as a **double**, **floatValue( )** returns the value
as a **float**, and so on. These methods are shown here:

```java
    byte byteValue( )
    double doubleValue( )
    float floatValue( )
    int intValue( )
    long longValue( )
    short shortValue( )
```

The values returned by these methods might be rounded, truncated, or result in a
“garbage” value due to the effects of a narrowing conversion.

**Number** has concrete subclasses that hold explicit values of each primitive numeric type:
**Double**, **Float**, **Byte**, **Short**, **Integer**, and **Long**.

**Double and Float**
**Double** and **Float** are wrappers for floating-point values of type double and float,
respectively. The constructors for **Float** are shown here:

```java
    Float(double num)
    Float(float num)
    Float(String str) throws NumberFormatException
```

As you can see, **Float** objects can be constructed with values of type float or
double. They can also be constructed from the string representation of a floating-point number.
The constructors for **Double** are shown here:

```java
    Double(double num)
    Double(String str) throws NumberFormatException
```
Double objects can be constructed with a double value or a string containing a floatingpoint value.
The methods defined by Float include those shown in Table 17-1. The methods defined by Double include those shown in Table 17-2. Both Float and Double define the following constants:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYTES</td>
<td>The width of a float or double in bytes (Added by JDK 8.)</td>
</tr>
<tr>
<td>MAX_EXPONENT</td>
<td>Maximum exponent</td>
</tr>
<tr>
<td>MAX_VALUE</td>
<td>Maximum positive value</td>
</tr>
<tr>
<td>MIN_EXPONENT</td>
<td>Minimum exponent</td>
</tr>
<tr>
<td>MIN_NORMAL</td>
<td>Minimum positive normal value</td>
</tr>
<tr>
<td>MIN_VALUE</td>
<td>Minimum positive value</td>
</tr>
<tr>
<td>NaN</td>
<td>Not a number</td>
</tr>
<tr>
<td>POSITIVE_INFINITY</td>
<td>Positive infinity</td>
</tr>
<tr>
<td>NEGATIVE_INFINITY</td>
<td>Negative infinity</td>
</tr>
<tr>
<td>SIZE</td>
<td>The bit width of the wrapped value</td>
</tr>
<tr>
<td>TYPE</td>
<td>The Class object for float or double</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td><code>byte byteValue()</code></td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td><code>static int compare(float num1, float num2)</code></td>
<td>Compares the values of <code>num1</code> and <code>num2</code>. Returns 0 if the values are equal. Returns a negative value if <code>num1</code> is less than <code>num2</code>. Returns a positive value if <code>num1</code> is greater than <code>num2</code>.</td>
</tr>
<tr>
<td><code>int compareTo(Float f)</code></td>
<td>Compares the numerical value of the invoking object with that of <code>f</code>. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td><code>double doubleValue()</code></td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td><code>boolean equals(Object obj)</code></td>
<td>Returns true if the invoking <code>Float</code> object is equivalent to <code>Float(obj)</code>. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static int floatToIntBits(Float num)</code></td>
<td>Returns the IEEE-compatible, single-precision bit pattern that corresponds to <code>num</code>.</td>
</tr>
<tr>
<td><code>static int floatToRawIntBits(Float num)</code></td>
<td>Returns the IEEE-compatible single-precision bit pattern that corresponds to <code>num</code>. A NaN value is preserved.</td>
</tr>
<tr>
<td><code>float floatValue()</code></td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td><code>int hashCode()</code></td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td><code>static int hashCode(float num)</code></td>
<td>Returns the hash code for <code>num</code>. (Added by JDK 8.1)</td>
</tr>
<tr>
<td><code>static float IntBitsToFloat(int num)</code></td>
<td>Returns <code>float</code> equivalent of the IEEE-compatible, single-precision bit pattern specified by <code>num</code>.</td>
</tr>
<tr>
<td><code>int intValue()</code></td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td><code>static boolean isInfinite(Float num)</code></td>
<td>Returns true if <code>num</code> is not NaN and is not infinite. (Added by JDK 8.1)</td>
</tr>
<tr>
<td><code>boolean isInfinite()</code></td>
<td>Returns true if the invoking object contains an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static boolean isInfinite(float num)</code></td>
<td>Returns true if <code>num</code> specifies an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>boolean isNaN()</code></td>
<td>Returns true if the invoking object contains a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static boolean isNaN(float num)</code></td>
<td>Returns true if <code>num</code> specifies a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>long longValue()</code></td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td><code>static float max(float val1, float val2)</code></td>
<td>Returns the maximum of <code>val1</code> and <code>val2</code>. (Added by JDK 8.1)</td>
</tr>
<tr>
<td><code>static float min(float val1, float val2)</code></td>
<td>Returns the minimum of <code>val1</code> and <code>val2</code>. (Added by JDK 8.1)</td>
</tr>
<tr>
<td><code>static float parseFloat(String str)</code></td>
<td>Throws <code>NumberFormatException</code> Returns the <code>float</code> equivalent of the number contained in the string specified by <code>str</code>.</td>
</tr>
<tr>
<td><code>short shortValue()</code></td>
<td>Returns the value of the invoking object as a short.</td>
</tr>
<tr>
<td><code>static float sum(float val1, float val2)</code></td>
<td>Returns the result of <code>val1 + val2</code>. (Added by JDK 8.1)</td>
</tr>
<tr>
<td><code>static String toHexString(float num)</code></td>
<td>Returns a string containing the value of <code>num</code> in hexadecimal format.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the invoking object.</td>
</tr>
<tr>
<td><code>static String toString(float num)</code></td>
<td>Returns the string equivalent of the value specified by <code>num</code>.</td>
</tr>
<tr>
<td><code>static Float valueOf(float num)</code></td>
<td>Returns a <code>Float</code> object containing the value passed in <code>num</code>.</td>
</tr>
<tr>
<td><code>static Float valueOf(String str)</code></td>
<td>Returns the <code>Float</code> object that contains the value specified by the string in <code>str</code>.</td>
</tr>
</tbody>
</table>

**Table 17-1** The Methods Defined by `Float`
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>byte byteValue()</code></td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td><code>static int compare(double num1, double num2)</code></td>
<td>Compares the values of <code>num1</code> and <code>num2</code>. Returns 0 if the values are equal. Returns a negative value if <code>num1</code> is less than <code>num2</code>. Returns a positive value if <code>num1</code> is greater than <code>num2</code>.</td>
</tr>
<tr>
<td><code>int compareTo(Double self)</code></td>
<td>Compares the numerical value of the invoking object with that of <code>self</code>. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td><code>static long doubleToLongBiased(double num)</code></td>
<td>Returns the IEEE-compatible, double-precision bit pattern that corresponds to <code>num</code>.</td>
</tr>
<tr>
<td><code>static long doubleToRawLongBiased(double num)</code></td>
<td>Returns the IEEE-compatible double-precision bit pattern that corresponds to <code>num</code>. A NaN value is preserved.</td>
</tr>
<tr>
<td><code>double doubleValue()</code></td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td><code>boolean equals(Object o)</code></td>
<td>Returns true if the invoking <code>Double</code> object is equivalent to <code>o</code>. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>float floatValue()</code></td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td><code>int hashCode()</code></td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td><code>static int hashCode(double num)</code></td>
<td>Returns the hash code for <code>num</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>int intValue()</code></td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td><code>static boolean isInfinite(double num)</code></td>
<td>Returns true if <code>num</code> is not NaN and is not infinite. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>boolean isInfinite()</code></td>
<td>Returns true if the invoking object contains an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static boolean isFinite(double num)</code></td>
<td>Returns true if <code>num</code> specifies an infinite value. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>boolean isNaN()</code></td>
<td>Returns true if the invoking object contains a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static boolean isNaN(double num)</code></td>
<td>Returns true if <code>num</code> specifies a value that is not a number. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>static double longBitsToDouble(long bits)</code></td>
<td>Returns double equivalent of the IEEE-compatible, double-precision bit pattern specified by <code>bits</code>.</td>
</tr>
<tr>
<td><code>long longValue()</code></td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td><code>static double max(double v1, double v2)</code></td>
<td>Returns the maximum of <code>v1</code> and <code>v2</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static double min(double v1, double v2)</code></td>
<td>Returns the minimum of <code>v1</code> and <code>v2</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static double parseDouble(String str)</code></td>
<td>Returns the double equivalent of the number contained in the string specified by <code>str</code> using radix 10.</td>
</tr>
</tbody>
</table>
| `throws NumberFormatException` |...
The following example creates two `Double` objects—one by using a `double` value and the other by passing a string that can be parsed as a `double`:

```java
class DoubleDemo {
    public static void main(String args[]) {
        Double d1 = new Double(3.14159);
        Double d2 = new Double("3.14159E-5");

        System.out.println("d1 + " + d2 + " -> " + d1.equals(d2));
    }
}
```

As you can see from the following output, both constructors created identical `Double` instances, as shown by the `equals()` method returning `true`:

```
3.14159 = 3.14159 -> true
```

### Understanding `isInfinite()` and `isNaN()`

`Float` and `Double` provide the methods `isInfinite()` and `isNaN()`, which help when manipulating two special `double` and `float` values. These methods test for two unique values defined by the IEEE floating-point specification: infinity and NaN (not a number). `isInfinite()` returns `true` if the value being tested is infinitely large or small in magnitude. `isNaN()` returns `true` if the value being tested is not a number.

The following example creates two `Double` objects; one is infinite, and the other is not a number:
This program generates the following output:

```
Infinity: true, false
NaN: false, true
```

**Byte, Short, Integer, and Long**

The **Byte**, **Short**, **Integer**, and **Long** classes are wrappers for **byte**, **short**, **int**, and **long** integer types, respectively. Their constructors are shown here:

- `Byte(byte num)`
- `Byte(String str) throws NumberFormatException`
- `Short(short num)`
- `Short(String str) throws NumberFormatException`
- `Integer(int num)`
- `Integer(String str) throws NumberFormatException`
- `Long(long num)`
- `Long(String str) throws NumberFormatException`

As you can see, these objects can be constructed from numeric values or from strings that contain valid whole number values.

The methods defined by these classes are shown in Tables 17-3 through 17-6. As you can see, they define methods for parsing integers from strings and converting strings back into integers. Variants of these methods allow you to specify the **radix**, or numeric base, for conversion. Common radixes are 2 for binary, 8 for octal, 10 for decimal, and 16 for hexadecimal.

The following constants are defined:

<table>
<thead>
<tr>
<th>CONSTANT</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYTES</td>
<td>The width of the integer type in bytes (Added by JDK 8.)</td>
</tr>
<tr>
<td>MIN_VALUE</td>
<td>Minimum value</td>
</tr>
<tr>
<td>MAX_VALUE</td>
<td>Maximum value</td>
</tr>
<tr>
<td>SIZE</td>
<td>The bit width of the wrapped value</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>byte byteValue()</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(byte num1, byte num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Byte b)</td>
<td>Compares the numerical value of the invoking object with that of b. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static Byte decode(String str) throws NumberFormatException</td>
<td>Returns a Byte object that contains the value specified by the string in str.</td>
</tr>
<tr>
<td>double doubleValue()</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if the invoking Byte object is equivalent to Byte obj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(Byte num)</td>
<td>Returns the hash code for num. (Added by JDK 8.)</td>
</tr>
<tr>
<td>int intValue()</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>long longValue()</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static Byte parseByte(String str) throws NumberFormatException</td>
<td>Returns the byte equivalent of the number contained in the string specified by str using radix 10.</td>
</tr>
<tr>
<td>static Byte parseByte(String str, int radix) throws NumberFormatException</td>
<td>Returns the byte equivalent of the number contained in the string specified by str using the specified radix.</td>
</tr>
<tr>
<td>short shortValue()</td>
<td>Returns the value of the invoking object as a short.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a string that contains the decimal equivalent of the invoking object.</td>
</tr>
<tr>
<td>static String toString(byte num)</td>
<td>Returns a string that contains the decimal equivalent of num.</td>
</tr>
<tr>
<td>static int toUnsignedInt(byte val)</td>
<td>Returns the value of val as an unsigned integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long toUnsignedLong(byte val)</td>
<td>Returns the value of val as an unsigned long integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static Byte valueOf(byte num)</td>
<td>Returns a Byte object containing the value passed in num.</td>
</tr>
<tr>
<td>static Byte valueOf(String str) throws NumberFormatException</td>
<td>Returns a Byte object that contains the value specified by the string in str.</td>
</tr>
<tr>
<td>static Byte valueOf(String str, int radix) throws NumberFormatException</td>
<td>Returns a Byte object that contains the value specified by the string in str using the specified radix.</td>
</tr>
</tbody>
</table>

*Table 17-3  The Methods Defined by Byte*
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>byteByteValue()</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(short num1, short num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareTo(Short s)</td>
<td>Compares the numerical value of the invoking object with that of s. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static Short decode(String s)</td>
<td>Returns a Short object that contains the value specified by the string in s.</td>
</tr>
<tr>
<td>double doubleValue()</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object o)</td>
<td>Returns true if the invoking Short object is equivalent to o. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(Short s)</td>
<td>Returns the hash code for s. (Added by JDK 8.)</td>
</tr>
<tr>
<td>int intValue()</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>long longValue()</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static short parseShort(String s)</td>
<td>Returns the short equivalent of the number contained in the string specified by s. (using radix 10.)</td>
</tr>
<tr>
<td>static short parseShort(String s, int radix)</td>
<td>Throws NumberFormatException.</td>
</tr>
<tr>
<td>static short reverseBytes(Short s)</td>
<td>Exchanges the high- and low-order bytes of s and returns the result.</td>
</tr>
<tr>
<td>short shortValue()</td>
<td>Returns the value of the invoking object as a short.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a string that contains the decimal equivalent of the invoking object.</td>
</tr>
<tr>
<td>static String toString(Short s)</td>
<td>Returns a string that contains the decimal equivalent of s.</td>
</tr>
<tr>
<td>static int toUnsignedInt(Short s)</td>
<td>Returns the value of s as an unsigned integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long toUnsignedLong(Short s)</td>
<td>Returns the value of s as an unsigned long integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static Short toShort(Short s)</td>
<td>Returns a Short object containing the value passed in s.</td>
</tr>
<tr>
<td>static Short toShort(String s)</td>
<td>Returns a Short object that contains the value specified by the string in s. (using radix 10.)</td>
</tr>
<tr>
<td>static Short toShort(String s, int radix)</td>
<td>Throws NumberFormatException.</td>
</tr>
<tr>
<td></td>
<td>Returns a Short object that contains the value specified by the string in s. (using radix 10.)</td>
</tr>
</tbody>
</table>

**Table 17-4** The Methods Defined by Short
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static long bitCount(int num)</td>
<td>Returns the number of set bits in num.</td>
</tr>
<tr>
<td>byte byteValue( )</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>int compare(int num1, int num2)</td>
<td>Compares the values of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2.</td>
</tr>
<tr>
<td>int compareToInteger(int)</td>
<td>Compares the numerical value of the invoking object with that of an int. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static int compareUnsigned(int num1, int num2)</td>
<td>Performs an unsigned comparison of num1 and num2. Returns 0 if the values are equal. Returns a negative value if num1 is less than num2. Returns a positive value if num1 is greater than num2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int divideUnsigned(int dividend, int divisor)</td>
<td>Returns the result, as an unsigned value, of the unsigned division of dividend by divisor. (Added by JDK 8.)</td>
</tr>
<tr>
<td>double doubleValue( )</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if the invoking Integer object is equivalent to obj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue( )</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName)</td>
<td>Returns the value associated with the environmental property specified by propertyName. A null is returned on failure.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName, int defaultValue)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of defaultValue is returned on failure.</td>
</tr>
<tr>
<td>static Integer getInteger(String propertyName, Integer defaultVal)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of defaultVal is returned on failure.</td>
</tr>
<tr>
<td>int hashCode( )</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(int num)</td>
<td>Returns the hash code for num. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int highestOneBit(int num)</td>
<td>Determines the position of the highest order set bit in num. It returns a value in which only this bit is set. If no bit is set to one, then zero is returned.</td>
</tr>
<tr>
<td>int intValue( )</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>long longValue( )</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static int lowestOneBit(int num)</td>
<td>Determines the position of the lowest order set bit in num. It returns a value in which only this bit is set. If no bit is set to one, then zero is returned.</td>
</tr>
<tr>
<td>static int maximum(int val1, int val2)</td>
<td>Returns the maximum of val1 and val2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int minimum(int val1, int val2)</td>
<td>Returns the minimum of val1 and val2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int numberOfLeadingZeros(int num)</td>
<td>Returns the number of high-order zero bits that precede the first high-order set bit in num. If num is zero, 32 is returned.</td>
</tr>
</tbody>
</table>
Table 17-5  The Methods Defined by Integer

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>static int numberTrailingZeros(int x)</code></td>
<td>Returns the number of lowest-order zero bits that precede the first non-zero bit in <code>x</code>. If <code>x</code> is zero, 32 is returned.</td>
</tr>
<tr>
<td><code>static int parse(String s)</code> throws <code>NumberFormatException</code></td>
<td>Returns the integer equivalent of the number contained in the string specified by <code>s</code> using radix 10.</td>
</tr>
<tr>
<td><code>static int parseInt(String s, int radix)</code> throws <code>NumberFormatException</code></td>
<td>Returns the integer equivalent of the number contained in the string specified by <code>s</code> using the specified radix.</td>
</tr>
<tr>
<td><code>static int parseUnsignedInt(String s)</code> throws <code>NumberFormatException</code></td>
<td>Returns the unsigned integer equivalent of the number contained in the string specified by <code>s</code> using the radix 10. (Added to JDK 8.)</td>
</tr>
<tr>
<td><code>static int parseUnsignedInt(String s, int radix)</code> throws <code>NumberFormatException</code></td>
<td>Returns the unsigned integer equivalent of the number contained in the string specified by <code>s</code> using the specified radix. (Added to JDK 8.)</td>
</tr>
<tr>
<td><code>static int remainderUnsignedInt(int dividend, int divisor)</code></td>
<td>Returns the remainder, as an unsigned value, of the unsigned division of <code>dividend</code> by <code>divisor</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static int reverse(int x)</code></td>
<td>Reverses the order of the bits in <code>x</code> and returns the result.</td>
</tr>
<tr>
<td><code>static int reverseBits(int x)</code></td>
<td>Reverses the order of the bits in <code>x</code> and returns the result.</td>
</tr>
<tr>
<td><code>static int rotateLeft(int x, int s)</code></td>
<td>Returns the result of rotating <code>x</code> <code>s</code> left positions.</td>
</tr>
<tr>
<td><code>static int rotateRight(int x, int s)</code></td>
<td>Returns the result of rotating <code>x</code> <code>s</code> right positions.</td>
</tr>
<tr>
<td><code>short shortValue()</code></td>
<td>Returns the value of the invoking object as a <code>short</code>.</td>
</tr>
<tr>
<td><code>static int signum(int x)</code></td>
<td>Returns −1 if <code>x</code> is negative, 0 if it is zero, and 1 if it is positive.</td>
</tr>
<tr>
<td><code>static int sum(int x, int y)</code></td>
<td>Returns the result of <code>x + y</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static String toBinaryString(int x)</code></td>
<td>Returns a string that contains the binary equivalent of <code>x</code>.</td>
</tr>
<tr>
<td><code>static String toHexString(int x)</code></td>
<td>Returns a string that contains the hexadecimal equivalent of <code>x</code>.</td>
</tr>
<tr>
<td><code>static String toOctalString(int x)</code></td>
<td>Returns a string that contains the octal equivalent of <code>x</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns a string that contains the decimal equivalent of the invoking object.</td>
</tr>
<tr>
<td><code>static String toString(int x)</code></td>
<td>Returns a string that contains the decimal equivalent of <code>x</code>.</td>
</tr>
<tr>
<td><code>static String toUnsignedString(int x, int radix)</code></td>
<td>Returns a string that contains the decimal equivalent of <code>x</code> using the specified radix. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static long toUnsignedLong(long x)</code></td>
<td>Returns the value of <code>x</code> as an unsigned long integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static String toUnsignedString(long x)</code></td>
<td>Returns a string that contains the decimal value of <code>x</code> as an unsigned integer. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static String toUnsignedString(String s)</code> throws <code>NumberFormatException</code></td>
<td>Returns a string that contains the value specified by the string in <code>s</code>.</td>
</tr>
<tr>
<td><code>static Integer toUnsignedValue(String s)</code> throws <code>NumberFormatException</code></td>
<td>Returns an <code>Integer</code> object that contains the value specified by the string in <code>s</code>.</td>
</tr>
<tr>
<td><code>static Integer toUnsignedValue(String s, int radix)</code> throws <code>NumberFormatException</code></td>
<td>Returns an <code>Integer</code> object that contains the value specified by the string in <code>s</code> using the specified radix.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>static int bitCount(long x)</td>
<td>Returns the number of set bits in x.</td>
</tr>
<tr>
<td>byte byteValue()</td>
<td>Returns the value of the invoking object as a byte.</td>
</tr>
<tr>
<td>static int compare(long x1, long x2)</td>
<td>Compares the values of x1 and x2. Returns 0 if the values are equal, returns a negative value if x1 is less than x2, returns a positive value if x1 is greater than x2.</td>
</tr>
<tr>
<td>int compareTo(Long l)</td>
<td>Compares the numerical value of the invoking object with that of l. Returns 0 if the values are equal. Returns a negative value if the invoking object has a lower value. Returns a positive value if the invoking object has a greater value.</td>
</tr>
<tr>
<td>static int compareUnsigned(long x1, long x2)</td>
<td>Performs an unsigned comparison of x1 and x2. Returns 0 if the values are equal. Returns a negative value if x1 is less than x2. Returns a positive value if x1 is greater than x2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static Long decode(String s) throws NumberFormatException</td>
<td>Returns a Long object that contains the value specified by the string s.</td>
</tr>
<tr>
<td>static long divideUnsigned(long dividend, long divisor)</td>
<td>Returns the result, as an unsigned value, of the unsigned division of dividend by divisor. (Added by JDK 8.)</td>
</tr>
<tr>
<td>double doubleValue()</td>
<td>Returns the value of the invoking object as a double.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if the invoking Long object is equivalent to Long obj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>float floatValue()</td>
<td>Returns the value of the invoking object as a float.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName)</td>
<td>Returns the value associated with the environmental property specified by propertyName. A null is returned on failure.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName, long defaultValue)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of defaultValue is returned on failure.</td>
</tr>
<tr>
<td>static Long getLong(String propertyName, String defaultValue)</td>
<td>Returns the value associated with the environmental property specified by propertyName. The value of defaultValue is returned on failure.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>static int hashCode(long x)</td>
<td>Returns the hash code for x. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long highestOneBit(long x)</td>
<td>Determines the position of the highest-order set bit in x. If no bit is set, then zero is returned.</td>
</tr>
<tr>
<td>int intValue()</td>
<td>Returns the value of the invoking object as an int.</td>
</tr>
<tr>
<td>long valueOf()</td>
<td>Returns the value of the invoking object as a long.</td>
</tr>
<tr>
<td>static long lowestOneBit(long x)</td>
<td>Determines the position of the lowest-order set bit in x. If no bit is set, then zero is returned.</td>
</tr>
<tr>
<td>static long maximum(long x1, long x2)</td>
<td>Returns the maximum of x1 and x2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long minimum(long x1, long x2)</td>
<td>Returns the minimum of x1 and x2. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int numberOfLeadingZeros(long x)</td>
<td>Returns the number of high-order zero bits that precede the first high-order set bit in x. If x is zero, 64 is returned.</td>
</tr>
</tbody>
</table>
Table 17-6  The Methods Defined by Long

Converting Numbers to and from Strings

One of the most common programming chores is converting the string representation of a number into its internal, binary format. Fortunately, Java provides an easy way to accomplish this. The Byte, Short, Integer, and Long classes provide the parseByte( ), parseShort( ), parseInt( ), and parseLong( ) methods, respectively. These methods return the byte, short, int, or long equivalent of the numeric string with which they are called. (Similar methods also exist for the Float and Double classes.)

The following program demonstrates parseInt( ). It sums a list of integers entered by the user. It reads the integers using readLine( ) and uses parseInt( ) to convert these strings into their int equivalents.
To convert a whole number into a decimal string, use the versions of `toString()` defined in the `Byte`, `Short`, `Integer`, or `Long` classes. The `Integer` and `Long` classes also provide the methods `toBinaryString()`, `toHexString()`, and `toOctalString()`, which convert a value into a binary, hexadecimal, or octal string, respectively.

The following program demonstrates binary, hexadecimal, and octal conversion:
class StringConversions {
    public static void main(String args[]) {
        int num = 19648;
        System.out.println(num + " in binary: " +
                            Integer.toBinaryString(num));

        System.out.println(num + " in octal: " +
                            Integer.toOctalString(num));

        System.out.println(num + " in hexadecimal: " +
                            Integer.toHexString(num));
    }
}

The output of this program is shown here:

```
19648 in binary: 100110011000000
19648 in octal: 46300
19648 in hexadecimal: 4cc0
```

**Character**

*Character* is a simple wrapper around a *char*. The constructor for *Character* is

```java
Character(char ch)
```

Here, `ch` specifies the character that will be wrapped by the *Character* object being created.

To obtain the *char* value contained in a *Character* object, call *charValue()*, shown here:

```java
char charValue()
```

It returns the character.

The *Character* class defines several constants, including the following:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BYTES</td>
<td>The width of a <em>char</em> in bytes (Added by JDK 8.)</td>
</tr>
<tr>
<td>MAX_RADIX</td>
<td>The largest radix</td>
</tr>
<tr>
<td>MIN_RADIX</td>
<td>The smallest radix</td>
</tr>
<tr>
<td>MAX_VALUE</td>
<td>The largest character value</td>
</tr>
</tbody>
</table>
Character includes several static methods that categorize characters and alter their case. A sampling is shown in Table 17-7. The following example demonstrates several of these methods:

```java
// Demonstrate several Is... methods.

class IsDemo {
    public static void main(String args[]) {
        char a[] = {'a', 'b', '5', '?', 'A', ' '};

        for(int i=0; i<a.length; i++) {
            if(Character.isDigit(a[i]))
                System.out.println(a[i] + " is a digit.");
            if(Character.isLetter(a[i]))
                System.out.println(a[i] + " is a letter.");
            if(Character.isWhitespace(a[i]))
                System.out.println(a[i] + " is whitespace.");
            if(Character.isUpperCase(a[i]))
                System.out.println(a[i] + " is uppercase.");
            if(Character.isLowerCase(a[i]))
                System.out.println(a[i] + " is lowercase.");
        }
    }
}
```

The output from this program is shown here:

```
a is a letter.
a is lowercase.
b is a letter.
b is lowercase.
5 is a digit.
A is a letter.
A is uppercase.
is whitespace.
```

Character defines two methods, forDigit() and digit(), that enable you to convert between integer values and the digits they represent. They are shown here:

```java
static char forDigit(int num, int radix)
```
static int digit(char digit, int radix)

forDigit( ) returns the digit character associated with the value of num. The radix of the conversion is specified by radix. digit( ) returns the integer value associated with the specified character (which is presumably a digit) according to the specified radix. (There is a second form of digit( ) that takes a code point. See the following section for a discussion of code points.)

Another method defined by Character is compareTo( ), which has the following form:

int compareTo(Character c)

It returns zero if the invoking object and c have the same value. It returns a negative value if the invoking object has a lower value. Otherwise, it returns a positive value.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static boolean isDigit(char ch)</td>
<td>Returns true if ch is a digit. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isDigit(char ch)</td>
<td>Returns true if ch is a digit. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isISOControl(char ch)</td>
<td>Returns true if ch is an ISO control character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isJavaIdentifierPart(char ch)</td>
<td>Returns true if ch is allowed as part of a Java identifier (other than the first character). Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isJavaIdentifierStart(char ch)</td>
<td>Returns true if ch is allowed as the first character of a Java identifier. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLetter(char ch)</td>
<td>Returns true if ch is a letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLetterOrDigit(char ch)</td>
<td>Returns true if ch is a letter or a digit. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isLowerCase(char ch)</td>
<td>Returns true if ch is a lowercase letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isMirrored(char ch)</td>
<td>Returns true if ch is a mirrored Unicode character. A mirrored character is one that is reversed (top to bottom) but is displayed right-to-left.</td>
</tr>
<tr>
<td>static boolean isSpaceChar(char ch)</td>
<td>Returns true if ch is a Unicode space character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isTitleCase(char ch)</td>
<td>Returns true if ch is a Unicode titlecase character. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUnicodeIdentifierPart(char ch)</td>
<td>Returns true if ch is allowed as part of a Unicode identifier (other than the first character). Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUnicodeIdentifierStart(char ch)</td>
<td>Returns true if ch is allowed as the first character of a Unicode identifier. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isUpperCase(char ch)</td>
<td>Returns true if ch is an uppercase letter. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static boolean isWhitespace(char ch)</td>
<td>Returns true if ch is whitespace. Otherwise, it returns false.</td>
</tr>
<tr>
<td>static char toLowerCase(char ch)</td>
<td>Returns lowercase equivalent of ch.</td>
</tr>
<tr>
<td>static char toTitleCase(char ch)</td>
<td>Returns titlecase equivalent of ch.</td>
</tr>
<tr>
<td>static char toUpperCase(char ch)</td>
<td>Returns uppercase equivalent of ch.</td>
</tr>
</tbody>
</table>

Table 17-7 Various Character Methods
**Character** includes a method called `getDirectionality()` which can be used to determine the direction of a character. Several constants are defined that describe directionality. Most programs will not need to use character directionality. **Character** also overrides the `equals()` and `hashCode()` methods.

Two other character-related classes are **Character.Subset**, used to describe a subset of Unicode, and **Character.UnicodeBlock**, which contains Unicode character blocks.

### Additions to Character for Unicode Code Point Support

Relatively recently, major additions were made to **Character**. Beginning with JDK 5, the **Character** class has included support for 32-bit Unicode characters. In the past, all Unicode characters could be held by 16 bits, which is the size of a char (and the size of the value encapsulated within a **Character**), because those values ranged from 0 to FFFF. However, the Unicode character set has been expanded, and more than 16 bits are required. Characters can now range from 0 to 10FFFF.

Here are three important terms. A **code point** is a character in the range 0 to 10FFFF. Characters that have values greater than FFFF are called **supplemental characters**. The **basic multilingual plane (BMP)** are those characters between 0 and FFFF. The expansion of the Unicode character set caused a fundamental problem for Java. Because a supplemental character has a value greater than a char can hold, some means of handling the supplemental characters was needed. Java addressed this problem in two ways. First, Java uses two chars to represent a supplemental character. The first char is called the **high surrogate**, and the second is called the **low surrogate**. New methods, such as `codePointAt()`, were provided to translate between code points and supplemental characters.

Secondly, Java overloaded several preexisting methods in the **Character** class. The overloaded forms use int rather than char data. Because an int is large enough to hold any character as a single value, it can be used to store any character. For example, all of the methods in Table 17-7 have overloaded forms that operate on int. Here is a sampling:

```java
static boolean isDigit(int cp)
static boolean isLetter(int cp)
static int toLowerCase(int cp)
```

In addition to the methods overloaded to accept code points, **Character** adds methods that provide additional support for code points. A sampling is shown in Table 17-8.

### Boolean

**Boolean** is a very thin wrapper around boolean values, which is useful mostly when you want to pass a boolean variable by reference. It contains the constants **TRUE** and **FALSE**, which define true and false **Boolean** objects. **Boolean** also defines the **TYPE** field, which is the **Class** object for boolean. **Boolean** defines these constructors:
In the first version, `boolValue` must be either `true` or `false`. In the second version, if `boolString` contains the string "true" (in uppercase or lowercase), then the new `Boolean` object will be `true`. Otherwise, it will be `false`.

`Boolean` defines the methods shown in Table 17-9.
Void

The Void class has one field, TYPE, which holds a reference to the Class object for type void. You do not create instances of this class.

Process

The abstract Process class encapsulates a process—that is, an executing program. It is used primarily as a superclass for the type of objects created by exec() in the Runtime class, or by start() in the ProcessBuilder class. Process contains the methods shown in Table 17-10.
The **Runtime** class encapsulates the run-time environment. You cannot instantiate a **Runtime** object. However, you can get a reference to the current **Runtime** object by calling the static method **Runtime.getRuntime()**. Once you obtain a reference to the current **Runtime** object, you can call several methods that control the state and behavior of the Java Virtual Machine. Applets and other untrusted code typically cannot call any of the **Runtime** methods without raising a **SecurityException**. Several commonly used methods defined by **Runtime** are shown in Table 17-11.

### Table 17-10  The Methods Defined by **Process**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void destroy()</td>
<td>Terminates the process.</td>
</tr>
<tr>
<td>Process destroyForced()</td>
<td>Forces termination of the invoking process. Returns a reference to the process. (Added by JDK 8.)</td>
</tr>
<tr>
<td>int exitValue()</td>
<td>Returns an exit code obtained from a subprocess.</td>
</tr>
<tr>
<td>InputStream getErrorStream()</td>
<td>Returns an input stream that reads input from the process’ error output stream.</td>
</tr>
<tr>
<td>InputStream getInputStream()</td>
<td>Returns an input stream that reads input from the process’ output stream.</td>
</tr>
<tr>
<td>OutputStream getOutputStream()</td>
<td>Returns an output stream that writes output to the process’ input stream.</td>
</tr>
<tr>
<td>boolean isAlive()</td>
<td>Returns true if the invoking process is still active. Otherwise, returns false. (Added by JDK 8.)</td>
</tr>
<tr>
<td>int wait() throws InterruptedException</td>
<td>Returns the exit code returned by the process. This method does not return until the process on which it is called terminates.</td>
</tr>
<tr>
<td>boolean wait(long time, TimeUnit unit) throws InterruptedException</td>
<td>Waits for the invoking process to end. The amount of time to wait is specified by <strong>time</strong> in the units specified by <strong>timeUnit</strong>. Returns <strong>true</strong> if the process has ended and <strong>false</strong> if the wait time runs out. (Added by JDK 8.)</td>
</tr>
</tbody>
</table>

### Table 17-11  Methods Defined by **Runtime**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addShutdownHook(Thread thread)</td>
<td>Registers <strong>thread</strong> as a thread to be run when the Java Virtual Machine terminates.</td>
</tr>
<tr>
<td>Process exec(String progName) throws IOException</td>
<td>Executes the program specified by <strong>progName</strong> as a separate process. An object of type <strong>Process</strong> is returned that describes the new process.</td>
</tr>
<tr>
<td>Process exec(String progName, String env[][]) throws IOException</td>
<td>Executes the program specified by <strong>progName</strong> as a separate process with the environment specified by <strong>env</strong>. An object of type <strong>Process</strong> is returned that describes the new process.</td>
</tr>
<tr>
<td>Process exec(String cmdLine[]) throws IOException</td>
<td>Executes the command line specified by the strings in <strong>cmdLine</strong> as a separate process. An object of type <strong>Process</strong> is returned that describes the new process.</td>
</tr>
</tbody>
</table>
Let's look at two of the most common uses of the Runtime class: memory management and executing additional processes.

**Memory Management**

Although Java provides automatic garbage collection, sometimes you will want to know how large the object heap is and how much of it is left. You can use this information, for example, to check your code for efficiency or to approximate how many more objects of a certain type can be instantiated. To obtain these values, use the totalMemory( ) and freeMemory( ) methods.

As mentioned in Part I, Java's garbage collector runs periodically to recycle unused objects. However, sometimes you will want to collect discarded objects prior to the collector’s next appointed rounds. You can run the garbage collector on demand by calling the gc( ) method. A good thing to try is to call gc( ) and then call freeMemory( ) to get a baseline memory usage. Next, execute your code and call freeMemory( ) again to see how much memory it is allocating. The following program illustrates this idea:
Sample output from this program is shown here (of course, your actual results may vary):

```
Total memory is: 1048568
Initial free memory: 751392
Free memory after garbage collection: 841424
Free memory after allocation: 824000
Memory used by allocation: 17424
Free memory after collecting discarded Integers: 842640
```

**Executing Other Programs**
In safe environments, you can use Java to execute other heavyweight processes (that is,
programs) on your multitasking operating system. Several forms of the `exec()` method allow you to name the program you want to run as well as its input parameters. The `exec()` method returns a `Process` object, which can then be used to control how your Java program interacts with this new running process. Because Java can run on a variety of platforms and under a variety of operating systems, `exec()` is inherently environment-dependent.

The following example uses `exec()` to launch `notepad`, Windows’ simple text editor. Obviously, this example must be run under the Windows operating system.

```java
// Demonstrate exec().
class ExecDemo {
    public static void main(String args[]) {
        Runtime r = Runtime.getRuntime();
        Process p = null;

        try {
            p = r.exec("notepad");
        } catch (Exception e) {
            System.out.println("Error executing notepad.");
        }
    }
}
```

There are several alternative forms of `exec()`, but the one shown in the example is the most common. The `Process` object returned by `exec()` can be manipulated by `Process` methods after the new program starts running. You can kill the subprocess with the `destroy()` method. The `waitFor()` method causes your program to wait until the subprocess finishes. The `exitValue()` method returns the value returned by the subprocess when it is finished. This is typically 0 if no problems occur. Here is the preceding `exec()` example modified to wait for the running process to exit:
While a subprocess is running, you can write to and read from its standard input and output. The `getOutputStream()` and `getInputStream()` methods return the handles to standard `in` and `out` of the subprocess. (I/O is examined in detail in Chapter 20.)

**ProcessBuilder**

`ProcessBuilder` provides another way to start and manage processes (that is, programs). As explained earlier, all processes are represented by the `Process` class, and a process can be started by `Runtime.exec()`. `ProcessBuilder` offers more control over the processes. For example, you can set the current working directory.

`ProcessBuilder` defines these constructors:

```
ProcessBuilder(List<String> args)
ProcessBuilder(String ... args)
```

Here, `args` is a list of arguments that specify the name of the program to be executed along with any required command-line arguments. In the first constructor, the arguments are passed in a `List`. In the second, they are specified through a varargs parameter. Table 17-12 describes the methods defined by `ProcessBuilder`.

In Table 17-12, notice the methods that use the `ProcessBuilder.Redirect` class. This abstract class encapsulates an I/O source or target linked to a subprocess. Among other things, these methods enable you to redirect the source or target of I/O operations. For example, you can redirect to a file by calling `to()`, redirect from a file by calling `from()`, and append to a file by calling `appendTo()`. A `File` object linked to the file can be obtained by calling `file()`. These methods are shown here:

```
static ProcessBuilder.Redirect to(File f)
static ProcessBuilder.Redirect from(File f)
static ProcessBuilder.Redirect appendTo(File f)
```
Another method supported by `ProcessBuilder.Redirect` is `type()`, which returns a value of the enumeration type `ProcessBuilder.Redirect.Type`. This enumeration describes the type of the redirection. It defines these values: **APPEND, INHERIT, PIPE, READ, or WRITE**. `ProcessBuilder.Redirect` also defines the constants **INHERIT** and **PIPE**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>List&lt;String&gt; command()</code></td>
<td>Returns a reference to a <code>List</code> that contains the name of the program and its arguments. Changes to this list affect the invoking object.</td>
</tr>
<tr>
<td><code>ProcessBuilder command(List&lt;String&gt; args)</code></td>
<td>Sets the name of the program and its arguments to those specified by <code>args</code>. Changes to this list affect the invoking object. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td><code>ProcessBuilder command(String ... args)</code></td>
<td>Sets the name of the program and its arguments to those specified by <code>args</code>. Returns a reference to the invoking object.</td>
</tr>
<tr>
<td><code>File directory()</code></td>
<td>Returns the current working directory of the invoking object. This value will be null if the directory is the same as that of the Java program that started the process.</td>
</tr>
</tbody>
</table>
To create a process using `ProcessBuilder`, simply create an instance of `ProcessBuilder`, specifying the name of the program and any needed arguments. To begin execution of the program, call `start()` on that instance. Here is an example that executes the Windows text editor `notepad`. Notice that it specifies the name of the file to edit as an argument.
System

The **System** class holds a collection of static methods and variables. The standard input, output, and error output of the Java runtime are stored in the **in**, **out**, and **err** variables. The methods defined by **System** are shown in Table 17-13. Many of the methods throw a **SecurityException** if the operation is not permitted by the security manager. Let’s look at some common uses of **System**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static void arraycopy(Object source, int sourceStart, Object target, int targetStart, int size)</td>
<td>Copies an array. The array to be copied is passed in <strong>source</strong>, and the index at which point the copy will begin within <strong>source</strong> is passed in <strong>sourceStart</strong>. The array that will receive the copy is passed in <strong>target</strong>, and the index at which point the copy will begin within <strong>target</strong> is passed in <strong>targetStart</strong>. <strong>size</strong> is the number of elements that are copied.</td>
</tr>
<tr>
<td>static String clearProperty(String name)</td>
<td>Deletes the environmental variable specified by <strong>name</strong>. The previous value associated with <strong>which</strong> is returned.</td>
</tr>
<tr>
<td>static Console console()</td>
<td>Returns the console associated with the JVM. <strong>null</strong> is returned if the JVM currently has no console.</td>
</tr>
<tr>
<td>static long currentTimeMillis()</td>
<td>Returns the current time in terms of milliseconds since midnight, January 1, 1970.</td>
</tr>
<tr>
<td>static void exit(int exitCode)</td>
<td>Halts execution and returns the value of <strong>exitCode</strong> to the parent process (usually the operating system). By convention, 0 indicates normal termination. All other values indicate some form of error.</td>
</tr>
<tr>
<td>static void gc()</td>
<td>Initiates garbage collection.</td>
</tr>
</tbody>
</table>
Using currentTimeMillis() to Time Program Execution

One use of the System class that you might find particularly interesting is to use the currentTimeMillis() method to time how long various parts of your program take to execute. The currentTimeMillis() method returns the current time in terms of milliseconds since midnight, January 1, 1970. To time a section of your program, store this value just before beginning the section in question. Immediately upon completion, call currentTimeMillis() again. The elapsed time will be the ending time minus the starting time. The following program demonstrates this:
Here is a sample run (remember that your results probably will differ):

Timing a for loop from 0 to 100,000,000
Elapsed time: 10

If your system has a timer that offers nanosecond precision, then you could rewrite the preceding program to use `nanoTime()` rather than `currentTimeMillis()`. For example, here is the key portion of the program rewritten to use `nanoTime()`:

```java
start = System.nanoTime(); // get starting time
for(long i=0; i < 100000000L; i++) {
    end = System.nanoTime(); // get ending time
    System.out.println("Elapsed time: " + (end-start));
}
```

**Using `arraycopy()`**
The `arraycopy()` method can be used to copy quickly an array of any type from one place to another. This is much faster than the equivalent loop written out longhand in Java. Here is an example of two arrays being copied by the `arraycopy()` method. First, `a` is copied to `b`. Next, all of `a`'s elements are shifted *down* by one. Then, `b` is shifted *up* by one.
As you can see from the following output, you can copy using the same source and
destination in either direction:

```
// Using arraycopy()

class ACDemo {
    static byte a[] = { 65, 66, 67, 68, 69, 70, 71, 72, 73, 74 };
    static byte b[] = { 77, 77, 77, 77, 77, 77, 77, 77, 77, 77 };
    public static void main(String args[]) {
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
        System.arraycopy(a, 0, b, 0, a.length);
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
        System.arraycopy(a, 0, a, 1, a.length - 1);
        System.arraycopy(b, 1, b, 0, b.length - 1);
        System.out.println("a = " + new String(a));
        System.out.println("b = " + new String(b));
    }
}
```

As you can see from the following output, you can copy using the same source and
destination in either direction:

```
    a = ABCDEFGHIJ
    b = MMMMMMMMM
    a = ABCDEFGHIJ
    b = ABCDEFGHIJ
    a = AABCDEFGHI
    b = BCDEFGHIJ
```

**Environment Properties**
The following properties are available in all cases:

```
file.separator   java.specification.version   java.vm.version
java.class.path  java.vendor               line.separator
java.class.version java.version              os.arch
java.compiler     java.vm.specification.name path.separator
java.ext.dirs     java.vm.name              os.version
java.home         java.specification.version user.dir
java.io.tmpdir    java.specification.version user.home
java.library.path java.specification.version user.name
java.specification.name java.vm.vendor
java.specification.vendor
```

You can obtain the values of various environment variables by calling the
`System.getProperty()` method. For example, the following program displays the path to
the current user directory:
Object
As mentioned in Part I, Object is a superclass of all other classes. Object defines the methods shown in Table 17-14, which are available to every object.

Using clone( ) and the Cloneable Interface
Most of the methods defined by Object are discussed elsewhere in this book. However, one deserves special attention: clone( ). The clone( ) method generates a duplicate copy of the object on which it is called. Only classes that implement the Cloneable interface can be cloned.

The Cloneable interface defines no members. It is used to indicate that a class allows a bitwise copy of an object (that is, a clone) to be made. If you try to call clone( ) on a class that does not implement Cloneable, a CloneNotSupportedException is thrown. When a clone is made, the constructor for the object being cloned is not called. As implemented by Object, a clone is simply an exact copy of the original.

Cloning is a potentially dangerous action, because it can cause unintended side effects. For example, if the object being cloned contains a reference variable called obRef, then when the clone is made, obRef in the clone will refer to the same object as does obRef in the original. If the clone makes a change to the contents of the object referred to by obRef, then it will be changed for the original object, too. Here is another example: If an object opens an I/O stream and is then cloned, two objects will be capable of operating on the same stream. Further, if one of these objects closes the stream, the other object might still attempt to write to it, causing an error. In some cases, you will need to override the clone( ) method defined by Object to handle these types of problems.

```java
class ShowUserDir {
    public static void main(String args[]) {
        System.out.println(System.getProperty("user.dir"));
    }
}
```
Because cloning can cause problems, `clone()` is declared as `protected` inside `Object`. This means that it must either be called from within a method defined by the class that implements `Cloneable`, or it must be explicitly overridden by that class so that it is public. Let’s look at an example of each approach.

The following program implements `Cloneable` and defines the method `cloneTest()`, which calls `clone()` in `Object`:

---

**Table 17-14  The Methods Defined by Object**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Object clone()</code></td>
<td>Creates a new object that is the same as the invoking object.</td>
</tr>
<tr>
<td><code>throws</code></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>boolean equals(Object obj)</code></td>
<td>Returns true if the invoking object is equivalent to <code>obj</code>.</td>
</tr>
<tr>
<td><code>void finalize()</code></td>
<td>Default finalize() method. It is called before an unused object is recycled.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final Class&lt;?&gt; getClass()</code></td>
<td>Obtains a Class object that describes the invoking object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>int hashCode()</code></td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final void notify()</code></td>
<td>Resumes execution of a thread waiting on the invoking object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final void notifyAll()</code></td>
<td>Resumes execution of all threads waiting on the invoking object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns a string that describes the object.</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final void wait()</code></td>
<td>Waits on another thread of execution.</td>
</tr>
<tr>
<td><code>throws InterruptedException</code></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final void wait(long milliseconds)</code></td>
<td>Waits up to the specified number of milliseconds on another thread of execution.</td>
</tr>
<tr>
<td><code>throws InterruptedException</code></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td><code>final void wait(long milliseconds, int nanoseconds)</code></td>
<td>Waits up to the specified number of milliseconds plus nanoseconds on another thread of execution.</td>
</tr>
<tr>
<td><code>throws InterruptedException</code></td>
<td></td>
</tr>
</tbody>
</table>
// Demonstrate the clone() method

class TestClone implements Cloneable {
    int a;
    double b;

    // This method calls Object's clone().
    TestClone cloneTest() {
        try {
            // call clone in Object.
            return (TestClone) super.clone();
        } catch (CloneNotSupportedException e) {
            System.out.println("Cloning not allowed.");
            return this;
        }
    }
}

class CloneDemo {
    public static void main(String args[]) {
        TestClone x1 = new TestClone();
        TestClone x2;

        x1.a = 10;
        x1.b = 20.98;

        x2 = x1.cloneTest(); // clone x1

        System.out.println("x1: " + x1.a + " " + x1.b);
        System.out.println("x2: " + x2.a + " " + x2.b);
    }
}

Here, the method cloneTest() calls clone() in Object and returns the result. Notice that
the object returned by clone() must be cast into its appropriate type (TestClone).
The following example overrides clone() so that it can be called from code outside of its
class. To do this, its access specifier must be public, as shown here:
The side effects caused by cloning are sometimes difficult to see at first. It is easy to think that a class is safe for cloning when it actually is not. In general, you should not implement `Cloneable` for any class without good reason.

**Class**

`Class` encapsulates the run-time state of a class or interface. Objects of type `Class` are created automatically, when classes are loaded. You cannot explicitly declare a `Class` object. Generally, you obtain a `Class` object by calling the `getClass()` method defined by `Object`. `Class` is a generic type that is declared as shown here:

```java
class Class<T>
```
Here, \( T \) is the type of the class or interface represented. A sampling of methods defined by \textbf{Class} is shown in Table 17-15.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>@see Class.forName(String name)</code></td>
<td>Returns a \texttt{Class} object given its complete name.</td>
</tr>
<tr>
<td><code>@see Class.forName(String name, boolean b)</code></td>
<td>Returns a \texttt{Class} object given its complete name. The object is loaded using the loader specified by \texttt{b}; if \texttt{b} is \texttt{true}, the object is initialized; otherwise, it is not.</td>
</tr>
<tr>
<td><code>&lt;\texttt{A} extends Annotation&gt;\ A getAnnotations\()</code></td>
<td>Returns an \texttt{Annotation} object that contains the annotation associated with \texttt{annoType} for the invoking object.</td>
</tr>
<tr>
<td><code>&lt;\texttt{A} extends Annotation&gt;\ @ A[] getAnnotations\(\texttt{byType}(\texttt{Class}\texttt{\langle A\rangle annoType})\)</code></td>
<td>Returns an \texttt{Annotation} object that contains the annotation associated with \texttt{annoType} for the invoking object.</td>
</tr>
<tr>
<td><code>\texttt{A} getAnnotations\(\)</code></td>
<td>Obtains all annotations associated with the invoking object and stores them in an array of \texttt{Annotation} objects. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>&lt;\texttt{A} extends Annotation&gt;\ A[] getAnnotations\(\texttt{byType}(\texttt{Class}\texttt{\langle A\rangle annoType})\)</code></td>
<td>Returns a \texttt{Class} object for each public class and interface that is a member of the class represented by the invoking object.</td>
</tr>
<tr>
<td><code>\texttt{A}[] getDeclaredAnnotations\()</code></td>
<td>Returns the \texttt{Class} object that loaded the class or interface.</td>
</tr>
<tr>
<td><code>Constructor\(\texttt{A} \rightarrow \texttt{... parameterTypes})\)</code></td>
<td>Returns a \texttt{Constructor} object that represents the constructor for the class represented by the invoking object that has the parameter types specified by \texttt{parameterTypes}.</td>
</tr>
<tr>
<td><code>\texttt{A}[] getDeclaredConstructors\()</code></td>
<td>Returns a \texttt{Constructor} object for each public constructor of the class represented by the invoking object and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>\texttt{A}[] getDeclaredAnnotations\(\)</code></td>
<td>Obtains an \texttt{Annotation} object for all the annotations that are declared by the invoking object and stores them in an array. Returns a reference to this array. (Inherited annotations are ignored.)</td>
</tr>
<tr>
<td><code>\texttt{A}[] getDeclaredAnnotations\(\texttt{byType}(\texttt{Class}\texttt{\langle A\rangle annoType})\)</code></td>
<td>Returns an array of the non-inherited annotations (including repeated annotations) of \texttt{annoType} associated with the invoking object. (Added by JBR.8.)</td>
</tr>
<tr>
<td><code>Construction\(\texttt{A} \rightarrow \texttt{... parameterTypes})\)</code></td>
<td>Obtains a \texttt{Constructor} object for each constructor declared by the class represented by the invoking object and stores them in an array. Returns a reference to this array. (Superclass constructors are ignored.)</td>
</tr>
<tr>
<td><code>Field\[\] getDeclaredFields\(</code></td>
<td>Obtain a \texttt{Field} object for each field declared by the class or interface represented by the invoking object and stores them in an array. Returns a reference to this array. (Inherited fields are ignored.)</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>getDeclaredMethods() throws SecurityException</td>
<td>Obtains a Method object for each method declared by the class or interface represented by the invoking object, and stores them in an array. Returns a reference to this array. (Inherited methods are ignored.)</td>
</tr>
<tr>
<td>getField(String fieldName) throws NoSuchFieldException, SecurityException</td>
<td>Returns a Field object that represents the public field specified by fieldName for the class or interface represented by the invoking object.</td>
</tr>
<tr>
<td>getFields() throws SecurityException</td>
<td>Obtains a Field object for each public field of the class or interface represented by the invoking object, and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td>getInterfaces()</td>
<td>When invoked on an object that represents a class, this method returns an array of the interfaces implemented by this class. When invoked on an object that represents an interface, this method returns an array of interfaces extended by that interface.</td>
</tr>
<tr>
<td>getMethod(String methodName, Class&lt;?&gt;... parameterTypes) throws NoSuchMethodException, SecurityException</td>
<td>Returns a Method object that represents the public method specified by methodName and having the parameter types specified by parameterTypes in the class or interface represented by the invoking object.</td>
</tr>
<tr>
<td>getMethods() throws SecurityException</td>
<td>Obtains a Method object for each public method of the class or interface represented by the invoking object, and stores them in an array. Returns a reference to this array.</td>
</tr>
<tr>
<td>getName()</td>
<td>Returns the complete name of the class or interface of the type represented by the invoking object.</td>
</tr>
<tr>
<td>getProtectionDomain()</td>
<td>Returns the protection domain associated with the invoking object.</td>
</tr>
<tr>
<td>getSuperclass()</td>
<td>Returns the superclass of the type represented by the invoking object. The return value is null if the represented type is Object or not a class.</td>
</tr>
<tr>
<td>isInterface()</td>
<td>Returns true if the type represented by the invoking object is an interface. Otherwise, it returns false.</td>
</tr>
<tr>
<td>newInstance() throws IllegalAccessException, InstantiationException</td>
<td>Creates a new instance (i.e., a new object) that is of the same type as the type represented by the invoking object. This is equivalent to using new with the class' default constructor. The new object is returned. This method will fail if the represented type is abstract, not a class, or does not have a default constructor.</td>
</tr>
<tr>
<td>toString()</td>
<td>Returns the string representation of the type represented by the invoking object or interface.</td>
</tr>
</tbody>
</table>

### Table 17-15  A Sampling of Methods Defined by Class

The methods defined by `Class` are often useful in situations where run-time type information about an object is required. As Table 17-15 shows, methods are provided that allow you to determine additional information about a particular class, such as its public constructors, fields, and methods. Among other things, this is important for the Java Beans functionality, which is discussed later in this book.

The following program demonstrates `getClass()` (inherited from `Object`) and `getSuperclass()` (from `Class`):
The output from this program is shown here:

```
x is object of type: X
y is object of type: Y
y's superclass is X
```

**ClassLoader**

The abstract class **ClassLoader** defines how classes are loaded. Your application can create subclasses that extend **ClassLoader**, implementing its methods. Doing so allows you to load classes in some way other than the way they are normally loaded by the Java run-time system. However, this is not something that you will normally need to do.

**Math**

The **Math** class contains all the floating-point functions that are used for geometry and
trigonometry, as well as several general-purpose methods. Math defines two double constants: \( E \) (approximately 2.72) and \( PI \) (approximately 3.14).

### Trigonometric Functions
The following methods accept a double parameter for an angle in radians and return the result of their respective trigonometric function:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double sin(double arg)</td>
<td>Returns the sine of the angle specified by ( arg ) in radians.</td>
</tr>
<tr>
<td>static double cos(double arg)</td>
<td>Returns the cosine of the angle specified by ( arg ) in radians.</td>
</tr>
<tr>
<td>static double tan(double arg)</td>
<td>Returns the tangent of the angle specified by ( arg ) in radians.</td>
</tr>
</tbody>
</table>

The next methods take as a parameter the result of a trigonometric function and return, in radians, the angle that would produce that result. They are the inverse of their non-arc companions.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double asin(double arg)</td>
<td>Returns the angle whose sine is specified by ( arg ).</td>
</tr>
<tr>
<td>static double acos(double arg)</td>
<td>Returns the angle whose cosine is specified by ( arg ).</td>
</tr>
<tr>
<td>static double atan(double arg)</td>
<td>Returns the angle whose tangent is specified by ( arg ).</td>
</tr>
<tr>
<td>static double atan2(double x, double y)</td>
<td>Returns the angle whose tangent is ( x/y ).</td>
</tr>
</tbody>
</table>

The next methods compute the hyperbolic sine, cosine, and tangent of an angle:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double sinh(double arg)</td>
<td>Returns the hyperbolic sine of the angle specified by ( arg ).</td>
</tr>
</tbody>
</table>
Exponential Functions

Math defines the following exponential methods:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static double cbrt(double arg)</td>
<td>Returns the cube root of arg.</td>
</tr>
<tr>
<td>static double exp(double arg)</td>
<td>Returns e to the arg.</td>
</tr>
<tr>
<td>static double expm1(double arg)</td>
<td>Returns e to the arg–1.</td>
</tr>
<tr>
<td>static double log(double arg)</td>
<td>Returns the natural logarithm of arg.</td>
</tr>
<tr>
<td>static double log10(double arg)</td>
<td>Returns the base 10 logarithm for arg.</td>
</tr>
<tr>
<td>static double log1p(double arg)</td>
<td>Returns the natural logarithm for arg + 1.</td>
</tr>
<tr>
<td>static double pow(double y, double x)</td>
<td>Returns y raised to the x; for example, pow(2.0, 3.0) returns 8.0.</td>
</tr>
<tr>
<td>static double scalb(double arg, int factor)</td>
<td>Returns $arg \times 2^{factor}$.</td>
</tr>
<tr>
<td>static float scalb(float arg, int factor)</td>
<td>Returns $arg \times 2^{factor}$.</td>
</tr>
<tr>
<td>static double sqrt(double arg)</td>
<td>Returns the square root of arg.</td>
</tr>
</tbody>
</table>

Rounding Functions

The Math class defines several methods that provide various types of rounding operations. They are shown in Table 17-16. Notice the two ulp() methods at the end of the table. In this context, ulp stands for units in the last place. It indicates the distance between a value and the next higher value. It can be used to help assess the accuracy of a result.
In addition to the methods just shown, **Math** defines several other methods, which are shown in Table 17-17. Notice that several of the methods use the suffix **Exact**. These were...
added by JDK 8. They throw an `ArithmeticException` if overflow occurs. Thus, these
methods give you an easy way to watch various operations for overflow.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int addExact(int arg1, int arg2)</td>
<td>Returns <code>arg1 + arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long addExact(long arg1, long arg2)</td>
<td>Returns <code>arg1 + arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static double copySign(double arg1, double arg2)</td>
<td>Returns <code>arg1</code> with same sign as that of <code>arg2</code>.</td>
</tr>
<tr>
<td>static float copySign(float arg1, float arg2)</td>
<td>Returns <code>arg1</code> with same sign as that of <code>arg2</code>.</td>
</tr>
<tr>
<td>static int decrementExact(int arg)</td>
<td>Returns <code>arg - 1</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long decrementExact(long arg)</td>
<td>Returns <code>arg - 1</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int gcdExponent(int arg)</td>
<td>Returns the base-2 exponent used by the binary representation of <code>arg</code>.</td>
</tr>
<tr>
<td>static int gcdExponent(long arg)</td>
<td>Returns the base-2 exponent used by the binary representation of <code>arg</code>.</td>
</tr>
<tr>
<td>static int hypot(double a, double b)</td>
<td>Returns the length of the hypotenuse of a right triangle given the length of the two opposing sides.</td>
</tr>
<tr>
<td>static double IEEEremainder(double dividend, double divisor)</td>
<td>Returns the remainder of <code>dividend / divisor</code>.</td>
</tr>
<tr>
<td>static int incrementExact(int arg)</td>
<td>Returns <code>arg + 1</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long incrementExact(long arg)</td>
<td>Returns <code>arg + 1</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int multiplyExact(int arg1, int arg2)</td>
<td>Returns <code>arg1 * arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long multiplyExact(long arg1, long arg2)</td>
<td>Returns <code>arg1 * arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static int negateExact(int arg)</td>
<td>Returns <code>-arg</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long negateExact(long arg)</td>
<td>Returns <code>-arg</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static double random()</td>
<td>Returns a pseudorandom number between 0 and 1.</td>
</tr>
<tr>
<td>static double round(double arg)</td>
<td>Determines the sign of a value. It returns 0 if <code>arg</code> is less than 0, and +1 if <code>arg</code> is greater than 0.</td>
</tr>
<tr>
<td>static double round(float arg)</td>
<td>Determines the sign of a value. It returns 0 if <code>arg</code> is less than 0, and +1 if <code>arg</code> is greater than 0.</td>
</tr>
<tr>
<td>static int subExact(int arg1, int arg2)</td>
<td>Returns <code>arg1 - arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static long subExact(long arg1, long arg2)</td>
<td>Returns <code>arg1 - arg2</code>. Throws an <code>ArithmeticException</code> if overflow occurs. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static double toRadians(double angle)</td>
<td>Converts radians to degrees. The angle passed to <code>toRadians</code> must be specified in radians. The result in degrees is returned.</td>
</tr>
<tr>
<td>static int toRadians(long arg)</td>
<td>Converts radians to degrees. The angle passed to <code>toRadians</code> must be specified in radians. The result in degrees is returned.</td>
</tr>
</tbody>
</table>

### Table 17-17 Other Methods Defined by Math

The following program demonstrates `toRadians()` and `toDegrees()`:
The output is shown here:

```
120.0 degrees is 2.0943951023931953 radians.
1.312 radians is 75.17206272116401 degrees.
```

**StrictMath**
The **StrictMath** class defines a complete set of mathematical methods that parallel those in **Math**. The difference is that the **StrictMath** version is guaranteed to generate precisely identical results across all Java implementations, whereas the methods in **Math** are given more latitude in order to improve performance.

**Compiler**
The **Compiler** class supports the creation of Java environments in which Java bytecode is compiled into executable code rather than interpreted. It is not for normal programming use.

**Thread, ThreadGroup, and Runnable**
The **Runnable** interface and the **Thread** and **ThreadGroup** classes support multithreaded programming. Each is examined next.

---

**NOTE** An overview of the techniques used to manage threads, implement the **Runnable** interface, and create multithreaded programs is presented in Chapter 11.

**The Runnable Interface**
The **Runnable** interface must be implemented by any class that will initiate a separate
Runnable only defines one abstract method, called run( ), which is the entry point to the thread. It is defined like this:

```java
void run()
```

Threads that you create must implement this method.

**Thread**

Thread creates a new thread of execution. It implements Runnable and defines the following commonly used constructors:

```java
Thread()
Thread(Runnable threadOb)
Thread(Runnable threadOb, String threadName)
Thread(String threadName)
Thread(ThreadGroup groupOb, Runnable threadOb)
Thread(ThreadGroup groupOb, Runnable threadOb, String threadName)
Thread(ThreadGroup groupOb, String threadName)
```

*threadOb* is an instance of a class that implements the Runnable interface and defines where execution of the thread will begin. The name of the thread is specified by *threadName*. When a name is not specified, one is created by the Java Virtual Machine. *groupOb* specifies the thread group to which the new thread will belong. When no thread group is specified, the new thread belongs to the same group as the parent thread.

The following constants are defined by Thread:

```java
MAX_PRIORITY
MIN_PRIORITY
NORM_PRIORITY
```

As expected, these constants specify the maximum, minimum, and default thread priorities.

The methods defined by Thread are shown in Table 17-18. In early versions of Java, Thread also included the methods stop( ), suspend( ), and resume( ). However, as explained in Chapter 11, these were deprecated because they were inherently unstable. Also deprecated are countStackFrames( ), because it calls suspend( ), and destroy( ), because it can cause deadlock.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static int activeCount()</td>
<td>Returns the approximate number of active threads in the group to which the thread belongs.</td>
</tr>
<tr>
<td>final void checkAccess()</td>
<td>Causes the security manager to verify that the current thread can access and/or change the thread on which checkAccess() is called.</td>
</tr>
<tr>
<td>static Thread currentThread()</td>
<td>Returns a Thread object that encapsulates the thread that calls this method.</td>
</tr>
<tr>
<td>static void dumpStack()</td>
<td>Displays the call stack for the thread.</td>
</tr>
<tr>
<td>static void enumerate(Thread thread[])</td>
<td>Puts copies of all Thread objects in the current thread's group into threads. The number of threads is returned.</td>
</tr>
<tr>
<td>static Map&lt;Thread, StackTraceElement[]&gt; getAllStackTraces()</td>
<td>Returns a Map that contains the stack traces for all active threads. In the map, each entry consists of a key, which is the Thread object, and its value, which is an array of StackTraceElement objects.</td>
</tr>
<tr>
<td>ClassLoader getBootstrapClassLoader()</td>
<td>Returns the context class loader that is used to load classes and resources for this thread.</td>
</tr>
<tr>
<td>static Thread.UncaughtExceptionHandler getBootstrapUncaughtExceptionHandler()</td>
<td>Returns the default uncaught exception handler.</td>
</tr>
<tr>
<td>long getID()</td>
<td>Returns the ID of the invoking thread.</td>
</tr>
<tr>
<td>final String getLocalizedMessage()</td>
<td>Returns the thread's name.</td>
</tr>
<tr>
<td>final int getPriority()</td>
<td>Returns the thread's priority setting.</td>
</tr>
<tr>
<td>StackTraceElement[] getStackTrace()</td>
<td>Returns an array containing the stack trace for the invoking thread.</td>
</tr>
<tr>
<td>ThreadState getState()</td>
<td>Returns the invoking thread's state.</td>
</tr>
<tr>
<td>final ThreadGroup getThreadGroup()</td>
<td>Returns the ThreadGroup object of which the invoking thread is a member.</td>
</tr>
<tr>
<td>Thread.UncaughtExceptionHandler getUncaughtExceptionHandler()</td>
<td>Returns the invoking thread's uncaught exception handler.</td>
</tr>
<tr>
<td>static boolean holdsLock(Object ob)</td>
<td>Returns true if the invoking thread owns the lock on ob. Returns false otherwise.</td>
</tr>
<tr>
<td>void interrupt()</td>
<td>Interrupts the thread.</td>
</tr>
<tr>
<td>static boolean interrupted()</td>
<td>Returns true if the currently executing thread has been interrupted. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final boolean isAlive()</td>
<td>Returns true if the thread is still active. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final boolean isDaemon()</td>
<td>Returns true if the thread is a daemon thread. Otherwise, it returns false.</td>
</tr>
<tr>
<td>boolean isInterrupted()</td>
<td>Returns true if the invoking thread has been interrupted. Otherwise, it returns false.</td>
</tr>
<tr>
<td>final void join()</td>
<td>Waits until the thread terminates.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>final void join(long milliseconds)</td>
<td>Waits up to the specified number of milliseconds for the thread on which it is called to terminate.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>final void join(long milliseconds, int nanoseconds)</td>
<td>Waits up to the specified number of milliseconds plus nanoseconds for the thread on which it is called to terminate.</td>
</tr>
<tr>
<td>throws InterruptedException</td>
<td></td>
</tr>
<tr>
<td>void run()</td>
<td>Begins execution of a thread.</td>
</tr>
<tr>
<td>void setContextClassLoader(ClassLoader cl)</td>
<td>Sets the context class loader that will be used by the invoking thread to load classes and resources for this thread.</td>
</tr>
<tr>
<td>final void setDaemon(boolean state)</td>
<td>Flags the thread as a daemon thread.</td>
</tr>
<tr>
<td>static void setDefaultUncaughtExceptionHandler(Thread.UncaughtExceptionHandler handler)</td>
<td>Sets the default uncaught exception handler to handler.</td>
</tr>
</tbody>
</table>
ThreadGroup

ThreadGroup creates a group of threads. It defines these two constructors:

ThreadGroup(String groupName)
ThreadGroup(ThreadGroup parentOb, String groupName)

For both forms, groupName specifies the name of the thread group. The first version creates a new group that has the current thread as its parent. In the second form, the parent is specified by parentOb. The non-deprecated methods defined by ThreadGroup are shown in Table 17-19.
Thread groups offer a convenient way to manage groups of threads as a unit. This is particularly valuable in situations in which you want to suspend and resume a number of related threads. For example, imagine a program in which one set of threads is used for printing a document, another set is used to display the document on the screen, and another set saves the document to a disk file. If printing is aborted, you will want an easy way to stop all threads related to printing. Thread groups offer this convenience. The following program, which creates two thread groups of two threads each, illustrates this usage:

```java
int enumerate(Thread group[]) // puts the active threads that comprise the invoking thread group into the group array.
int enumerate(Thread group[],
    boolean all) // puts the active threads that comprise the invoking thread group into the group array. If all is true, then threads in all subgroups of the thread are also put into group.
int enumerate(ThreadGroup group[]) // puts the active subgroups (including subgroups of subgroups and so on) of the invoking thread group into the group array.
int enumerate(ThreadGroup group[],
    boolean all) // puts the active subgroups of the invoking thread group into the group array. If all is true, then all active subgroups of the subgroups (and so on) are also put into group.
final int getMaxPriority() // returns the maximum priority setting for the group.
final String getName() // returns the name of the group.
final ThreadGroup getParent() // returns null if the invoking ThreadGroup object has no parent. Otherwise, it returns the parent of the invoking object.
final void interrupt() // invokes the interrupt() method of all threads in the group and any subgroups.
final boolean isDaemon() // returns true if the group is a daemon group. Otherwise, it returns false.
boolean isDestroyed() // returns true if the group has been destroyed. Otherwise, it returns false.
void list() // displays information about the group.
final boolean parentOf(ThreadGroup group) // returns true if the invoking thread is the parent of group (or group, itself). Otherwise, it returns false.
final void setDaemon(boolean isDaemon) // if isDaemon is true, then the invoking group is flagged as a daemon group.
final void setMaxPriority(int priority) // sets the maximum priority of the invoking group to priority.
String toString() // returns the string equivalent of the group.
void uncaughtException(Thread thread, Throwable t) // This method is called when an exception goes uncaught.
```

Table 17-19 The Methods Defined by ThreadGroup

Thread groups offer a convenient way to manage groups of threads as a unit. This is particularly valuable in situations in which you want to suspend and resume a number of related threads. For example, imagine a program in which one set of threads is used for printing a document, another set is used to display the document on the screen, and another set saves the document to a disk file. If printing is aborted, you will want an easy way to stop all threads related to printing. Thread groups offer this convenience. The following program, which creates two thread groups of two threads each, illustrates this usage:
// Demonstrate thread groups.
class NewThread extends Thread {
    boolean suspendFlag;

    NewThread(String threadname, ThreadGroup tgOb) {
        super(tgOb, threadname);
        System.out.println("New thread: " + this);
        suspendFlag = false;
        start(); // Start the thread
    }

    // This is the entry point for thread.
    public void run() {
        try {
            for(int i = 5; i > 0; i--)
                System.out.println(getName() + ": " + i);
            Thread.sleep(1000);
            synchronized(this) {
                while(suspendFlag) {
                    wait();
                }
            }
        } catch (Exception e) {
            System.out.println("Exception in " + getName());
        }
        System.out.println(getName() + " exiting.");

        synchronized void mysuspend() {
            suspendFlag = true;
        }

        synchronized void myresume() {
            suspendFlag = false;
            notify();
        }
    }
}

class ThreadGroupDemo {
    public static void main(String args[]) {
        ThreadGroup groupA = new ThreadGroup("Group A");
        ThreadGroup groupB = new ThreadGroup("Group B");
        NewThread tA1 = new NewThread("Thread A 1", groupA);
        NewThread tA2 = new NewThread("Thread A 2", groupA);
        NewThread tB1 = new NewThread("Thread B 1", groupB);
        NewThread tB2 = new NewThread("Thread B 2", groupB);
    }
}
Sample output from this program is shown here (the precise output you see may differ):

```java
NewThread obj1 = new NewThread("One", groupA);
NewThread obj2 = new NewThread("Two", groupA);
NewThread obj3 = new NewThread("Three", groupB);
NewThread obj4 = new NewThread("Four", groupB);

System.out.println("\nHere is output from list():");
groupA.list();
groupB.list();
System.out.println();

System.out.println("Suspending Group A");
Thread tga[] = new Thread[groupA.activeCount()];
groupA.enumerate(tga); // get threads in group
for(int i = 0; i < tga.length; i++) {
    ((NewThread)tga[i]).mysuspend(); // suspend each thread
}

try {
    Thread.sleep(4000);
} catch (InterruptedException e) {
    System.out.println("Main thread interrupted.");
}

System.out.println("Resuming Group A");
for(int i = 0; i < tga.length; i++) {
    ((NewThread)tga[i]).myresume(); // resume threads in group
}

// wait for threads to finish
try {
    System.out.println("Waiting for threads to finish.");
    obj1.join();
    obj2.join();
    obj3.join();
    obj4.join();
} catch (Exception e) {
    System.out.println("Exception in Main thread");
}

System.out.println("Main thread exiting.");
```
Inside the program, notice that thread group A is suspended for four seconds. As the output confirms, this causes threads One and Two to pause, but threads Three and Four continue running. After the four seconds, threads One and Two are resumed. Notice how thread group A is suspended and resumed. First, the threads in group A are obtained by calling

```
java.lang.ThreadGroup[name=Group A, maxpri=10]
    Thread[One,5,Group A]
    Thread[Two,5,Group A]
```

```
java.lang.ThreadGroup[name=Group B, maxpri=10]
    Thread[Three,5,Group B]
    Thread[Four,5,Group B]
```

Suspending Group A
Three: 5
Four: 5
Three: 4
Four: 4
Three: 3
Four: 3
Three: 2
Four: 2

Resuming Group A
Waiting for threads to finish.
One: 5
Two: 5
Three: 1
Four: 1
One: 4
Two: 4
Three exiting.
Four exiting.
One: 3
Two: 3
One: 2
Two: 2
One: 1
Two: 1
One exiting.
Two exiting.
Main thread exiting.
`enumerate()` on group A. Then, each thread is suspended by iterating through the resulting array. To resume the threads in A, the list is again traversed and each thread is resumed. One last point: This example uses the recommended approach to suspending and resuming threads. It does not rely upon the deprecated methods `suspend()` and `resume()`.

**ThreadLocal and InheritableThreadLocal**
Java defines two additional thread-related classes in `java.lang`:

- **ThreadLocal** Used to create thread local variables. Each thread will have its own copy of a thread local variable.
- **InheritableThreadLocal** Creates thread local variables that may be inherited.

**Package**
`Package` encapsulates version data associated with a package. `Package` version information is becoming more important because of the proliferation of packages and because a Java program may need to know what version of a package is available. The methods defined by `Package` are shown in Table 17-20. The following program demonstrates `Package`, displaying the packages about which the program currently is aware:

```java
// Demonstrate Package
class PkgTest {
    public static void main(String args[]) {
        Package pkgs[];

        pkgs = Package.getPackage();

        for(int i = 0; i < pkgs.length; i++)
            System.out.println(
                pkgs[i].getName() + " " +
                pkgs[i].getImplementationTitle() + " " +
                pkgs[i].getImplementationVendor() + " " +
                pkgs[i].getImplementationVersion();
    }
}
```
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;A extends Annotation&gt; A getAnnotation(Class&lt;? extends A&gt; annoType)</code></td>
<td>Returns an Annotation object that contains the annotation associated with <code>annoType</code> for the invoking object.</td>
</tr>
<tr>
<td><code>Annotation[] getAnnotations()</code></td>
<td>Returns all annotations associated with the invoking object in an array of <code>Annotation</code> objects. Returns a reference to this array.</td>
</tr>
<tr>
<td><code>&lt;A extends Annotation&gt; A[] getAnnotationsByType(Class&lt;? super A&gt; annoType)</code></td>
<td>Returns an array of the annotations (including repeated annotations) of <code>annoType</code> associated with the invoking object. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>&lt;A extends Annotation&gt; A[] getDeclaredAnnotations()</code></td>
<td>Returns an Annotation object that contains the non-inherited annotation associated with <code>annoType</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>A[] getDeclaredAnnotations()</code></td>
<td>Returns an Annotation object for all the annotations that are declared by the invoking object. (Inherited annotations are ignored.)</td>
</tr>
<tr>
<td><code>&lt;A extends Annotation&gt; A[] getDeclaredAnnotationsByType(Class&lt;? super A&gt; annoType)</code></td>
<td>Returns an array of the non-inherited annotations (including repeated annotations) of <code>annoType</code> associated with the invoking object. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>String getImplementationTitle()</code></td>
<td>Returns the title of the invoking package.</td>
</tr>
<tr>
<td><code>String getImplementationVendor()</code></td>
<td>Returns the name of the implementor of the invoking package.</td>
</tr>
<tr>
<td><code>String getImplementationVersion()</code></td>
<td>Returns the version number of the invoking package.</td>
</tr>
<tr>
<td><code>String getName()</code></td>
<td>Returns the name of the invoking package.</td>
</tr>
<tr>
<td><code>static Package getPackage(String pkgName)</code></td>
<td>Returns a Package object with the name specified by <code>pkgName</code>.</td>
</tr>
<tr>
<td><code>static Package[] getPackages()</code></td>
<td>Returns all packages about which the invoking program is currently aware.</td>
</tr>
<tr>
<td><code>String getSpecificationTitle()</code></td>
<td>Returns the title of the invoking package’s specification.</td>
</tr>
<tr>
<td><code>String getSpecificationVendor()</code></td>
<td>Returns the name of the owner of the specification for the invoking package.</td>
</tr>
<tr>
<td><code>String getSpecificationVersion()</code></td>
<td>Returns the invoking package’s specification version number.</td>
</tr>
<tr>
<td><code>int hashcode()</code></td>
<td>Returns the hash code for the invoking package.</td>
</tr>
<tr>
<td><code>boolean isAnnotationPresent(Class&lt;?&gt; extends Annotation&gt; anno)</code></td>
<td>Returns true if the annotation described by <code>anno</code> is associated with the invoking object. Returns false otherwise.</td>
</tr>
<tr>
<td><code>boolean isCompatibleWith(String verName) throws NumberFormatException</code></td>
<td>Returns true if <code>verName</code> is less than or equal to the invoking package’s version number.</td>
</tr>
<tr>
<td><code>boolean isSealed()</code></td>
<td>Returns true if the invoking package is sealed. Returns false otherwise.</td>
</tr>
<tr>
<td><code>boolean isSealed(URLConnection)</code></td>
<td>Returns true if the invoking package is sealed relative to <code>url</code>. Returns false otherwise.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the invoking package.</td>
</tr>
</tbody>
</table>

**Table 17-20**  The Methods Defined by `Package`

**RuntimePermission**

`RuntimePermission` relates to Java’s security mechanism and is not examined further here.

**Throwable**
The **Throwable** class supports Java’s exception-handling system and is the class from which all exception classes are derived. It is discussed in Chapter 10.

**SecurityManager**

**SecurityManager** supports Java’s security system. A reference to the current security manager can be obtained by calling `getSecurityManager()` defined by the **System** class.

**StackTraceElement**

The **StackTraceElement** class describes a single *stack frame*, which is an individual element of a stack trace when an exception occurs. Each stack frame represents an *execution point*, which includes such things as the name of the class, the name of the method, the name of the file, and the source-code line number. An array of **StackTraceElements** is returned by the `getStackTrace()` method of the **Throwable** class.

**StackTraceElement** has one constructor:

```
StackTraceElement(String className, String methName, String fileName, int line)
```

Here, the name of the class is specified by `className`, the name of the method is specified in `methName`, the name of the file is specified by `fileName`, and the line number is passed in `line`. If there is no valid line number, use a negative value for `line`. Furthermore, a value of –2 for `line` indicates that this frame refers to a native method.

The methods supported by **StackTraceElement** are shown in Table 17-21. These methods give you programmatic access to a stack trace.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean equals(Object obj)</code></td>
<td>Returns true if the invoking <strong>StackTraceElement</strong> is the same as the one passed in. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>String getClassName()</code></td>
<td>Returns the name of the class in which the execution point described by the invoking <strong>StackTraceElement</strong> occurred.</td>
</tr>
<tr>
<td><code>String getFile.Name()</code></td>
<td>Returns the name of the file in which the source code of the execution point described by the invoking <strong>StackTraceElement</strong> is stored.</td>
</tr>
<tr>
<td><code>int getLineNumber()</code></td>
<td>Returns the source-code line number at which the execution point described by the invoking <strong>StackTraceElement</strong> occurred. In some situations, the line number will not be available, in which case a negative value is returned.</td>
</tr>
<tr>
<td><code>String getMethodName()</code></td>
<td>Returns the name of the method in which the execution point described by the invoking <strong>StackTraceElement</strong> occurred.</td>
</tr>
<tr>
<td><code>int hashCode()</code></td>
<td>Returns the hash code for the invoking <strong>StackTraceElement</strong>.</td>
</tr>
<tr>
<td><code>boolean isNativeMethod()</code></td>
<td>Returns true if the execution point described by the invoking <strong>StackTraceElement</strong> occurred in a native method. Otherwise, it returns false.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the String equivalent of the invoking sequence.</td>
</tr>
</tbody>
</table>

**Table 17-21** The Methods Defined by **StackTraceElement**
As described in Chapter 12, an enumeration is a list of named constants. (Recall that an enumeration is created by using the keyword `enum`.) All enumerations automatically inherit `Enum`. `Enum` is a generic class that is declared as shown here:

```java
class Enum<E extends Enum<E>>
```

Here, `E` stands for the enumeration type. `Enum` has no public constructors. `Enum` defines several methods that are available for use by all enumerations, which are shown in Table 17-22.

**Table 17-22** The Methods Defined by `Enum`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>protect final Object clone()</code></td>
<td>Invoking this method causes a <code>CloneNotSupportedException</code> to be thrown. This prevents enumerations from being cloned.</td>
</tr>
<tr>
<td><code>final int compareTo(T o)</code></td>
<td>Compares the ordinal value of two constants of the same enumeration. Returns a negative value if the invoking constant has an ordinal value less than <code>o</code>, zero if the two ordinal values are the same, and a positive value if the invoking constant has an ordinal value greater than <code>o</code>.</td>
</tr>
<tr>
<td><code>final boolean equals(Object obj)</code></td>
<td>Returns <code>true</code> if <code>obj</code> and the invoking object refer to the same constant.</td>
</tr>
<tr>
<td><code>final Class&lt;E&gt; getDeclaringClass()</code></td>
<td>Returns the type of enumeration of which the invoking constant is a member.</td>
</tr>
<tr>
<td><code>final int hashCode()</code></td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td><code>final String name()</code></td>
<td>Returns the unaltered name of the invoking constant.</td>
</tr>
<tr>
<td><code>final int ordinal()</code></td>
<td>Returns a value that indicates an enumeration constant’s position in the list of constants.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the name of the invoking constant. This name may differ from the one used in the enumeration’s declaration.</td>
</tr>
<tr>
<td><code>static &lt;T extends Enum&lt;T&gt;&gt; T valueOf(Class&lt;T&gt; enumClass, String name)</code></td>
<td>Returns the constant associated with <code>name</code> in the enumeration type specified by <code>enumClass</code>.</td>
</tr>
</tbody>
</table>

**ClassValue**

`ClassValue` can be used to associate a value with a type. It is a generic type defined like this:

```java
Class ClassValue<T>
```

It is designed for highly specialized uses, not for normal programming.

**The CharSequence Interface**

The `CharSequence` interface defines methods that grant read-only access to a sequence of characters. These methods are shown in Table 17-23. This interface is implemented by `String`, `StringBuffer`, and `StringBuilder`, among others.

**The Comparable Interface**
Objects of classes that implement `Comparable` can be ordered. In other words, classes that implement `Comparable` contain objects that can be compared in some meaningful manner. `Comparable` is generic and is declared like this:

```java
interface Comparable<T>
```

Here, `T` represents the type of objects being compared.

### Table 17-23  The Methods Defined by `CharSequence`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>char charAt(int i)</code></td>
<td>Returns the character at the index specified by <code>i</code>.</td>
</tr>
<tr>
<td><code>default InputStream chars()</code></td>
<td>Returns a stream (in the form of an <code>InputStream</code>) to the characters in the invoking object. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>default InputStream codePoints()</code></td>
<td>Returns a stream (in the form of an <code>InputStream</code>) to the code points in the invoking object. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>int length()</code></td>
<td>Returns the number of characters in the invoking sequence.</td>
</tr>
<tr>
<td><code>CharSequence subSequence(int start, int stop)</code></td>
<td>Returns a subset of the invoking sequence beginning at <code>start</code> and ending at <code>stop+1</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the <code>String</code> equivalent of the invoking sequence.</td>
</tr>
</tbody>
</table>

The `Comparable` interface declares one method that is used to determine what Java calls the *natural ordering* of instances of a class. The signature of the method is shown here:

```java
int compareTo(T obj)
```

This method compares the invoking object with `obj`. It returns 0 if the values are equal. A negative value is returned if the invoking object has a lower value. Otherwise, a positive value is returned.

This interface is implemented by several of the classes already reviewed in this book. Specifically, the `Byte`, `Character`, `Double`, `Float`, `Long`, `Short`, `String`, and `Integer` classes define a `compareTo()` method. So does `Enum`.

### The Appendable Interface

Objects of a class that implements `Appendable` can have a character or character sequences appended to it. `Appendable` defines these three methods:

- Appendable `append(char ch)` throws IOException
- Appendable `append(CharSequence chars)` throws IOException
- Appendable `append(CharSequence chars, int begin, int end)` throws IOException

In the first form, the character `ch` is appended to the invoking object. In the second form, the character sequence `chars` is appended to the invoking object. The third form allows you to indicate a portion (the characters running from `begin` through `end-1`) of the sequence specified by `chars`. In all cases, a reference to the invoking object is returned.
The Iterable Interface

`Iterable` must be implemented by any class whose objects will be used by the for-each version of the `for` loop. In other words, in order for an object to be used within a for-each style `for` loop, its class must implement `Iterable`. `Iterable` is a generic interface that has this declaration:

```java
interface Iterable<T>
```

Here, `T` is the type of the object being iterated. It defines one abstract method, `iterator( )`, which is shown here:

```java
Iterator<T> iterator( )
```

It returns an iterator to the elements contained in the invoking object. Beginning with JDK 8, `Iterable` also defines two default methods. The first is called `forEach( )`:

```java
default void forEach(Consumer<? super T> action)
```

For each element being iterated, `forEach( )` executes the code specified by `action`. (`Consumer` is a functional interface added by JDK 8 and defined in `java.util.function`. See Chapter 19.)

The second default method is `spliterator( )`, shown next:

```java
default Spliterator<T> spliterator( )
```

It returns a `Spliterator` to the sequence being iterated. (See Chapters 18 and 29 for details on spliterators.)

---

**NOTE** Iterators are described in detail in Chapter 18.

The Readable Interface

The `Readable` interface indicates that an object can be used as a source for characters. It defines one method called `read( )`, which is shown here:

```java
int read(CharBuffer buf) throws IOException
```

This method reads characters into `buf`. It returns the number of characters read, or −1 if an EOF is encountered.

The AutoCloseable Interface

`AutoCloseable` provides support for the `try`-with-resources statement, which implements what is sometimes referred to as automatic resource management (ARM). The `try`-with-
resources statement automates the process of releasing a resource (such as a stream) when it is no longer needed. (See Chapter 13 for details.) Only objects of classes that implement `AutoCloseable` can be used with `try-with-resources`. The `AutoCloseable` interface defines only the `close( )` method, which is shown here:

```java
void close( ) throws Exception
```

This method closes the invoking object, releasing any resources that it may hold. It is automatically called at the end of a `try-with-resources` statement, thus eliminating the need to explicitly invoke `close( )`. `AutoCloseable` is implemented by several classes, including all of the I/O classes that open a stream that can be closed.

**The `Thread.UncaughtExceptionHandler` Interface**

The static `Thread.UncaughtExceptionHandler` interface is implemented by classes that want to handle uncaught exceptions. It is implemented by `ThreadGroup`. It declares only one method, which is shown here:

```java
void uncaughtException(Thread thrd, Throwable exc)
```

Here, `thrd` is a reference to the thread that generated the exception and `exc` is a reference to the exception.

**The `java.lang` Subpackages**

Java defines several subpackages of `java.lang`:

- `java.lang.annotation`
- `java.lang.instrument`
- `java.lang.invoke`
- `java.lang.management`
- `java.lang.ref`
- `java.lang.reflect`

Each is briefly described here.

**`java.lang.annotation`**

Java’s annotation facility is supported by `java.lang.annotation`. It defines the `Annotation` interface, the `ElementType` and `RetentionPolicy` enumerations, and several predefined annotations. Annotations are described in Chapter 12.

**`java.lang.instrument`**

`java.lang.instrument` defines features that can be used to add instrumentation to various aspects of program execution. It defines the `Instrumentation` and `ClassFileTransformer` interfaces, and the `ClassDefinition` class.
java.lang.invoke

java.lang.invoke supports dynamic languages. It includes classes such as CallSite, MethodHandle, and MethodType.

java.lang.management

The java.lang.management package provides management support for the JVM and the execution environment. Using the features in java.lang.management, you can observe and manage various aspects of program execution.

java.lang.ref

You learned earlier that the garbage collection facilities in Java automatically determine when no references exist to an object. The object is then assumed to be no longer needed and its memory is reclaimed. The classes in the java.lang.ref package provide more flexible control over the garbage collection process.

java.lang.reflect

Reflection is the ability of a program to analyze code at run time. The java.lang.reflect package provides the ability to obtain information about the fields, constructors, methods, and modifiers of a class. Among other reasons, you need this information to build software tools that enable you to work with Java Beans components. The tools use reflection to determine dynamically the characteristics of a component. Reflection was introduced in Chapter 12 and is also examined in Chapter 30.

java.lang.reflect defines several classes, including Method, Field, and Constructor. It also defines several interfaces, including AnnotatedElement, Member, and Type. In addition, the java.lang.reflect package includes the Array class that enables you to create and access arrays dynamically.
This chapter begins our examination of java.util. This important package contains a large assortment of classes and interfaces that support a broad range of functionality. For example, java.util has classes that generate pseudorandom numbers, manage date and time, observe events, manipulate sets of bits, tokenize strings, and handle formatted data. The java.util package also contains one of Java’s most powerful subsystems: the Collections Framework. The Collections Framework is a sophisticated hierarchy of interfaces and classes that provide state-of-the-art technology for managing groups of objects. It merits close attention by all programmers.

Because java.util contains a wide array of functionality, it is quite large. Here is a list of its top-level classes:
<table>
<thead>
<tr>
<th>java.util Class</th>
<th>Interface/Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbstractCollection</td>
<td>FormattableFlags</td>
<td>Properties</td>
</tr>
<tr>
<td>AbstractList</td>
<td>Formatter</td>
<td>PropertyPermission</td>
</tr>
<tr>
<td>AbstractMap</td>
<td>GregorianCalendar</td>
<td>PropertyResourceBundle</td>
</tr>
<tr>
<td>AbstractQueue</td>
<td>HashMap</td>
<td>Random</td>
</tr>
<tr>
<td>AbstractSequentialList</td>
<td>HashSet</td>
<td>ResourceBundle</td>
</tr>
<tr>
<td>AbstractSet</td>
<td>Hashtable</td>
<td>Scanner</td>
</tr>
<tr>
<td>ArrayDeque</td>
<td>IdentityHashMap</td>
<td>ServiceLoader</td>
</tr>
<tr>
<td>ArrayList</td>
<td>InSummaryStatistics (Added by JDK 8.)</td>
<td>SimpleTimeZone</td>
</tr>
<tr>
<td>Arrays</td>
<td>LinkedHashMap</td>
<td>Splitters (Added by JDK 8.)</td>
</tr>
<tr>
<td>Base64 (Added by JDK 8.)</td>
<td>LinkedHashMap</td>
<td>SplittableRandom (Added by JDK 8.)</td>
</tr>
<tr>
<td>BitSet</td>
<td>LinkedList</td>
<td>Stack</td>
</tr>
<tr>
<td>Calendar</td>
<td>ListResourceBundle</td>
<td>StringJoiner (Added by JDK 8.)</td>
</tr>
<tr>
<td>Collections</td>
<td>Locale</td>
<td>StringTokenizer</td>
</tr>
<tr>
<td>Currency</td>
<td>LongSummaryStatistics (Added by JDK 8.)</td>
<td>Timer</td>
</tr>
<tr>
<td>Date</td>
<td>Objects</td>
<td>TimerTask</td>
</tr>
<tr>
<td>Dictionary</td>
<td>Observable</td>
<td>TimeZone</td>
</tr>
<tr>
<td>DoubleSummaryStatistics</td>
<td>Optional (Added by JDK 8.)</td>
<td>TreeMap</td>
</tr>
<tr>
<td>(Added by JDK 8.)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>EnumMap</td>
<td>OptionalDouble (Added by JDK 8.)</td>
<td>TreeSet</td>
</tr>
<tr>
<td>EnumSet</td>
<td>OptionalInt (Added by JDK 8.)</td>
<td>UUID</td>
</tr>
<tr>
<td>EventListenerProxy</td>
<td>OptionalLong (Added by JDK 8.)</td>
<td>Vector</td>
</tr>
<tr>
<td>EventObject</td>
<td>PriorityQueue</td>
<td>WeakHashMap</td>
</tr>
</tbody>
</table>

The interfaces defined by java.util are shown next:
Because of its size, the description of `java.util` is broken into two chapters. This chapter examines those members of `java.util` that are part of the Collections Framework. Chapter 18 discusses its other classes and interfaces.

### Collections Overview

The Java Collections Framework standardizes the way in which groups of objects are handled by your programs. Collections were not part of the original Java release, but were added by J2SE 1.2. Prior to the Collections Framework, Java provided ad hoc classes such as `Dictionary`, `Vector`, `Stack`, and `Properties` to store and manipulate groups of objects. Although these classes were quite useful, they lacked a central, unifying theme. The way that you used `Vector` was different from the way that you used `Properties`, for example. Also, this early, ad hoc approach was not designed to be easily extended or adapted. Collections are an answer to these (and other) problems.

The Collections Framework was designed to meet several goals. First, the framework had to be high-performance. The implementations for the fundamental collections (dynamic arrays, linked lists, trees, and hash tables) are highly efficient. You seldom, if ever, need to code one of these “data engines” manually. Second, the framework had to allow different types of collections to work in a similar manner and with a high degree of interoperability. Third, extending and/or adapting a collection had to be easy. Toward this end, the entire Collections Framework is built upon a set of standard interfaces. Several standard implementations (such as `LinkedList`, `HashSet`, and `TreeSet`) of these interfaces are provided that you may use as-is. You may also implement your own collection, if you choose. Various special-purpose implementations are created for your convenience, and some partial implementations are provided that make creating your own collection class easier. Finally, mechanisms were added that allow the integration of standard arrays into the Collections Framework.

<table>
<thead>
<tr>
<th>Collection</th>
<th>Map.Entry</th>
<th>Set</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparator</td>
<td>NavigableMap</td>
<td>SortedMap</td>
</tr>
<tr>
<td>Deque</td>
<td>NavigableSet</td>
<td>SortedSet</td>
</tr>
<tr>
<td>Enumeration</td>
<td>Observer</td>
<td>Spliterator (Added by JDK 8)</td>
</tr>
<tr>
<td>EventListener</td>
<td>PrimitiveIterator (Added by JDK 8)</td>
<td>Spliterator.OfDouble (Added by JDK 8)</td>
</tr>
<tr>
<td>Formattable</td>
<td>PrimitiveIterator.OfDouble (Added by JDK 8)</td>
<td>Spliterator.OfInt (Added by JDK 8)</td>
</tr>
<tr>
<td>Iterator</td>
<td>PrimitiveIterator.OfInt (Added by JDK 8)</td>
<td>Spliterator.OfLong (Added by JDK 8)</td>
</tr>
<tr>
<td>List</td>
<td>PrimitiveIterator.OfLong (Added by JDK 8)</td>
<td>Spliterator.OfPrimitive (Added by JDK 8)</td>
</tr>
<tr>
<td>ListIterator</td>
<td>Queue</td>
<td></td>
</tr>
<tr>
<td>Map</td>
<td>RandomAccess</td>
<td></td>
</tr>
</tbody>
</table>
Algorithms are another important part of the collection mechanism. Algorithms operate on
collections and are defined as static methods within the Collections class. Thus, they are
available for all collections. Each collection class need not implement its own versions. The
algorithms provide a standard means of manipulating collections.

Another item closely associated with the Collections Framework is the Iterator interface. An
iterator offers a general-purpose, standardized way of accessing the elements within a
collection, one at a time. Thus, an iterator provides a means of enumerating the contents of
a collection. Because each collection provides an iterator, the elements of any collection
class can be accessed through the methods defined by Iterator. Thus, with only small
changes, the code that cycles through a set can also be used to cycle through a list, for
example.

JDK 8 adds another type of iterator called a spliterator. In brief, spliterators are iterators
that provide support for parallel iteration. The interfaces that support spliterators are
Spliterator and several nested interfaces that support primitive types. JDK 8 also adds
iterator interfaces designed for use with primitive types, such as PrimitiveIterator and
PrimitiveIterator.OfDouble.

In addition to collections, the framework defines several map interfaces and classes. Maps
store key/value pairs. Although maps are part of the Collections Framework, they are not
“collections” in the strict use of the term. You can, however, obtain a collection-view of a
map. Such a view contains the elements from the map stored in a collection. Thus, you can
process the contents of a map as a collection, if you choose.

The collection mechanism was retrofitted to some of the original classes defined by
java.util so that they too could be integrated into the new system. It is important to
understand that although the addition of collections altered the architecture of many of the
original utility classes, it did not cause the deprecation of any. Collections simply provide a
better way of doing several things.

NOTE If you are familiar with C++, then you will find it helpful to know
that the Java collections technology is similar in spirit to the Standard
Template Library (STL) defined by C++. What C++ calls a container, Java
calls a collection. However, there are significant differences between the
Collections Framework and the STL. It is important to not jump to
conclusions.

JDK 5 Changed the Collections Framework

When JDK 5 was released, some fundamental changes were made to the Collections
Framework that significantly increased its power and streamlined its use. These changes
include the addition of generics, autoboxing/unboxing, and the for-each style for loop. Although JDK 8 is three major Java releases after JDK 5, the effects of the JDK 5 features were so profound that they still warrant special attention. The main reason is that you may encounter pre-JDK 5 code. Understanding the effects and reasons for the changes is important if you will be maintaining or updating older code.

**Generics Fundamentally Changed the Collections Framework**

The addition of generics caused a significant change to the Collections Framework because the entire Collections Framework was reengineered for it. All collections are now generic, and many of the methods that operate on collections take generic type parameters. Simply put, the addition of generics affected every part of the Collections Framework.

Generics added the one feature that collections had been missing: type safety. Prior to generics, all collections stored Object references, which meant that any collection could store any type of object. Thus, it was possible to accidentally store incompatible types in a collection. Doing so could result in run-time type mismatch errors. With generics, it is possible to explicitly state the type of data being stored, and run-time type mismatch errors can be avoided.

Although the addition of generics changed the declarations of most of its classes and interfaces, and several of their methods, overall, the Collections Framework still works the same as it did prior to generics. Of course, to gain the advantages that generics bring collections, older code will need to be rewritten. This is also important because pre-generics code will generate warning messages when compiled by a modern Java compiler. To eliminate these warnings, you will need to add type information to all your collections code.

**Autoboxing Facilitates the Use of Primitive Types**

Autoboxing/unboxing facilitates the storing of primitive types in collections. As you will see, a collection can store only references, not primitive values. In the past, if you wanted to store a primitive value, such as an int, in a collection, you had to manually box it into its type wrapper. When the value was retrieved, it needed to be manually unboxed (by using an explicit cast) into its proper primitive type. Because of autoboxing/unboxing, Java can automatically perform the proper boxing and unboxing needed when storing or retrieving primitive types. There is no need to manually perform these operations.

**The For-Each Style for Loop**

All collection classes in the Collections Framework were retrofitted to implement the Iterable interface, which means that a collection can be cycled through by use of the for-each style for loop. In the past, cycling through a collection required the use of an iterator (described later in this chapter), with the programmer manually constructing the loop. Although iterators are still needed for some uses, in many cases, iterator-based loops can be replaced by for loops.

**The Collection Interfaces**
The Collections Framework defines several core interfaces. This section provides an overview of each interface. Beginning with the collection interfaces is necessary because they determine the fundamental nature of the collection classes. Put differently, the concrete classes simply provide different implementations of the standard interfaces. The interfaces that underpin collections are summarized in the following table:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Collection</td>
<td>Enables you to work with groups of objects; it is at the top of the collections hierarchy.</td>
</tr>
<tr>
<td>Deque</td>
<td>Extends Queue to handle a double-ended queue.</td>
</tr>
<tr>
<td>List</td>
<td>Extends Collection to handle sequences (lists of objects).</td>
</tr>
<tr>
<td>NavigableSet</td>
<td>Extends SortedSet to handle retrieval of elements based on closest-match searches.</td>
</tr>
<tr>
<td>Queue</td>
<td>Extends Collection to handle special types of lists in which elements are removed only from the head.</td>
</tr>
<tr>
<td>Set</td>
<td>Extends Collection to handle sets, which must contain unique elements.</td>
</tr>
<tr>
<td>SortedSet</td>
<td>Extends Set to handle sorted sets.</td>
</tr>
</tbody>
</table>

In addition to the collection interfaces, collections also use the Comparator, RandomAccess, Iterator, and ListIterator interfaces, which are described in depth later in this chapter. Beginning with JDK 8, Spliterator can also be used. Briefly, Comparator defines how two objects are compared; Iterator, ListIterator, and Spliterator enumerate the objects within a collection. By implementing RandomAccess, a list indicates that it supports efficient, random access to its elements.

To provide the greatest flexibility in their use, the collection interfaces allow some methods to be optional. The optional methods enable you to modify the contents of a collection. Collections that support these methods are called modifiable. Collections that do not allow their contents to be changed are called unmodifiable. If an attempt is made to use one of these methods on an unmodifiable collection, an UnsupportedOperationException is thrown. All the built-in collections are modifiable.

The following sections examine the collection interfaces.

**The Collection Interface**

The Collection interface is the foundation upon which the Collections Framework is built because it must be implemented by any class that defines a collection. Collection is a generic interface that has this declaration:

```java
interface Collection<E>
```
Here, E specifies the type of objects that the collection will hold. **Collection** extends the **Iterable** interface. This means that all collections can be cycled through by use of the for-each style **for** loop. (Recall that only classes that implement **Iterable** can be cycled through by the **for**.)

**Collection** declares the core methods that all collections will have. These methods are summarized in Table 18-1. Because all collections implement **Collection**, familiarity with its methods is necessary for a clear understanding of the framework. Several of these methods can throw an **UnsupportedOperationException**. As explained, this occurs if a collection cannot be modified. A **ClassCastException** is generated when one object is incompatible with another, such as when an attempt is made to add an incompatible object to a collection. A **NullPointerException** is thrown if an attempt is made to store a **null** object and **null** elements are not allowed in the collection. An **IllegalArgumentException** is thrown if an attempt is made to add an element to a fixed-length collection that is full.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean add(E obj)</td>
<td>Adds obj to the invoking collection. Returns true if obj was added to the collection. Returns false if obj is already a member of the collection and the collection does not allow duplicates.</td>
</tr>
<tr>
<td>boolean addAll(Collection&lt;? extends E&gt; e)</td>
<td>Adds all the elements of e to the invoking collection. If the collection was modified, returns true. Otherwise, returns false.</td>
</tr>
<tr>
<td>void clear()</td>
<td>Removes all elements from the invoking collection. Returns true if the collection was modified. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean contains(Object obj)</td>
<td>Returns true if obj is an element of the invoking collection. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean containsAll(Collection&lt;? extends E&gt; e)</td>
<td>Returns true if the invoking collection contains all elements of e. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if the invoking collection and obj are equal. Otherwise, returns false.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking collection.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the invoking collection is empty. Otherwise, returns false.</td>
</tr>
<tr>
<td>Iterator&lt;E&gt; iterator()</td>
<td>Returns an iterator for the invoking collection.</td>
</tr>
<tr>
<td>default Stream&lt;E&gt; parallelStream()</td>
<td>Returns a stream that uses the invoking collection as its source for elements. If possible, the stream supports parallel operations. (Added by JDK 8.)</td>
</tr>
<tr>
<td>boolean remove(Object obj)</td>
<td>Removes one instance of obj from the invoking collection. Returns true if the element was removed. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean removeAll(Collection&lt;? super E&gt; e)</td>
<td>Removes all elements of e from the invoking collection. Returns true if the collection was modified (i.e., elements were removed). Otherwise, returns false.</td>
</tr>
<tr>
<td>default boolean removeIf(Predicate&lt;? super E&gt; predicate)</td>
<td>Removes from the invoking collection those elements that satisfy the condition specified by predicate. (Added by JDK 8.)</td>
</tr>
</tbody>
</table>
Objects are added to a collection by calling `add()`. Notice that `add()` takes an argument of type `E`, which means that objects added to a collection must be compatible with the type of data expected by the collection. You can add the entire contents of one collection to another by calling `addAll()`.

You can remove an object by using `remove()`. To remove a group of objects, call `removeAll()`. Beginning with JDK 8, to remove an element only if it satisfies some condition, you can use `removeIf()`. (Predicate is a functional interface added by JDK 8. See Chapter 19.) To empty a collection, call `clear()`.

You can determine whether a collection contains a specific object by calling `contains()`. To determine whether one collection contains all the members of another, call `containsAll()`. You can determine when a collection is empty by calling `isEmpty()`. The number of elements currently held in a collection can be determined by calling `size()`.

The `toArray()` methods return an array that contains the elements stored in the invoking collection. The first returns an array of `Object`. The second returns an array of elements that have the same type as the array specified as a parameter. Normally, the second form is more convenient because it returns the desired array type. These methods are more important than it might at first seem. Often, processing the contents of a collection by using array-like syntax is advantageous. By providing a pathway between collections and arrays, you can have the best of both worlds.

Two collections can be compared for equality by calling `equals()`. The precise meaning of “equality” may differ from collection to collection. For example, you can implement `equals()`
so that it compares the values of elements stored in the collection. Alternatively, equals( ) can compare references to those elements.

Another important method is iterator( ), which returns an iterator to a collection. The new spliterator( ) method returns a spliterator to the collection. Iterators are frequently used when working with collections. Finally, the stream( ) and parallelStream( ) methods return a Stream that uses the collection as a source of elements. (See Chapter 29 for a detailed discussion of the new Stream interface.)

The List Interface

The List interface extends Collection and declares the behavior of a collection that stores a sequence of elements. Elements can be inserted or accessed by their position in the list, using a zero-based index. A list may contain duplicate elements. List is a generic interface that has this declaration:

interface List<E>

Here, E specifies the type of objects that the list will hold.

In addition to the methods defined by Collection, List defines some of its own, which are summarized in Table 18-2. Note again that several of these methods will throw an UnsupportedOperationException if the list cannot be modified, and a ClassCastException is generated when one object is incompatible with another, such as when an attempt is made to add an incompatible object to a list. Also, several methods will throw an IndexOutOfBoundsException if an invalid index is used. A NullPointerException is thrown if an attempt is made to store a null object and null elements are not allowed in the list. An IllegalArgumentException is thrown if an invalid argument is used.

To the versions of add( ) and addAll( ) defined by Collection, List adds the methods add(int, E) and addAll(int, Collection). These methods insert elements at the specified index. Also, the semantics of add(E) and addAll(Collection) defined by Collection are changed by List so that they add elements to the end of the list. You can modify each element in the collection by using replaceAll( ). (UnaryOperator is a functional interface added by JDK 8. See Chapter 19.)

To obtain the object stored at a specific location, call get( ) with the index of the object. To assign a value to an element in the list, call set( ), specifying the index of the object to be changed. To find the index of an object, use indexOf( ) or lastIndexOf( ).

You can obtain a sublist of a list by calling subList( ), specifying the beginning and ending indexes of the sublist. As you can imagine, subList( ) makes list processing quite convenient. One way to sort a list is with the sort( ) method defined by List.

The Set Interface

The Set interface defines a set. It extends Collection and specifies the behavior of a collection that does not allow duplicate elements. Therefore, the add( ) method returns false if an attempt is made to add duplicate elements to a set. It does not specify any
additional methods of its own. **Set** is a generic interface that has this declaration:

```java
interface Set<E>
```

Here, **E** specifies the type of objects that the set will hold.

### The SortedSet Interface

The **SortedSet** interface extends **Set** and declares the behavior of a set sorted in ascending order. **SortedSet** is a generic interface that has this declaration:

```java
interface SortedSet<E>
```

Here, **E** specifies the type of objects that the set will hold.

In addition to those methods provided by **Set**, the **SortedSet** interface declares the methods summarized in Table 18-3. Several methods throw a **NoSuchElementException** when no items are contained in the invoking set. A **ClassCastException** is thrown when an object is incompatible with the elements in a set. A **NullPointerException** is thrown if

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void add(int index, E obj)</td>
<td>Inserts obj into the invoking list at the index passed in index. Any preexisting elements at or beyond the point of insertion are shifted up. Thus, no elements are overwritten.</td>
</tr>
<tr>
<td>boolean addAll(int index,</td>
<td>Inserts all elements of i into the invoking list at the index passed in index. Any preexisting elements at or beyond the point of insertion are shifted up. Thus, no elements are overwritten. Returns true if the invoking list changes and returns false otherwise.</td>
</tr>
<tr>
<td>Collections&lt;? extends E&gt; i)</td>
<td></td>
</tr>
<tr>
<td>E get(int index)</td>
<td>Returns the object stored at the specified index within the invoking collection.</td>
</tr>
<tr>
<td>int indexOf(Object obj)</td>
<td>Returns the index of the first instance of obj in the invoking list. If obj is not an element of the list, -1 is returned.</td>
</tr>
<tr>
<td>int lastIndexOf(Object obj)</td>
<td>Returns the index of the last instance of obj in the invoking list. If obj is not an element of the list, -1 is returned.</td>
</tr>
<tr>
<td>ListIterator&lt;E&gt; listIterator()</td>
<td>Returns an iterator to the start of the invoking list.</td>
</tr>
<tr>
<td>ListIterator&lt;E&gt; listIterator(int index)</td>
<td>Returns an iterator to the invoking list that begins at the specified index.</td>
</tr>
<tr>
<td>E remove(int index)</td>
<td>Removes the element at position index from the invoking list and returns the deleted element. The resulting list is compacted. That is, the indexes of subsequent elements are decremented by one.</td>
</tr>
<tr>
<td>default void replaceAll(</td>
<td>Updates each element in the list with the value obtained from the ( \text{map} ) function. (Added by JDK 8.)</td>
</tr>
<tr>
<td>UnaryOperator&lt;E&gt; map)</td>
<td></td>
</tr>
<tr>
<td>E set(int index, E obj)</td>
<td>Assigns obj to the location specified by index within the invoking list. Returns the old value.</td>
</tr>
<tr>
<td>default void sort(Comparator&lt;? super E&gt; cmp)</td>
<td>Sorts the list using the comparator specified by ( \text{comparator} ). (Added by JDK 8.)</td>
</tr>
<tr>
<td>List&lt;E&gt; subList(int start, int end)</td>
<td>Returns a list that includes elements from ( \text{start} ) to ( \text{end} ) in the invoking list. Elements in the returned list are also referenced by the invoking object.</td>
</tr>
</tbody>
</table>

Table 18-2  The Methods Declared by **List**
an attempt is made to use a **null** object and **null** is not allowed in the set. An **IllegalArgumentException** is thrown if an invalid argument is used. **SortedSet** defines several methods that make set processing more convenient. To obtain the first object in the set, call **first( )**. To get the last element, use **last( )**. You can obtain a subset of a sorted set by calling **subSet( )**, specifying the first and last object in the set. If you need the subset that starts with the first element in the set, use **headSet( )**. If you want the subset that ends the set, use **tailSet( )**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparator&lt; E&gt;</td>
<td>super E: comparator( ) Returns the invoking sorted set’s comparator. If the natural ordering is used for this set, null is returned.</td>
</tr>
<tr>
<td>E: first( )</td>
<td>Returns the first element in the invoking sorted set.</td>
</tr>
<tr>
<td>SortedSet&lt; E&gt;:</td>
<td>headSet( E: end ); Returns a SortedSet containing those elements less than end that are contained in the invoking sorted set. Elements in the returned sorted set are also referenced by the invoking sorted set.</td>
</tr>
<tr>
<td>E: last( )</td>
<td>Returns the last element in the invoking sorted set.</td>
</tr>
<tr>
<td>SortedSet&lt; E&gt;:</td>
<td>subSet( E: start; E: end ); Returns a SortedSet that includes those elements between start and end-1. Elements in the returned collection are also referenced by the invoking object.</td>
</tr>
<tr>
<td>SortedSet&lt; E&gt;:</td>
<td>tailSet( E: start ); Returns a SortedSet that contains those elements greater than or equal to start that are contained in the sorted set. Elements in the returned set are also referenced by the invoking object.</td>
</tr>
</tbody>
</table>

**Table 18-3** The Methods Declared by SortedSet

---

**The NavigableSet Interface**

The **NavigableSet** interface extends **SortedSet** and declares the behavior of a collection that supports the retrieval of elements based on the closest match to a given value or values. **NavigableSet** is a generic interface that has this declaration:

```
interface NavigableSet<E>
```

Here, **E** specifies the type of objects that the set will hold. In addition to the methods that it inherits from **SortedSet**, **NavigableSet** adds those summarized in Table 18-4. A **ClassCastException** is thrown when an object is incompatible with the elements in the set. A **NullPointerException** is thrown if an attempt is made to use a **null** object and **null** is not allowed in the set. An **IllegalArgumentException** is thrown if an invalid argument is used.
The Queue Interface

The **Queue** interface extends **Collection** and declares the behavior of a queue, which is often a first-in, first-out list. However, there are types of queues in which the ordering is based upon other criteria. **Queue** is a generic interface that has this declaration:

```java
interface Queue<E>
```

Here, `E` specifies the type of objects that the queue will hold. The methods declared by **Queue** are shown in Table 18-5.

Several methods throw a **ClassCastException** when an object is incompatible with the elements in the queue. A **NullPointerException** is thrown if an attempt is made to store a `null` object and `null` elements are not allowed in the queue. An **IllegalArgumentException** is thrown if an invalid argument is used. An **IllegalStateException** is thrown if an attempt is made to
remove an element from an empty queue.

Despite its simplicity, Queue offers several points of interest. First, elements can only be removed from the head of the queue. Second, there are two methods that obtain and remove elements: poll( ) and remove( ). The difference between them is that poll( ) returns null if the queue is empty, but remove( ) throws an exception. Third, there are two methods, element( ) and peek( ), that obtain but don’t remove the element at the head of the queue. They differ only in that element( ) throws an exception if the queue is empty, but peek( ) returns null. Finally, notice that offer( ) only attempts to add an element to a queue. Because some queues have a fixed length and might be full, offer( ) can fail.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>E element( )</td>
<td>Returns the element at the head of the queue. The element is not removed.</td>
</tr>
<tr>
<td>boolean offer(E obj)</td>
<td>Attempts to add obj to the queue. Returns true if obj was added and false otherwise.</td>
</tr>
<tr>
<td>E peek( )</td>
<td>Returns the element at the head of the queue. It returns null if the queue is empty. The element is not removed.</td>
</tr>
<tr>
<td>E poll( )</td>
<td>Returns the element at the head of the queue, removing the element in the process. It returns null if the queue is empty.</td>
</tr>
<tr>
<td>E remove( )</td>
<td>Removes the element at the head of the queue, returning the element in the process. It throws NoSuchElementException if the queue is empty.</td>
</tr>
</tbody>
</table>

**Table 18-5** The Methods Declared by Queue

**The Deque Interface**
The Deque interface extends Queue and declares the behavior of a double-ended queue. Double-ended queues can function as standard, first-in, first-out queues or as last-in, first-out stacks. Deque is a generic interface that has this declaration:

```java
interface Deque<E>
```

Here, E specifies the type of objects that the deque will hold. In addition to the methods that it inherits from Queue, Deque adds those methods summarized in Table 18-6. Several methods throw a ClassCastException when an object is incompatible with the elements in the deque. A NullPointerException is thrown if an attempt is made to store a null object and null elements are not allowed in the deque. An IllegalArgumentException is thrown if an invalid argument is used. An IllegalStateException is thrown if an attempt is made to add an element to a fixed-length deque that is full. A NoSuchElementException is thrown if an attempt is made to remove an element from an empty deque.
Notice that Deque includes the methods `push()` and `pop()`. These methods enable a Deque to function as a stack. Also, notice the `descendingIterator()` method. It returns an iterator that returns elements in reverse order. In other words, it returns an iterator that moves from the end of the collection to the start. A Deque implementation can be capacity-restricted, which means that only a limited number of elements can be added to the deque. When this is the case, an attempt to add an element to the deque can fail. Deque allows you

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void addFirst(E obj)</code></td>
<td>Adds obj to the head of the deque. Throws an <code>IllegalArgumentException</code> if a capacity-restricted deque is out of space.</td>
</tr>
<tr>
<td><code>void addLast(E obj)</code></td>
<td>Adds obj to the tail of the deque. Throws an <code>IllegalArgumentException</code> if a capacity-restricted deque is out of space.</td>
</tr>
<tr>
<td><code>E getFirst()</code></td>
<td>Returns the first element in the deque. The object is not removed from the deque. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E getLast()</code></td>
<td>Returns the last element in the deque. The object is not removed from the deque. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>boolean offerFirst(E obj)</code></td>
<td>Attempts to add obj to the head of the deque. Returns true if obj was added and false otherwise. Therefore, this method returns false when an attempt is made to add obj to a full, capacity-restricted deque.</td>
</tr>
<tr>
<td><code>boolean offerLast(E obj)</code></td>
<td>Attempts to add obj to the tail of the deque. Returns true if obj was added and false otherwise.</td>
</tr>
<tr>
<td><code>E peekFirst()</code></td>
<td>Returns the element at the head of the deque. It returns <code>null</code> if the deque is empty. The object is not removed.</td>
</tr>
<tr>
<td><code>E peekLast()</code></td>
<td>Returns the element at the tail of the deque. It returns <code>null</code> if the deque is empty. The object is not removed.</td>
</tr>
<tr>
<td><code>E pollFirst()</code></td>
<td>Returns the element at the head of the deque, removing the element from the deque. It returns <code>null</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E pollLast()</code></td>
<td>Returns the element at the tail of the deque, removing the element from the deque. It returns <code>null</code> if the deque is empty.</td>
</tr>
<tr>
<td><code>E pop()</code></td>
<td>Remove the element at the head of the deque, removing it from the deque. It throws <code>NoSuchElementException</code> if the deque is empty.</td>
</tr>
</tbody>
</table>

Table 18-6 The MethodsDeclared by Deque
to handle such a failure in two ways. First, methods such as `addFirst()` and `addLast()` throw an `IllegalStateException` if a capacity-restricted deque is full. Second, methods such as `offerFirst()` and `offerLast()` return `false` if the element cannot be added.

### The Collection Classes

Now that you are familiar with the collection interfaces, you are ready to examine the standard classes that implement them. Some of the classes provide full implementations that can be used as-is. Others are abstract, providing skeletal implementations that are used as starting points for creating concrete collections. As a general rule, the collection classes are not synchronized, but as you will see later in this chapter, it is possible to obtain synchronized versions.

The core collection classes are summarized in the following table:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbstractCollection</td>
<td>Implements most of the <code>Collection</code> interface.</td>
</tr>
<tr>
<td>AbstractList</td>
<td>Extends <code>AbstractCollection</code> and implements most of the <code>List</code> interface.</td>
</tr>
<tr>
<td>AbstractQueue</td>
<td>Extends <code>AbstractCollection</code> and implements parts of the <code>Queue</code> interface.</td>
</tr>
<tr>
<td>AbstractSequentialList</td>
<td>Extends <code>AbstractList</code> for use by a collection that uses sequential rather than random access of its elements.</td>
</tr>
<tr>
<td>LinkedList</td>
<td>Implements a linked list by extending <code>AbstractSequentialList</code>.</td>
</tr>
<tr>
<td>ArrayList</td>
<td>Implements a dynamic array by extending <code>AbstractList</code>.</td>
</tr>
<tr>
<td>ArrayDeque</td>
<td>Implements a dynamic double-ended queue by extending <code>AbstractCollection</code> and implementing the <code>Deque</code> interface.</td>
</tr>
<tr>
<td>AbstractSet</td>
<td>Extends <code>AbstractCollection</code> and implements most of the <code>Set</code> interface.</td>
</tr>
<tr>
<td>EnumSet</td>
<td>Extends <code>AbstractSet</code> for use with <code>enum</code> elements.</td>
</tr>
<tr>
<td>HashSet</td>
<td>Extends <code>AbstractSet</code> for use with a hash table.</td>
</tr>
<tr>
<td>LinkedHashSet</td>
<td>Extends <code>HashSet</code> to allow insertion-order iterations.</td>
</tr>
<tr>
<td>PriorityQueue</td>
<td>Extends <code>AbstractQueue</code> to support a priority-based queue.</td>
</tr>
<tr>
<td>TreeSet</td>
<td>Implements a set stored in a tree. Extends <code>AbstractSet</code>.</td>
</tr>
</tbody>
</table>

The following sections examine the concrete collection classes and illustrate their use.
NOTE In addition to the collection classes, several legacy classes, such as Vector, Stack, and Hashtable, have been reengineered to support collections. These are examined later in this chapter.

The ArrayList Class

The ArrayList class extends AbstractList and implements the List interface. ArrayList is a generic class that has this declaration:

```java
class ArrayList<E>
```

Here, E specifies the type of objects that the list will hold.

ArrayList supports dynamic arrays that can grow as needed. In Java, standard arrays are of a fixed length. After arrays are created, they cannot grow or shrink, which means that you must know in advance how many elements an array will hold. But, sometimes, you may not know until run time precisely how large an array you need. To handle this situation, the Collections Framework defines ArrayList. In essence, an ArrayList is a variable-length array of object references. That is, an ArrayList can dynamically increase or decrease in size. Array lists are created with an initial size. When this size is exceeded, the collection is automatically enlarged. When objects are removed, the array can be shrunk.

NOTE Dynamic arrays are also supported by the legacy class Vector, which is described later in this chapter.

ArrayList has the constructors shown here:

```java
ArrayList( )
ArrayList(Collection<? extends E> c)
ArrayList(int capacity)
```

The first constructor builds an empty array list. The second constructor builds an array list that is initialized with the elements of the collection c. The third constructor builds an array list that has the specified initial capacity. The capacity is the size of the underlying array that is used to store the elements. The capacity grows automatically as elements are added to an array list.

The following program shows a simple use of ArrayList. An array list is created for objects of type String, and then several strings are added to it. (Recall that a quoted string is translated into a String object.) The list is then displayed. Some of the elements are removed and the list is displayed again.
// Demonstrate ArrayList.
import java.util.*;

class ArrayListDemo {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<String> al = new ArrayList<String>();

        System.out.println("Initial size of al: " + al.size());

        // Add elements to the array list.
        al.add("C");
        al.add("A");
        al.add("E");
        al.add("B");
        al.add("D");
        al.add("F");
        al.add(1, "A2");

        System.out.println("Size of al after additions: " + al.size());

        // Display the array list.
        System.out.println("Contents of al: " + al);

        // Remove elements from the array list.
        al.remove("F");
        al.remove(2);

        System.out.println("Size of al after deletions: " + al.size());

        System.out.println("Contents of al: " + al);
    }
}

The output from this program is shown here:

<table>
<thead>
<tr>
<th>Initial size of al: 0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size of al after additions: 7</td>
</tr>
<tr>
<td>Contents of al: [C, A2, A, E, B, D, F]</td>
</tr>
<tr>
<td>Size of al after deletions: 5</td>
</tr>
<tr>
<td>Contents of al: [C, A2, E, B, D]</td>
</tr>
</tbody>
</table>
Notice that a1 starts out empty and grows as elements are added to it. When elements are removed, its size is reduced.

In the preceding example, the contents of a collection are displayed using the default conversion provided by toString( ), which was inherited from AbstractCollection.

Although it is sufficient for short, sample programs, you seldom use this method to display the contents of a real-world collection. Usually, you provide your own output routines. But, for the next few examples, the default output created by toString( ) is sufficient.

Although the capacity of an ArrayList object increases automatically as objects are stored in it, you can increase the capacity of an ArrayList object manually by calling ensureCapacity( ). You might want to do this if you know in advance that you will be storing many more items in the collection than it can currently hold. By increasing its capacity once, at the start, you can prevent several reallocations later. Because reallocations are costly in terms of time, preventing unnecessary ones improves performance. The signature for ensureCapacity( ) is shown here:

```java
void ensureCapacity(int cap)
```

Here, cap specifies the new minimum capacity of the collection.

Conversely, if you want to reduce the size of the array that underlies an ArrayList object so that it is precisely as large as the number of items that it is currently holding, call trimToSize( ), shown here:

```java
void trimToSize()
```

### Obtaining an Array from an ArrayList

When working with ArrayList, you will sometimes want to obtain an actual array that contains the contents of the list. You can do this by calling toArray( ), which is defined by Collection. Several reasons exist why you might want to convert a collection into an array, such as:

- To obtain faster processing times for certain operations
- To pass an array to a method that is not overloaded to accept a collection
- To integrate collection-based code with legacy code that does not understand collections

Whatever the reason, converting an ArrayList to an array is a trivial matter. As explained earlier, there are two versions of toArray( ), which are shown again here for your convenience:

```java
object[ ] toArray( )
<T> T[ ] toArray(T array[ ])
```

The first returns an array of Object. The second returns an array of elements that have the same type as T. Normally, the second form is more convenient because it
returns the proper type of array. The following program demonstrates its use:

```java
// Convert an ArrayList into an array.
import java.util.*;

class ArrayListToArray {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<Integer> al = new ArrayList<Integer>();

        // Add elements to the array list.
        al.add(1);
        al.add(2);
        al.add(3);
        al.add(4);

        System.out.println("Contents of al: " + al);

        // Get the array.
        Integer ia[] = new Integer[al.size()];
        ia = al.toArray(ia);

        int sum = 0;

        // Sum the array.
        for(int i : ia) sum += i;

        System.out.println("Sum is: " + sum);
    }
}
```

The output from the program is shown here:
```
Contents of al: [1, 2, 3, 4]
Sum is: 10
```

The program begins by creating a collection of integers. Next, `toArray()` is called and it obtains an array of `Integer`. Then, the contents of that array are summed by use of a for-each style for loop.

There is something else of interest in this program. As you know, collections can store only references, not values of primitive types. However, autoboxing makes it possible to pass values of type `int` to `add()` without having to manually wrap them within an `Integer`, as the program shows. Autoboxing causes them to be automatically wrapped. In this way, autoboxing significantly improves the ease with which collections can be used to store primitive values.
The LinkedList Class
The LinkedList class extends AbstractSequentialList and implements the List, Deque, and Queue interfaces. It provides a linked-list data structure. LinkedList is a generic class that has this declaration:

```java
class LinkedList<E>
```

Here, E specifies the type of objects that the list will hold. LinkedList has the two constructors shown here:

```java
LinkedList()
LinkedList(Collection<? extends E>c)
```

The first constructor builds an empty linked list. The second constructor builds a linked list that is initialized with the elements of the collection c.

Because LinkedList implements the Deque interface, you have access to the methods defined by Deque. For example, to add elements to the start of a list, you can use addFirst() or offerFirst(). To add elements to the end of the list, use addLast() or offerLast(). To obtain the first element, you can use getFirst() or peekFirst(). To obtain the last element, use getLast() or peekLast(). To remove the first element, use removeFirst() or pollFirst(). To remove the last element, use removeLast() or pollLast().

The following program illustrates LinkedList:
// Demonstrate LinkedList.
import java.util.*;

class LinkedListDemo {
    public static void main(String args[]) {
        // Create a linked list.
        LinkedList<String> ll = new LinkedList<String>();

        // Add elements to the linked list.
        ll.add("F");
        ll.add("B");
        ll.add("D");
        ll.add("E");
        ll.add("C");
        ll.addLast("Z");
        ll.addFirst("A");
        ll.add(1, "A2");

        System.out.println("Original contents of ll: " + ll);

        // Remove elements from the linked list.
        ll.remove("F");
        ll.remove(2);

        System.out.println("Contents of ll after deletion: " + ll);

        // Remove first and last elements.
        ll.removeFirst();
        ll.removeLast();

        System.out.println("ll after deleting first and last: " + ll);

        // Get and set a value.
        String val = ll.get(2);
        ll.set(2, val + " Changed");

        System.out.println("ll after change: " + ll);
    }
}
Because **LinkedList** implements the **List** interface, calls to **add(E)** append items to the end of the list, as do calls to **addLast()**. To insert items at a specific location, use the **add(int, E)** form of **add()**, as illustrated by the call to **add(1, "A2")** in the example. Notice how the third element in **ll** is changed by employing calls to **get()** and **set()**. To obtain the current value of an element, pass **get()** the index at which the element is stored. To assign a new value to that index, pass **set()** the index and its new value.

**The HashSet Class**

**HashSet** extends **AbstractSet** and implements the **Set** interface. It creates a collection that uses a hash table for storage. **HashSet** is a generic class that has this declaration:

```
class HashSet<E>
```

Here, **E** specifies the type of objects that the set will hold.

As most readers likely know, a hash table stores information by using a mechanism called hashing. In hashing, the informational content of a key is used to determine a unique value, called its **hash code**. The hash code is then used as the index at which the data associated with the key is stored. The transformation of the key into its hash code is performed automatically—you never see the hash code itself. Also, your code can’t directly index the hash table. The advantage of hashing is that it allows the execution time of **add()**, **contains()**, **remove()**, and **size()** to remain constant even for large sets.

The following constructors are defined:

```
HashSet()  // The first form constructs a default hash set.
HashSet(Collection<? extends E> c)  // The second form initializes the hash set by using the elements of c.
HashSet(int capacity)  // The third form initializes the capacity of the hash set to capacity. (The default capacity is 16.)
HashSet(int capacity, float fillRatio)  // The fourth form initializes both the capacity and the fill ratio (also called load capacity) of the hash set from its arguments. The fill ratio must be between 0.0 and 1.0, and it determines how full the hash set can be before it is resized upward. Specifically, when the number of elements is greater than the capacity of the hash set multiplied by its fill ratio, the hash set is expanded. For constructors that do not take a fill ratio, 0.75 is used.
```

**HashSet** does not define any additional methods beyond those provided by its superclasses and interfaces.
It is important to note that **HashSet** does not guarantee the order of its elements, because the process of hashing doesn’t usually lend itself to the creation of sorted sets. If you need sorted storage, then another collection, such as **TreeSet**, is a better choice.

Here is an example that demonstrates **HashSet**:

```java
// Demonstrate HashSet.
import java.util.*;

class HashSetDemo {
    public static void main(String args[]) {
        // Create a hash set.
        HashSet<String> hs = new HashSet<String>();

        // Add elements to the hash set.
        hs.add("Beta");
        hs.add("Alpha");
        hs.add("Eta");
        hs.add("Gamma");
        hs.add("Epsilon");
        hs.add("Omega");

        System.out.println(hs);
    }
}
```

The following is the output from this program:

```
[Gamma, Eta, Alpha, Epsilon, Omega, Beta]
```

As explained, the elements are not stored in sorted order, and the precise output may vary.

**The LinkedHashSet Class**

The **LinkedHashSet** class extends **HashSet** and adds no members of its own. It is a generic class that has this declaration:

```java
class LinkedHashSet<E>
```

Here, **E** specifies the type of objects that the set will hold. Its constructors parallel those in **HashSet**.

**LinkedHashSet** maintains a linked list of the entries in the set, in the order in which they were inserted. This allows insertion-order iteration over the set. That is, when cycling through a **LinkedHashSet** using an iterator, the elements will be returned in the order in which they were inserted. This is also the order in which they are contained in the string returned by **toString()** when called on a **LinkedHashSet** object. To see the effect of **LinkedHashSet**, try substituting **LinkedHashSet** for **HashSet** in the preceding program. The output will be
which is the order in which the elements were inserted.

**The TreeSet Class**

`TreeSet` extends `AbstractSet` and implements the `NavigableSet` interface. It creates a collection that uses a tree for storage. Objects are stored in sorted, ascending order. Access and retrieval times are quite fast, which makes `TreeSet` an excellent choice when storing large amounts of sorted information that must be found quickly.

`TreeSet` is a generic class that has this declaration:

```java
class TreeSet<E>
```

Here, `E` specifies the type of objects that the set will hold.

`TreeSet` has the following constructors:

- `TreeSet()`
- `TreeSet(Collection<? extends E> c)`
- `TreeSet(Comparator<? super E> comp)`
- `TreeSet(SortedSet<E> ss)`

The first form constructs an empty tree set that will be sorted in ascending order according to the natural order of its elements. The second form builds a tree set that contains the elements of `c`. The third form constructs an empty tree set that will be sorted according to the comparator specified by `comp`. (Comparators are described later in this chapter.) The fourth form builds a tree set that contains the elements of `ss`.

Here is an example that demonstrates a `TreeSet`:
The output from this program is shown here:

```
[A, B, C, D, E, F]
```

As explained, because `TreeSet` stores its elements in a tree, they are automatically arranged in sorted order, as the output confirms.

Because `TreeSet` implements the `NavigableSet` interface, you can use the methods defined by `NavigableSet` to retrieve elements of a `TreeSet`. For example, assuming the preceding program, the following statement uses `subSet()` to obtain a subset of `ts` that contains the elements between `C` (inclusive) and `F` (exclusive). It then displays the resulting set.

```
System.out.println(ts.subSet("C", "F"));
```

The output from this statement is shown here:

```
[C, D, E]
```

You might want to experiment with the other methods defined by `NavigableSet`.

**The PriorityQueue Class**

`PriorityQueue` extends `AbstractQueue` and implements the `Queue` interface. It creates a queue that is prioritized based on the queue’s comparator. `PriorityQueue` is a generic class that has this declaration:

```
class PriorityQueue<E>
```
Here, \( E \) specifies the type of objects stored in the queue. **PriorityQueue**s are dynamic, growing as necessary. **PriorityQueue** defines the six constructors shown here:

- `PriorityQueue()`
- `PriorityQueue(int capacity)`
- `PriorityQueue(Comparator<? super E> comp)` (Added by JDK 8.)
- `PriorityQueue(int capacity, Comparator<? super E> comp)`
- `PriorityQueue(Collection<? extends E> c)`
- `PriorityQueue(PriorityQueue<? extends E> c)`
- `PriorityQueue(SortedSet<? extends E> c)`

The first constructor builds an empty queue. Its starting capacity is 11. The second constructor builds a queue that has the specified initial capacity. The third constructor specifies a comparator, and the fourth builds a queue with the specified capacity and comparator. The last three constructors create queues that are initialized with the elements of the collection passed in \( c \). In all cases, the capacity grows automatically as elements are added.

If no comparator is specified when a **PriorityQueue** is constructed, then the default comparator for the type of data stored in the queue is used. The default comparator will order the queue in ascending order. Thus, the head of the queue will be the smallest value. However, by providing a custom comparator, you can specify a different ordering scheme. For example, when storing items that include a time stamp, you could prioritize the queue such that the oldest items are first in the queue.

You can obtain a reference to the comparator used by a **PriorityQueue** by calling its `comparator()` method, shown here:

```java
Comparator<? super E> comparator()
```

It returns the comparator. If natural ordering is used for the invoking queue, **null** is returned.

One word of caution: Although you can iterate through a **PriorityQueue** using an iterator, the order of that iteration is undefined. To properly use a **PriorityQueue**, you must call methods such as `offer()` and `poll()`, which are defined by the **Queue** interface.

**The ArrayDeque Class**

The **ArrayDeque** class extends **AbstractCollection** and implements the **Deque** interface. It adds no methods of its own. **ArrayDeque** creates a dynamic array and has no capacity restrictions. (The **Deque** interface supports implementations that restrict capacity, but does not require such restrictions.) **ArrayDeque** is a generic class that has this declaration:

```java
class ArrayDeque<E>
```

Here, \( E \) specifies the type of objects stored in the collection.
**ArrayDeque** defines the following constructors:

```java
ArrayDeque()
ArrayDeque(int size)
ArrayDeque(Collection<? extends E> c)
```

The first constructor builds an empty deque. Its starting capacity is 16. The second constructor builds a deque that has the specified initial capacity. The third constructor creates a deque that is initialized with the elements of the collection passed in `c`. In all cases, the capacity grows as needed to handle the elements added to the deque.

The following program demonstrates **ArrayDeque** by using it to create a stack:

```java
// Demonstrate ArrayDeque.
import java.util.*;

class ArrayDequeDemo {
    public static void main(String args[]) {
        // Create an array deque.
        ArrayDeque<String> adq = new ArrayDeque<String>();

        // Use an ArrayDeque like a stack.
        adq.push("A");
        adq.push("B");
        adq.push("C");
        adq.push("D");
        adq.push("E");
        adq.push("F");

        System.out.print("Popping the stack: ");

        while(adq.peek() != null)
            System.out.print(adq.pop() + " ");

        System.out.println();
    }
}
```

The output is shown here:

```
Popping the stack: F E D B A
```

**The EnumSet Class**

**EnumSet** extends **AbstractSet** and implements **Set**. It is specifically for use with elements of an **enum** type. It is a generic class that has this declaration:

```java
class EnumSet<E extends Enum<E>>
```
Here, \( E \) specifies the elements. Notice that \( E \) must extend \texttt{Enum<E>}\texttt{, which}\n
\texttt{EnumSet} defines no constructors. Instead, it uses the factory methods shown in Table 18-7\n
to create objects. All methods can throw \texttt{NullPointerException}. The \texttt{copyOf( )} and\n\texttt{range( )} methods can also throw \texttt{IllegalArgumentException}. Notice that the \texttt{of( )}\nmethod is overloaded a number of times. This is in the interest of efficiency. Passing a\nknown number of arguments can be faster than using a vararg parameter when the number\nof arguments is small.

\textbf{Accessing a Collection via an Iterator}

Often, you will want to cycle through the elements in a collection. For example, you might\nwant to display each element. One way to do this is to employ an \texttt{iterator}, which is an\nobject that implements either the \texttt{Iterator} or the \texttt{ListIterator} interface. \texttt{Iterator} enables\nyou to cycle through a collection, obtaining or removing elements. \texttt{ListIterator} extends\n\texttt{Iterator} to allow bidirectional traversal of a list, and the modification of elements.\n\texttt{Iterator} and \texttt{ListIterator} are generic interfaces which are declared as shown here:\n
\begin{verbatim}
interface Iterator<E>

interface ListIterator<E>
\end{verbatim}

Here, \( E \) specifies the type of objects being iterated. The \texttt{Iterator} interface declares\nthe methods shown in Table 18-8. The methods declared by \texttt{ListIterator} (along\nwith those inherited from \texttt{Iterator}) are shown in Table 18-9. In both cases,\noperations that modify the underlying collection are optional. For example,\n\texttt{remove( )} will throw \texttt{UnsupportedOperationException} when used with a\nread-only collection. Various other exceptions are possible.
Table 18-7  The Methods Declared by EnumSet

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; allOf(Class&lt;E&gt; e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains the elements in the enumeration specified by e.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; complementOf(EnumSet&lt;E&gt; e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that is comprised of those elements not stored in e.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; copyOf(EnumSet&lt;E&gt; e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet from the elements stored in e.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; copyOf(Collection&lt;E&gt; e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet from the elements stored in e.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; emptyOf(Class&lt;E&gt; e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains the elements that are not in the enumeration specified by e, which is an empty set by definition.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; of(E e)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains e.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; of(E e1, E e2)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains e1 and e2.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; of(E e1, E e2, E e3)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains e1 through e3.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; of(E e1, E e2, E e3, E e4)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains e1 through e4.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; of(E e1, E e2, E e3, E e4, E e5)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains e1 through e5.</td>
</tr>
<tr>
<td>static &lt;E&gt; extends Enum&lt;E&gt;</td>
<td>EnumSet&lt;E&gt; range(E start, E end)</td>
</tr>
<tr>
<td></td>
<td>Creates an EnumSet that contains the elements in the range specified by start and end.</td>
</tr>
</tbody>
</table>

Table 18-8  The Methods Declared by Iterator

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>default void forEachRemaining(</td>
<td>The action specified by action is executed on each unprocessed element in the collection. (Added by JDK 8, )</td>
</tr>
<tr>
<td>Consumer&lt;? super E&gt; action</td>
<td></td>
</tr>
<tr>
<td>boolean hasNext()</td>
<td>Returns true if there are more elements. Otherwise, returns false.</td>
</tr>
<tr>
<td>E next()</td>
<td>Returns the next element. Throws NoSuchElementException if there is not a next element.</td>
</tr>
<tr>
<td>default void remove()</td>
<td>Removes the current element. Throws IllegalStateException if an attempt is made to call remove() that is not preceded by a call to next(). The default version throws an UnsupportedOperationException.</td>
</tr>
</tbody>
</table>
NOTE Beginning with JDK 8, you can also use a Spliterator to cycle through a collection. Spliterator works differently than does Iterator, and it is described later in this chapter.

Using an Iterator

Before you can access a collection through an iterator, you must obtain one. Each of the collection classes provides an iterator() method that returns an iterator to the start of the collection. By using this iterator object, you can access each element in the collection, one element at a time. In general, to use an iterator to cycle through the contents of a collection, follow these steps:

1. Obtain an iterator to the start of the collection by calling the collection’s iterator() method.
2. Set up a loop that makes a call to hasNext(). Have the loop iterate as long as hasNext() returns true.
3. Within the loop, obtain each element by calling next().

For collections that implement List, you can also obtain an iterator by calling

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void add(E e)</td>
<td>Inserts e into the list in front of the element that will be returned in the next call to next().</td>
</tr>
<tr>
<td>default void forEachRemaining(Consumer&lt;? super E&gt; action)</td>
<td>The action specified by action is executed on each unprocessed element in the collection. (Added by JDK 8)</td>
</tr>
<tr>
<td>boolean hasNext()</td>
<td>Returns true if there is a next element. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean hasPrevious()</td>
<td>Returns true if there is a previous element. Otherwise, returns false.</td>
</tr>
<tr>
<td>E next()</td>
<td>Returns the next element. A NoSuchElementException is thrown if there is not a next element.</td>
</tr>
<tr>
<td>int nextIndex()</td>
<td>Returns the index of the next element. If there is not a next element, returns the size of the list.</td>
</tr>
<tr>
<td>E previous()</td>
<td>Returns the previous element. A NoSuchElementException is thrown if there is not a previous element.</td>
</tr>
<tr>
<td>int previousIndex()</td>
<td>Returns the index of the previous element. If there is not a previous element, returns -1.</td>
</tr>
<tr>
<td>void remove()</td>
<td>Removes the current element from the list. An IllegalStateException is thrown if remove() is called before next() or previous() is invoked.</td>
</tr>
<tr>
<td>void set(E e)</td>
<td>Assigns e to the current element. This is the element last returned by a call to either next() or previous().</td>
</tr>
</tbody>
</table>

Table 18-9 The Methods Provided by ListIterator
listIterator( ). As explained, a list iterator gives you the ability to access the
collection in either the forward or backward direction and lets you modify an
element. Otherwise, ListIterator is used just like Iterator.
The following example implements these steps, demonstrating both the Iterator and
ListIterator interfaces. It uses an ArrayList object, but the general principles apply to
any type of collection. Of course, ListIterator is available only to those collections that
implement the List interface.
// Demonstrate iterators.
import java.util.*;

class IteratorDemo {
    public static void main(String args[]) {
        // Create an array list.
        ArrayList<String> al = new ArrayList<String>();

        // Add elements to the array list.
        al.add("C");
        al.add("A");
        al.add("E");
        al.add("B");
        al.add("D");
        al.add("F");

        // Use iterator to display contents of al.
        System.out.print("Original contents of al: ");
        Iterator<String> itr = al.iterator();
        while(itr.hasNext()) {
            String element = itr.next();
            System.out.print(element + " ");
        }
        System.out.println();

        // Modify objects being iterated.
        ListIterator<String> litr = al.listIterator();
        while(litr.hasNext()) {
            String element = litr.next();
            litr.set(element + "+");
        }

        System.out.print("Modified contents of al: ");
        itr = al.iterator();
        while(itr.hasNext()) {
            String element = itr.next();
            System.out.print(element + " ");
        }
        System.out.println();

        // Now, display the list backwards.
        System.out.print("Modified list backwards: ");
        while(litr.hasPrevious()) {
            String element = litr.previous();
            System.out.print(element + " ");
        }
        System.out.println();
    }
}
Pay special attention to how the list is displayed in reverse. After the list is modified, `litr` points to the end of the list. (Remember, `litr.hasNext()` returns `false` when the end of the list has been reached.) To traverse the list in reverse, the program continues to use `litr`, but this time it checks to see whether it has a previous element. As long as it does, that element is obtained and displayed.

**The For-Each Alternative to Iterators**

If you won't be modifying the contents of a collection or obtaining elements in reverse order, then the for-each version of the `for` loop is often a more convenient alternative to cycling through a collection than is using an iterator. Recall that the `for` can cycle through any collection of objects that implement the `Iterable` interface. Because all of the collection classes implement this interface, they can all be operated upon by the `for`.

The following example uses a `for` loop to sum the contents of a collection:

```java
// Use the for-each for loop to cycle through a collection.
import java.util.*;

classForEachDemo {
    public static void main(String args[]) {
        // Create an array list for integers.
        ArrayList<Integer> vals = new ArrayList<Integer>();

        // Add values to the array list.
        vals.add(1);
        vals.add(2);
        vals.add(3);
        vals.add(4);
        vals.add(5);

        // Use for loop to display the values.
        System.out.print("Contents of vals: ");
        for(int v : vals)
            System.out.print(v + " ");
        System.out.println();

        // Now, sum the values by using a for loop.
        int sum = 0;
        for(int v : vals)
            sum += v;

        System.out.println("Sum of values: " + sum);
    }
}
```

The output from the program is shown here:
As you can see, the for loop is substantially shorter and simpler to use than the iterator-based approach. However, it can only be used to cycle through a collection in the forward direction, and you can’t modify the contents of the collection.

Spliterator
JDK 8 adds a new type of iterator called a spliterator that is defined by the Spliterator interface. A spliterator cycles through a sequence of elements, and in this regard, it is similar to the iterators just described. However, the techniques required to use it differ. Furthermore, it offers substantially more functionality than does either Iterator or ListIterator. Perhaps the most important aspect of Spliterator is its ability to provide support for parallel iteration of portions of the sequence. Thus, Spliterator supports parallel programming. (See Chapter 28 for information on concurrency and parallel programming.) However, you can use Spliterator even if you won’t be using parallel execution. One reason you might want to do so is because it offers a streamlined approach that combines the hasNext and next operations into one method.

Spliterator is a generic interface that is declared like this:

```
interface Spliterator<T>
```

Here, T is the type of elements being iterated. Spliterator declares the methods shown in Table 18-10.

Using Spliterator for basic iteration tasks is quite easy: simply call tryAdvance() until it returns false. If you will be applying the same action to each element in the sequence, forEachRemaining() offers a streamlined alternative. In both cases, the action that will occur with each iteration is defined by what the Consumer object does with each element. Consumer is a functional interface that applies an action to an object. It is a generic functional interface declared in java.util.function. (See Chapter 19 for information on java.util.function.) Consumer specifies only one abstract method, accept(), which is shown here:

```
void accept(T objRef)
```

In the case of tryAdvance(), each iteration passes the next element in the sequence to objRef. Often, the easiest way to implement Consumer is by use of a lambda expression.
Table 18-10  The Methods Declared by Spliterator

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int characteristics()</td>
<td>Returns the characteristics of the invoking spliterator, encoded into an integer.</td>
</tr>
<tr>
<td>long estimateSize()</td>
<td>Estimates the number of elements left to iterate and returns the result. Returns Long.MAX_VALUE if the count cannot be obtained for any reason.</td>
</tr>
<tr>
<td>default void forEachRemaining(Consumer&lt;? super T&gt; action)</td>
<td>Applies action to each unprocessed element in the data source.</td>
</tr>
<tr>
<td>default Comparator&lt;? super T&gt; getComparator()</td>
<td>Returns the comparator used by the invoking spliterator or null if natural ordering is used. If the sequence is unordered, IllegalStateException is thrown.</td>
</tr>
<tr>
<td>default long getExactSizeIfKnown()</td>
<td>If the invoking spliterator is sized, returns the number of elements left to iterate. Returns -1 otherwise.</td>
</tr>
<tr>
<td>default boolean hasCharacteristics(int width)</td>
<td>Returns true if the invoking spliterator has the characteristics passed in width. Returns false otherwise.</td>
</tr>
<tr>
<td>boolean tryAdvance(Consumer&lt;? super T&gt; action)</td>
<td>Executes action on the next element in the iteration. Returns true if there is a next element. Returns false if no elements remain.</td>
</tr>
<tr>
<td>Spliterator&lt;T&gt; trySplit()</td>
<td>If possible, splits the invoking spliterator, returning a reference to a new spliterator for the partition. Otherwise, returns null. Thus, if successful, the original spliterator iterates over one portion of the sequence and the returned spliterator iterates over the other portion.</td>
</tr>
</tbody>
</table>

The following program provides a simple example of Spliterator. Notice that the program demonstrates both tryAdvance( ) and forEachRemaining( ). Also notice how these methods combine the actions of Iterator’s next( ) and hasNext( ) methods into a single call.
// A simple Splitterator demonstration.
import java.util.*;

class SplitteratorDemo {

    public static void main(String args[]) {
        // Create an array list for doubles.
        ArrayList<Double> vals = new ArrayList<>();

        // Add values to the array list.
        vals.add(1.0);
        vals.add(2.0);
        vals.add(3.0);
        vals.add(4.0);
        vals.add(5.0);

        // Use tryAdvance() to display contents of vals.
        System.out.print("Contents of vals:\n");
        Splitterator<Double> splitr = vals.splitterator();
        while(splitr.tryAdvance((n) -> System.out.println(n)));
        System.out.println();

        // Create new list that contains square roots.
        splitr = vals.splitterator();
        ArrayList<Double> sqrs = new ArrayList<>();
        while(splitr.tryAdvance((n) -> sqrs.add(Math.sqrt(n))));

        // Use forEachRemaining() to display contents of sqrs.
        System.out.print("Contents of sqrs:\n");
        splitr = sqrs.splitterator();
        splitr.forEachRemaining((n) -> System.out.println(n));
        System.out.println();
    }
}
Although this program demonstrates the mechanics of using Spliterator, it does not reveal its full power. As mentioned, Spliterator's maximum benefit is found in situations that involve parallel processing.

In Table 18-10, notice the methods characteristics() and hasCharacteristics(). Each Spliterator has a set of attributes, called characteristics, associated with it. These are defined by static int fields in Spliterator, such as SORTED, DISTINCT, SIZED, and IMMUTABLE, to name a few. You can obtain the characteristics by calling characteristics(). You can determine if a characteristic is present by calling hasCharacteristics(). Often, you won’t need to access a Spliterator’s characteristics, but in some cases, they can aid in creating efficient, resilient code.

There are several nested subinterfaces of Spliterator designed for use with the primitive types double, int, and long. These are called Spliterator.OfDouble, Spliterator.OfInt, and Spliterator.OfLong. There is also a generalized version called Spliterator.OfPrimitive(), which offers additional flexibility and serves as a superinterface of the aforementioned ones.

**Storing User-Defined Classes in Collections**

For the sake of simplicity, the foregoing examples have stored built-in objects, such as
String or Integer, in a collection. Of course, collections are not limited to the storage of built-in objects. Quite the contrary. The power of collections is that they can store any type of object, including objects of classes that you create. For example, consider the following example that uses a LinkedList to store mailing addresses:

```java
// A simple mailing list example
import java.util.*;

class Address {
    private String name;
    private String street;
    private String city;
    private String state;
    private String code;

    Address(String n, String s, String c, String st, String cd) {
        name = n;
        street = s;
        city = c;
        state = st;
        code = cd;
    }

    public String toString() {
        return name + "\n" + street + "\n" +
                city + " " + state + " " + code;
    }
}

class MailList {
    public static void main(String[] args) {
        LinkedList<Address> ml = new LinkedList<Address>();

        // Add elements to the linked list.
        ml.add(new Address("J.W. West", "11 Oak Ave", "Urbana", "IL", "61801"));
        ml.add(new Address("Ralph Baker", "1142 Maple Lane", "Mahomet", "IL", "61853"));
        ml.add(new Address("Tom Carlton", "867 Elm St", "Champaign", "IL", "61820"));

        // Display the mailing list.
        for (Address element : ml)
            System.out.println(element + "\n");

        System.out.println();
    }
```
The output from the program is shown here:

<table>
<thead>
<tr>
<th>J.W. West</th>
<th>11 Oak Ave</th>
<th>Urbana IL 61801</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ralph Baker</td>
<td>1142 Maple Lane</td>
<td>Mahomet IL 61853</td>
</tr>
<tr>
<td>Tom Carlton</td>
<td>967 Elm St</td>
<td>Champaign IL 61820</td>
</tr>
</tbody>
</table>

Aside from storing a user-defined class in a collection, another important thing to notice about the preceding program is that it is quite short. When you consider that it sets up a linked list that can store, retrieve, and process mailing addresses in about 50 lines of code, the power of the Collections Framework begins to become apparent. As most readers know, if all of this functionality had to be coded manually, the program would be several times longer. Collections offer off-the-shelf solutions to a wide variety of programming problems. You should use them whenever the situation presents itself.

**The RandomAccess Interface**

The **RandomAccess** interface contains no members. However, by implementing this interface, a collection signals that it supports efficient random access to its elements. Although a collection might support random access, it might not do so efficiently. By checking for the **RandomAccess** interface, client code can determine at run time whether a collection is suitable for certain types of random access operations—especially as they apply to large collections. (You can use `instanceof` to determine if a class implements an interface.) **RandomAccess** is implemented by **ArrayList** and by the legacy **Vector** class, among others.

**Working with Maps**

A **map** is an object that stores associations between keys and values, or **key/value pairs**. Given a key, you can find its value. Both keys and values are objects. The keys must be unique, but the values may be duplicated. Some maps can accept a **null** key and **null** values, others cannot.

There is one key point about maps that is important to mention at the outset: they don’t implement the **Iterable** interface. This means that you **cannot** cycle through a map using a for-each style **for** loop. Furthermore, you can’t obtain an iterator to a map. However, as you will soon see, you can obtain a collection-view of a map, which does allow the use of either the **for** loop or an iterator.
The Map Interfaces
Because the map interfaces define the character and nature of maps, this discussion of maps begins with them. The following interfaces support maps:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map</td>
<td>Maps unique keys to values.</td>
</tr>
<tr>
<td>Map.Entry</td>
<td>Describes an element (a key/value pair) in a map. This is an inner class of Map.</td>
</tr>
<tr>
<td>NavigableMap</td>
<td>Extends SortedMap to handle the retrieval of entries based on closest-match searches.</td>
</tr>
<tr>
<td>SortedMap</td>
<td>Extends Map so that the keys are maintained in ascending order.</td>
</tr>
</tbody>
</table>

Each interface is examined next, in turn.

The Map Interface
The Map interface maps unique keys to values. A key is an object that you use to retrieve a value at a later date. Given a key and a value, you can store the value in a Map object. After the value is stored, you can retrieve it by using its key. Map is generic and is declared as shown here:

```java
interface Map<K, V>
```

Here, K specifies the type of keys, and V specifies the type of values. The methods declared by Map are summarized in Table 18-11. Several methods throw a ClassCastException when an object is incompatible with the elements in a map. A NullPointerException is thrown if an attempt is made to use a null object and null is not allowed in the map. An UnsupportedOperationException is thrown when an attempt is made to change an unmodifiable map. An IllegalArgumentException is thrown if an invalid argument is used.

Maps revolve around two basic operations: get() and put(). To put a value into a map, use put(), specifying the key and the value. To obtain a value, call get(), passing the key as an argument. The value is returned.

As mentioned earlier, although part of the Collections Framework, maps are not, themselves, collections because they do not implement the Collection interface. However, you can obtain a collection-view of a map. To do this, you can use the entrySet() method. It returns a Set that contains the elements in the map. To obtain a collection-view of the keys, use keySet(). To get a collection-view of the values, use values(). For all three collection-views, the collection is backed by the map. Changing one affects the other. Collection-views are the means by which maps are integrated into the larger Collections.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void clear()</td>
<td>Removes all key/value pairs from the invoking map.</td>
</tr>
<tr>
<td>default V compute(K k, BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</td>
<td>Calls func to construct a new value. If func returns non-null, the new key/value pair is added to the map, any preexisting pairing is removed, and the new value is returned. If func returns null, any preexisting pairing is removed, and null is returned. (Added by JDK 8.)</td>
</tr>
<tr>
<td>default V computeIfAbsent(K k, BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</td>
<td>Returns the value associated with the key k. Otherwise, the value is constructed through a call to func and the pairing is entered into the map and the constructed value is returned. If no value can be constructed, null is returned. (Added by JDK 8.)</td>
</tr>
<tr>
<td>default V computeIfPresent(K k, BiFunction&lt;? super K, ? super V, ? extends V&gt; func)</td>
<td>If k is in the map, a new value is constructed through a call to func and the new value replaces the old value in the map. In this case, the new value is returned. If the value returned by func is null, the existing key and value are removed from the map and null is returned. (Added by JDK 8.)</td>
</tr>
<tr>
<td>boolean containsKey(Object k)</td>
<td>Returns true if the invoking map contains k as a key. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean containsValue(Object v)</td>
<td>Returns true if the map contains v as a value. Otherwise, returns false.</td>
</tr>
<tr>
<td>Set&lt;Map.Entry&lt;K, V&gt;&gt; entrySet()</td>
<td>Returns a Set that contains the entries in the map. The set contains objects of type Map.Entry. Thus, this method provides a set view of the invoking map.</td>
</tr>
<tr>
<td>boolean equals(Object obj)</td>
<td>Returns true if obj is a Map and contains the same entries. Otherwise, returns false.</td>
</tr>
<tr>
<td>default void forEach(BiConsumer&lt;? super K, ? super V&gt; action)</td>
<td>Executes action on each element in the invoking map. A ConcurrentModificationException will be thrown if an element is removed during the process. (Added by JDK 8.)</td>
</tr>
<tr>
<td>V get(Object k)</td>
<td>Returns the value associated with the key k. Returns null if the key is not found.</td>
</tr>
<tr>
<td>default V getOrDefault(Object k, V defNull)</td>
<td>Returns the value associated with k if it is in the map. Otherwise, defNull is returned. (Added by JDK 8.)</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for the invoking map.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the invoking map is empty. Otherwise, returns false.</td>
</tr>
<tr>
<td>Set&lt;K&gt; keySet()</td>
<td>Returns a Set that contains the keys in the invoking map. This method provides a set view of the keys in the invoking map.</td>
</tr>
</tbody>
</table>
Table 18-11 The Methods Declared by Map

The SortedMap Interface

The **SortedMap** interface extends **Map**. It ensures that the entries are maintained in ascending order based on the keys. **SortedMap** is generic and is declared as shown here:

```
interface SortedMap<K, V> {
    default V merge(K k, V v, BiFunction<? super V, ? super V, ? extends V> func) {
        // Implementation...
    }
    // Other methods...
}
```

Here, **K** specifies the type of keys, and **V** specifies the type of values.

The methods declared by **SortedMap** are summarized in Table 18-12. Several methods throw a **NoSuchElementException** when no items are in the invoking map. A **ClassCastException** is thrown when an object is incompatible with the elements in a map. A **NullPointerException** is thrown if an attempt is made to use a null object when null is not allowed in the map. An **IllegalArgumentException** is thrown if an invalid argument is used.

Sorted maps allow very efficient manipulations of **submaps** (in other words, subsets of a
map). To obtain a submap, use `headMap()`, `tailMap()`, or `subMap()`. The submap returned by these methods is backed by the invoking map. Changing one changes the other. To get the first key in the set, call `firstKey()`. To get the last key, use `lastKey()`.

**The NavigableMap Interface**

The `NavigableMap` interface extends `SortedMap` and declares the behavior of a map that supports the retrieval of entries based on the closest match to a given key or keys. `NavigableMap` is a generic interface that has this declaration:

```java
interface NavigableMap<K, V>
```

Here, `K` specifies the type of the keys, and `V` specifies the type of the values associated with the keys. In addition to the methods that it inherits from `SortedMap`, `NavigableMap` adds those summarized in Table 18-13. Several methods throw a `ClassCastException` when an object is incompatible with the keys in the map. A `NullPointerException` is thrown if an attempt is made to use a `null` object and `null` keys are not allowed in the set. An `IllegalArgumentException` is thrown if an invalid argument is used.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Comparator&lt;? super K&gt; comparator()</code></td>
<td>Returns the invoking sorted map’s comparator. If natural ordering is used for the invoking map, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>K firstKey()</code></td>
<td>Returns the first key in the invoking map.</td>
</tr>
<tr>
<td><code>SortedMap&lt;K, V&gt; headMap(K end)</code></td>
<td>Returns a sorted map for those map entries with keys that are less than <code>end</code>.</td>
</tr>
<tr>
<td><code>K lastKey()</code></td>
<td>Returns the last key in the invoking map.</td>
</tr>
<tr>
<td><code>SortedMap&lt;K, V&gt; subMap(K start, K end)</code></td>
<td>Returns a map containing those entries with keys that are greater than or equal to <code>start</code> and less than <code>end</code>.</td>
</tr>
<tr>
<td><code>SortedMap&lt;K, V&gt; tailMap(K start)</code></td>
<td>Returns a map containing those entries with keys that are greater than or equal to <code>start</code>.</td>
</tr>
</tbody>
</table>

Table 18-12 The Methods Declared by `SortedMap`
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Map.Entry&lt;K,V&gt; ceilingEntry(K,k)</td>
<td>Searches the map for the smallest key k such that k &lt;= obj. If such a key is found, its entry is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>K ceilingKey(K,k)</td>
<td>Searches the map for the smallest key k such that k &lt;= obj. If such a key is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>NavigableSet&lt;K&gt; descendingKeySet()</td>
<td>Returns a NavigableSet that contains the keys in the invoking map in reverse order. Thus, it returns a reverse set-view of the keys. The resulting set is backed by the map.</td>
</tr>
<tr>
<td>NavigableMap&lt;K,V&gt; descendingMap()</td>
<td>Returns a NavigableMap that is the reverse of the invoking map. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td>Map.Entry&lt;K,V&gt; firstEntry()</td>
<td>Returns the first entry in the map. This is the entry with the least key.</td>
</tr>
<tr>
<td>Map.Entry&lt;K,V&gt; floorEntry(K,k)</td>
<td>Searches the map for the largest key k such that k &lt;= obj. If such a key is found, its entry is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>K floorKey(K,k)</td>
<td>Searches the map for the largest key k such that k &lt;= obj. If such a key is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>NavigableMap&lt;K,V&gt; headMap(K upperBound, boolean include)</td>
<td>Returns a NavigableMap that includes all entries from the invoking map that have keys that are less than upperBound. If include is true, then an element equal to upperBound is included. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td>Map.Entry&lt;K,V&gt; higherEntry(K,k)</td>
<td>Searches the set for the largest key k such that k &gt; obj. If such a key is found, its entry is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>K higherKey(K,k)</td>
<td>Searches the set for the largest key k such that k &gt; obj. If such a key is found, it is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>Map.Entry&lt;K,V&gt; lastEntry()</td>
<td>Returns the last entry in the map. This is the entry with the largest key.</td>
</tr>
<tr>
<td>Map.Entry&lt;K,V&gt; lowerEntry(K,k)</td>
<td>Searches the set for the largest key k such that k &lt; obj. If such a key is found, its entry is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>K lowerKey(K,k)</td>
<td>Searches the set for the largest key k such that k &lt; obj. If such a key is found, it is returned. Otherwise, null is returned.</td>
</tr>
</tbody>
</table>
The Map.Entry Interface

The Map.Entry interface enables you to work with a map entry. Recall that the entrySet() method declared by the Map interface returns a Set containing the map entries. Each of these set elements is a Map.Entry object. Map.Entry is generic and is declared like this:

interface Map.Entry<K, V>

Here, K specifies the type of keys, and V specifies the type of values. Table 18-14 summarizes the non-static methods declared by Map.Entry. JDK 8 adds two static methods. The first is comparingByKey(), which returns a Comparator that compares entries by key. The second is comparingByValue(), which returns a Comparator that compares entries by value.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean equals(Object o)</td>
<td>Returns true if o is a Map.Entry whose key and value are equal to that of the invoking object.</td>
</tr>
<tr>
<td>K getKey()</td>
<td>Returns the key for this map entry.</td>
</tr>
<tr>
<td>V getValue()</td>
<td>Returns the value for this map entry.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code for this map entry.</td>
</tr>
<tr>
<td>V setValue(V v)</td>
<td>Sets the value for this map entry to v. A ClassCastException is thrown if v is not the correct type for the map. An IllegalArgumentException is thrown if there is a problem with v. A NullPointerException is thrown if v is null and the map does not permit null keys. An UnsupportedOperationException is thrown if the map cannot be changed.</td>
</tr>
</tbody>
</table>

Table 18-13 The Methods Declared by NavigableMap

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NavigableSet&lt;K&gt; navigableKeySet( )</td>
<td>Returns a NavigableSet that contains the keys in the invoking map. The resulting set is backed by the invoking map.</td>
</tr>
<tr>
<td>Map.Entry&lt;K, V&gt; pollFirstEntry()</td>
<td>Returns the first entry, removing the entry in the process. Because the map is sorted, this is the entry with the least key value. null is returned if the map is empty.</td>
</tr>
<tr>
<td>Map.Entry&lt;K, V&gt; pollLastEntry( )</td>
<td>Returns the last entry, removing the entry in the process. Because the map is sorted, this is the entry with the greatest key value. null is returned if the map is empty.</td>
</tr>
<tr>
<td>NavigableMap&lt;K, V&gt; subMap(K lowerBound, boolean includeLower, K upperBound, boolean includeUpper)</td>
<td>Returns a NavigableMap that includes all entries from the invoking map that have keys that are greater than lowerBound and less than upperBound. If includeLower is true, then an element equal to lowerBound is included. If includeUpper is true, then an element equal to upperBound is included. The resulting map is backed by the invoking map.</td>
</tr>
<tr>
<td>NavigableMap&lt;K, V&gt; tailMap(K key, boolean inclusive)</td>
<td>Returns a NavigableMap that contains all entries from the invoking map that have keys that are greater than key. If inclusive is true, then an element equal to key is included. The resulting map is backed by the invoking map.</td>
</tr>
</tbody>
</table>

Table 18-14 The Non-Static Methods Declared by Map.Entry
The Map Classes
Several classes provide implementations of the map interfaces. The classes that can be used for maps are summarized here:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AbstractMap</td>
<td>Implements most of the <strong>Map</strong> interface.</td>
</tr>
<tr>
<td>EnumMap</td>
<td>Extends <strong>AbstractMap</strong> for use with <strong>enum</strong> keys.</td>
</tr>
<tr>
<td>HashMap</td>
<td>Extends <strong>AbstractMap</strong> to use a hash table.</td>
</tr>
<tr>
<td>TreeMap</td>
<td>Extends <strong>AbstractMap</strong> to use a tree.</td>
</tr>
<tr>
<td>WeakHashMap</td>
<td>Extends <strong>AbstractMap</strong> to use a hash table with weak keys.</td>
</tr>
<tr>
<td>LinkedHashMap</td>
<td>Extends <strong>HashMap</strong> to allow insertion-order iterations.</td>
</tr>
<tr>
<td>IdentityHashMap</td>
<td>Extends <strong>AbstractMap</strong> and uses reference equality when comparing documents.</td>
</tr>
</tbody>
</table>

Notice that **AbstractMap** is a superclass for all concrete map implementations. **WeakHashMap** implements a map that uses "weak keys," which allows an element in a map to be garbage-collected when its key is otherwise unused. This class is not discussed further here. The other map classes are described next.

The HashMap Class
The **HashMap** class extends **AbstractMap** and implements the **Map** interface. It uses a hash table to store the map. This allows the execution time of **get()** and **put()** to remain constant even for large sets. **HashMap** is a generic class that has this declaration:

```java
class HashMap<K, V>
```

Here, **K** specifies the type of keys, and **V** specifies the type of values.

The following constructors are defined:

```java
HashMap()  
HashMap(Map<? extends K, ? extends V> m)  
HashMap(int capacity)  
HashMap(int capacity, float fillRatio)
```

The first form constructs a default hash map. The second form initializes the hash map by using the elements of **m**. The third form initializes the capacity of the hash map to **capacity**. The fourth form initializes both the capacity and fill ratio of the hash map by using its arguments. The meaning of capacity and fill ratio is the same as for **HashSet**, described earlier. The default capacity is 16. The default fill ratio is 0.75.

**HashMap** implements **Map** and extends **AbstractMap**. It does not add any methods of
You should note that a hash map does not guarantee the order of its elements. Therefore, the order in which elements are added to a hash map is not necessarily the order in which they are read by an iterator.

The following program illustrates HashMap. It maps names to account balances. Notice how a set-view is obtained and used.

```java
import java.util.*;

class HashMapDemo {
    public static void main(String args[]) {
        // Create a hash map.
        HashMap<String, Double> hm = new HashMap<String, Double>();

        // Put elements to the map
        hm.put("John Doe", new Double(3494.34));
        hm.put("Tom Smith", new Double(123.22));
        hm.put("Jane Baker", new Double(1379.00));
        hm.put("Ted Hall", new Double(99.22));
        hm.put("Ralph Smith", new Double(-19.08));

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = hm.entrySet();

        // Display the set.
        for(Map.Entry<String, Double> me : set) {
            System.out.println(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = hm.get("John Doe");
        hm.put("John Doe", balance + 1000);
        System.out.println("John Doe's new balance: "+
                          hm.get("John Doe"));
    }
}
```

Output from this program is shown here (the precise order may vary):
The program begins by creating a hash map and then adds the mapping of names to balances. Next, the contents of the map are displayed by using a set-view, obtained by calling `entrySet()`. The keys and values are displayed by calling the `getKey()` and `getValue()` methods that are defined by `Map.Entry`. Pay close attention to how the deposit is made into John Doe's account. The `put()` method automatically replaces any preexisting value that is associated with the specified key with the new value. Thus, after John Doe's account is updated, the hash map will still contain just one "John Doe" account.

The `TreeMap` Class
The `TreeMap` class extends `AbstractMap` and implements the `NavigableMap` interface. It creates maps stored in a tree structure. A `TreeMap` provides an efficient means of storing key/value pairs in sorted order and allows rapid retrieval. You should note that, unlike a hash map, a tree map guarantees that its elements will be sorted in ascending key order. `TreeMap` is a generic class that has this declaration:

```java
class TreeMap<K, V> {
    //...}
```

Here, `K` specifies the type of keys, and `V` specifies the type of values. The following `TreeMap` constructors are defined:

```java
TreeMap() 
TreeMap(Comparator<? super K> comp)
TreeMap(Map<? extends K, ? extends V> m)
TreeMap(SortedMap<K, ? extends V> sm)
```

The first form constructs an empty tree map that will be sorted by using the natural order of its keys. The second form constructs an empty tree-based map that will be sorted by using the `Comparator comp`. (Comparators are discussed later in this chapter.) The third form initializes a tree map with the entries from `m`, which will be sorted by using the natural order of the keys. The fourth form initializes a tree map with the entries from `sm`, which will be sorted in the same order as `sm`.

`TreeMap` has no map methods beyond those specified by the `NavigableMap` interface and the `AbstractMap` class. The following program reworks the preceding example so that it uses `TreeMap`:

```
Ralph Smith: -19.08
Tom Smith: 123.22
John Doe: 3434.34
Tod Hall: 99.22
Jane Baker: 1378.0

John Doe's new balance: 4434.34
```
The following is the output from this program:

<table>
<thead>
<tr>
<th>Name</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jane Baker</td>
<td>1378.0</td>
</tr>
<tr>
<td>John Doe</td>
<td>3434.34</td>
</tr>
<tr>
<td>Ralph Smith</td>
<td>-19.08</td>
</tr>
<tr>
<td>Todd Hall</td>
<td>99.22</td>
</tr>
<tr>
<td>Tom Smith</td>
<td>123.22</td>
</tr>
</tbody>
</table>

John Doe's current balance: 4434.34

Notice that `TreeMap` sorts the keys. However, in this case, they are sorted by first name instead of last name. You can alter this behavior by specifying a comparator when the map is created, as described shortly.

The `LinkedHashMap` Class
**LinkedHashMap** extends **HashMap**. It maintains a linked list of the entries in the map, in the order in which they were inserted. This allows insertion-order iteration over the map. That is, when iterating through a collection-view of a **LinkedHashMap**, the elements will be returned in the order in which they were inserted. You can also create a **LinkedHashMap** that returns its elements in the order in which they were last accessed. **LinkedHashMap** is a generic class that has this declaration:

```java
class LinkedHashMap<K, V>
```
Here, **K** specifies the type of keys, and **V** specifies the type of values.

**LinkedHashMap** defines the following constructors:

- `LinkedHashMap()`
- `LinkedHashMap(Map<? extends K, ? extends V> m)`
- `LinkedHashMap(int capacity)`
- `LinkedHashMap(int capacity, float fillRatio)`
- `LinkedHashMap(int capacity, float fillRatio, boolean Order)`

The first form constructs a default **LinkedHashMap**. The second form initializes the **LinkedHashMap** with the elements from **m**. The third form initializes the capacity. The fourth form initializes both capacity and fill ratio. The meaning of capacity and fill ratio are the same as for **HashMap**. The default capacity is 16. The default ratio is 0.75. The last form allows you to specify whether the elements will be stored in the linked list by insertion order, or by order of last access. If **Order** is **true**, then access order is used. If **Order** is **false**, then insertion order is used.

**LinkedHashMap** adds only one method to those defined by **HashMap**. This method is `removeEldestEntry()`, and it is shown here:

```java
protected boolean removeEldestEntry(Map.Entry<K, V> e)
```

This method is called by `put()` and `putAll()`. The oldest entry is passed in **e**. By default, this method returns **false** and does nothing. However, if you override this method, then you can have the **LinkedHashMap** remove the oldest entry in the map. To do this, have your override return **true**. To keep the oldest entry, return **false**.

**The IdentityHashMap Class**
**IdentityHashMap** extends **AbstractMap** and implements the **Map** interface. It is similar to **HashMap** except that it uses reference equality when comparing elements. **IdentityHashMap** is a generic class that has this declaration:

```java
class IdentityHashMap<K, V>
```
Here, **K** specifies the type of key, and **V** specifies the type of value. The API documentation explicitly states that **IdentityHashMap** is not for general use.
The EnumMap Class

EnumMap extends AbstractMap and implements Map. It is specifically for use with keys of a enum type. It is a generic class that has this declaration:

class EnumMap<K extends Enum<K>, V>

Here, K specifies the type of key, and V specifies the type of value. Notice that K must extend Enum<K>, which enforces the requirement that the keys must be of an enum type.

EnumMap defines the following constructors:

EnumMap(Class<K> kType)
EnumMap(Map<K, ? extends V> m)
EnumMap(EnumMap<K, ? extends V> em)

The first constructor creates an empty EnumMap of type kType. The second creates an EnumMap map that contains the same entries as m. The third creates an EnumMap initialized with the values in em.

EnumMap defines no methods of its own.

Comparators

Both TreeSet and TreeMap store elements in sorted order. However, it is the comparator that defines precisely what “sorted order” means. By default, these classes store their elements by using what Java refers to as “natural ordering,” which is usually the ordering that you would expect (A before B, 1 before 2, and so forth). If you want to order elements a different way, then specify a Comparator when you construct the set or map. Doing so gives you the ability to govern precisely how elements are stored within sorted collections and maps.

Comparator is a generic interface that has this declaration:

interface Comparator<T>

Here, T specifies the type of objects being compared.

Prior to JDK 8, the Comparator interface defined only two methods: compare() and equals(). The compare() method, shown here, compares two elements for order:

int compare(T obj1, T obj2)

obj1 and obj2 are the objects to be compared. Normally, this method returns zero if the objects are equal. It returns a positive value if obj1 is greater than obj2. Otherwise, a negative value is returned. The method can throw a ClassCastException if the types of the objects are not compatible for comparison. By implementing compare(), you can alter the way that objects are ordered. For example, to sort in reverse order, you can create a comparator that reverses the outcome of a comparison.
The `equals()` method, shown here, tests whether an object equals the invoking comparator:

```java
boolean equals(object obj)
```

Here, `obj` is the object to be tested for equality. The method returns `true` if `obj` and the invoking object are both `Comparator` objects and use the same ordering. Otherwise, it returns `false`. Overriding `equals()` is not necessary, and most simple comparators will not do so.

For many years, the preceding two methods were the only methods defined by `Comparator`. With the release of JDK 8, the situation has dramatically changed. JDK 8 adds significant new functionality to `Comparator` through the use of default and static interface methods. Each is described here.

You can obtain a comparator that reverses the ordering of the comparator on which it is called by using `reversed()`, shown here:

```java
default Comparator<T> reversed()
```

It returns the reverse comparator. For example, assuming a comparator that uses natural ordering for the characters A through Z, a reverse order comparator would put B before A, C before B, and so on.

A method related to `reversed()` is `reverseOrder()`, shown next:

```java
static <T extends Comparable<? super T>> Comparator<T> reverseOrder()
```

It returns a comparator that reverses the natural order of the elements. Conversely, you can obtain a comparator that uses natural ordering by calling the static method `naturalOrder()`, shown next:

```java
static <T extends Comparable<? super T>> Comparator<T> naturalOrder()
```

If you want a comparator that can handle `null` values, use `nullsFirst()` or `nullsLast()`, shown here:

```java
static <T> Comparator<T> nullsFirst(Comparator<? super T> comp)
static <T> Comparator<T> nullsLast(Comparator<? super T> comp)
```

The `nullsFirst()` method returns a comparator that views `null` values as less than other values. The `nullsLast()` method returns a comparator that views `null` values as greater than other values. In both cases, if the two values being compared are non-`null`, `comp` performs the comparison. If `comp` is passed `null`, then all non-`null` values are viewed as equivalent.

Another default method added by JDK 8 is `thenComparing()`. It returns a comparator that performs a second comparison when the outcome of the first comparison indicates that the objects being compared are equal. Thus, it can be used to create a “compare by X then compare by Y” sequence. For example, when comparing cities, the first comparison might compare names, with the second comparison comparing states. (Therefore, Springfield,
Illinois, would come before Springfield, Missouri, assuming normal, alphabetical order.) The `thenComparing()` method has three forms. The first, shown here, lets you specify the second comparator by passing an instance of `Comparator`:

```
default Comparator<T> thenComparing(Comparator<? super T> thenByComp)
```

Here, `thenByComp` specifies the comparator that is called if the first comparison returns equal.

The next versions of `thenComparing()` let you specify the standard functional interface `Function` (defined by `java.util.function`). They are shown here:

```
default <U extends Comparable<? super U>> Comparator<T> thenComparing(Function<? super T, ? extends U> getKey)
default <U> Comparator<T> thenComparing(Function<? super T, ? extends U> getKey, Comparator<? super U> keyComp)
```

In both, `getKey` refers to function that obtains the next comparison key, which is used if the first comparison returns equal. In the second version, `keyComp` specifies the comparator used to compare keys. (Here, and in subsequent uses, `U` specifies the type of the key.)

`Comparator` also adds the following specialized versions of “then comparing” methods for the primitive types:

```
default Comparator<T> thenComparingDouble(ToDoubleFunction<? super T> getKey)
default Comparator<T> thenComparingInt(ToIntFunction<? super T> getKey)
default Comparator<T> thenComparingLong(ToLongFunction<? super T> getKey)
```

In all methods, `getKey` refers to a function that obtains the next comparison key.

Finally, JDK 8 adds to `Comparator` a method called `comparing()`. It returns a comparator that obtains its comparison key from a function passed to the method. There are two versions of `comparing()`, shown here:

```
static <T, U extends Comparable<? super U>> Comparator<T> comparing(Function<? super T, ? extends U> getKey)
static <T, U> Comparator<T> comparing(Function<? super T, ? extends U> getKey, Comparator<? super U> keyComp)
```
In both, \textit{getKey} refers to a function that obtains the next comparison key. In the second version, \textit{keyComp} specifies the comparator used to compare keys. \textbf{Comparator} also adds the following specialized versions of these methods for the primitive types:

\begin{verbatim}
static <T> Comparator<T> ComparingDouble(ToDoubleFunction<? super T> getKey)
static <T> Comparator<T> ComparingInt(ToIntFunction<? super T> getKey)
static <T> Comparator<T> ComparingLong(ToLongFunction<? super T> getKey)
\end{verbatim}

In all methods, \textit{getKey} refers to a function that obtains the next comparison key.

**Using a Comparator**

The following is an example that demonstrates the power of a custom comparator. It implements the \texttt{compare()} method for strings that operates in reverse of normal. Thus, it causes a tree set to be sorted in reverse order.
As the following output shows, the tree is now sorted in reverse order:

F E D C B A

Look closely at the MyComp class, which implements Comparator by implementing compare(). (As explained earlier, overriding equals() is neither necessary nor common. It is also not necessary to override the default methods added by JDK 8.) Inside compare(), the String method compareTo() compares the two strings. However, bStr—not aStr—invokes compareTo(). This causes the outcome of the comparison to be reversed. Although the way in which the reverse order comparator is implemented by the preceding program is perfectly adequate, beginning with JDK 8, there is another way to approach a solution. It is now possible to simply call reversed() on a natural-order comparator. It will
return an equivalent comparator, except that it runs in reverse. For example, assuming the preceding program, you can rewrite **MyComp** as a natural-order comparator, as shown here:

```java
class MyComp implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        return aStr.compareTo(bStr);
    }
}
```

Next, you can use the following sequence to create a **TreeSet** that orders its string elements in reverse:

```java
MyComp mc = new MyComp(); // Create a comparator

// Pass a reverse order version of MyComp to TreeSet.
TreeSet<String> ts = new TreeSet<String>(mc.reversed());
```

If you plug this new code into the preceding program, it will produce the same results as before. In this case, there is no advantage gained by using `reversed()` . However, in cases in which you need to create both a natural-order comparator and a reversed comparator, then using `reversed()` gives you an easy way to obtain the reverse-order comparator without having to code it explicitly.

Beginning with JDK 8, it is not actually necessary to create the **MyComp** class in the preceding examples because a lambda expression can be easily used instead. For example, you can remove the **MyComp** class entirely and create the string comparator by using this statement:

```java
// Use a lambda expression to implement Comparator<String>.
Comparator<String> mc = (aStr, bStr) -> aStr.compareTo(bStr);
```

One other point: in this simple example, it would also be possible to specify a reverse comparator via a lambda expression directly in the call to the **TreeSet()** constructor, as shown here:

```java
// Pass a reversed comparator to TreeSet() via a lambda expression.
TreeSet<String> ts = new TreeSet<String>(
    (aStr, bStr) -> bStr.compareTo(aStr));
```

By making these changes, the program is substantially shortened, as its final version shown here illustrates:
For a more practical example that uses a custom comparator, the following program is an updated version of the TreeMap program shown earlier that stores account balances. In the previous version, the accounts were sorted by name, but the sorting began with the first name. The following program sorts the accounts by last name. To do so, it uses a comparator that compares the last name of each account. This results in the map being sorted by last name.
import java.util.*;

// Compare last whole words in two strings.
class TComp implements Comparator<String> {
    public int compare(String aStr, String bStr) {
        int i, j, k;
        // Find index of beginning of last name.
        i = aStr.lastIndexOf(' ');  
        j = bStr.lastIndexOf(' ');
        k = aStr.substring(i).compareToIgnoreCase(bStr.substring(j));
        if (k==0) // last names match, check entire name
            return aStr.compareToIgnoreCase(bStr);
        else
            return k;
    }
    // No need to override equals.
}

// Use a comparator to sort accounts by last name.

class TreeMapDemo2 {
    public static void main(String args[]) {
        // Create a tree map.
        TreeMap<String, Double> tm = new TreeMap<String, Double>(new TComp());

        // Put elements to the map.
        tm.put("John Doe", new Double(3434.34));
        tm.put("Tom Smith", new Double(123.22));
        tm.put("Jane Baker", new Double(1378.00));
        tm.put("Ted Hall", new Double(99.22));
        tm.put("Ralph Smith", new Double(-19.08));

        // Get a set of the entries.
        Set<Map.Entry<String, Double>> set = tm.entrySet();

        // Display the elements.
        for (Map.Entry<String, Double> me : set) {
            System.out.print(me.getKey() + " : ");
            System.out.println(me.getValue());
        }
        System.out.println();

        // Deposit 1000 into John Doe's account.
        double balance = tm.get("John Doe");
        balance += 1000;
        tm.put("John Doe", balance);

        System.out.println("John Doe's new balance: " + tm.get("John Doe"));
    }
}
The comparator class `TComp` compares two strings that hold first and last names. It does so by first comparing last names. To do this, it finds the index of the last space in each string and then compares the substrings of each element that begin at that point. In cases where last names are equivalent, the first names are then compared. This yields a tree map that is sorted by last name, and within last name by first name. You can see this because Ralph Smith comes before Tom Smith in the output.

If you are using JDK 8 or later, then there is another way that you could code the preceding program so the map is sorted by last name and then by first name. This approach uses the `thenComparing()` method. Recall that `thenComparing()` lets you specify a second comparator that will be used if the invoking comparator returns equal. This approach is put into action by the following program, which reworks the preceding example to use `thenComparing()`:

```
<table>
<thead>
<tr>
<th>First Name</th>
<th>Last Name</th>
<th>Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jane</td>
<td>Baker</td>
<td>1378.0</td>
</tr>
<tr>
<td>John</td>
<td>Doe</td>
<td>3434.34</td>
</tr>
<tr>
<td>Todd</td>
<td>Hall</td>
<td>99.22</td>
</tr>
<tr>
<td>Ralph</td>
<td>Smith</td>
<td>-19.08</td>
</tr>
<tr>
<td>Tom</td>
<td>Smith</td>
<td>123.22</td>
</tr>
</tbody>
</table>

John Doe's new balance: 4434.34
```
This version produces the same output as before. It differs only in how it accomplishes its job. To begin, notice that a comparator called `CompLastNames` is created. This comparator compares only the last names. A second comparator, called `CompThenByFirstName`, compares the entire name, starting with the first name. Next, the `TreeMap` is then created by the following sequence:
Here, the primary comparator is `compLN`. It is an instance of `CompLastNames`. On it is called `thenComparing()`, passing in an instance of `CompThenByFirstName`. The result is assigned to the comparator called `compLastThenFirst`. This comparator is used to construct the `TreeMap`, as shown here:

```java
TreeMap<String, Double> tm =
    new TreeMap<String, Double>(compLastThenFirst);
```

Now, whenever the last names of the items being compared are equal, the entire name, beginning with the first name, is used to order the two. This means that names are ordered based on last name, and within last names, by first names.

One last point: in the interest of clarity, this example explicitly creates two comparator classes called `CompLastNames` and `ThenByFirstNames`, but lambda expressions could have been used instead. You might want to try this on your own. Just follow the same general approach described for the `CompDemo2` example shown earlier.

**The Collection Algorithms**

The Collections Framework defines several algorithms that can be applied to collections and maps. These algorithms are defined as static methods within the `Collections` class. They are summarized in Table 18-15. As explained earlier, beginning with JDK 5 all of the algorithms were retrofitted for generics.

Several of the methods can throw a `ClassCastException`, which occurs when an attempt is made to compare incompatible types, or an `UnsupportedOperationException`, which occurs when an attempt is made to modify an unmodifiable collection. Other exceptions are possible, depending on the method.

One thing to pay special attention to is the set of `checked` methods, such as `checkedCollection()`, which returns what the API documentation refers to as a “dynamically typesafe view” of a collection. This view is a reference to the collection that monitors insertions into the collection for type compatibility at run time. An attempt to insert an incompatible element will cause a `ClassCastException`. Using such a view is especially helpful during debugging because it ensures that the collection always contains valid elements. Related methods include `checkedSet()`, `checkedList()`, `checkedMap()`, and so on. They obtain a type-safe view for the indicated collection.

Notice that several methods, such as `synchronizedList()` and `synchronizedSet()`, are used to obtain synchronized (thread-safe) copies of the various collections. As a general rule, the standard collections implementations are not synchronized. You must use the synchronization algorithms to provide synchronization. One other point: iterators to synchronized collections must be used within `synchronized` blocks.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static <code>&lt;T&gt;</code> boolean <code>addAll(Collection&lt;? super T&gt; e, T... elements)</code></td>
<td>Inserts the elements specified by <code>elements</code> into the collection specified by <code>e</code>. Returns true if the elements were added and false otherwise.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> Queue&lt;E&gt; <code>&lt;E&gt; lifeQueueDeque&lt;E&gt;</code></td>
<td>Returns a last-in, first-out view of <code>e</code>.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> <code>int binarySearch(List&lt;T&gt; extends T, T value, Comparator&lt;? super T&gt; a)</code></td>
<td>Searches for <code>value</code> in <code>list</code> ordered according to <code>c</code>. Returns the position of <code>value</code> in <code>list</code>, or a negative value if <code>value</code> is not found.</td>
</tr>
<tr>
<td>static <code>&lt;T&gt;</code> <code>int binarySearch(List&lt;T&gt; extends Comparable&lt;? super T&gt; list, T value)</code></td>
<td>Searches for <code>value</code> in <code>list</code>. The list must be sorted. Returns the position of <code>value</code> in <code>list</code>, or a negative value if <code>value</code> is not found.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> Collection&lt;E&gt; <code>Collection&lt;E&gt; extends T, Class&lt;E&gt; extends Class&lt;T&gt; extends Class&lt;E&gt;</code></td>
<td>Returns a run-time type-safe view of a collection. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> List&lt;E&gt; <code>List&lt;E&gt; extends T, Class&lt;E&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a <code>List</code>. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> Map&lt;K, V&gt; <code>Map&lt;K, V&gt; extends T, Class&lt;K&gt; extends Class&lt;T&gt;, Class&lt;V&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a <code>Map</code>. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>static <code>&lt;K, V&gt;</code> NavigableMap&lt;K, V&gt; <code>NavigableMap&lt;K, V&gt; extends T, Class&lt;K&gt; extends Class&lt;T&gt;, Class&lt;V&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a NavigableMap. An attempt to insert an incompatible element will cause a ClassCastException. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> NavigableSet&lt;E&gt; <code>NavigableSet&lt;E&gt; extends T, Class&lt;E&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a NavigableSet. An attempt to insert an incompatible element will cause a ClassCastException. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> Queue&lt;E&gt; <code>Queue&lt;E&gt; extends T, Class&lt;E&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a <code>Queue</code>. An attempt to insert an incompatible element will cause a ClassCastException. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static <code>&lt;E&gt;</code> List&lt;E&gt; <code>List&lt;E&gt; extends T, Class&lt;E&gt; extends Class&lt;T&gt;</code></td>
<td>Returns a run-time type-safe view of a <code>List</code>. An attempt to insert an incompatible element will cause a ClassCastException.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; SortedMap&lt;K, V&gt;</code></td>
<td>Returns a runtime-type-safe view of a <code>SortedMap</code>. An attempt to insert an incompatible element will cause a <code>ClassCastException</code>.</td>
</tr>
<tr>
<td><code>static &lt;E&gt; SortedSet&lt;E&gt;</code></td>
<td>Returns a runtime-type-safe view of a <code>SortedSet</code>. An attempt to insert an incompatible element will cause a <code>ClassCastException</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; void copy(List&lt;? super T&gt; list1, List&lt;? extends T&gt; list2)</code></td>
<td>Copies the elements of <code>list2</code> to <code>list1</code>.</td>
</tr>
<tr>
<td><code>static boolean disjoint(Collection&lt;? a, Collection&lt;? b))</code></td>
<td>Compares the elements in <code>a</code> to elements in <code>b</code>. Returns <code>true</code> if the two collections contain no common elements (i.e., the collections contain disjoint sets of elements). Otherwise, returns <code>false</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Enumeration&lt;T&gt; emptyEnumeration()</code></td>
<td>Returns an empty <code>Enumeration</code>, which is an enumeration with no elements.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Iterator&lt;T&gt; emptyIterator()</code></td>
<td>Returns an empty <code>Iterator</code>, which is an iterator with no elements.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; List&lt;T&gt; emptyList()</code></td>
<td>Returns an immutable, empty <code>List</code> object of the inferred type.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; ListIterator&lt;T&gt; emptyListIterator()</code></td>
<td>Returns an empty <code>ListIterator</code>, which is a list iterator that has no elements.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt;</code></td>
<td><code>Map&lt;K, V&gt;</code> emptyMap()`</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; NavigableMap&lt;K, V&gt;</code></td>
<td><code>NavigableMap&lt;K, V&gt;</code> emptyNavigableMap()`</td>
</tr>
<tr>
<td><code>static &lt;E&gt; NavigableSet&lt;E&gt;</code></td>
<td><code>NavigableSet&lt;E&gt;</code> emptyNavigableSet()`</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Set&lt;T&gt;</code></td>
<td><code>Set&lt;T&gt;</code> emptySet()`</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; SortedMap&lt;K, V&gt;</code></td>
<td><code>SortedMap&lt;K, V&gt;</code> emptySortedMap()`</td>
</tr>
<tr>
<td><code>static &lt;E&gt; SortedSet&lt;E&gt;</code></td>
<td><code>SortedSet&lt;E&gt;</code> emptySortedSet()`</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Enumeration&lt;T&gt; enumeration(Collection&lt;T&gt; c)</code></td>
<td>Returns an <code>Enumeration</code> over <code>c</code>. (See “The Enumeration Interface,” later in this chapter.)</td>
</tr>
<tr>
<td><code>static &lt;T&gt; void fill(List&lt;? super T&gt; list, T obj)</code></td>
<td>Assigns <code>obj</code> to each element of <code>list</code>.</td>
</tr>
<tr>
<td><code>static int frequency(Collection&lt;? c, object obj)</code></td>
<td>Counts the number of occurrences of <code>obj</code> in <code>c</code> and returns the result.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>--------</td>
<td>-------------</td>
</tr>
<tr>
<td>static int indexOfSubList(List&lt;T&gt; list, List&lt;T&gt; subList)</td>
<td>Searches list for the first occurrence of subList. Returns the index of the first match, or -1 if no match is found.</td>
</tr>
<tr>
<td>static int lastIndexOfSubList(List&lt;T&gt; list, List&lt;T&gt; subList)</td>
<td>Searches list for the last occurrence of subList. Returns the index of the last match, or -1 if no match is found.</td>
</tr>
<tr>
<td>static &lt;T&gt; ArrayList&lt;T&gt; list(Enumerations&lt;? super T&gt; enum)</td>
<td>Returns an ArrayList that contains the elements of enum.</td>
</tr>
<tr>
<td>static &lt;T&gt; T max(Collection&lt;? extends T&gt; c, Comparator&lt;? super T&gt; comp)</td>
<td>Returns the maximum element in c as determined by comp. If the collection need not be sorted.</td>
</tr>
<tr>
<td>static &lt;T extends Object &amp; Comparable&lt;? super T&gt;&gt; T max(Collection&lt;? extends T&gt; c)</td>
<td>Returns the maximum element in c as determined by natural ordering. The collection need not be sorted.</td>
</tr>
<tr>
<td>static &lt;T extends Object &amp; Comparable&lt;? super T&gt;&gt; T min(Collection&lt;? extends T&gt; c)</td>
<td>Returns the minimum element in c as determined by natural ordering. The collection need not be sorted.</td>
</tr>
<tr>
<td>static &lt;T&gt; List&lt;T&gt; nCopies(int n, T obj)</td>
<td>Returns n copies of obj contained in an immutable list. n must be greater than or equal to zero.</td>
</tr>
<tr>
<td>static &lt;E&gt; Set&lt;E&gt; newSetFromMap(Map&lt;E, Boolean&gt; m)</td>
<td>Creates and returns a set backed by the map specified by m, which must be empty at the time this method is called.</td>
</tr>
<tr>
<td>static &lt;T&gt; boolean replaceAll(List&lt;T&gt; list, T old, T new)</td>
<td>Replaces all occurrences of old with new in list. Returns true if at least one replacement occurred. Returns false otherwise.</td>
</tr>
<tr>
<td>static void reverse(List&lt;T&gt; list)</td>
<td>Reverses the sequence in list.</td>
</tr>
<tr>
<td>static &lt;T extends Comparator&lt;T&gt;&gt; reverseOrder(Comparator&lt;T&gt; comp)</td>
<td>Returns a reverse comparator based on the one passed in comp. That is, the returned comparator reverses the outcome of a comparison that uses comp.</td>
</tr>
<tr>
<td>static &lt;T extends Comparator&lt;T&gt;&gt; reverseOrder(T o)</td>
<td>Returns a reverse comparator, which is a comparator that reverses the outcome of a comparison between two elements.</td>
</tr>
<tr>
<td>static void rotate(List&lt;T&gt; list, int n)</td>
<td>Rotates list by n places to the right. To rotate left, use a negative value for n.</td>
</tr>
<tr>
<td>static void shuffle(List&lt;T&gt; list, Random r)</td>
<td>Shuffles (i.e., randomizes) the elements in list by using r as a source of random numbers.</td>
</tr>
<tr>
<td>static void shuffle(List&lt;T&gt; list)</td>
<td>Shuffles (i.e., randomizes) the elements in list.</td>
</tr>
</tbody>
</table>
The set of methods that begins with **unmodifiable** returns views of the various collections that cannot be modified. These will be useful when you want to grant some process read—

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>static &lt;T&gt; Set&lt;T&gt; singleton(T obj)</code></td>
<td>Returns <code>obj</code> as an immutable set. This is an easy way to convert a single object into a set.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; List&lt;T&gt; singletonList(T obj)</code></td>
<td>Returns <code>obj</code> as an immutable list. This is an easy way to convert a single object into a list.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt; singletonMap(K k, V v)</code></td>
<td>Returns the key/value pair <code>k/v</code> as an immutable map. This is an easy way to convert a single key/value pair into a map.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; void sort(List&lt;T&gt; list, Comparator&lt;? super T&gt; comp)</code></td>
<td>Sorts the elements of <code>list</code> as determined by <code>comp</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; void sort(List&lt;T&gt; list)</code></td>
<td>Sorts the elements of <code>list</code> as determined by their natural ordering.</td>
</tr>
<tr>
<td><code>static void swap(List&lt;T&gt; list, int idx1, int idx2)</code></td>
<td>Exchanges the elements in <code>list</code> at the indices specified by <code>idx1</code> and <code>idx2</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Collection&lt;T&gt; synchronizedCollection(Collection&lt;T&gt; c)</code></td>
<td>Returns a thread-safe collection backed by <code>c</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; List&lt;T&gt; synchronizedList(List&lt;T&gt; list)</code></td>
<td>Returns a thread-safe list backed by <code>list</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt; synchronizedMap(Map&lt;K, V&gt; m)</code></td>
<td>Returns a thread-safe map backed by <code>m</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; NavigableMap&lt;K, V&gt; synchronizedNavigableMap(NavigableMap&lt;K, V&gt; m)</code></td>
<td>Returns a synchronized navigable map backed by <code>m</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static &lt;T&gt; NavigableSet&lt;T&gt; synchronizedNavigableSet(NavigableSet&lt;T&gt; n)</code></td>
<td>Returns a synchronized navigable set backed by <code>n</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Set&lt;T&gt; synchronizedSet(Set&lt;T&gt; s)</code></td>
<td>Returns a thread-safe set backed by <code>s</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; SortedMap&lt;K, V&gt; synchronizedSortedMap(SortedMap&lt;K, V&gt; m)</code></td>
<td>Returns a thread-safe sorted map backed by <code>m</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; SortedSet&lt;T&gt; synchronizedSortedSet(SortedSet&lt;T&gt; s)</code></td>
<td>Returns a thread-safe sorted set backed by <code>s</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Collection&lt;T&gt; unmodifiableCollection(Collection&lt;T&gt; c)</code></td>
<td>Returns an unmodifiable collection backed by <code>c</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; List&lt;T&gt; unmodifiableList(List&lt;T&gt; list)</code></td>
<td>Returns an unmodifiable list backed by <code>list</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; Map&lt;K, V&gt; unmodifiableMap(Map&lt;K, V&gt; m)</code></td>
<td>Returns an unmodifiable map backed by <code>m</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; NavigableMap&lt;K, V&gt; unmodifiableNavigableMap(NavigableMap&lt;K, V&gt; m)</code></td>
<td>Returns an unmodifiable navigable map backed by <code>m</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static &lt;T&gt; NavigableSet&lt;T&gt; unmodifiableNavigableSet(NavigableSet&lt;T&gt; n)</code></td>
<td>Returns an unmodifiable navigable set backed by <code>n</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>static &lt;T&gt; Set&lt;T&gt; unmodifiableSet(Set&lt;T&gt; s)</code></td>
<td>Returns an unmodifiable set backed by <code>s</code>.</td>
</tr>
<tr>
<td><code>static &lt;K, V&gt; SortedMap&lt;K, V&gt; unmodifiableSortedMap(SortedMap&lt;K, V&gt; m)</code></td>
<td>Returns an unmodifiable sorted map backed by <code>m</code>.</td>
</tr>
<tr>
<td><code>static &lt;T&gt; SortedSet&lt;T&gt; unmodifiableSortedSet(SortedSet&lt;T&gt; s)</code></td>
<td>Returns an unmodifiable sorted set backed by <code>s</code>.</td>
</tr>
</tbody>
</table>
but not write—capabilities on a collection.

**Collections** defines three static variables: `EMPTY_SET`, `EMPTY_LIST`, and `EMPTY_MAP`. All are immutable.

The following program demonstrates some of the algorithms. It creates and initializes a linked list. The `reverseOrder()` method returns a `Comparator` that reverses the comparison of `Integer` objects. The list elements are sorted according to this comparator and then are displayed. Next, the list is randomized by calling `shuffle()`, and then its minimum and maximum values are displayed.

```java
// Demonstrate various algorithms.
import java.util.*;

class AlgorithmsDemo {
    public static void main(String args[]) {

        // Create and initialize linked list.
        LinkedList<Integer> ll = new LinkedList<Integer>();
        ll.add(-8);
        ll.add(20);
        ll.add(-20);
        ll.add(8);

        // Create a reverse order comparator.
        Comparator<Integer> r = Collections.reverseOrder();

        // Sort list by using the comparator.
        Collections.sort(ll, r);

        System.out.print("List sorted in reverse: ");
        for(int i : ll)
            System.out.print(i + " ");
        System.out.println();

        // Shuffle list.
        Collections.shuffle(ll);

        // Display randomized list.
        System.out.print("List shuffled: ");
        for(int i : ll)
            System.out.print(i + " ");
        System.out.println();
        System.out.println("Minimum: " + Collections.min(ll));
        System.out.println("Maximum: " + Collections.max(ll));
    }
}
```
Output from this program is shown here:

```
List sorted in reverse: 20 8 -8 -20
List shuffled: 20 -20 8 -8
Minimum: -20
Maximum: 20
```

Notice that \( \text{min}() \) and \( \text{max}() \) operate on the list after it has been shuffled. Neither requires a sorted list for its operation.

**Arrays**

The `Arrays` class provides various methods that are useful when working with arrays. These methods help bridge the gap between collections and arrays. Each method defined by `Arrays` is examined in this section.

The `asList()` method returns a `List` that is backed by a specified array. In other words, both the list and the array refer to the same location. It has the following signature:

```
static <T> List asList(T… array)
```

Here, `array` is the array that contains the data.

The `binarySearch()` method uses a binary search to find a specified value. This method must be applied to sorted arrays. Here are some of its forms. (Additional forms let you search a subrange):

```
static int binarySearch(byte array[ ], byte value)
static int binarySearch(char array[ ], char value)
static int binarySearch(double array[ ], double value)
static int binarySearch(float array[ ], float value)
static int binarySearch(int array[ ], int value)
static int binarySearch(long array[ ], long value)
static int binarySearch(short array[ ], short value)
static int binarySearch(Object array[ ], Object value)
static <T> int binarySearch(T[] array, T value, Comparator<? super T> c)
```

Here, `array` is the array to be searched, and `value` is the value to be located. The last two forms throw a `ClassCastException` if `array` contains elements that cannot be compared (for example, `Double` and `StringBuffer`) or if `value` is not compatible with the types in `array`. In the last form, the `Comparator` `c` is used to determine the order of the elements in `array`. In all cases, if `value` exists in `array`, the index of the element is returned. Otherwise, a negative value is returned.

The `copyOf()` method returns a copy of an array and has the following forms:

```
static boolean[ ] copyOf(boolean[ ] source, int len)
static byte[ ] copyOf(byte[ ] source, int len)
```
The original array is specified by `source`, and the length of the copy is specified by `len`. If the copy is longer than `source`, then the copy is padded with zeros (for numeric arrays), `null` (for object arrays), or `false` (for boolean arrays). If the copy is shorter than `source`, then the copy is truncated. In the last form, the type of `resultT` becomes the type of the array returned. If `len` is negative, a `NegativeArraySizeException` is thrown. If `source` is `null`, a `NullPointerException` is thrown. If `resultT` is incompatible with the type of `source`, an `ArrayStoreException` is thrown.

The `copyOfRange( )` method returns a copy of a range within an array and has the following forms:

```java
static boolean[ ] copyOfRange(boolean[ ] source, int start, int end)
static byte[ ] copyOfRange(byte[ ] source, int start, int end)
static char[ ] copyOfRange(char[ ] source, int start, int end)
static double[ ] copyOfRange(double[ ] source, int start, int end)
static float[ ] copyOfRange(float[ ] source, int start, int end)
static int[ ] copyOfRange(int[ ] source, int start, int end)
static long[ ] copyOfRange(long[ ] source, int start, int end)
static short[ ] copyOfRange(short[ ] source, int start, int end)
static <T> T[ ] copyOfRange(T[ ] source, int start, int end)
static <T,U> T[ ] copyOfRange(U[ ] source, int start, int end, Class<? extends T[ ]> resultT)
```

The original array is specified by `source`. The range to copy is specified by the indices passed via `start` and `end`. The range runs from `start` to `end` – 1. If the range is longer than `source`, then the copy is padded with zeros (for numeric arrays), `nulls` (for object arrays), or `false` (for boolean arrays). In the last form, the type of `resultT` becomes the type of the array returned. If `start` is negative or greater than the length of `source`, an `ArrayIndexOutOfBoundsException` is thrown. If `start` is greater than `end`, an `IllegalArgumentException` is thrown. If `source` is `null`, a `NullPointerException` is thrown. If `resultT` is incompatible with the type of `source`, an `ArrayStoreException` is thrown.

The `equals( )` method returns `true` if two arrays are equivalent. Otherwise, it returns `false`. The `equals( )` method has the following forms:
static boolean equals(boolean array1[], boolean array2[])
static boolean equals(byte array1[], byte array2[])
static boolean equals(char array1[], char array2[])
static boolean equals(double array1[], double array2[])
static boolean equals(float array1[], float array2[])
static boolean equals(int array1[], int array2[])
static boolean equals(long array1[], long array2[])
static boolean equals(short array1[], short array2[])
static boolean equals(Object array1[], Object array2[])

Here, array1 and array2 are the two arrays that are compared for equality. The `deepEquals()` method can be used to determine if two arrays, which might contain nested arrays, are equal. It has this declaration:

    static boolean deepEquals(Object[] a, Object[] b)

    It returns true if the arrays passed in a and b contain the same elements. If a and b contain nested arrays, then the contents of those nested arrays are also checked.

    It returns false if the arrays, or any nested arrays, differ.

The `fill()` method assigns a value to all elements in an array. In other words, it fills an array with a specified value. The `fill()` method has two versions. The first version, which has the following forms, fills an entire array:

    static void fill(boolean array[], boolean value)
    static void fill(byte array[], byte value)
    static void fill(char array[], char value)
    static void fill(double array[], double value)
    static void fill(float array[], float value)
    static void fill(int array[], int value)
    static void fill(long array[], long value)
    static void fill(short array[], short value)
    static void fill(Object array[], Object value)

    Here, value is assigned to all elements in array. The second version of the `fill()` method assigns a value to a subset of an array.

The `sort()` method sorts an array so that it is arranged in ascending order. The `sort()` method has two versions. The first version, shown here, sorts the entire array:

    static void sort(byte array[])
    static void sort(char array[])
    static void sort(double array[])
    static void sort(float array[])
    static void sort(int array[])
    static void sort(long array[])
    static void sort(Object array[])

    Here, the elements are compared using the `compareTo()` method of their type.
static void sort(short array[ ])  
static void sort(Object array[ ])  
static <T> void sort(T array[ ], Comparator<? super T> c)  

Here, array is the array to be sorted. In the last form, c is a Comparator that is 
used to order the elements of array. The last two forms can throw a  
ClassCastException if elements of the array being sorted are not comparable. 
The second version of sort( ) enables you to specify a range within an array that 
you want to sort.

JDK 8 adds several new methods to Arrays. Perhaps the most important is parallelSort( ) 
because it sorts, into ascending order, portions of an array in parallel and then merges the 
results. This approach can greatly speed up sorting times. Like sort( ), there are two basic 
types of parallelSort( ), each with several overloads. The first type sorts the entire array. It 
is shown here:

    static void parallelSort(byte array[ ])  
static void parallelSort(char array[ ])  
static void parallelSort(double array[ ])  
static void parallelSort(float array[ ])  
static void parallelSort(int array[ ])  
static void parallelSort(long array[ ])  
static void parallelSort(short array[ ])  
static <T extends Comparable<? super T>> void parallelSort(T array[ ])  
static <T> void parallelSort(T array[ ], Comparator<? super T> c)  

Here, array is the array to be sorted. In the last form, c is a comparator that is 
used to order the elements in the array. The last two forms can throw a  
ClassCastException if the elements of the array being sorted are not 
comparable. The second version of parallelSort( ) enables you to specify a range 
within the array that you want to sort.

JDK 8 gives Arrays support for spliterators by including the spliterator( ) method. It has 
two basic forms. The first type returns a spliterator to an entire array. It is shown here:

    static Spliterator.OfDouble spliterator(double array[ ])  
static Spliterator.OfInt spliterator(int array[ ])  
static Spliterator.OfLong spliterator(long array[ ])  
static <T> Spliterator spliterator(T array[ ])  

Here, array is the array that the spliterator will cycle through. The second version 
of spliterator( ) enables you to specify a range to iterate within the array.

Beginning with JDK 8, Arrays supports the new Stream interface (see Chapter 29) by 
including the stream( ) method. It has two forms. The first is shown here:

    static DoubleStream stream(double array[ ])
static IntStream stream(int array[ ])
static LongStream stream(long array[ ])
static <T> Stream stream(T array[ ])

Here, array is the array to which the stream will refer. The second version of
stream() enables you to specify a range within the array.

In addition to those just discussed, JDK 8 adds three other new methods. Two are related:
setAll() and parallelSetAll(). Both assign values to all of the elements, but
parallelSetAll() works in parallel. Here is an example of each:

```java
static void setAll(double array[ ],
                   IntToDoubleFunction<? extends T> genVal)
static void parallelSetAll(double array[ ],
                           IntToDoubleFunction<? extends T> genVal)
```

Several overloads exist for each of these that handle types int, long, and generic.

Finally, JDK 8 includes one of the more intriguing additions to Arrays. It is called
parallelPrefix(), and it modifies an array so that each element contains the cumulative
result of an operation applied to all previous elements. For example, if the operation is
multiplication, then on return, the array elements will contain the values associated with the
running product of the original values. It has several overloads. Here is one example:

```java
static void parallelPrefix(double array[ ], DoubleBinaryOperator func)
```

Here, array is the array being acted upon, and func specifies the operation
applied. (DoubleBinaryOperator is a functional interface defined in
java.util.function.) Many other versions are provided, including those that
operate on types int, long, and generic, and those that let you specify a range
within the array on which to operate.

Arrays also provides toString() and hashCode() for the various types of arrays. In
addition, deepToString() and deepHashCode() are provided, which operate effectively
on arrays that contain nested arrays.

The following program illustrates how to use some of the methods of the Arrays class:
The following is the output from this program:
The Legacy Classes and Interfaces

As explained at the start of this chapter, early versions of \texttt{java.util} did not include the Collections Framework. Instead, it defined several classes and an interface that provided an ad hoc method of storing objects. When collections were added (by J2SE 1.2), several of the original classes were reengineered to support the collection interfaces. Thus, they are now technically part of the Collections Framework. However, where a modern collection duplicates the functionality of a legacy class, you will usually want to use the newer collection class. In general, the legacy classes are supported because there is still code that uses them.

One other point: none of the modern collection classes described in this chapter are synchronized, but all the legacy classes are synchronized. This distinction may be important in some situations. Of course, you can easily synchronize collections by using one of the algorithms provided by \texttt{Collections}.

The legacy classes defined by \texttt{java.util} are shown here:

| Dictionary | Hashtable | Properties | Stack | Vector |

There is one legacy interface called \texttt{Enumeration}. The following sections examine \texttt{Enumeration} and each of the legacy classes, in turn.

The \texttt{Enumeration} Interface

The \texttt{Enumeration} interface defines the methods by which you can enumerate (obtain one at a time) the elements in a collection of objects. This legacy interface has been superseded by \texttt{Iterator}. Although not deprecated, \texttt{Enumeration} is considered obsolete for new code. However, it is used by several methods defined by the legacy classes (such as \texttt{Vector} and \texttt{Properties}) and is used by several other API classes. Because it is still in use, it was retrofitted for generics by JDK 5. It has this declaration:

\begin{verbatim}
interface Enumeration<E>
 where E specifies the type of element being enumerated.

Enumeration specifies the following two methods:

  boolean hasMoreElements( )
  E nextElement( )
\end{verbatim}

When implemented, \texttt{hasMoreElements( )} must return \texttt{true} while there are still
more elements to extract, and false when all the elements have been enumerated.

nextElement( ) returns the next object in the enumeration. That is, each call to
nextElement( ) obtains the next object in the enumeration. It throws
NoSuchElementException when the enumeration is complete.

Vector
Vector implements a dynamic array. It is similar to ArrayList, but with two differences:
Vector is synchronized, and it contains many legacy methods that duplicate the
functionality of methods defined by the Collections Framework. With the advent of
collections, Vector was reengineered to extend AbstractList and to implement the List
interface. With the release of JDK 5, it was retrofitted for generics and reengineered to
implement Iterable. This means that Vector is fully compatible with collections, and a
Vector can have its contents iterated by the enhanced for loop.
Vector is declared like this:

class Vector<E>

Here, E specifies the type of element that will be stored.

Here are the Vector constructors:

Vector( )
Vector(int size)
Vector(int size, int incr)
Vector(Collection<? extends E> c)

The first form creates a default vector, which has an initial size of 10. The second
form creates a vector whose initial capacity is specified by size. The third form
creates a vector whose initial capacity is specified by size and whose increment is
specified by incr. The increment specifies the number of elements to allocate each
time that a vector is resized upward. The fourth form creates a vector that contains
the elements of collection c.

All vectors start with an initial capacity. After this initial capacity is reached, the next time
that you attempt to store an object in the vector, the vector automatically allocates space for
that object plus extra room for additional objects. By allocating more than just the required
memory, the vector reduces the number of allocations that must take place as the vector
grows. This reduction is important, because allocations are costly in terms of time. The
amount of extra space allocated during each reallocation is determined by the increment
that you specify when you create the vector. If you don’t specify an increment, the vector’s
size is doubled by each allocation cycle.

Vector defines these protected data members:

    int capacityIncrement;
    int elementCount;
    Object[ ] elementData;
The increment value is stored in `capacityIncrement`. The number of elements currently in the vector is stored in `elementCount`. The array that holds the vector is stored in `elementData`.

In addition to the collections methods specified by `List`, `Vector` defines several legacy methods, which are summarized in Table 18-16.

Because `Vector` implements `List`, you can use a vector just like you use an `ArrayList` instance. You can also manipulate one using its legacy methods. For example, after you instantiate a `Vector`, you can add an element to it by calling `addElement()`. To obtain the element at a specific location, call `elementAt()`. To obtain the first element in the vector, call `firstElement()`. To retrieve the last element, call `lastElement()`. You can obtain the index of an element by using `indexOf()` and `lastIndexOf()`. To remove an element, call `removeElement()` or `removeElementAt()`.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addElement(E element)</td>
<td>The object specified by <code>element</code> is added to the vector.</td>
</tr>
<tr>
<td>int capacity( )</td>
<td>Returns the capacity of the vector.</td>
</tr>
<tr>
<td>Object clone( )</td>
<td>Returns a duplicate of the invoking vector.</td>
</tr>
<tr>
<td>boolean contains(Object element)</td>
<td>Returns true if <code>element</code> is contained by the vector, and returns false if it is not.</td>
</tr>
<tr>
<td>void copyInto(Object array[ ] )</td>
<td>The elements contained in the invoking vector are copied into the array specified by <code>array</code>.</td>
</tr>
<tr>
<td>E elementAt(int index)</td>
<td>Returns the element at the location specified by <code>index</code>.</td>
</tr>
<tr>
<td>Enumeration&lt;E&gt; elements( )</td>
<td>Returns an enumeration of the elements in the vector.</td>
</tr>
<tr>
<td>void ensureCapacity(int size)</td>
<td>Sets the minimum capacity of the vector to <code>size</code>.</td>
</tr>
<tr>
<td>E firstElement( )</td>
<td>Returns the first element in the vector.</td>
</tr>
<tr>
<td>int indexOf(Object element)</td>
<td>Returns the index of the first occurrence of <code>element</code>. If the object is not in the vector, -1 is returned.</td>
</tr>
</tbody>
</table>
The following program uses a vector to store various types of numeric objects. It demonstrates several of the legacy methods defined by Vector. It also demonstrates the Enumeration interface.
The output from this program is shown here:
Instead of relying on an enumeration to cycle through the objects (as the preceding program does), you can use an iterator. For example, the following iterator-based code can be substituted into the program:

```java
// Use an iterator to display contents.
Iterator<Integer> vItr = v.iterator();
System.out.println("\nElements in vector:");
while(vItr.hasNext())
    System.out.print(vItr.next() + " ");
System.out.println();
```

You can also use a for-each for loop to cycle through a Vector, as the following version of the preceding code shows:

```java
// Use an enhanced for loop to display contents
System.out.println("\nElements in vector:");
for(int i : v)
    System.out.print(i + " ");
System.out.println();
```

Because the Enumeration interface is not recommended for new code, you will usually use an iterator or a for-each for loop to enumerate the contents of a vector. Of course, legacy code will employ Enumeration. Fortunately, enumerations and iterators work in nearly the same manner.

**Stack**

Stack is a subclass of Vector that implements a standard last-in, first-out stack. Stack only defines the default constructor, which creates an empty stack. With the release of JDK
5. **Stack** was retrofitted for generics and is declared as shown here:

   ```java
   class Stack<E>
   
   Here, `E` specifies the type of element stored in the stack.
   **Stack** includes all the methods defined by **Vector** and adds several of its own, shown in Table 18-17.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean empty()</td>
<td>Returns true if the stack is empty and returns false if the stack contains elements.</td>
</tr>
<tr>
<td>E peek()</td>
<td>Returns the element on the top of the stack, but does not remove it.</td>
</tr>
<tr>
<td>E pop()</td>
<td>Returns the element on the top of the stack, removing it in the process.</td>
</tr>
<tr>
<td>E push(E element)</td>
<td>Pushes <code>element</code> onto the stack, <code>element</code> is also returned.</td>
</tr>
<tr>
<td>int search(Object element)</td>
<td>Searches for <code>element</code> in the stack. If found, its offset from the top of the stack is returned. Otherwise, -1 is returned.</td>
</tr>
</tbody>
</table>

**Table 18-17** The Methods Defined by **Stack**

To put an object on the top of the stack, call `push()`. To remove and return the top element, call `pop()`. You can use `peek()` to return, but not remove, the top object. An **EmptyStackException** is thrown if you call `pop()` or `peek()` when the invoking stack is empty. The `empty()` method returns `true` if nothing is on the stack. The `search()` method determines whether an object exists on the stack and returns the number of pops that are required to bring it to the top of the stack. Here is an example that creates a stack, pushes several `Integer` objects onto it, and then pops them off again:
The following is the output produced by the program; notice how the exception handler for **EmptyStackException** is caught so that you can gracefully handle a stack underflow:
One other point: although **Stack** is not deprecated, **ArrayDeque** is a better choice.

**Dictionary**

**Dictionary** is an abstract class that represents a key/value storage repository and operates much like **Map**. Given a key and value, you can store the value in a **Dictionary** object. Once the value is stored, you can retrieve it by using its key. Thus, like a map, a dictionary can be thought of as a list of key/value pairs. Although not currently deprecated, **Dictionary** is classified as obsolete, because it is fully superseded by **Map**. However, **Dictionary** is still in use and thus is discussed here.

With the advent of JDK 5, **Dictionary** was made generic. It is declared as shown here:

```java
class Dictionary<K, V>
```

Here, **K** specifies the type of keys, and **V** specifies the type of values. The abstract methods defined by **Dictionary** are listed in Table 18-18.

To add a key and a value, use the **put()** method. Use **get()** to retrieve the value of a given key. The keys and values can each be returned as an **Enumeration** by the **keys()** and **elements()** methods, respectively. The **size()** method returns the number of key/value pairs stored in a dictionary, and **isEmpty()** returns **true** when the dictionary is empty. You can use the **remove()** method to delete a key/value pair.

---

**REMEMBER** The **Dictionary** class is obsolete. You should implement the **Map** interface to obtain key/value storage functionality.
Hashtable

Hashtable was part of the original java.util and is a concrete implementation of a Dictionary. However, with the advent of collections, Hashtable was reengineered to also implement the Map interface. Thus, Hashtable is integrated into the Collections Framework. It is similar to HashMap, but is synchronized.

Like HashMap, Hashtable stores key/value pairs in a hash table. However, neither keys nor values can be null. When using a Hashtable, you specify an object that is used as a key, and the value that you want linked to that key. The key is then hashed, and the resulting hash code is used as the index at which the value is stored within the table.

Hashtable was made generic by JDK 5. It is declared like this:

class Hashtable<K, V>

Here, K specifies the type of keys, and V specifies the type of values.

A hash table can only store objects that override the hashCode() and equals() methods that are defined by Object. The hashCode() method must compute and return the hash code for the object. Of course, equals() compares two objects. Fortunately, many of Java’s built-in classes already implement the hashCode() method. For example, the most common type of Hashtable uses a String object as the key. String implements both hashCode() and equals().

The Hashtable constructors are shown here:

    Hashtable()
    Hashtable(int size)
    Hashtable(int size, float fillRatio)
    Hashtable(Map<? extends K, ? extends V> m)

The first version is the default constructor. The second version creates a hash table
that has an initial size specified by size. (The default size is 11.) The third version creates a hash table that has an initial size specified by size and a fill ratio specified by fillRatio. This ratio must be between 0.0 and 1.0, and it determines how full the hash table can be before it is resized upward. Specifically, when the number of elements is greater than the capacity of the hash table multiplied by its fill ratio, the hash table is expanded. If you do not specify a fill ratio, then 0.75 is used. Finally, the fourth version creates a hash table that is initialized with the elements in m. The default load factor of 0.75 is used.

In addition to the methods defined by the Map interface, which Hashtable now implements, Hashtable defines the legacy methods listed in Table 18-19. Several methods throw NullPointerException if an attempt is made to use a null key or value.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void clear()</td>
<td>Resets and empties the hash table.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Returns a duplicate of the invoking object.</td>
</tr>
<tr>
<td>boolean contains(Object value)</td>
<td>Returns true if some value equal to value exists within the hash table. Returns false if the value isn’t found.</td>
</tr>
<tr>
<td>boolean containsKey(Object key)</td>
<td>Returns true if some key equal to key exists within the hash table. Returns false if the key isn’t found.</td>
</tr>
<tr>
<td>boolean containsValue(Object value)</td>
<td>Returns true if some value equal to value exists within the hash table. Returns false if the value isn’t found.</td>
</tr>
<tr>
<td>Enumeration&lt;V&gt; elements()</td>
<td>Returns an enumeration of the values contained in the hash table.</td>
</tr>
<tr>
<td>V get(Object key)</td>
<td>Returns the object that contains the value associated with key. If key is not in the hash table, a null object is returned.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if the hash table is empty; returns false if it contains at least one key.</td>
</tr>
<tr>
<td>Enumeration&lt;K&gt; keys()</td>
<td>Returns an enumeration of the keys contained in the hash table.</td>
</tr>
<tr>
<td>V put(K key, V value)</td>
<td>Inserts a key and a value into the hash table. Returns null if key isn’t already in the hash table; returns the previous value associated with key if key is already in the hash table.</td>
</tr>
<tr>
<td>void rehash()</td>
<td>Increases the size of the hash table and rehashes all of its keys.</td>
</tr>
<tr>
<td>V remove(Object key)</td>
<td>Removes key and its value. Returns the value associated with key. If key is not in the hash table, a null object is returned.</td>
</tr>
<tr>
<td>int size()</td>
<td>Returns the number of entries in the hash table.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the string equivalent of a hash table.</td>
</tr>
</tbody>
</table>

The following example reworks the bank account program, shown earlier, so that it uses a Hashtable to store the names of bank depositors and their current balances:
// Demonstrate a Hashtable.
import java.util.*;

class HTDemo {
    public static void main(String args[]) {
        Hashtable<String, Double> balance =
            new Hashtable<String, Double>();

        Enumeration<String> names;
        String str;
        double bal;

        balance.put("John Doe", 3434.34);
        balance.put("Tom Smith", 123.22);
        balance.put("Jane Baker", 1378.00);
        balance.put("Tod Hall", 99.22);
        balance.put("Ralph Smith", -19.08);

        // Show all balances in hashtable.
        names = balance.keys();
        while (names.hasMoreElements()) {
            str = names.nextElement();
            System.out.println(str + " : "+
                balance.get(str));
        }

        System.out.println();

        // Deposit 1,000 into John Doe's account.
        bal = balance.get("John Doe");
        balance.put("John Doe", bal+1000);
        System.out.println("John Doe's new balance: "+
            balance.get("John Doe");
    }
}

The output from this program is shown here:

Todd Hall: 99.22
Ralph Smith: -19.08
John Doe: 3434.34
Jane Baker: 1378.0
Tom Smith: 123.22

John Doe's new balance: 4434.34
One important point: Like the map classes, *Hashtable* does not directly support iterators. Thus, the preceding program uses an enumeration to display the contents of *balance*. However, you can obtain set-views of the hash table, which permits the use of iterators. To do so, you simply use one of the collection-view methods defined by *Map*, such as *entrySet()* or *keySet()* . For example, you can obtain a set-view of the keys and cycle through them using either an iterator or an enhanced *for* loop. Here is a reworked version of the program that shows this technique:
Properties

Properties is a subclass of Hashtable. It is used to maintain lists of values in which the key is a String and the value is also a String. The Properties class is used by some other Java classes. For example, it is the type of object returned by System.getProperties() when obtaining environmental values. Although the Properties class, itself, is not generic, several of its methods are.

```java
// Use iterators with a Hashtable.
import java.util.*;

class HTDemo2 {
    public static void main(String args[]) {
        Hashtable<String, Double> balance =
            new Hashtable<String, Double>();

        String str;
        double bal;

        balance.put("John Doe", 3434.34);
        balance.put("Tom Smith", 123.22);
        balance.put("Jane Baker", 1378.00);
        balance.put("Tod Hall", 99.22);
        balance.put("Ralph Smith", -19.08);

        // Show all balances in hashtable.
        // First, get a set view of the keys.
        Set<String> set = balance.keySet();

        // Get an iterator.
        Iterator<String> itr = set.iterator();
        while(itr.hasNext()) {
            str = itr.next();
            System.out.println(str + ": " +
                balance.get(str));
        }

        System.out.println();

        // Deposit 1,000 into John Doe's account.
        bal = balance.get("John Doe");
        balance.put("John Doe", bal+1000);
        System.out.println("John Doe's new balance: " +
            balance.get("John Doe"));
    }
}
```
**Properties** defines the following instance variable:

Properties defaults;

This variable holds a default property list associated with a **Properties** object.

**Properties** defines these constructors:

Properties()
Properties(Properties propDefault)

The first version creates a **Properties** object that has no default values. The second creates an object that uses `propDefault` for its default values. In both cases, the property list is empty.

In addition to the methods that **Properties** inherits from **Hashtable**, **Properties** defines the methods listed in Table 18-20. **Properties** also contains one deprecated method: `save()`. This was replaced by `store()` because `save()` did not handle errors correctly.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>String getProperty(String key)</code></td>
<td>Returns the value associated with <code>key</code>. A null object is returned if <code>key</code> is neither in the list nor in the default property list.</td>
</tr>
<tr>
<td><code>String getProperty(String key, String defaultValue)</code></td>
<td>Returns the value associated with <code>key</code>. <code>defaultValue</code> is returned if <code>key</code> is neither in the list nor in the default property list.</td>
</tr>
<tr>
<td><code>void list(PrintStream streamOut)</code></td>
<td>Sends the property list to the output stream linked to <code>streamOut</code>.</td>
</tr>
<tr>
<td><code>void list(PrintWriter streamOut)</code></td>
<td>Sends the property list to the output stream linked to <code>streamOut</code>.</td>
</tr>
<tr>
<td><code>void load(InputStream streamIn)</code> throws IOException</td>
<td>Imports a property list from the input stream linked to <code>streamIn</code>.</td>
</tr>
<tr>
<td><code>void load(Reader streamIn)</code> throws IOException</td>
<td>Imports a property list from the input stream linked to <code>streamIn</code>.</td>
</tr>
<tr>
<td><code>void loadFromXML(InputStream streamIn)</code> throws IOException, InvalidPropertiesFormatException</td>
<td>Imports a property list from an XML document linked to <code>streamIn</code>.</td>
</tr>
<tr>
<td><code>Enumeration&lt;? super propertyName&gt;()</code></td>
<td>Returns an enumeration of the keys. This includes those keys found in the default property list, too.</td>
</tr>
<tr>
<td><code>Object setProperty(String key, String value)</code></td>
<td>Associates value with <code>key</code>. Returns the previous value associated with <code>key</code>, or returns null if no such association exists.</td>
</tr>
<tr>
<td><code>void store(OutputStream streamOut, String description)</code> throws IOException</td>
<td>After writing the string specified by <code>description</code>, the property list is written to the output stream linked to <code>streamOut</code>.</td>
</tr>
<tr>
<td><code>void store(Writer streamOut, String description)</code> throws IOException</td>
<td>After writing the string specified by <code>description</code>, the property list is written to the output stream linked to <code>streamOut</code>.</td>
</tr>
<tr>
<td><code>void storeToXML(OutputStream streamOut, String description)</code> throws IOException</td>
<td>After writing the string specified by <code>description</code>, the property list is written to the XML document linked to <code>streamOut</code>.</td>
</tr>
<tr>
<td><code>void storeToXML(OutputStream streamOut, String description, String encoding)</code></td>
<td>The property list and the string specified by <code>description</code> is written to the XML document linked to <code>streamOut</code> using the specified character encoding</td>
</tr>
<tr>
<td><code>Set&lt;String&gt; stringPropertyNames()</code></td>
<td>Returns a set of keys.</td>
</tr>
</tbody>
</table>
One useful capability of the `Properties` class is that you can specify a default property that will be returned if no value is associated with a certain key. For example, a default value can be specified along with the key in the `getProperty()` method—such as `getProperty( "name","default value")`. If the "name" value is not found, then "default value" is returned. When you construct a `Properties` object, you can pass another instance of `Properties` to be used as the default properties for the new instance. In this case, if you call `getProperty("foo")` on a given `Properties` object, and "foo" does not exist, Java looks for "foo" in the default `Properties` object. This allows for arbitrary nesting of levels of default properties.

The following example demonstrates `Properties`. It creates a property list in which the keys are the names of states and the values are the names of their capitals. Notice that the attempt to find the capital for Florida includes a default value.

```java
// Demonstrate a Property list.
import java.util.*;

class PropDemo {
    public static void main(String args[]) {
        Properties capitals = new Properties();
        capitals.put("Illinois", "Springfield");
        capitals.put("Missouri", "Jefferson City");
        capitals.put("Washington", "Olympia");
        capitals.put("California", "Sacramento");
        capitals.put("Indiana", "Indianapolis");

        // Get a set-view of the keys.
        Set<?> states = capitals.keySet();

        // Show all of the states and capitals.
        for(Object nome : states)
            System.out.println("The capital of " +
                               nome + " is " +
                               capitals.getProperty((String)nome) + ".");

        System.out.println();

        // Look for state not in list -- specify default.
        String str = capitals.getProperty("Florida", "Not Found");
        System.out.println("The capital of Florida is " + str + ".");
    }
}
```

The output from this program is shown here:
Since Florida is not in the list, the default value is used.
Although it is perfectly valid to use a default value when you call `getProperty()`, as the preceding example shows, there is a better way of handling default values for most applications of property lists. For greater flexibility, specify a default property list when constructing a `Properties` object. The default list will be searched if the desired key is not found in the main list. For example, the following is a slightly reworked version of the preceding program, with a default list of states specified. Now, when Florida is sought, it will be found in the default list:
Using store( ) and load( )

One of the most useful aspects of Properties is that the information contained in a Properties object can be easily stored to or loaded from disk with the store( ) and load( ) methods. At any time, you can write a Properties object to a stream or read it back. This makes property lists especially convenient for implementing simple databases. For example, the following program uses a property list to create a simple computerized telephone book that stores names and phone numbers. To find a person’s number, you enter his or her name. The program uses the store( ) and load( ) methods to store and retrieve the list. When the program executes, it first tries to load the list from a file called phonebook.dat. If this file exists, the list is loaded. You can then add to the list. If you do, the new list is
saved when you terminate the program. Notice how little code is required to implement a small, but functional, computerized phone book.

```java
/* A simple telephone number database that uses a property list. */
import java.io.*;
import java.util.*;

class Phonebook {
    public static void main(String args[])
        throws IOException
    {
        Properties ht = new Properties();
        BufferedReader br =
            new BufferedReader(new InputStreamReader(System.in));
        String name, number;
        FileInputStream fin = null;
        boolean changed = false;

        // Try to open phonebook.dat file.
        try {
            fin = new FileInputStream("phonebook.dat");
        } catch (FileNotFoundException e) {
            // ignore missing file
        }

        /* If phonebook file already exists, load existing telephone numbers. */
        try {
            if (fin != null) {
                ht.load(fin);
                fin.close();
            }
        } catch (IOException e) {
            System.out.println("Error reading file.");
        }

        // Let user enter new names and numbers.
        do {
            System.out.println("Enter new name + "
                + " ('quit' to stop): ");
        } while (true);
    }
}
```
Parting Thoughts on Collections

The Collections Framework gives you, the programmer, a powerful set of well-engineered solutions to some of programming’s most common tasks. Consider using a collection the next time that you need to store and retrieve information. Remember, collections need not be reserved for only the “large jobs,” such as corporate databases, mailing lists, or inventory systems. They are also effective when applied to smaller jobs. For example, a **TreeMap** might make an excellent collection to hold the directory structure of a set of files. A **TreeSet** could be quite useful for storing project-management information. Frankly, the types of problems that will benefit from a collections-based solution are limited only by your imagination. One last point: In Chapter 29, the new stream API is discussed. Because streams are now integrated with collections, consider using a stream when operating on a collection.
This chapter continues our discussion of `java.util` by examining those classes and interfaces that are not part of the Collections Framework. These include classes that tokenize strings, work with dates, compute random numbers, bundle resources, and observe events. Also covered are the `Formatter` and `Scanner` classes which make it easy to write and read formatted data, and the new `Optional` class, which makes it easier to handle situations in which a value may be absent. Finally, the subpackages of `java.util` are summarized at the end of this chapter. Of particular interest is `java.util.function`, which defines several standard functional interfaces.

### StringTokenizer

The processing of text often consists of parsing a formatted input string. Parsing is the division of text into a set of discrete parts, or tokens, which in a certain sequence can convey a semantic meaning. The `StringTokenizer` class provides the first step in this parsing process, often called the lexer (lexical analyzer) or scanner. `StringTokenizer` implements the `Enumeration` interface. Therefore, given an input string, you can enumerate the individual tokens contained in it using `StringTokenizer`.

To use `StringTokenizer`, you specify an input string and a string that contains delimiters. Delimiters are characters that separate tokens. Each character in the delimiters string is considered a valid delimiter—for example, ",;:" sets the delimiters to a comma, semicolon, and colon. The default set of delimiters consists of the whitespace characters: space, tab, form feed, newline, and carriage return.

The `StringTokenizer` constructors are shown here:

```
StringTokenizer(String str)
StringTokenizer(String str, String delimiters)
StringTokenizer(String str, String delimiters, boolean delimAsToken)
```

In all versions, `str` is the string that will be tokenized. In the first version, the default delimiters are used. In the second and third versions, `delimiters` is a string that specifies the delimiters. In the third version, if `delimAsToken` is `true`, then the delimiters are also returned as tokens when the string is parsed. Otherwise, the
Delimiters are not returned. Delimiters are not returned as tokens by the first two forms.

Once you have created a `StringTokenizer` object, the `nextToken()` method is used to extract consecutive tokens. The `hasMoreTokens()` method returns `true` while there are more tokens to be extracted. Since `StringTokenizer` implements `Enumeration`, the `hasMoreElements()` and `nextElement()` methods are also implemented, and they act the same as `hasMoreTokens()` and `nextToken()`, respectively. The `StringTokenizer` methods are shown in Table 19-1.

Here is an example that creates a `StringTokenizer` to parse "key=value" pairs. Consecutive sets of "key=value" pairs are separated by a semicolon.

```java
// Demonstrate StringTokenizer.
import java.util.StringTokenizer;

class STDemo {
    static String in = "title=Java: The Complete Reference; " +
        "author=Schildt; " +
        "publisher=McGraw-Hill; " +
        "copyright=2014; ";

    public static void main(String args[]) {
        StringTokenizer st = new StringTokenizer(in, "=;");

        while(st.hasMoreTokens()) {
            String key = st.nextToken();
            String val = st.nextToken();
            System.out.println(key + "\t" + val);
        }
    }
}
```

The output from this program is shown here:

```
title  Java: The Complete Reference
author  Schildt
publisher  McGraw-Hill
copyright  2014
```
BitSet

A **BitSet** class creates a special type of array that holds bit values in the form of `boolean` values. This array can increase in size as needed. This makes it similar to a vector of bits.

The **BitSet** constructors are shown here:

- `BitSet()`
- `BitSet(int size)`

The first version creates a default object. The second version allows you to specify its initial size (that is, the number of bits that it can hold). All bits are initialized to `false`.

**BitSet** defines the methods listed in Table 19-2.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void and(BitSet bitsSet)</td>
<td>ANDs the contents of the invoking BitSet object with those specified by bitsSet. The result is placed into the invoking object.</td>
</tr>
<tr>
<td>void andNot(BitSet bitsSet)</td>
<td>For each set bit in bitsSet, the corresponding bit in the invoking BitSet is cleared.</td>
</tr>
<tr>
<td>int cardinality()</td>
<td>Returns the number of set bits in the invoking object.</td>
</tr>
<tr>
<td>void clear()</td>
<td>Zeros all bits.</td>
</tr>
<tr>
<td>void clear(int index)</td>
<td>Zeros the bit specified by index.</td>
</tr>
<tr>
<td>void clear(int startindex, int endindex)</td>
<td>Zeros the bits from startindex to endindex-1.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Duplicates the invoking BitSet object.</td>
</tr>
<tr>
<td>boolean equals(Object bitsSet)</td>
<td>Returns true if the invoking bit set is equivalent to the one passed in bitsSet. Otherwise, the method returns false.</td>
</tr>
<tr>
<td>void flip(int index)</td>
<td>Reverses the bit specified by index.</td>
</tr>
<tr>
<td>void flip(int startindex, int endindex)</td>
<td>Reverses the bits from startindex to endindex-1.</td>
</tr>
<tr>
<td>boolean get(int index)</td>
<td>Returns the current state of the bit at the specified index.</td>
</tr>
<tr>
<td>BitSet get(int startindex, int endindex)</td>
<td>Returns a BitSet that consists of the bits from startindex to endindex-1. The invoking object is not changed.</td>
</tr>
<tr>
<td>int hashcode()</td>
<td>Returns the hash code for the invoking object.</td>
</tr>
<tr>
<td>boolean intersects(BitSet bitsSet)</td>
<td>Returns true if at least one pair of corresponding bits within the invoking object and bitsSet are set.</td>
</tr>
<tr>
<td>boolean isEmpty()</td>
<td>Returns true if all bits in the invoking object are cleared.</td>
</tr>
<tr>
<td>int length()</td>
<td>Returns the number of bits required to hold the contents of the invoking BitSet. This value is determined by the location of the last set bit.</td>
</tr>
<tr>
<td>int nextClearBit(int startindex)</td>
<td>Returns the index of the next cleared bit (that is, the next false bit), starting from the index specified by startindex.</td>
</tr>
</tbody>
</table>
Here is an example that demonstrates ` BitSet`: 

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int nextSetBit(int startIndex)</code></td>
<td>Returns the index of the next set bit (that is, the next true bit), starting from the index specified by <code>startIndex</code>. If no bit is set, <code>-1</code> is returned.</td>
</tr>
<tr>
<td><code>void get(BitSet bs)</code></td>
<td>Gets the contents of the invoking <code> BitSet</code> object with that specified by <code>bs</code>. The result is placed into the invoking object.</td>
</tr>
<tr>
<td><code>int previousClearBit(int startindex)</code></td>
<td>Returns the index of the next cleared bit (that is, the next false bit) at or prior to the index specified by <code>startIndex</code>. If no cleared bit is found, <code>-1</code> is returned.</td>
</tr>
<tr>
<td><code>int previousSetBit(int startindex)</code></td>
<td>Returns the index of the next set bit (that is, the next true bit) at or prior to the index specified by <code>startIndex</code>. If no set bit is found, <code>-1</code> is returned.</td>
</tr>
<tr>
<td><code>void set(int index)</code></td>
<td>Sets the bit specified by <code>index</code>.</td>
</tr>
<tr>
<td><code>void set(int index, boolean v)</code></td>
<td>Sets the bit specified by <code>index</code> to the value passed in <code>v</code>. <code>true</code> sets the bit; <code>false</code> clears the bit.</td>
</tr>
<tr>
<td><code>void set(int startindex, int endIndex)</code></td>
<td>Sets the bits from <code>startindex</code> to <code>endIndex</code>—1.</td>
</tr>
<tr>
<td><code>void set(int startindex, int endIndex, boolean v)</code></td>
<td>Sets the bits from <code>startindex</code> to <code>endIndex</code>—1 to the value passed in <code>v</code>. <code>true</code> sets the bits; <code>false</code> clears the bits.</td>
</tr>
<tr>
<td><code>int size()</code></td>
<td>Returns the number of bits in the invoking <code> BitSet</code> object.</td>
</tr>
<tr>
<td><code>IntStream stream()</code></td>
<td>Returns a stream that contains the bit positions, from low to high, that have set bits. (Added by JDK 8.)</td>
</tr>
<tr>
<td><code>byte[] toByteArray()</code></td>
<td>Returns a byte array that contains the invoking <code> BitSet</code> object.</td>
</tr>
<tr>
<td><code>long[] toLongArray()</code></td>
<td>Returns a long array that contains the invoking <code> BitSet</code> object.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the invoking <code> BitSet</code> object.</td>
</tr>
<tr>
<td><code>static BitSet valueOf(byte[] v)</code></td>
<td>Returns a <code> BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td><code>static BitSet valueOf(ByteBuffer v)</code></td>
<td>Returns a <code> BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td><code>static BitSet valueOf(long[] v)</code></td>
<td>Returns a <code> BitSet</code> that contains the bits in <code>v</code>.</td>
</tr>
<tr>
<td><code>void xor(BitSet bs)</code></td>
<td>XORs the contents of the invoking <code> BitSet</code> object with that specified by <code>bs</code>. The result is placed into the invoking object.</td>
</tr>
</tbody>
</table>

Table 19-2  The Methods Defined by ` BitSet`
// BitSet Demonstration.
import java.util.BitSet;

class BitSetDemo {
    public static void main(String args[]) {
        BitSet bits1 = new BitSet(16);
        BitSet bits2 = new BitSet(16);

        // set some bits
        for(int i=0; i<16; i++) {
            if((i%2) == 0) bits1.set(i);
            if((i%5) != 0) bits2.set(i);
        }

        System.out.println("Initial pattern in bits1: ");
        System.out.println(bits1);
        System.out.println("\nInitial pattern in bits2: ");
        System.out.println(bits2);

        // AND bits
        bits2.and(bits1);
        System.out.println("\nbits2 AND bits1: ");
        System.out.println(bits2);

        // OR bits
        bits2.or(bits1);
        System.out.println("\nbits2 OR bits1: ");
        System.out.println(bits2);

        // XOR bits
        bits2.xor(bits1);
        System.out.println("\nbits2 XOR bits1: ");
        System.out.println(bits2);
    }
}

The output from this program is shown here. When toString() converts a BitSet object to its string equivalent, each set bit is represented by its bit position. Cleared bits are not shown.
Optional, OptionalDouble, OptionalInt, and OptionalLong

JDK 8 adds classes called `Optional`, `OptionalDouble`, `OptionalInt`, and `OptionalLong` that offer a way to handle situations in which a value may or may not be present. In the past, you would normally use the value `null` to indicate that no value is present. However, this can lead to null pointer exceptions if an attempt is made to dereference a null reference. As a result, frequent checks for a `null` value were necessary to avoid generating an exception. These classes provide a better way to handle such situations.

The first and most general of these classes is `Optional`. For this reason, it is the primary focus of this discussion. It is shown here:

```java
class Optional<T>
```

Here, `T` specifies the type of value stored. It is important to understand that an `Optional` instance can either contain a value of type `T` or be empty. In other words, an `Optional` object does not necessarily contain a value. `Optional` does not define any constructors, but it does define several methods that let you work with `Optional` objects. For example, you can determine if a value is present, obtain the value if it is present, obtain a default value when no value is present, and construct an `Optional` value. The `Optional` methods are shown in Table 19-3.
The best way to understand `Optional` is to work through an example that uses its core methods. At the foundation of `Optional` are `isPresent()` and `get()`. You can determine if a value is present by calling `isPresent()`. If a value is available, it will return `true`. Otherwise, `false` is returned. If a value is present in an `Optional` instance, you can obtain it by calling `get()`. However, if you call `get()` on an object that does not contain a value, `NoSuchElementException` is thrown. For this reason, you should always first confirm that a value is present before calling `get()` on an `Optional` object.

Of course, having to call two methods to retrieve a value adds overhead to each access. Fortunately, `Optional` defines methods that combine the check for a value with the retrieval of the value. One such method is `orElse()`. If the object on which it is called contains a value, the value is returned. Otherwise, a default value is returned.

`Optional` does not define any constructors. Instead, you will use one of its methods to
create an instance. For example, you can create an **Optional** instance with a specified value by using `of()`. You can create an instance of **Optional** that does not contain a value by using `empty()`.

The following program demonstrates these methods:

```java
// Demonstrate several Optional<T> methods
import java.util.*;

class OptionalDemo {
    public static void main(String args[]) {
        Optional<String> noVal = Optional.empty();
        Optional<String> hasVal = Optional.of("ABCD\046FG");
        if(noVal.isPresent()) System.out.println("This won’t be displayed");
        else System.out.println("noVal has no value");
        if(hasVal.isPresent()) System.out.println("The string in hasVal is: "+
            hasVal.get());
        String defStr = noVal.orElse("Default String");
        System.out.println(defStr);
    }
}
```

The output is shown here:

```
noVal has no value
The string in hasVal is: ABC\046FG
Default String
```

As the output shows, a value can be obtained from an **Optional** object only if one is present. This basic mechanism enables **Optional** to prevent null pointer exceptions.

The **OptionalDouble**, **OptionalInt**, and **OptionalLong** classes work much like **Optional**, except that they are designed expressly for use on `double`, `int`, and `long` values, respectively. As such, they specify the methods `getAsDouble()`, `getAsInt()`, and `getAsLong()`, respectively, rather than `get()`.

Also, they do not support the `filter()`, `ofNullable()`, `map()` and `flatMap()` methods.

### Date

The **Date** class encapsulates the current date and time. Before beginning our examination of **Date**, it is important to point out that it has changed substantially from its original version defined by Java 1.0. When Java 1.1 was released, many of the functions carried out by the original **Date** class were moved into the **Calendar** and **DateFormat** classes, and as a result, many of the original 1.0 **Date** methods were deprecated. Since the deprecated 1.0 methods should not be used for new code, they are not described here.
The `Date` class supports the following non-deprecated constructors:

- `Date()` initializes the object with the current date and time.
- `Date(long millisec)` accepts one argument that equals the number of milliseconds that have elapsed since midnight, January 1, 1970. The non-deprecated methods defined by `Date` are shown in Table 19-4. `Date` also implements the `Comparable` interface.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean after(Date date)</td>
<td>Returns true if the invoking <code>Date</code> object contains a date that is later than the one specified by <code>date</code>. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td>boolean before(Date date)</td>
<td>Returns true if the invoking <code>Date</code> object contains a date that is earlier than the one specified by <code>date</code>. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td>Object clone()</td>
<td>Duplicates the invoking <code>Date</code> object.</td>
</tr>
<tr>
<td>int compareTo(Date date)</td>
<td>Compares the value of the invoking object with that of <code>date</code>. Returns 0 if the values are equal. Returns a negative value if the invoking object is earlier than <code>date</code>. Returns a positive value if the invoking object is later than <code>date</code>.</td>
</tr>
<tr>
<td>boolean equals(Object date)</td>
<td>Returns true if the invoking <code>Date</code> object contains the same time and date as the one specified by <code>date</code>. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td>static Date from(Instant i)</td>
<td>Returns a <code>Date</code> object corresponding to the <code>Instant</code> object passed in <code>i</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td>long getTime()</td>
<td>Returns the number of milliseconds that have elapsed since January 1, 1970.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns a hash code for the invoking object.</td>
</tr>
<tr>
<td>void setTime(long time)</td>
<td>Sets the time and date as specified by <code>time</code>, which represents the number of elapsed time in milliseconds from midnight, January 1, 1970.</td>
</tr>
<tr>
<td>Instant toInstant(1)</td>
<td>Returns an <code>Instant</code> object corresponding to the invoking <code>Date</code> object. (Added by JDK 8.)</td>
</tr>
<tr>
<td>String toString()</td>
<td>Converts the invoking <code>Date</code> object into a string and returns the result.</td>
</tr>
</tbody>
</table>

**Table 19-4**  The Nondeprecated Methods Defined by `Date`  

As you can see by examining Table 19-4, the non-deprecated `Date` features do not allow you to obtain the individual components of the date or time. As the following program demonstrates, you can only obtain the date and time in terms of milliseconds, in its default string representation as returned by `toString()`, or (beginning with JDK 8) as an `Instant` object. To obtain more-detailed information about the date and time, you will use the `Calendar` class.
The abstract `Calendar` class provides a set of methods that allows you to convert a time in milliseconds to a number of useful components. Some examples of the type of information that can be provided are year, month, day, hour, minute, and second. It is intended that subclasses of `Calendar` will provide the specific functionality to interpret time information according to their own rules. This is one aspect of the Java class library that enables you to write programs that can operate in international environments. An example of such a subclass is `GregorianCalendar`.

NOTE  JDK 8 defines a new date and time API in `java.time`, which new applications may want to employ. See Chapter 30.

`Calendar` provides no public constructors. `Calendar` defines several protected instance variables. `areFieldsSet` is a `boolean` that indicates if the time components have been set. `fields` is an array of `ints` that holds the components of the time. `isSet` is a `boolean` array that indicates if a specific time component has been set. `time` is a `long` that holds the current time for this object. `isTimeSet` is a `boolean` that indicates if the current time has been set.

A sampling of methods defined by `Calendar` are shown in Table 19-5.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
</table>
| `add(int which, int val)` | Adds `val` to the time or date component specified by `which`. To subtract, add a negative value. `which` must be one of the fields defined by `Calendar`, such as `Calendar.HOUR`.
| `after(Object calendarObj)` | Returns `true` if the invoking `Calendar` object contains a date that is later than the one specified by `calendarObj`. Otherwise, it returns `false`.
| `before(Object calendarObj)` | Returns `true` if the invoking `Calendar` object contains a date that is earlier than the one specified by `calendarObj`. Otherwise, it returns `false`.
| `clear()` | Zeroes all time components in the invoking object.
| `clear(int which)` | Zeroes the time component specified by `which` in the invoking object.
| `clone()` | Returns a duplicate of the invoking object.
| `equals(Object calendarObj)` | Returns `true` if the invoking `Calendar` object contains a date that is equal to the one specified by `calendarObj`. Otherwise, it returns `false`.
| `get(int calendarField)` | Returns the value of one component of the invoking object. The component is indicated by `calendarField`. Examples of the components that can be requested are `Calendar.YEAR`, `Calendar.MONTH`, `Calendar.DAY_OF_MONTH`, and so forth.
| `getAvailableLocales()` | Returns an array of `Locale` objects that contains the locales for which calendars are available.
| `getInstance()` | Returns a `Calendar` object for the default locale and time zone.
| `getInstance(TimeZone tz)` | Returns a `Calendar` object for the time zone specified by `tz`. The default locale is used.
| `getInstance(Locale locale)` | Returns a `Calendar` object for the locale specified by `locale`. The default time zone is used.
| `getInstance(TimeZone tz, Locale locale)` | Returns a `Calendar` object for the time zone specified by `tz` and the locale specified by `locale`.
| `getDate()` | Returns a `Date` object equivalent to the time of the invoking object.
| `getTime()` | Returns the time zone for the invoking object.
| `set(int which)` | Returns `true` if the specified time component is set. Otherwise, it returns `false`.
| `set(int which, int val)` | Sets the date or time component specified by `which` to the value specified by `val` in the invoking object. `which` must be one of the fields defined by `Calendar`, such as `Calendar.HOUR`.
| `set(int year, int month, int day)` | Sets various date and time components of the invoking object.
| `set(int year, int month, int day, int hours, int minutes, int seconds)` | Sets various date and time components of the invoking object.
| `set(DATE, int date)` | Sets the date for the invoking object. This information is obtained from the `Date` object `date`.
| `setZone(TimeZone tz)` | Sets the time zone for the invoking object to that specified by `tz`.
| `toInstant()` | Returns an `Instant` object corresponding to the invoking `Calendar` instance. (Added by JDK 8.)

Table 19-5  A Sampling of the Methods Defined by `Calendar`
Calendar defines the following int constants, which are used when you get or set components of the calendar. (The ones with the suffix FORMAT or STANDALONE were added by JDK 8.)

<table>
<thead>
<tr>
<th>ALL_STYLES</th>
<th>HOUR_OF_DAY</th>
<th>PM</th>
</tr>
</thead>
<tbody>
<tr>
<td>AM</td>
<td>JANUARY</td>
<td>SATURDAY</td>
</tr>
<tr>
<td>AM_PM</td>
<td>JULY</td>
<td>SECOND</td>
</tr>
<tr>
<td>APRIL</td>
<td>JUNE</td>
<td>SEPTEMBER</td>
</tr>
<tr>
<td>AUGUST</td>
<td>LONG</td>
<td>SHORT</td>
</tr>
<tr>
<td>DATE</td>
<td>LONG_FORMAT</td>
<td>SHORT_FORMAT</td>
</tr>
<tr>
<td>DAY_OF_MONTH</td>
<td>LONG_STANDALONE</td>
<td>SHORT_STANDALONE</td>
</tr>
<tr>
<td>DAY_OF_WEEK</td>
<td>MARCH</td>
<td>SUNDAY</td>
</tr>
<tr>
<td>DAY_OF_WEEK_IN_MONTH</td>
<td>MAY</td>
<td>THURSDAY</td>
</tr>
<tr>
<td>DAY_OF_YEAR</td>
<td>MILLISECOND</td>
<td>TUESDAY</td>
</tr>
<tr>
<td>DECEMBER</td>
<td>MINUTE</td>
<td>UNDECEMBER</td>
</tr>
<tr>
<td>DST_OFFSET</td>
<td>MONDAY</td>
<td>WEDNESDAY</td>
</tr>
<tr>
<td>ERA</td>
<td>MONTH</td>
<td>WEEK_OF_MONTH</td>
</tr>
<tr>
<td>FEBRUARY</td>
<td>NARROW_FORMAT</td>
<td>WEEK_OF_YEAR</td>
</tr>
<tr>
<td>FIELD_COUNT</td>
<td>NARROW_STANDALONE</td>
<td>YEAR</td>
</tr>
<tr>
<td>FRIDAY</td>
<td>NOVEMBER</td>
<td>ZONE_OFFSET</td>
</tr>
<tr>
<td>HOUR</td>
<td>OCTOBER</td>
<td></td>
</tr>
</tbody>
</table>

The following program demonstrates several Calendar methods:
GregorianCalendar

GregorianCalendar is a concrete implementation of a Calendar that implements the normal Gregorian calendar with which you are familiar. The getInstance() method of Calendar will typically return a GregorianCalendar initialized with the current date and time in the default locale and time zone.

Sample output is shown here:

```
Date: Jan 1 2014
Time: 11:29:39
Updated time: 10:29:22
```
GregorianCalendar defines two fields: AD and BC. These represent the two eras defined by the Gregorian calendar. There are also several constructors for GregorianCalendar objects. The default, GregorianCalendar(), initializes the object with the current date and time in the default locale and time zone. Three more constructors offer increasing levels of specificity:

```
GregorianCalendar(int year, int month, int dayOfMonth)
GregorianCalendar(int year, int month, int dayOfMonth, int hours, int minutes)
GregorianCalendar(int year, int month, int dayOfMonth, int hours, int minutes, int seconds)
```

All three versions set the day, month, and year. Here, `year` specifies the year. The month is specified by `month`, with zero indicating January. The day of the month is specified by `dayOfMonth`. The first version sets the time to midnight. The second version also sets the hours and the minutes. The third version adds seconds.

You can also construct a GregorianCalendar object by specifying the locale and/or time zone. The following constructors create objects initialized with the current date and time using the specified time zone and/or locale:

```
GregorianCalendar(Locale locale)
GregorianCalendar(TimeZone timeZone)
GregorianCalendar(TimeZone timeZone, Locale locale)
```

GregorianCalendar provides an implementation of all the abstract methods in Calendar. It also provides some additional methods. Perhaps the most interesting is `isLeapYear()`, which tests if the year is a leap year. Its form is

```
boolean isLeapYear(int year)
```

This method returns `true` if `year` is a leap year and `false` otherwise. JDK 8 also adds the following methods: `from()` and `toZonedDateTime()`, which support the new date and time API, and `getCalendarType()`, which returns the calendar type as a string, which is “gregory”.

The following program demonstrates GregorianCalendar:
Sample output is shown here:

```
Date: Jan 1 2014
Time: 1:45:5
The current year is not a leap year
```

**TimeZone**

Another time-related class is **TimeZone**. The abstract **TimeZone** class allows you to work with time zone offsets from Greenwich mean time (GMT), also referred to as Coordinated Universal Time (UTC). It also computes daylight saving time. **TimeZone** only supplies the default constructor.

A sampling of methods defined by **TimeZone** is given in Table 19-6.
SimpleTimeZone

The SimpleTimeZone class is a convenient subclass of TimeZone. It implements TimeZone's abstract methods and allows you to work with time zones for a Gregorian calendar. It also computes daylight saving time.

SimpleTimeZone defines four constructors. One is

```
SimpleTimeZone(int timeDelta, String tzName)
```

This constructor creates a SimpleTimeZone object. The offset relative to Greenwich mean time (GMT) is timeDelta. The time zone is named tzName.

The second SimpleTimeZone constructor is

```
SimpleTimeZone(int timeDelta, String tzId, int dstMonth0, int dstMonth1, int dstDayInMonth0, int dstDayInMonth1, int dstDay0, int dstDay1, int dstMonth0, int dstMonth1, int dstDayInMonth0, int dstDayInMonth1, int dstDay0, int dstDay1)
```
Here, the offset relative to GMT is specified in \texttt{timeDelta}. The time zone name is passed in \texttt{tzId}. The start of daylight saving time is indicated by the parameters \texttt{dstMonth0}, \texttt{dstDayInMonth0}, \texttt{dstDay0}, and \texttt{time0}. The end of daylight saving time is indicated by the parameters \texttt{dstMonth1}, \texttt{dstDayInMonth1}, \texttt{dstDay1}, and \texttt{time1}.

The third \texttt{SimpleTimeZone} constructor is:

\begin{verbatim}
SimpleTimeZone(int timeDelta, String tzId, int dstMonth0,
    int dstDayInMonth0, int dstDay0, int time0,
    int dstMonth1, int dstDayInMonth1,
    int dstDay1, int time1, int dstDelta)
\end{verbatim}

Here, \texttt{dstDelta} is the number of milliseconds saved during daylight saving time.

The fourth \texttt{SimpleTimeZone} constructor is:

\begin{verbatim}
SimpleTimeZone(int timeDelta, String tzId, int dstMonth0,
    int dstDayInMonth0, int dstDay0, int time0,
    int time0mode, int dstMonth1, int dstDayInMonth1,
    int dstDay1, int time1, int time1mode, int dstDelta)
\end{verbatim}

Here, \texttt{time0mode} specifies the mode of the starting time, and \texttt{time1mode} specifies the mode of the ending time. Valid mode values include:

\begin{verbatim}
| STANDARD_TIME | WALL_TIME   | UTC_TIME   |
\end{verbatim}

The time mode indicates how the time values are interpreted. The default mode used by the other constructors is \texttt{WALL\_TIME}.

\textbf{Locale}

The \texttt{Locale} class is instantiated to produce objects that describe a geographical or cultural region. It is one of several classes that provide you with the ability to write programs that can execute in different international environments. For example, the formats used to display dates, times, and numbers are different in various regions.

Internationalization is a large topic that is beyond the scope of this book. However, many programs will only need to deal with its basics, which include setting the current locale.

The \texttt{Locale} class defines the following constants that are useful for dealing with several common locales:
For example, the expression `Locale.CANADA` represents the `Locale` object for Canada. The constructors for `Locale` are

```java
Locale(String language)
Locale(String language, String country)
Locale(String language, String country, String variant)
```

These constructors build a `Locale` object to represent a specific `language` and in the case of the last two, `country`. These values must contain standard language and country codes. Auxiliary variant information can be provided in `variant`.

`Locale` defines several methods. One of the most important is `setDefault()`, shown here:

```java
static void setDefault(Locale localeObj)
```

This sets the default locale used by the JVM to that specified by `localeObj`.

Some other interesting methods are the following:

```java
final String getDisplayCountry()
final String getDisplayLanguage()
final String getDisplayName()
```

These return human-readable strings that can be used to display the name of the country, the name of the language, and the complete description of the locale.

The default locale can be obtained using `getDefault()`, shown here:

```java
static Locale getDefault()
```

JDK 7 added significant upgrades to the `Locale` class that support Internet Engineering Task Force (IETF) BCP 47, which defines tags for identifying languages, and Unicode Technical Standard (UTS) 35, which defines the Locale Data Markup Language (LDML). Support for BCP 47 and UTS 35 caused several features to be added to `Locale`, including several new methods and the `Locale.Builder` class. Among others, new methods include `getScript()`, which obtains the locale's script, and `toLanguageTag()`, which obtains a string that contains the locale's language tag. The `Locale.Builder` class constructs `Locale` instances. It ensures that a locale specification is well-formed as defined by BCP 47. (The `Locale` constructors do not provide such a check.) Several new methods...
have also been added to Locale by JDK 8. Among these are methods that support filtering, extensions, and lookups. **Calendar** and **GregorianCalendar** are examples of classes that operate in a locale-sensitive manner. **DateFormat** and **SimpleDateFormat** also depend on the locale.

**Random**
The **Random** class is a generator of pseudorandom numbers. These are called *pseudorandom* numbers because they are simply uniformly distributed sequences. **Random** defines the following constructors:

- `Random()`
- `Random(long seed)`

The first version creates a number generator that uses a reasonably unique seed. The second form allows you to specify a seed value manually.

If you initialize a **Random** object with a seed, you define the starting point for the random sequence. If you use the same seed to initialize another **Random** object, you will extract the same random sequence. If you want to generate different sequences, specify different seed values. One way to do this is to use the current time to seed a **Random** object. This approach reduces the possibility of getting repeated sequences.

The core public methods defined by **Random** are shown in Table 19-7. These are the methods that have been available in **Random** for several years (many since Java 1.0) and are widely used.

As you can see, there are seven types of random numbers that you can extract from a **Random** object. Random Boolean values are available from **nextBoolean()**. Random bytes can be obtained by calling **nextBytes()**. Integers can be extracted via the **nextInt()** method. Long integers, uniformly distributed over their range, can be obtained with **nextLong()**. The **nextFloat()** and **nextDouble()** methods return a uniformly distributed *float* and *double*, respectively, between 0.0 and 1.0. Finally, **nextGaussian()** returns a *double* value centered at 0.0 with a standard deviation of 1.0. This is what is known as a *bell curve*.

Here is an example that demonstrates the sequence produced by **nextGaussian()**. It obtains 100 random Gaussian values and averages these values. The program also counts the number of values that fall within two standard deviations, plus or minus, using increments of 0.5 for each category. The result is graphically displayed sideways on the screen.
Here is a sample program run. As you can see, a bell-like distribution of numbers is
JDK 8 adds three new methods to Random that support the new stream API (see Chapter 29). They are called doubles(), ints(), and longs(), and each returns a reference to a stream that contains a sequence of pseudorandom values of the specified type. Each method defines several overloads. Here are their simplest forms:

```java
DoubleStream doubles()
IntStream ints()
LongStream longs()
```

The doubles() method returns a stream that contains pseudorandom double values. (The range of these values will be less than 1.0 but greater than 0.0.) The ints() method returns a stream that contains pseudorandom int values. The longs() method returns a stream that contains pseudorandom long values. For these three methods, the stream returned is effectively infinite. Several overloads of each method are provided that let you specify the size of the stream, an origin, and an upper bound.

**Observable**

The Observable class is used to create subclasses that other parts of your program can observe. When an object of such a subclass undergoes a change, observing classes are notified. Observing classes must implement the Observer interface, which defines the update() method. The update() method is called when an observer is notified of a change in an observed object.

Observable defines the methods shown in Table 19-8. An object that is being observed must follow two simple rules. First, if it has changed, it must call setChanged(). Second, when it is ready to notify observers of this change, it must call notifyObservers(). This causes the update() method in the observing object(s) to be called. Be careful—if the object calls notifyObservers() without having previously called setChanged(), no action will take place. The observed object must call both setChanged() and
notifyObservers( ) before update( ) will be called.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void addObserver(Observable obj)</td>
<td>Adds obj to the list of objects observing the invoking object.</td>
</tr>
<tr>
<td>protected void clearChanged()</td>
<td>Calling this method returns the status of the invoking object to “unchanged.”</td>
</tr>
<tr>
<td>int countObservers()</td>
<td>Returns the number of objects observing the invoking object.</td>
</tr>
<tr>
<td>void deleteObserver(Observable obj)</td>
<td>Removes obj from the list of objects observing the invoking object.</td>
</tr>
<tr>
<td>void deleteObservers()</td>
<td>Removes all observers for the invoking object.</td>
</tr>
<tr>
<td>boolean hasChanged()</td>
<td>Returns true if the invoking object has been modified and false if it has not.</td>
</tr>
<tr>
<td>void notifyObservers()</td>
<td>Notifies all observers of the invoking object that it has changed by calling update( ). A null is passed as the second argument to update( ).</td>
</tr>
<tr>
<td>void notifyObservers(Object obj)</td>
<td>Notifies all observers of the invoking object that it has changed by calling update( ), obj is passed as an argument to update( ).</td>
</tr>
<tr>
<td>protected void setChanged()</td>
<td>Called when the invoking object has changed.</td>
</tr>
</tbody>
</table>

Table 19-8  The Methods Defined by Observable

Notice that notifyObservers( ) has two forms: one that takes an argument and one that does not. If you call notifyObservers( ) with an argument, this object is passed to the observer’s update( ) method as its second parameter. Otherwise, null is passed to update( ). You can use the second parameter for passing any type of object that is appropriate for your application.

The Observer Interface
To observe an observable object, you must implement the Observer interface. This interface defines only the one method shown here:

void update(Observable observOb, Object arg)

Here, observOb is the object being observed, and arg is the value passed by notifyObservers( ). The update( ) method is called when a change in the observed object takes place.

An Observer Example
Here is an example that demonstrates an observable object. It creates an observer class, called Watcher, that implements the Observer interface. The class being monitored is called BeingWatched. It extends Observable. Inside BeingWatched is the method counter( ), which simply counts down from a specified value. It uses sleep( ) to wait a tenth of a second between counts. Each time the count changes, notifyObservers( ) is called with the current count passed as its argument. This causes the update( ) method inside Watcher to be called, which displays the current count. Inside main( ), a Watcher and a BeingWatched object, called observing and observed, respectively, are created. Then, observing is added to the list of observers for observed. This means that
observing.update() will be called each time counter() calls notifyObservers().

```java
/* Demonstrate the Observable class and the
 Observer interface.
 */
import java.util.*;

// This is the observing class.
class Watcher implements Observer {
    public void update(Observable obj, Object arg) {
        System.out.println("update() called, count is " + ((Integer)arg).intValue());
    }
}

// This is the class being observed.
class BeingWatched extends Observable {
    void counter(int period) {
        for( ; period >0; period--) {
            setChanged();
            notifyObservers(new Integer(period));
            try {
                Thread.sleep(100);
            } catch(InterruptedException e) {
                System.out.println("Sleep interrupted");
            }
        }
    }
}

class ObserverDemo {
    public static void main(String args[]) {
        BeingWatched observed = new BeingWatched();
        Watcher observing = new Watcher();

        /* Add the observing to the list of observers for 
         * observed object. */
        observed.addObserver(observing);

        observed.counter(10);
    }
}
```

The output from this program is shown here:
More than one object can be an observer. For example, the following program implements two observing classes and adds an object of each class to the `BeingWatched` observer list.

The second observer waits until the count reaches zero and then rings the bell.

```java
/* An object may be observed by two or more observers. */

import java.util.*;

// This is the first observing class.
class Watcher1 implements Observer {
    public void update(Observable obj, Object arg) {
        System.out.println("update() called, count is " + ((java.lang.Integer)arg).intValue());
    }
}
```
The **Observable** class and the **Observer** interface allow you to implement sophisticated program architectures based on the document/view methodology.

**Timer and TimerTask**

An interesting and useful feature offered by **java.util** is the ability to schedule a task for
execution at some future time. The classes that support this are **Timer** and **TimerTask**.

Using these classes, you can create a thread that runs in the background, waiting for a specific time. When the time arrives, the task linked to that thread is executed. Various options allow you to schedule a task for repeated execution, and to schedule a task to run on a specific date. Although it was always possible to manually create a task that would be executed at a specific time using the **Thread** class, **Timer** and **TimerTask** greatly simplify this process.

**Timer** and **TimerTask** work together. **Timer** is the class that you will use to schedule a task for execution. The task being scheduled must be an instance of **TimerTask**. Thus, to schedule a task, you will first create a **TimerTask** object and then schedule it for execution using an instance of **Timer**.

**TimerTask** implements the **Runnable** interface; thus, it can be used to create a thread of execution. Its constructor is shown here:

```java
protected TimerTask()
```

**TimerTask** defines the methods shown in Table 19-9. Notice that **run( )** is abstract, which means that it must be overridden. The **run( )** method, defined by the **Runnable** interface, contains the code that will be executed. Thus, the easiest way to create a timer task is to extend **TimerTask** and override **run( )**.

Once a task has been created, it is scheduled for execution by an object of type **Timer**. The constructors for **Timer** are shown here:

```java
Timer()
Timer(boolean DThread)
Timer(String tName)
Timer(String tName, boolean DThread)
```

The first version creates a **Timer** object that runs as a normal thread. The second uses a daemon thread if **DThread** is **true**. A daemon thread will execute only as long as the rest of the program continues to execute. The third and fourth constructors allow you to specify a name for the **Timer** thread. The methods defined by **Timer** are shown in Table 19-9.

Once a **Timer** has been created, you will schedule a task by calling **schedule( )** on the **Timer** that you created. As Table 19-10 shows, there are several forms of **schedule( )** which allow you to schedule tasks in a variety of ways.
If you create a non-daemon task, then you will want to call `cancel()` to end the task when your program ends. If you don’t do this, then your program may “hang” for a period of time.

The following program demonstrates `Timer` and `TimerTask`. It defines a timer task whose `run()` method displays the message "Timer task executed." This task is scheduled to run once every half second after an initial delay of one second.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void cancel()</code></td>
<td>Cancels the timer thread.</td>
</tr>
<tr>
<td><code>int purge()</code></td>
<td>Deletes canceled tasks from the timer’s queue.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TTask, long unit)</code></td>
<td><code>TTask</code> is scheduled for execution after the period passed in <code>unit</code> has elapsed. The <code>unit</code> parameter is specified in milliseconds.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TTask, long unit, long repeat)</code></td>
<td><code>TTask</code> is scheduled for execution after the period passed in <code>unit</code> has elapsed. The task is then executed repeatedly at the interval specified by <code>repeat</code>. Both <code>unit</code> and <code>repeat</code> are specified in milliseconds.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TTask, Date targetTime)</code></td>
<td><code>TTask</code> is scheduled for execution at the time specified by <code>targetTime</code>.</td>
</tr>
<tr>
<td><code>void schedule(TimerTask TTask, Date targetTime, long repeat)</code></td>
<td><code>TTask</code> is scheduled for execution at the time specified by <code>targetTime</code>. The task is then executed repeatedly at the interval specified by <code>repeat</code>. The <code>repeat</code> parameter is specified in milliseconds.</td>
</tr>
<tr>
<td><code>void scheduleAtFixedRate(TimerTask TTask, long unit, long repeat)</code></td>
<td><code>TTask</code> is scheduled for execution after the period passed in <code>unit</code> has elapsed. The task is then executed repeatedly at the interval specified by <code>repeat</code>. Both <code>unit</code> and <code>repeat</code> are specified in milliseconds. The time of each repetition is relative to the first execution, not the preceding execution. Thus, the overall rate of execution is fixed.</td>
</tr>
<tr>
<td><code>void scheduleAtFixedRate(TimerTask TTask, Date targetTime, long repeat)</code></td>
<td><code>TTask</code> is scheduled for execution at the time specified by <code>targetTime</code>. The task is then executed repeatedly at the interval specified in <code>repeat</code>. The <code>repeat</code> parameter is specified in milliseconds. The time of each repetition is relative to the first execution, not the preceding execution. Thus, the overall rate of execution is fixed.</td>
</tr>
</tbody>
</table>
Currency

The Currency class encapsulates information about a currency. It defines no constructors. The methods supported by Currency are shown in Table 19-11. The following program demonstrates Currency:

```java
// Demonstrate Currency.
import java.util.*;

class MyCurrency extends Currency {
    public void run() {
        System.out.println("Currency executed.");
    }
}

class MyCurrencyTest {
    public static void main(String args[]) {
        MyCurrency myCurrency = new MyCurrency();
        myCurrency.run();
    }
}
```
At the core of Java’s support for creating formatted output is the **Formatter** class. It provides *format conversions* that let you display numbers, strings, and time and date in virtually any format you like. It operates in a manner similar to the C/C++ `printf()` function, which means that if you are familiar with C/C++, then learning to use **Formatter** will be very easy. It also further streamlines the conversion of C/C++ code to Java. If you are not familiar with C/C++, it is still quite easy to format data.

**Formatter**

```java
class CurDemo {
    public static void main(String args[]) {
        Currency c;

        c = Currency.getInstance(Locale.US);

        System.out.println("Symbol: " + c.getSymbol());
        System.out.println("Default fractional digits: " + c.getDefaultFractionDigits());
    }
}
```

The output is shown here:

```
Symbol: $
Default fractional digits: 2
```
NOTE Although Java’s `Formatter` class operates in a manner very similar to the C/C++ `printf()` function, there are some differences, and some new features. Therefore, if you have a C/C++ background, a careful reading is advised.

The `Formatter` Constructors
Before you can use `Formatter` to format output, you must create a `Formatter` object. In general, `Formatter` works by converting the binary form of data used by a program into formatted text. It stores the formatted text in a buffer, the contents of which can be obtained by your program whenever they are needed. It is possible to let `Formatter` supply this buffer automatically, or you can specify the buffer explicitly when a `Formatter` object is created. It is also possible to have `Formatter` output its buffer to a file.

The `Formatter` class defines many constructors, which enable you to construct a `Formatter` in a variety of ways. Here is a sampling:

```java
Formatter( )
Formatter(Appendable buf)
Formatter(Appendable buf, Locale loc)
Formatter(String filename)
    throws FileNotFoundException
Formatter(String filename, String charset)
    throws FileNotFoundException, UnsupportedEncodingException
Formatter(File outF)
    throws FileNotFoundException
Formatter(OutputStream outStrm)
```

Here, `buf` specifies a buffer for the formatted output. If `buf` is null, then `Formatter` automatically allocates a `StringBuilder` to hold the formatted output. The `loc` parameter specifies a locale. If no locale is specified, the default locale is used. The `filename` parameter specifies the name of a file that will receive the formatted output. The `charset` parameter specifies the character set. If no character set is specified, then the default character set is used. The `outF` parameter specifies a reference to an open file that will receive output. The `outStrm` parameter specifies a reference to an output stream that will receive output. When using a file, output is also written to the file.
Perhaps the most widely used constructor is the first, which has no parameters. It automatically uses the default locale and allocates a **StringBuilder** to hold the formatted output.

**The Formatter Methods**

*Formatter* defines the methods shown in Table 19-12.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>close()</td>
<td>Closes the invoking <em>Formatter</em>. This causes any resources used by the object to be released. After a <em>Formatter</em> has been closed, it cannot be reused. An attempt to use a closed <em>Formatter</em> results in a <em>FormatterClosedException</em>.</td>
</tr>
<tr>
<td>flush()</td>
<td>Flushes the format buffer. This causes any output currently in the buffer to be written to the destination. This applies mostly to a <em>Formatter</em> tied to a file.</td>
</tr>
<tr>
<td>format(String fmtString, Object ... args)</td>
<td>Formats the arguments passed via args according to the format specifiers contained in fmtString. Returns the invoking object.</td>
</tr>
<tr>
<td>format(Locale loc, String fmtString, Object ... args)</td>
<td>Formats the arguments passed via args according to the format specifiers contained in fmtString. The locale-specified by loc is used for this format. Returns the invoking object.</td>
</tr>
<tr>
<td>IOException IOException()</td>
<td>If the underlying object that is the destination for output throws an IOException, then this exception is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>locale()</td>
<td>Returns the invoking object’s locale.</td>
</tr>
<tr>
<td>appendable out()</td>
<td>Returns a reference to the underlying object that is the destination for output.</td>
</tr>
<tr>
<td>toString()</td>
<td>Returns a <em>String</em> containing the formatted output.</td>
</tr>
</tbody>
</table>

**Table 19-12** The Methods Defined by *Formatter*

**Formatting Basics**

After you have created a *Formatter*, you can use it to create a formatted string. To do so, use the `format()` method. The most commonly used version is shown here:

```
Formatter format(String fmtString, Object ... args)
```

The `fmtString` consists of two types of items. The first type is composed of characters that are simply copied to the output buffer. The second type contains *format specifiers* that define the way the subsequent arguments are displayed. In its simplest form, a format specifier begins with a percent sign followed by the format *conversion specifier*. All format conversion specifiers consist of a single character. For example, the format specifier for floating-point data is `%f`. In general, there must be the same number of arguments as there are format specifiers, and the format specifiers and the arguments are matched in order from left to right. For example, consider this fragment:

```
Formatter fmt = new Formatter();
fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);
```

This sequence creates a *Formatter* that contains the following string:
In this example, the format specifiers, %s, %d, and %f, are replaced with the arguments that follow the format string. Thus, %s is replaced by “with Java”, %d is replaced by 10, and %f is replaced by 98.6. All other characters are simply used as-is. As you might guess, the format specifier %s specifies a string, and %d specifies an integer value. As mentioned earlier, the %f specifies a floating-point value.

The `format()` method accepts a wide variety of format specifiers, which are shown in Table 19-13. Notice that many specifiers have both upper- and lowercase forms. When an uppercase specifier is used, then letters are shown in uppercase. Otherwise, the upper- and lowercase specifiers perform the same conversion. It is important to understand that Java type-checks each format specifier against its corresponding argument. If the argument doesn’t match, an `IllegalFormatException` is thrown.

<table>
<thead>
<tr>
<th>Format Specifier</th>
<th>Conversion Applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>%a</td>
<td>Floating-point, hexadecimal</td>
</tr>
<tr>
<td>%A</td>
<td></td>
</tr>
<tr>
<td>%b</td>
<td>Boolean</td>
</tr>
<tr>
<td>%h</td>
<td>Character</td>
</tr>
<tr>
<td>%d</td>
<td>Decimal integer</td>
</tr>
<tr>
<td>%h</td>
<td>Hash code of the argument</td>
</tr>
<tr>
<td>%I</td>
<td>Scientific notation</td>
</tr>
<tr>
<td>%E</td>
<td>Decimal floating-point</td>
</tr>
<tr>
<td>%F</td>
<td>Use %e or %f, based on the value being formatted and the precision.</td>
</tr>
<tr>
<td>%o</td>
<td>Octal integer</td>
</tr>
<tr>
<td>%x</td>
<td>Inserts a newline character</td>
</tr>
<tr>
<td>%s</td>
<td>String</td>
</tr>
<tr>
<td>%S</td>
<td></td>
</tr>
<tr>
<td>%t</td>
<td>Time and date</td>
</tr>
<tr>
<td>%T</td>
<td>Integer hexadecimal</td>
</tr>
<tr>
<td>%X</td>
<td></td>
</tr>
<tr>
<td>%%</td>
<td>Inserts a % sign</td>
</tr>
</tbody>
</table>

Table 19-13 The Format Specifiers

Once you have formatted a string, you can obtain it by calling `toString()`. For example, continuing with the preceding example, the following statement obtains the formatted string contained in `fmt`:

```java
String str = fmt.toString();
```
Of course, if you simply want to display the formatted string, there is no reason to first assign it to a `String` object. When a `Formatter` object is passed to `println()`, for example, its `toString()` method is automatically called.

Here is a short program that puts together all of the pieces, showing how to create and display a formatted string:

```java
// A very simple example that uses Formatter.
import java.util.*;

class FormatDemo {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();
        fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);
        System.out.println(fmt);
        fmt.close();
    }
}
```

One other point: You can obtain a reference to the underlying output buffer by calling `out()`. It returns a reference to an `Appendable` object.

Now that you know the general mechanism used to create a formatted string, the remainder of this section discusses in detail each conversion. It also describes various options, such as justification, minimum field width, and precision.

**Formatting Strings and Characters**
To format an individual character, use `%c`. This causes the matching character argument to be output, unmodified. To format a string, use `%s`.

**Formatting Numbers**
To format an integer in decimal format, use `%d`. To format a floating-point value in decimal format, use `%f`. To format a floating-point value in scientific notation, use `%e`. Numbers represented in scientific notation take this general form:

```
x.ddddde+/–yy
```

The `%g` format specifier causes `Formatter` to use either `%f` or `%e`, based on the value being formatted and the precision, which is 6 by default. The following program demonstrates the effect of the `%f` and `%e` format specifiers:
You can display integers in octal or hexadecimal format by using %o and %x, respectively. For example, this fragment:

```java
fmt.format("Hex: %x, Octal: %o", 196, 196);
```

produces this output:

```
Hex: c4, Octal: 304
```

You can display floating-point values in hexadecimal format by using %a. The format produced by %a appears a bit strange at first glance. This is because its representation uses a form similar to scientific notation that consists of a hexadecimal significand and a decimal exponent of powers of 2. Here is the general format:

```
0x1.sigexp
```

Here, `sig` contains the fractional portion of the significand and `exp` contains the exponent. The `p` indicates the start of the exponent. For example, this call:

```java
fmt.format("%a", 512.0);
```

produces this output:

```
0x1.0p9
```
Formatting Time and Date

One of the more powerful conversion specifiers is \%t. It lets you format time and date information. The \%t specifier works a bit differently than the others because it requires the use of a suffix to describe the portion and precise format of the time or date desired. The suffixes are shown in Table 19-14. For example, to display minutes, you would use \%tM, where M indicates minutes in a two-character field. The argument corresponding to the \%t specifier must be of type Calendar, Date, Long, or long.

Here is a program that demonstrates several of the formats:

```java
// Formatting time and date.
import java.util.*;

class TimeDateFormat {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();
        Calendar cal = Calendar.getInstance();

        // Display standard 12-hour time format.
        fmt.format("%tr", cal);
        System.out.println(fmt);
        fmt.close();

        // Display complete time and date information.
        fmt = new Formatter();
        fmt.format("%tc", cal);
        System.out.println(fmt);
        fmt.close();

        // Display just hour and minute.
        fmt = new Formatter();
        fmt.format("%tl:%tM", cal, cal);
        System.out.println(fmt);
        fmt.close();

        // Display month by name and number.
        fmt = new Formatter();
        fmt.format("%tB %tb %tm", cal, cal, cal);
        System.out.println(fmt);
        fmt.close();
    }
}
```
Table 19-14  The Time and Date Format Suffixes

<table>
<thead>
<tr>
<th>Suffix</th>
<th>Replaced By</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>Abbreviated weekday name</td>
</tr>
<tr>
<td>A</td>
<td>Full weekday name</td>
</tr>
<tr>
<td>b</td>
<td>Abbreviated month name</td>
</tr>
<tr>
<td>B</td>
<td>Full month name</td>
</tr>
<tr>
<td>c</td>
<td>Standard date and time string formatted as day month date hour:minutes year</td>
</tr>
<tr>
<td>C</td>
<td>First two digits of year</td>
</tr>
<tr>
<td>d</td>
<td>Day of month as a decimal (01—31)</td>
</tr>
<tr>
<td>D</td>
<td>Month/day/year</td>
</tr>
<tr>
<td>e</td>
<td>Day of month as a decimal (1—31)</td>
</tr>
<tr>
<td>F</td>
<td>Year/month/day</td>
</tr>
<tr>
<td>h</td>
<td>Abbreviated month name</td>
</tr>
<tr>
<td>H</td>
<td>Hour (00 to 23)</td>
</tr>
<tr>
<td>I</td>
<td>Hour (01 to 12)</td>
</tr>
<tr>
<td>j</td>
<td>Day of year as a decimal (001 to 366)</td>
</tr>
<tr>
<td>k</td>
<td>Hour (0 to 23)</td>
</tr>
<tr>
<td>l</td>
<td>Hour (1 to 12)</td>
</tr>
<tr>
<td>L</td>
<td>Millisecond (000 to 999)</td>
</tr>
<tr>
<td>m</td>
<td>Month as decimal (01 to 13)</td>
</tr>
<tr>
<td>M</td>
<td>Minute as decimal (00 to 59)</td>
</tr>
<tr>
<td>N</td>
<td>Nanosecond (000000000 to 999999999)</td>
</tr>
<tr>
<td>p</td>
<td>Locale’s equivalent of AM or PM in lowercase</td>
</tr>
<tr>
<td>Q</td>
<td>Milliseconds from 1/1/1970</td>
</tr>
<tr>
<td>r</td>
<td>12-hour (12-hour format)</td>
</tr>
<tr>
<td>R</td>
<td>24-hour (24-hour format)</td>
</tr>
<tr>
<td>S</td>
<td>Seconds (00 to 60)</td>
</tr>
<tr>
<td>s</td>
<td>Seconds from 1/1/1970 UTC</td>
</tr>
<tr>
<td>T</td>
<td>24-hour (24-hour format)</td>
</tr>
<tr>
<td>y</td>
<td>Year in decimal without century (00 to 99)</td>
</tr>
<tr>
<td>Y</td>
<td>Year in decimal including century (0001 to 9999)</td>
</tr>
<tr>
<td>z</td>
<td>Offset from UTC</td>
</tr>
<tr>
<td>Z</td>
<td>Time zone name</td>
</tr>
</tbody>
</table>

Sample output is shown here:

03:15:34 PM
Wed Jan 01 15:15:34 CST 2014
3:15
January Jan 01

**The %n and %% Specifiers**
The %n and%% format specifiers differ from the others in that they do not match an argument. Instead, they are simply escape sequences that insert a character into the output sequence. The %n inserts a newline. The %% inserts a percent sign. Neither of these
characters can be entered directly into the format string. Of course, you can also use the standard escape sequence \n to embed a newline character.

Here is an example that demonstrates the %n and %p format specifiers:

```java
// Demonstrate the %n and %p format specifiers.
import java.util.*;

class FormatDemo3 {
    public static void main(String[] args) {
        Formatter fmt = new Formatter();

        fmt.format("Copying file\nTransfer is %p complete", 88);
        System.out.println(fmt);
        fmt.close();
    }
}
```

It displays the following output:

```
Copying file
Transfer is 88% complete
```

**Specifying a Minimum Field Width**

An integer placed between the % sign and the format conversion code acts as a minimum field-width specifier. This pads the output with spaces to ensure that it reaches a certain minimum length. If the string or number is longer than that minimum, it will still be printed in full. The default padding is done with spaces. If you want to pad with 0's, place a 0 before the field-width specifier. For example, %05d will pad a number of less than five digits with 0's so that its total length is five. The field-width specifier can be used with all format specifiers except %n.

The following program demonstrates the minimum field-width specifier by applying it to the %f conversion:
This program produces the following output:

| 10.123450 |
| 10.123450 |
| 00010.123450 |

The first line displays the number 10.12345 in its default width. The second line displays that value in a 12-character field. The third line displays the value in a 12-character field, padded with leading zeros.

The minimum field-width modifier is often used to produce tables in which the columns line up. For example, the next program produces a table of squares and cubes for the numbers between 1 and 10:
Specifying Precision

A *precision specifier* can be applied to the %f, %e, %g, and %s format specifiers. It follows the minimum field-width specifier (if there is one) and consists of a period followed by an integer. Its exact meaning depends upon the type of data to which it is applied.

When you apply the precision specifier to floating-point data using the %f or %e specifiers, it determines the number of decimal places displayed. For example, %10.4f displays a number at least ten characters wide with four decimal places. When using %g, the precision determines the number of significant digits. The default precision is 6.

Applied to strings, the precision specifier specifies the maximum field length. For example, %5.7s displays a string of at least five and not exceeding seven characters long. If the string is longer than the maximum field width, the end characters will be truncated.

The following program illustrates the precision specifier:

```
1   1   1
2   4   8
3   9  27
4  16  64
5  25 125
6  36 216
7  49 343
8  64 512
9  81 729
10 100 1000
```
It produces the following output:

```
123.1235
1.23e+02
Formatting with
```

**Using the Format Flags**

Formatter recognizes a set of format flags that lets you control various aspects of a conversion. All format flags are single characters, and a format flag follows the % in a format specification. The flags are shown here:

<table>
<thead>
<tr>
<th>Flag</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>–</td>
<td>Left justification</td>
</tr>
<tr>
<td>#</td>
<td>Alternate conversion format</td>
</tr>
<tr>
<td>0</td>
<td>Output is padded with zeros rather than spaces</td>
</tr>
<tr>
<td>space</td>
<td>Positive numeric output is preceded by a space</td>
</tr>
<tr>
<td>+</td>
<td>Positive numeric output is preceded by a + sign</td>
</tr>
<tr>
<td>----</td>
<td>---------------------------------------------</td>
</tr>
<tr>
<td>,</td>
<td>Numeric values include grouping separators</td>
</tr>
<tr>
<td>(</td>
<td>Negative numeric values are enclosed within parentheses</td>
</tr>
</tbody>
</table>

Not all flags apply to all format specifiers. The following sections explain each in detail.

**Justifying Output**

By default, all output is right-justified. That is, if the field width is larger than the data printed, the data will be placed on the right edge of the field. You can force output to be left-justified by placing a minus sign directly after the %. For instance, `%–10.2f` left-justifies a floating-point number with two decimal places in a 10-character field. For example, consider this program:

```java
// Demonstrate left justification.
import java.util.*;

class LeftJustify {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        // Right justify by default
        fmt.format("%10.2f", 123.123);
        System.out.println(fmt);
        fmt.close();

        // Now, left justify.
        fmt = new Formatter();
        fmt.format("%–10.2f", 123.123);
        System.out.println(fmt);
        fmt.close();
    }
}
```

It produces the following output:

```
   123.12
  123.12
```

As you can see, the second line is left-justified within a 10-character field.

**The Space, +, 0, and ( Flags**

To cause a + sign to be shown before positive numeric values, add the + flag. For example,
When creating columns of numbers, it is sometimes useful to output a space before positive values so that positive and negative values line up. To do this, add the space flag. For example,

```java
// Demonstrate the space format specifiers.
import java.util.*;

class FormatDemo5 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();

        fmt.format("%+d", 100);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("%+d", -100);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("%+d", 100);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("%+d", -200);
        System.out.println(fmt);
        fmt.close();

        fmt = new Formatter();
        fmt.format("%+d", 200);
        System.out.println(fmt);
        fmt.close();
    }
}
```

The output is shown here:

```
+100
-100
+100
-200
+200
```
Notice that the positive values have a leading space, which causes the digits in the column to line up properly.

To show negative numeric output inside parentheses, rather than with a leading -, use the ( flag. For example,

```python
fmt.format("%(d", -100);
```

creates this string:

```
(-100)
```

The o flag causes output to be padded with zeros rather than spaces.

**The Comma Flag**

When displaying large numbers, it is often useful to add grouping separators, which in English are commas. For example, the value 1234567 is more easily read when formatted as 1,234,567. To add grouping specifiers, use the comma (,) flag. For example,

```python
fmt.format("%,.2f", 4356783497.34);
```

creates this string:

```
4,356,783,497.34
```

**The # Flag**

The # can be applied to %o, %x, %e, and %f. For %e and %f, the # ensures that there will be a decimal point even if there are no decimal digits. If you precede the %x format specifier with a #, the hexadecimal number will be printed with a 0x prefix. Preceding the %o specifier with # causes the number to be printed with a leading zero.

**The Uppercase Option**

As mentioned earlier, several of the format specifiers have uppercase versions that cause the conversion to use uppercase where appropriate. The following table describes the effect.

<table>
<thead>
<tr>
<th>Specifier</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>%A</td>
<td>Causes the hexadecimal digits a through f to be displayed in uppercase as A through F. Also, the prefix ox is displayed as 0X, and the p will be displayed as P.</td>
</tr>
<tr>
<td>%B</td>
<td>Uppercases the values true and false.</td>
</tr>
<tr>
<td>%E</td>
<td>Causes the e symbol that indicates the exponent to be displayed in uppercase.</td>
</tr>
</tbody>
</table>
%G  Causes the e symbol that indicates the exponent to be displayed in uppercase.

%H  Causes the hexadecimal digits a through f to be displayed in uppercase as A through F.

%S  Uppercases the corresponding string.

%T  Causes all alphabetical output to be displayed in uppercase.

%X  Causes the hexadecimal digits a through f to be displayed in uppercase as A through F. Also, the optional prefix ox is displayed as oX, if present.

For example, this call:

```python
fmt.format("%X", 250);
```

creates this string:

```
FA
```

This call:

```python
fmt.format("%E", 123.1234);
```

creates this string:

```
1.231234e+02
```

**Using an Argument Index**

Formatter includes a very useful feature that lets you specify the argument to which a format specifier applies. Normally, format specifiers and arguments are matched in order, from left to right. That is, the first format specifier matches the first argument, the second format specifier matches the second argument, and so on. However, by using an argument index, you can explicitly control which argument a format specifier matches. An argument index immediately follows the % in a format specifier. It has the following format:

```
n$
```

where n is the index of the desired argument, beginning with 1. For example, consider this example:
In this example, the first format specifier matches 30, the second matches 10, and the third matches 20. Thus, the arguments are used in an order other than strictly left to right. One advantage of argument indexes is that they enable you to reuse an argument without having to specify it twice. For example, consider this line:

```java
fmt.format("%3$d %1$d %2$d", 10, 20, 30);
```

It produces this string:

```
30 10 20
```

In this example, the first format specifier matches 30, the second matches 10, and the third matches 20. Thus, the arguments are used in an order other than strictly left to right. One advantage of argument indexes is that they enable you to reuse an argument without having to specify it twice. For example, consider this line:

```java
fmt.format("%d in hex is %1$x", 255);
```

It produces the following string:

```
255 in hex is ff
```

As you can see, the argument 255 is used by both format specifiers. There is a convenient shorthand called a relative index that enables you to reuse the argument matched by the preceding format specifier. Simply specify `<` for the argument index. For example, the following call to `format()` produces the same results as the previous example:

```java
fmt.format("%d in hex is %<x", 255);
```

Relative indexes are especially useful when creating custom time and date formats. Consider the following example:

```java
// Use relative indexes to simplify the
// creation of a custom time and date format.
import java.util.*;

class FormatDemo6 {
    public static void main(String args[]) {
        Formatter fmt = new Formatter();
        Calendar cal = Calendar.getInstance();

        fmt.format("Today is day %te of %tB, %tY", cal);
        System.out.println(fmt);
        fmt.close();
    }
}
```

Here is sample output:
Because of relative indexing, the argument `cal` need only be passed once, rather than three times.

**Closing a Formatter**

In general, you should close a `Formatter` when you are done using it. Doing so frees any resources that it was using. This is especially important when formatting to a file, but it can be important in other cases, too. As the previous examples have shown, one way to close a `Formatter` is to explicitly call `close()`. However, beginning with JDK 7, `Formatter` implements the `AutoCloseable` interface. This means that it supports the `try`-with-resources statement. Using this approach, the `Formatter` is automatically closed when it is no longer needed.

The `try`-with-resources statement is described in Chapter 13, in connection with files, because files are some of the most commonly used resources that must be closed. However, the same basic techniques apply here. For example, here is the first `Formatter` example reworked to use automatic resource management:

```java
// Use automatic resource management with Formatter.
import java.util.*;

class FormatDemo {
    public static void main(String args[]) {
        try (Formatter fmt = new Formatter()) {
            fmt.format("Formatting %s is easy %d %f", "with Java", 10, 98.6);
            System.out.println(fmt);
        }
    }
}
```

The output is the same as before.

**The Java printf( ) Connection**

Although there is nothing technically wrong with using `Formatter` directly (as the preceding examples have done) when creating output that will be displayed on the console, there is a more convenient alternative: the `printf()` method. The `printf()` method automatically uses `Formatter` to create a formatted string. It then displays that string on `System.out`, which is the console by default. The `printf()` method is defined by both `PrintStream` and `PrintWriter`. The `printf()` method is described in Chapter 20.
Scanner

Scanner is the complement of Formatter. It reads formatted input and converts it into its binary form. Scanner can be used to read input from the console, a file, a string, or any source that implements the Readable interface or ReadableByteChannel. For example, you can use Scanner to read a number from the keyboard and assign its value to a variable. As you will see, given its power, Scanner is surprisingly easy to use.

The Scanner Constructors

Scanner defines the constructors shown in Table 19-15. In general, a Scanner can be created for a String, an InputStream, a File, or any object that implements the Readable or ReadableByteChannel interfaces. Here are some examples.

The following sequence creates a Scanner that reads the file Test.txt:

```java
FileReader fin = new FileReader("Test.txt");
Scanner src = new Scanner(fin);
```

This works because FileReader implements the Readable interface. Thus, the call to the constructor resolves to Scanner(Readable).

This next line creates a Scanner that reads from standard input, which is the keyboard by default:

```java
Scanner cinin = new Scanner(System.in);
```

This works because System.in is an object of type InputStream. Thus, the call to the constructor maps to Scanner(InputStream).

The next sequence creates a Scanner that reads from a string.

```java
String instr = "10 99.88 scanning is easy."
Scanner conin = new Scanner(instr);
```

Scanning Basics

Once you have created a Scanner, it is a simple matter to use it to read formatted input. In general, a Scanner reads tokens from the underlying source that you specified when the Scanner was created. As it relates to Scanner, a token is a portion of input that is delineated by a set of delimiters, which is whitespace by default. A token is read by matching it with a particular regular expression, which defines the format of the data. Although Scanner allows you to define the specific type of expression that its next input operation will match, it includes many predefined patterns, which match the primitive types, such as int and double, and strings. Thus, often you won’t need to specify a pattern to match.
In general, to use `Scanner`, follow this procedure:

1. Determine if a specific type of input is available by calling one of `Scanner`'s `hasNextX` methods, where `X` is the type of data desired.
2. If input is available, read it by calling one of `Scanner`'s `nextX` methods.
3. Repeat the process until input is exhausted.
4. Close the `Scanner` by calling `close()`.

As the preceding indicates, `Scanner` defines two sets of methods that enable you to read input. The first are the `hasNextX` methods, which are shown in Table 19-16. These methods determine if the specified type of input is available. For example, calling `hasNextInt()` returns `true` only if the next token to be read is an integer. If the desired data is available, then you read it by calling one of `Scanner`'s `nextX` methods, which are shown in Table 19-17.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>hasNext()</td>
<td>Returns true if another token of any type is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Pattern pattern)</td>
<td>Returns true if a token that matches the pattern passed in <code>pattern</code> is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(String pattern)</td>
<td>Returns true if a token that matches the pattern passed in <code>pattern</code> is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(BigDecimal)</td>
<td>Returns true if a value that can be stored in a <code>BigDecimal</code> object is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(BigInteger)</td>
<td>Returns true if a value that can be stored in a <code>BigInteger</code> object is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>hasNext(BigInteger radix)</td>
<td>Returns true if a value in the specified radix that can be stored in a <code>BigInteger</code> object is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Boolean)</td>
<td>Returns true if a boolean value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Byte)</td>
<td>Returns true if a byte value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>hasNext(Short)</td>
<td>Returns true if a boolean value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>hasNext(Doubles)</td>
<td>Returns true if a double value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Floats)</td>
<td>Returns true if a float value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Chars)</td>
<td>Returns true if a char value is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Longs)</td>
<td>Returns true if a long value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>hasNext(Longs radix)</td>
<td>Returns true if a long value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
<tr>
<td>hasNext(Shorts)</td>
<td>Returns true if a short value is available to be read. Returns false otherwise. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>hasNext(Shorts radix)</td>
<td>Returns true if a short value in the specified radix is available to be read. Returns false otherwise.</td>
</tr>
</tbody>
</table>

**Table 19-16** The Scanner `hasNext` Methods
Table 19-17  The Scanner next Methods

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String next( )</td>
<td>Returns the next token of any type from the input source.</td>
</tr>
<tr>
<td>String next(Pattern pattern)</td>
<td>Returns the next token that matches the pattern passed in pattern from the input source.</td>
</tr>
<tr>
<td>String next(String pattern)</td>
<td>Returns the next token that matches the pattern passed in pattern from the input source.</td>
</tr>
<tr>
<td>BigDecimal nextBigDecimal( )</td>
<td>Returns the next token as a BigDecimal object.</td>
</tr>
<tr>
<td>BigInteger nextBigInteger( )</td>
<td>Returns the next token as a BigInteger object. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>BigInteger nextBigInteger(int radix)</td>
<td>Returns the next token (using the specified radix) as a BigInteger object.</td>
</tr>
<tr>
<td>boolean nextBoolean( )</td>
<td>Returns the next token as a boolean value.</td>
</tr>
<tr>
<td>byte nextByte( )</td>
<td>Returns the next token as a byte value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>byte nextByte(int radix)</td>
<td>Returns the next token (using the specified radix) as a byte value.</td>
</tr>
<tr>
<td>double nextDouble( )</td>
<td>Returns the next token as a double value.</td>
</tr>
<tr>
<td>float nextFloat( )</td>
<td>Returns the next token as a float value.</td>
</tr>
<tr>
<td>int nextInt( )</td>
<td>Returns the next token as an int value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>int nextInt(int radix)</td>
<td>Returns the next token (using the specified radix) as an int value.</td>
</tr>
<tr>
<td>String nextLine( )</td>
<td>Returns the next line of input as a string.</td>
</tr>
<tr>
<td>long nextLong( )</td>
<td>Returns the next token as a long value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>long nextLong(int radix)</td>
<td>Returns the next token (using the specified radix) as a long value.</td>
</tr>
<tr>
<td>short nextShort( )</td>
<td>Returns the next token as a short value. The default radix is used. (Unless changed, the default radix is 10.)</td>
</tr>
<tr>
<td>short nextShort(int radix)</td>
<td>Returns the next token (using the specified radix) as a short value.</td>
</tr>
</tbody>
</table>

For example, to read the next integer, call `nextInt()`. The following sequence shows how to read a list of integers from the keyboard.

```java
Scanner cinin = new Scanner(System.in);
int i;

// Read a list of integers.
while(cinin.hasNextInt()) {
    i = cinin.nextInt();
    // ...
}
```

The `while` loop stops as soon as the next token is not an integer. Thus, the loop stops reading integers as soon as a non-integer is encountered in the input stream. If a `next` method cannot find the type of data it is looking for, it throws an
**InputMismatchException.** A `NoSuchElementException` is thrown if no more input is available. For this reason, it is best to first confirm that the desired type of data is available by calling a `hasNext` method before calling its corresponding `next` method.

**Some Scanner Examples**

`Scanner` makes what could be a tedious task into an easy one. To understand why, let’s look at some examples. The following program averages a list of numbers entered at the keyboard:

```java
// Use Scanner to compute an average of the values.
import java.util.*;

class AvgNums {
    public static void main(String args[]) {
        Scanner cin = new Scanner(System.in);

        int count = 0;
        double sum = 0.0;

        System.out.println("Enter numbers to average.");

        // Read and sum numbers.
        while(cin.hasNext()) {
            if(cin.hasNextDouble()) {
                sum += cin.nextDouble();
                count++;
            } else {
                String str = cin.next();
                if(str.equals("done")) break;
                else {
                    System.out.println("Data format error.");
                    return;
                }
            }
        }

        cin.close();
        System.out.println("Average is " + sum / count);
    }
}
```

The program reads numbers from the keyboard, summing them in the process, until the user enters the string "done". It then stops input and displays the average of the numbers. Here is a sample run:
The program reads numbers until it encounters a token that does not represent a valid `double` value. When this occurs, it confirms that the token is the string "done". If it is, the program terminates normally. Otherwise, it displays an error.

Notice that the numbers are read by calling `nextDouble()`.

This method reads any number that can be converted into a `double` value, including an integer value, such as 2, and a floating-point value like 3.4. Thus, a number read by `nextDouble()` need not specify a decimal point. This same general principle applies to all `next` methods. They will match and read any data format that can represent the type of value being requested.

One thing that is especially nice about `Scanner` is that the same technique used to read from one source can be used to read from another. For example, here is the preceding program reworked to average a list of numbers contained in a text file:
Here is the output:

```
Average is 6.2
```

The preceding program illustrates another important feature of `Scanner`. Notice that the file reader referred to by `fin` is not closed directly. Rather, it is closed automatically when `src` calls `close()`. When you close a `Scanner`, the `Readable` associated with it is also closed (if that `Readable` implements the `Closeable` interface). Therefore, in this case, the
Beginning with JDK 7, **Scanner** also implements the **AutoCloseable** interface. This means that it can be managed by a **try**-with-resources block. As explained in Chapter 13, when **try**-with-resources is used, the scanner is automatically closed when the block ends.

For example, **src** in the preceding program could have been managed like this:

```java
try (Scanner src = new Scanner(fin)) {
    // Read and sum numbers.
    while(src.hasNext()) {
        if(src.hasNextDouble()) {
            sum += src.nextDouble();
            count++;
        } else {
            String str = src.next();
            if(str.equals("done")) break;
            else {
                System.out.println("File format error.");
                return;
            }
        }
    }
}
```

To clearly demonstrate the closing of a **Scanner**, the following examples will call **close()** explicitly. (Doing so also allows them to be compiled by versions of Java prior to JDK 7.) However, the **try**-with-resources approach is more streamlined and can help prevent errors. Its use is recommended for new code.

One other point: To keep this and the other examples in this section compact, I/O exceptions are simply thrown out of **main()**. However, your real-world code will normally handle I/O exceptions itself.

You can use **Scanner** to read input that contains several different types of data—even if the order of that data is unknown in advance. You must simply check what type of data is available before reading it. For example, consider this program:
import java.util.*;
import java.io.*;

class ScanMixed {
    public static void main(String args[])
        throws IOException {
        int i;
        double d;
        boolean b;
        String str;

        // Write output to a file.
        FileWriter fout = new FileWriter("test.txt");
        fout.write("Testing Scanner 10 11.2 one true two false");
        fout.close();

        FileReader fin = new FileReader("Test.txt");

        Scanner src = new Scanner(fin);

        // Read to end.
        while(src.hasNext()) {
            if(src.hasNextInt()) {
                i = src.nextInt();
                System.out.println("int: " + i);
            }
            else if(src.hasNextDouble()) {
                d = src.nextDouble();
                System.out.println("double: " + d);
            }
            else if(src.hasNextBoolean()) {
                b = src.nextBoolean();
                System.out.println("boolean: " + b);
            }
            else {
                str = src.next();
                System.out.println("String: " + str);
            }
        }

        src.close();
    }
}
When reading mixed data types, as the preceding program does, you need to be a bit careful about the order in which you call the `next` methods. For example, if the loop reversed the order of the calls to `nextInt( )` and `nextDouble( )`, both numeric values would have been read as doubles, because `nextDouble( )` matches any numeric string that can be represented as a `double`.

**Setting Delimiters**

`Scanner` defines where a token starts and ends based on a set of delimiters. The default delimiters are the whitespace characters, and this is the delimiter set that the preceding examples have used. However, it is possible to change the delimiters by calling the `useDelimiter( )` method, shown here:

```java
Scanner useDelimiter(String pattern)
Scanner useDelimiter(Pattern pattern)
```

Here, `pattern` is a regular expression that specifies the delimiter set.

Here is the program that reworks the average program shown earlier so that it reads a list of numbers that are separated by commas, and any number of spaces:
In this version, the numbers written to *test.txt* are separated by commas and spaces. The use of the delimiter pattern ", * " tells *Scanner* to match a comma and zero or more spaces as delimiters. The output is the same as before.
You can obtain the current delimiter pattern by calling *delimiter( )*, shown here:
Other Scanner Features

Scanner defines several other methods in addition to those already discussed. One that is particularly useful in some circumstances is `findInLine()`. Its general forms are shown here:

```java
String findInLine(Pattern pattern)
String findInLine(String pattern)
```

This method searches for the specified pattern within the next line of text. If the pattern is found, the matching token is consumed and returned. Otherwise, null is returned. It operates independently of any delimiter set. This method is useful if you want to locate a specific pattern. For example, the following program locates the Age field in the input string and then displays the age:

```java
// Demonstrate findInLine().
import java.util.*;

class FindInLineDemo {
    public static void main(String args[]) {
        String instr = "Name: Tom Age: 28 ID: 77";
        Scanner conin = new Scanner(instr);

        // Find and display age.
        conin.findInLine("Age: "); // find Age

        if (conin.hasNext())
            System.out.println(conin.next());
        else
            System.out.println("Error!");

        conin.close();
    }
}
```

The output is 28. In the program, `findInLine()` is used to find an occurrence of the pattern "Age". Once found, the next token is read, which is the age.

Related to `findInLine()` is `findWithinHorizon()`. It is shown here:

```java
String findWithinHorizon(Pattern pattern, int count)
String findWithinHorizon(String pattern, int count)
```

This method attempts to find an occurrence of the specified pattern within the next `count` characters. If successful, it returns the matching pattern. Otherwise, it
returns \texttt{null}. If \textit{count} is zero, then all input is searched until either a match is found or the end of input is encountered.

You can bypass a pattern using \texttt{skip()}, shown here:

\begin{verbatim}
Scanner skip(Pattern pattern)

Scanner skip(String pattern)
\end{verbatim}

If \textit{pattern} is matched, \texttt{skip()} simply advances beyond it and returns a reference to the invoking object. If pattern is not found, \texttt{skip()} throws \texttt{NoSuchElementException}.

Other \texttt{Scanner} methods include \texttt{radix()}, which returns the default radix used by the \texttt{Scanner}; \texttt{useRadix()}, which sets the radix; \texttt{reset()}, which resets the scanner; and \texttt{close()}, which closes the scanner.

\textbf{The ResourceBundle, ListResourceBundle, and PropertyResourceBundle Classes}

The \texttt{java.util} package includes three classes that aid in the internationalization of your program. The first is the abstract class \texttt{ResourceBundle}. It defines methods that enable you to manage a collection of locale-sensitive resources, such as the strings that are used to label the user interface elements in your program. You can define two or more sets of translated strings that support various languages, such as English, German, or Chinese, with each translation set residing in its own bundle. You can then load the bundle appropriate to the current locale and use the strings to construct the program's user interface.

Resource bundles are identified by their \textit{family name} (also called their \textit{base name}). To the \textit{family name} can be added a two-character lowercase \textit{language code} which specifies the language. In this case, if a requested locale matches the language code, then that version of the resource bundle is used. For example, a resource bundle with a family name of \texttt{SampleRB} could have a German version called \texttt{SampleRB_de} and a Russian version called \texttt{SampleRB_ru}. (Notice that an underscore links the family name to the language code.) Therefore, if the locale is \texttt{Locale.GERMAN}, \texttt{SampleRB_de} will be used.

It is also possible to indicate specific variants of a language that relate to a specific country by specifying a \textit{country code} after the language code. A \textit{country code} is a two-character uppercase identifier, such as \texttt{AU} for Australia or \texttt{IN} for India. A \textit{country code} is also preceded by an underscore when linked to the resource bundle name. A resource bundle that has only the family name is the default bundle. It is used when no language-specific bundles are applicable.

\begin{quote}
\textbf{NOTE} The language codes are defined by ISO standard 639 and the country codes by ISO standard 3166.
\end{quote}
The methods defined by `ResourceBundle` are summarized in Table 19-18. One important point: **null** keys are not allowed and several of the methods will throw a `NullPointerException` if **null** is passed as the key. Notice the nested class `ResourceBundle.Control`. It is used to control the resource-bundle loading process.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static final void clearCache( )</td>
<td>Deletes all resource bundles from the cache that were loaded by the default class loader.</td>
</tr>
<tr>
<td>static final void clearCache(ClassLoader cl)</td>
<td>Deletes all resource bundles from the cache that were loaded by <code>cl</code>.</td>
</tr>
<tr>
<td>boolean containsKey(String k)</td>
<td>Returns true if <code>k</code> is a key within the invoking resource bundle (or its parent).</td>
</tr>
<tr>
<td>String getBaseBundleName( )</td>
<td>Returns the resource bundle’s base name if available. Returns null otherwise. (Added by JDK 8.)</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String familyName)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the default locale and the default class loader. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
<tr>
<td>static final ResourceBundle getBundle(String familyName, Locale loc)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the default class loader. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
<tr>
<td>static ResourceBundle getBundle(String familyName, Locale loc, ClassLoader cl)</td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the specified class loader. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
</tbody>
</table>
There are two subclasses of `ResourceBundle`. The first is `PropertyResourceBundle`, which manages resources by using property files. `PropertyResourceBundle` adds no methods of its own. The second is the abstract class `ListResourceBundle`, which manages resources in an array of key/value pairs. `ListResourceBundle` adds the method `getContents()`, which all subclasses must implement. It is shown here:

```java
protected abstract Object[] getContents()
```

It returns a two-dimensional array that contains key/value pairs that represent resources. The keys must be strings. The values are typically strings, but can be

---

**Table 19-18** The Methods Defined by `ResourceBundle`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>getBundle(String familyName, Locale loc)</code></td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the default locale and the default class loader. The loading process is under the control of <code>null</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
<tr>
<td><code>getBundle(String familyName, Locale loc)</code></td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the default class loader. The loading process is under the control of <code>null</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
<tr>
<td><code>getBundle(String familyName, Locale loc)</code></td>
<td>Loads the resource bundle with a family name of <code>familyName</code> using the specified locale and the specified class loader. The loading process is under the control of <code>null</code>. Throws <code>MissingResourceException</code> if no resource bundle matching the family name specified by <code>familyName</code> is available.</td>
</tr>
<tr>
<td><code>getContents()</code></td>
<td>Returns the resource bundle keys as an enumeration of strings. Any parent’s keys are also obtained.</td>
</tr>
<tr>
<td><code>getLocale()</code></td>
<td>Returns the locale supported by the resource bundle.</td>
</tr>
<tr>
<td><code>getObjects(String k)</code></td>
<td>Returns the object associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td><code>getString(String k)</code></td>
<td>Returns the string associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td><code>getString(String k)</code></td>
<td>Returns the string array associated with the key passed via <code>k</code>. Throws <code>MissingResourceException</code> if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td><code>handleGetObject(String k)</code></td>
<td>Returns the object associated with the key passed via <code>k</code>. Returns null if <code>k</code> is not in the resource bundle.</td>
</tr>
<tr>
<td><code>handleKeySet()</code></td>
<td>Returns the resource bundle keys as a set of strings. No parent’s keys are obtained. Also, keys with null values are not obtained.</td>
</tr>
<tr>
<td><code>keySet()</code></td>
<td>Returns the resource bundle keys as a set of strings. Any parent keys are also obtained.</td>
</tr>
<tr>
<td><code>parent()</code></td>
<td>Sets <code>parent</code> as the parent bundle for the resource bundle. When a key is looked up, the parent will be searched if the key is not found in the invoking resource object.</td>
</tr>
</tbody>
</table>
other types of objects.

Here is an example that demonstrates using a resource bundle. The resource bundle has the family name SampleRB. Two resource bundle classes of this family are created by extending ListResourceBundle. The first is called SampleRB, and it is the default bundle (which uses English). It is shown here:

```java
import java.util.*;
public class SampleRB extends ListResourceBundle {
    protected Object[][] getContents() {
        Object[][] resources = new Object[3][2];

        resources[0][0] = "title";
        resources[0][1] = "My Program";

        resources[1][0] = "StopText";
        resources[1][1] = "Stop";

        resources[2][0] = "StartText";
        resources[2][1] = "Start";

        return resources;
    }
}
```

The second resource bundle, shown next, is called SampleRB_de. It contains the German translation.

```java
import java.util.*;

// German version.
public class SampleRB_de extends ListResourceBundle {
    protected Object[][] getContents() {
        Object[][] resources = new Object[3][2];

        resources[0][0] = "title";
        resources[0][1] = "Mein Programm";

        resources[1][0] = "StopText";
        resources[1][1] = "Anschlag";

        resources[2][0] = "StartText";
        resources[2][1] = "Anfang";
        return resources;
    }
}
```
The following program demonstrates these two resource bundles by displaying the string associated with each key for both the default (English) version and the German version:

```java
// Demonstrate a resource bundle.
import java.util.*;

class LRBDemo {
    public static void main(String args[]) {
        // Load the default bundle.
        ResourceBundle rd = ResourceBundle.getBundle("SampleRB");
        System.out.println("English version: ");
        System.out.println("String for Title key : "+
                           rd.getString("title");
        System.out.println("String for StopText key : "+
                           rd.getString("StopText");
        System.out.println("String for StartText key : "+
                           rd.getString("StartText");

        // Load the German bundle.
        rd = ResourceBundle.getBundle("SampleRB", Locale.GERMANY);
        System.out.println("\nGerman version: ");
        System.out.println("String for Title key : "+
                           rd.getString("title");
        System.out.println("String for StopText key : "+
                           rd.getString("StopText");
        System.out.println("String for StartText key : "+
                           rd.getString("StartText");
    }
}
```

The output from the program is shown here:

**English version:**
- String for Title key : My Program
- String for StopText key : Stop
- String for StartText key : Start

**German version:**
- String for Title key : Mein Programm
- String for StopText key : Anschlag
- String for StartText key : Anfang
### Miscellaneous Utility Classes and Interfaces

In addition to the classes already discussed, **java.util** includes the following classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base64</td>
<td>Supports Base64 encoding. <strong>Encoder</strong> and <strong>Decoder</strong> nested classes are also defined. (Added by JDK 8.)</td>
</tr>
<tr>
<td>DoubleSummaryStatistics</td>
<td>Supports the compilation of <strong>double</strong> values. The following statistics are available: average, minimum, maximum, count, and sum. (Added by JDK 8.)</td>
</tr>
<tr>
<td>EventListenerProxy</td>
<td>Extends the <strong>EventListener</strong> class to allow additional parameters. See Chapter 24 for a discussion of event listeners.</td>
</tr>
<tr>
<td>EventObject</td>
<td>The superclass for all event classes. Events are discussed in Chapter 24.</td>
</tr>
<tr>
<td>FormattableFlags</td>
<td>Defines formatting flags that are used with the <strong>Formattable</strong> interface.</td>
</tr>
<tr>
<td>IntSummaryStatistics</td>
<td>Supports the compilation of <strong>int</strong> values. The following statistics are available: average, minimum, maximum, count, and sum. (Added by JDK 8.)</td>
</tr>
<tr>
<td>Objects</td>
<td>Various methods that operate on objects.</td>
</tr>
<tr>
<td>PropertyPermission</td>
<td>Manages property permissions.</td>
</tr>
<tr>
<td>ServiceLoader</td>
<td>Provides a means of finding service providers.</td>
</tr>
<tr>
<td>StringJoiner</td>
<td>Supports the concatenation of <strong>CharSequences</strong>, which may include a separator, a prefix, and a suffix. (Added by JDK 8.)</td>
</tr>
<tr>
<td>UUID</td>
<td>Encapsulates and manages Universally Unique Identifiers (UUIDs).</td>
</tr>
</tbody>
</table>

The following interfaces are also packaged in **java.util**: 
<table>
<thead>
<tr>
<th>EventListener</th>
<th>Indicates that a class is an event listener. Events are discussed in Chapter 24.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formattable</td>
<td>Enables a class to provide custom formatting.</td>
</tr>
</tbody>
</table>

The **java.util Subpackages**
Java defines the following subpackages of **java.util**:

- java.util.concurrent
- java.util.concurrent.atomic
- java.util.concurrent.locks
- java.util.function
- java.util.jar
- java.util.logging
- java.util.prefs
- java.util.regex
- java.util.spi
- java.util.stream
- java.util.zip

Each is briefly examined here.

**java.util.concurrent, java.util.concurrent.atomic, and java.util.concurrent.locks**
The **java.util.concurrent** package along with its two subpackages, **java.util.concurrent.atomic** and **java.util.concurrent.locks**, support concurrent programming. These packages provide a high-performance alternative to using Java’s built-in synchronization features when thread-safe operation is required. Beginning with JDK 7, **java.util.concurrent** also provides the Fork/Join Framework. These packages are examined in detail in Chapter 28.

**java.util.function**
The **java.util.function** package defines several predefined functional interfaces that you can use when creating lambda expressions or method references. They are also widely used throughout the Java API. The functional interfaces defined by **java.util.function** are shown in Table 19-19 along with a synopsis of their abstract methods. Be aware that some of these interfaces also define default or static methods that supply additional functionality. You will want to explore them fully on your own. (For a discussion of the use of functional interfaces, see Chapter 15.)
<table>
<thead>
<tr>
<th>Interface</th>
<th>Abstract Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>RXConsumer&lt;T, U&gt;</td>
<td>void accept(T t, U u)</td>
<td>Acts on the given values.</td>
</tr>
<tr>
<td>BiFunction&lt;T, U, R&gt;</td>
<td>R apply(T t, U u)</td>
<td>Acts on two objects and returns the result.</td>
</tr>
<tr>
<td>BinaryOperator&lt;T&gt;</td>
<td>T apply(T t, T t2)</td>
<td>Acts on two objects of the same type and returns the result, which is also of the same type.</td>
</tr>
<tr>
<td>BiPredicate&lt;T, U&gt;</td>
<td>boolean test(T t, U u)</td>
<td>Acts on two objects, returns true if both satisfy the condition described by test().</td>
</tr>
<tr>
<td>BooleanSupplier</td>
<td>boolean getAsBoolean()</td>
<td>Acts on a boolean value.</td>
</tr>
<tr>
<td>Consumer&lt;T&gt;</td>
<td>void accept(T t)</td>
<td>Acts on the given value.</td>
</tr>
</tbody>
</table>

| DoubleBinaryOperator            | double applyAsDouble(double u1, double u2)                                      | Acts on two double values and returns a double result.                      |
| DoubleConsumer                  | void accept(double u)                                                            | Acts on a double value.                                                     |
| DoubleFunction<T>               | R apply(double u)                                                                | Acts on a double value and returns the result.                              |
| DoublePredicate                 | boolean test(double u)                                                           | Acts on a double value, returns true if it satisfies the condition described by test(). |
| DoubleSupplier                  | double getAsDouble()                                                             | Acts on a double value.                                                     |
| DoubleToIntFunction             | int applyAsInt(double u)                                                         | Acts on a double value and returns the result as an int.                    |
| DoubleToLongFunction            | long applyAsLong(double u)                                                        | Acts on a double value and returns the result as a long.                    |
| DoubleUnaryOperator             | double applyAsDouble(double u)                                                    | Acts on a double value and returns a double result.                         |
| Functions<T, R>                 | R apply(T t)                                                                     | Acts on an object and returns the result.                                   |
| IntBinaryOperator               | int applyAsInt(int u1, int u2)                                                     | Acts on two int values and returns an int result.                           |
| IntConsumer                     | int accept(int u)                                                                | Acts on an int value.                                                      |
| IntFunction<T>                  | R apply(int u)                                                                   | Acts on an int value and returns the result.                                |
| IntPredicate                    | boolean test(int u)                                                              | Acts on an int value, returns true if it satisfies the condition described by test(). |
| IntSupplier                     | int getAsInt()                                                                   | Acts on an int value.                                                      |
| IntToDoubleFunction             | double applyAsDouble(int u)                                                       | Acts on an int value and returns the result as a double.                    |
| IntToLongFunction               | long applyAsLong(int u)                                                           | Acts on an int value and returns the result as a long.                      |
### Table 19-19  Functional Interfaces Defined by `java.util.function` and Their Abstract Methods

<table>
<thead>
<tr>
<th>Interface/Type</th>
<th>Functional Interface Description</th>
<th>Method Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>UnaryOperator</td>
<td></td>
<td><code>T apply(T t)</code> Description: Acts on <code>t</code> and returns a result.</td>
</tr>
<tr>
<td>BinaryOperator</td>
<td></td>
<td><code>T apply(T t, T u)</code> Description: Acts on <code>t</code> and <code>u</code> and returns a result.</td>
</tr>
<tr>
<td>Consumer</td>
<td></td>
<td><code>void accept(T t)</code> Description: Acts on <code>t</code> and no return.</td>
</tr>
<tr>
<td>Predicate</td>
<td></td>
<td><code>boolean test(T t)</code> Description: Returns <code>true</code> if <code>t</code> satisfies a condition.</td>
</tr>
<tr>
<td>Supplier</td>
<td></td>
<td><code>T get()</code> Description: Returns an object of type <code>T</code>.</td>
</tr>
<tr>
<td>ToDoubleBiFunction&lt;T, U&gt;</td>
<td></td>
<td><code>double applyAsDouble(T t, U u)</code> Description: Acts on <code>t</code> and <code>u</code> and returns a double.</td>
</tr>
<tr>
<td>ToDoubleFunction&lt;T&gt;</td>
<td></td>
<td><code>double applyAsDouble(T t)</code> Description: Acts on <code>t</code> and returns a double.</td>
</tr>
<tr>
<td>ToIntBiFunction&lt;T, U&gt;</td>
<td></td>
<td><code>int applyAsInt(T t, U u)</code> Description: Acts on <code>t</code> and <code>u</code> and returns an <code>int</code>.</td>
</tr>
<tr>
<td>ToIntFunction&lt;T&gt;</td>
<td></td>
<td><code>int applyAsInt(T t)</code> Description: Acts on <code>t</code> and returns a result as an <code>int</code>.</td>
</tr>
<tr>
<td>ToLongBiFunction&lt;T, U&gt;</td>
<td></td>
<td><code>long applyAsLong(T t, U u)</code> Description: Acts on <code>t</code> and <code>u</code> and returns a <code>long</code>.</td>
</tr>
<tr>
<td>ToLongFunction&lt;T&gt;</td>
<td></td>
<td><code>long applyAsLong(T t)</code> Description: Acts on <code>t</code> and returns a result as a <code>long</code>.</td>
</tr>
<tr>
<td>UnaryOperator&lt;T&gt;</td>
<td></td>
<td><code>T apply(T t)</code> Description: Acts on <code>t</code> and returns a result.</td>
</tr>
</tbody>
</table>

**java.util.jar**

The `java.util.jar` package provides the ability to read and write Java Archive (JAR) files.
java.util.logging
The java.util.logging package provides support for program activity logs, which can be used to record program actions, and to help find and debug problems.

java.util.prefs
The java.util.prefs package provides support for user preferences. It is typically used to support program configuration.

java.util.regex
The java.util.regex package provides support for regular expression handling. It is described in detail in Chapter 30.

java.util.spi
The java.util.spi package provides support for service providers.

java.util.stream
The java.util.stream package contains Java’s stream API, which was added by JDK 8. A discussion of the stream API is found in Chapter 29.

java.util.zip
The java.util.zip package provides the ability to read and write files in the popular ZIP and GZIP formats. Both ZIP and GZIP input and output streams are available.
This chapter explores **java.io**, which provides support for I/O operations. Chapter 13 presented an overview of Java's I/O system, including basic techniques for reading and writing files, handling I/O exceptions, and closing a file. Here, we will examine the Java I/O system in greater detail.

As all programmers learn early on, most programs cannot accomplish their goals without accessing external data. Data is retrieved from an **input** source. The results of a program are sent to an **output** destination. In Java, these sources or destinations are defined very broadly. For example, a network connection, memory buffer, or disk file can be manipulated by the Java I/O classes. Although physically different, these devices are all handled by the same abstraction: the **stream**. An I/O stream, as explained in Chapter 13, is a logical entity that either produces or consumes information. An I/O stream is linked to a physical device by the Java I/O system. All I/O streams behave in the same manner, even if the actual physical devices they are linked to differ.

**NOTE** The stream-based I/O system packaged in **java.io** and described in this chapter has been part of Java since its original release and is widely used. However, beginning with version 1.4, a second I/O system was added to Java. It is called NIO (which was originally an acronym for New I/O). NIO is packaged in **java.nio** and its subpackages. The NIO system is described in Chapter 21.

**NOTE** It is important not to confuse the I/O streams used by the I/O system discussed here with the new stream API added by JDK 8.
Although conceptually related, they are two different things. Therefore, when the term stream is used in this chapter, it refers to an I/O stream.

The I/O Classes and Interfaces

The I/O classes defined by java.io are listed here:

<table>
<thead>
<tr>
<th>Class</th>
<th>Class</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedInputStream</td>
<td>FileWriter</td>
<td>PipedOutputStream</td>
</tr>
<tr>
<td>BufferedOutputStream</td>
<td>FilterInputStream</td>
<td>PipedReader</td>
</tr>
<tr>
<td>BufferedReader</td>
<td>FilterOutputStream</td>
<td>PipedWriter</td>
</tr>
<tr>
<td>BufferedWriter</td>
<td>FilterReader</td>
<td>PrintStream</td>
</tr>
<tr>
<td>ByteArrayInputStream</td>
<td>FilterWriter</td>
<td>PrintWriter</td>
</tr>
<tr>
<td>ByteArrayOutputStream</td>
<td>InputStreamReader</td>
<td>PushbackInputStream</td>
</tr>
<tr>
<td>CharArrayReader</td>
<td>InputStreamReader</td>
<td>PushbackReader</td>
</tr>
<tr>
<td>CharArrayWriter</td>
<td>LineNumberReader</td>
<td>RandomAccessFile</td>
</tr>
<tr>
<td>Console</td>
<td>ObjectInputStream</td>
<td>Reader</td>
</tr>
<tr>
<td>DataInputStream</td>
<td>ObjectInputStream,GetField</td>
<td>SequenceInputStream</td>
</tr>
<tr>
<td>DataOutputStream</td>
<td>ObjectOutputStream</td>
<td>SerializablePermission</td>
</tr>
<tr>
<td>File</td>
<td>ObjectOutputStream,PutField</td>
<td>StreamTokenizer</td>
</tr>
<tr>
<td>FileDescriptor</td>
<td>ObjectStreamClass</td>
<td>StreamingReader</td>
</tr>
<tr>
<td>FileInputStream</td>
<td>ObjectStreamField</td>
<td>StringWriter</td>
</tr>
<tr>
<td>FileOutputStream</td>
<td>OutputStream</td>
<td>Writer</td>
</tr>
<tr>
<td>FilePermission</td>
<td>OutputStreamWriter</td>
<td></td>
</tr>
<tr>
<td>FileReader</td>
<td>PipedInputStream</td>
<td></td>
</tr>
</tbody>
</table>

The java.io package also contains two deprecated classes that are not shown in the preceding table: LineNumberInputStream and StringBufferInputStream. These classes should not be used for new code.

The following interfaces are defined by java.io:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Interface</th>
<th>Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Closeable</td>
<td>Filter</td>
<td>ObjectInputValidation</td>
</tr>
<tr>
<td>DataInput</td>
<td>FilenameFilter</td>
<td>ObjectOutput</td>
</tr>
<tr>
<td>DataOutput</td>
<td>Flushable</td>
<td>ObjectStreamConstants</td>
</tr>
<tr>
<td>Externalizable</td>
<td>ObjectInput</td>
<td>Serializable</td>
</tr>
</tbody>
</table>

As you can see, there are many classes and interfaces in the java.io package. These include byte and character streams, and object serialization (the storage and retrieval of objects). This chapter examines several commonly used I/O components. We begin our discussion with one of the most distinctive I/O classes: File.

File
Although most of the classes defined by `java.io` operate on streams, the `File` class does not. It deals directly with files and the file system. That is, the `File` class does not specify how information is retrieved from or stored in files; it describes the properties of a file itself. A `File` object is used to obtain or manipulate the information associated with a disk file, such as the permissions, time, date, and directory path, and to navigate subdirectory hierarchies.

**NOTE**  The `Path` interface and `Files` class, which are part of the NIO system, offer a powerful alternative to `File` in many cases. See Chapter 21 for details.

Files are a primary source and destination for data within many programs. Although there are severe restrictions on their use within applets for security reasons, files are still a central resource for storing persistent and shared information. A directory in Java is treated simply as a `File` with one additional property—a list of filenames that can be examined by the `list()` method.

The following constructors can be used to create `File` objects:

```java
File(String directoryPath)
File(String directoryPath, String filename)
File(File dirObj, String filename)
File(URI uriObj)
```

Here, `directoryPath` is the path name of the file; `filename` is the name of the file or subdirectory; `dirObj` is a `File` object that specifies a directory; and `uriObj` is a `URI` object that describes a file.

The following example creates three files: `f1`, `f2`, and `f3`. The first `File` object is constructed with a directory path as the only argument. The second includes two arguments—the path and the filename. The third includes the file path assigned to `f1` and a filename; `f3` refers to the same file as `f2`.

```java
File f1 = new File("/");
File f2 = new File("/", "autoexec.bat");
File f3 = new File(f1, "autoexec.bat");
```

**NOTE**  Java does the right thing with path separators between UNIX
and Windows conventions. If you use a forward slash (/) on a Windows version of Java, the path will still resolve correctly. Remember, if you are using the Windows convention of a backslash character (\), you will need to use its escape sequence (\") within a string.

**File** defines many methods that obtain the standard properties of a **File** object. For example, **getName()** returns the name of the file; **getParent()** returns the name of the parent directory; and **exists()** returns **true** if the file exists, **false** if it does not. The following example demonstrates several of the **File** methods. It assumes that a directory called **java** exists off the root directory and that it contains a file called **COPYRIGHT**.

```java
// Demonstrate File.
import java.io.File;

class FileDemo {
    static void p(String s) {
        System.out.println(s);
    }

    public static void main(String args[]) {
        File f1 = new File("/java/COPYRIGHT");
        p("File Name: " + f1.getName());
        p("Path: " + f1.getPath());
        p("Abs Path: " + f1.getAbsolutePath());
        p("Parent: " + f1.getParent());
        p((f1.exists() ? "exists" : "does not exist");
        p((f1.canWrite() ? "is writeable" : "is not writeable");
        p((f1.canRead() ? "is readable" : "is not readable");
        p("is " + (f1.isDirectory() ? "" : "not" ) + " a directory");
        p((f1.isFile() ? "is normal file": "might be a named pipe");
        p((f1.isAbsolute() ? "is absolute": "is not absolute");
        p("File last modified: " + f1.lastModified());
        p("File size: " + f1.length() + " Bytes");
    }
}
```

This program will produce output similar to this:
Most of the File methods are self-explanatory. isFile() and isAbsolute() are not. isFile() returns true if called on a file and false if called on a directory. Also, isFile() returns false for some special files, such as device drivers and named pipes, so this method can be used to make sure the file will behave as a file. The isAbsolute() method returns true if the file has an absolute path and false if its path is relative.

File includes two useful utility methods of special interest. The first is renameTo(), shown here:

```java
boolean renameTo(File newName)
```

Here, the filename specified by newName becomes the new name of the invoking File object. It will return true upon success and false if the file cannot be renamed (if you attempt to rename a file so that it uses an existing filename, for example).

The second utility method is delete(), which deletes the disk file represented by the path of the invoking File object. It is shown here:

```java
boolean delete()
```

You can also use delete() to delete a directory if the directory is empty. delete() returns true if it deletes the file and false if the file cannot be removed.

Here are some other File methods that you will find helpful:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void deleteOnExit( )</td>
<td>Removes the file associated with the invoking object when the Java Virtual Machine terminates.</td>
</tr>
<tr>
<td>long getFreeSpace( )</td>
<td>Returns the number of free bytes of storage available on the partition associated with the invoking object.</td>
</tr>
<tr>
<td>Method</td>
<td>Description</td>
</tr>
<tr>
<td>----------------------------------------------------</td>
<td>---------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>long getTotalSpace()</td>
<td>Returns the storage capacity of the partition associated with the invoking object.</td>
</tr>
<tr>
<td>long getUsableSpace()</td>
<td>Returns the number of usable free bytes of storage available on the partition associated with the invoking object.</td>
</tr>
<tr>
<td>boolean isHidden()</td>
<td>Returns true if the invoking file is hidden. Returns false otherwise.</td>
</tr>
<tr>
<td>boolean setLastModified(long millisec)</td>
<td>Sets the time stamp on the invoking file to that specified by millisec, which is the number of milliseconds from January 1, 1970, Coordinated Universal Time (UTC).</td>
</tr>
<tr>
<td>boolean setReadOnly()</td>
<td>Sets the invoking file to read-only.</td>
</tr>
</tbody>
</table>

Methods also exist to mark files as readable, writable, and executable. Because File implements the Comparable interface, the method compareTo() is also supported. JDK 7 added a method to File called toPath(), which is shown here:

```java
Path toPath() {
    toPath() returns a Path object that represents the file encapsulated by the invoking File object. (In other words, toPath() converts a File into a Path.)
    Path is packaged in java.nio.file and is part of NIO. Thus, toPath() forms a bridge between the older File class and the newer Path interface. (See Chapter 21 for a discussion of Path.)
}
```

**Directories**

A directory is a File that contains a list of other files and directories. When you create a File object that is a directory, the isDirectory() method will return true. In this case, you can call list() on that object to extract the list of other files and directories inside. It has two forms. The first is shown here:

```java
String[ ] list() {
    The list of files is returned in an array of String objects.
}
```

The program shown here illustrates how to use list() to examine the contents of a directory:
Here is sample output from the program. (Of course, the output you see will be different, based on what is in the directory.)

Directory of /java
bin is a directory
lib is a directory
demo is a directory
COPYRIGHT is a file
README is a file
index.html is a file
include is a directory
src.zip is a file
src is a directory

Using FilenameFilter
You will often want to limit the number of files returned by the list() method to include only those files that match a certain filename pattern, or filter. To do this, you must use a second form of list(), shown here:

String[] list(FilenameFilter FFObj)
In this form, $FFObj$ is an object of a class that implements the **FilenameFilter** interface.

**FilenameFilter** defines only a single method, **accept( )**, which is called once for each file in a list. Its general form is given here:

```java
boolean accept(File directory, String filename)
```

The **accept( )** method returns **true** for files in the directory specified by **directory** that should be included in the list (that is, those that match the **filename** argument) and returns **false** for those files that should be excluded.

The **OnlyExt** class, shown next, implements **FilenameFilter**. It will be used to modify the preceding program to restrict the visibility of the filenames returned by **list( )** to files with names that end in the file extension specified when the object is constructed.

```java
import java.io.*;

public class OnlyExt implements FilenameFilter {
  String ext;

  public OnlyExt(String ext) {
    this.ext = "." + ext;
  }

  public boolean accept(File dir, String name) {
    return name.endsWith(ext);
  }
}
```

The modified directory listing program is shown here. Now it will only display files that use the **.html** extension.
The listFiles( ) Alternative

There is a variation to the list( ) method, called listFiles( ), which you might find useful. The signatures for listFiles( ) are shown here:

File[ ] listFiles()
File[ ] listFiles(FilenameFilter FObj)
File[ ] listFiles(FileFilter FObj)

These methods return the file list as an array of File objects instead of strings. The first method returns all files, and the second returns those files that satisfy the specified FilenameFilter. Aside from returning an array of File objects, these two versions of listFiles( ) work like their equivalent list( ) methods.

The third version of listFiles( ) returns those files with path names that satisfy the specified FileFilter. FileFilter defines only a single method, accept( ), which is called once for each file in a list. Its general form is given here:

boolean accept(File path)

The accept( ) method returns true for files that should be included in the list (that is, those that match the path argument) and false for those that should be excluded.

Creating Directories

Another two useful File utility methods are mkdir( ) and mkdirs( ). The mkdir( ) method creates a directory, returning true on success and false on failure. Failure can occur for various reasons, such as the path specified in the File object already exists, or the directory cannot be created because the entire path does not exist yet. To create a directory for which no path exists, use the mkdirs( ) method. It creates both a directory and all the parents of the directory.
The AutoCloseable, Closeable, and Flushable Interfaces

There are three interfaces that are quite important to the stream classes. Two are Closeable and Flushable. They are defined in java.io and were added by JDK 5. The third, AutoCloseable, was added by JDK 7. It is packaged in java.lang. AutoCloseable provides support for the try-with-resources statement, which automates the process of closing a resource. (See Chapter 13.) Only objects of classes that implement AutoCloseable can be managed by try-with-resources. AutoCloseable is discussed in Chapter 17, but it is reviewed here for convenience. The AutoCloseable interface defines only the close() method:

```java
void close() throws Exception
```

This method closes the invoking object, releasing any resources that it may hold. It is called automatically at the end of a try-with-resources statement, thus eliminating the need to explicitly call close(). Because this interface is implemented by all of the I/O classes that open a stream, all such streams can be automatically closed by a try-with-resources statement. Automatically closing a stream ensures that it is properly closed when it is no longer needed, thus preventing memory leaks and other problems.

The Closeable interface also defines the close() method. Objects of a class that implement Closeable can be closed. Beginning with JDK 7, Closeable extends AutoCloseable. Therefore, any class that implements Closeable also implements AutoCloseable.

Objects of a class that implements Flushable can force buffered output to be written to the stream to which the object is attached. It defines the flush() method, shown here:

```java
void flush() throws IOException
```

Flushing a stream typically causes buffered output to be physically written to the underlying device. This interface is implemented by all of the I/O classes that write to a stream.

I/O Exceptions

Two exceptions play an important role in I/O handling. The first is IOException. As it relates to most of the I/O classes described in this chapter, if an I/O error occurs, an IOException is thrown. In many cases, if a file cannot be opened, a FileNotFoundException is thrown. FileNotFoundException is a subclass of IOException, so both can be caught with a single catch that catches IOException. For brevity, this is the approach used by most of the sample code in this chapter. However, in your own applications, you might find it useful to catch each exception separately.

Another exception class that is sometimes important when performing I/O is SecurityException. As explained in Chapter 13, in situations in which a security manager is present, several of the file classes will throw a SecurityException if a security violation...
occurs when attempting to open a file. By default, applications run via java do not use a security manager. For that reason, the I/O examples in this book do not need to watch for a possible SecurityException. However, applets will use the security manager provided by the browser, and file I/O performed by an applet could generate a SecurityException. In such a case, you will need to handle this exception.

**Two Ways to Close a Stream**

In general, a stream must be closed when it is no longer needed. Failure to do so can lead to memory leaks and resource starvation. The techniques used to close a stream were described in Chapter 13, but because of their importance, they warrant a brief review here before the stream classes are examined.

Beginning with JDK 7, there are two basic ways in which you can close a stream. The first is to explicitly call close() on the stream. This is the traditional approach that has been used since the original release of Java. With this approach, close() is typically called within a finally block. Thus, a simplified skeleton for the traditional approach is shown here:

```java
try {
    // open and access file
} catch (I/O-exception) {
    // ...
} finally {
    // close the file
}
```

This general technique (or variation thereof) is common in code that predates JDK 7.

The second approach to closing a stream is to automate the process by using the try-with-resources statement that was added by JDK 7 (and, of course, supported by JDK 8). The try-with-resources statement is an enhanced form of try that has the following form:

```java
try (resource-specification) {
    // use the resource
}
```

Here, resource-specification is a statement or statements that declares and initializes a resource, such as a file or other stream-related resource. It consists of a variable declaration in which the variable is initialized with a reference to the object being managed. When the try block ends, the resource is automatically released. In the case of a file, this means that the file is automatically closed. Thus, there is no need to call close() explicitly. Here are three key points about the try-with-resources statement:
Resources managed by `try-with-resources` must be objects of classes that implement `AutoCloseable`.

- The resource declared in the `try` is implicitly `final`.
- You can manage more than one resource by separating each declaration by a semicolon.

Also, remember that the scope of the declared resource is limited to the `try-with-resources` statement.

The principal advantage of `try-with-resources` is that the resource (in this case, a stream) is closed automatically when the `try` block ends. Thus, it is not possible to forget to close the stream, for example. The `try-with-resources` approach also typically results in shorter, clearer, easier-to-maintain source code.

Because of its advantages, `try-with-resources` is expected to be used extensively in new code. As a result, most of the code in this chapter (and in this book) will use it. However, because a large amount of older code still exists, it is important for all programmers to also be familiar with the traditional approach to closing a stream. For example, you will quite likely have to work on legacy code that uses the traditional approach or in an environment that uses an older version of Java. There may also be times when the automated approach is not appropriate because of other aspects of your code. For this reason, a few I/O examples in this book will demonstrate the traditional approach so you can see it in action.

One last point: The examples that use `try-with-resources` must be compiled by a modern version of Java. They won’t work with an older compiler. The examples that use the traditional approach can be compiled by older versions of Java.

---

**REMEMBER** Because `try-with-resources` streamlines the process of releasing a resource and eliminates the possibility of accidentally forgetting to release a resource, it is the approach recommended for new code when its use is appropriate.

---

**The Stream Classes**

Java’s stream-based I/O is built upon four abstract classes: `InputStream`, `OutputStream`, `Reader`, and `Writer`. These classes were briefly discussed in Chapter 13. They are used to create several concrete stream subclasses. Although your programs perform their I/O operations through concrete subclasses, the top-level classes define the basic functionality common to all stream classes.

- `InputStream` and `OutputStream` are designed for byte streams. `Reader` and `Writer` are designed for character streams. The byte stream classes and the character stream classes
form separate hierarchies. In general, you should use the character stream classes when working with characters or strings and use the byte stream classes when working with bytes or other binary objects.
In the remainder of this chapter, both the byte- and character-oriented streams are examined.

The Byte Streams
The byte stream classes provide a rich environment for handling byte-oriented I/O. A byte stream can be used with any type of object, including binary data. This versatility makes byte streams important to many types of programs. Since the byte stream classes are topped by **InputStream** and **OutputStream**, our discussion begins with them.

**InputStream**
**InputStream** is an abstract class that defines Java's model of streaming byte input. It implements the **AutoCloseable** and **Closeable** interfaces. Most of the methods in this class will throw an **IOException** when an I/O error occurs. (The exceptions are **mark**( ) and **markSupported**( ).) Table 20-1 shows the methods in **InputStream**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>mark</strong>( )</td>
<td>Marks the input source</td>
</tr>
<tr>
<td><strong>markSupported</strong>( )</td>
<td>Determines if the input source supports marking</td>
</tr>
</tbody>
</table>

**OutputStream**
**OutputStream** is an abstract class that defines streaming byte output. It implements the **AutoCloseable**, **Closeable**, and **Flushable** interfaces. Most of the methods defined by this class return **void** and throw an **IOException** in the case of I/O errors. Table 20-2 shows the methods in **OutputStream**.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>write</strong>( )</td>
<td>Writes bytes to the output source</td>
</tr>
<tr>
<td><strong>flush</strong>( )</td>
<td>Flushes the output buffer</td>
</tr>
<tr>
<td><strong>close</strong>( )</td>
<td>Closes the output source</td>
</tr>
</tbody>
</table>

**NOTE** Most of the methods described in Table 20-1 are implemented by the subclasses of **InputStream**. The **mark**( ) and **reset**( ) methods are exceptions; notice their use, or lack thereof, by each subclass in the discussions that follow.
Table 20-1  The Methods Defined by InputStream

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int available( )</td>
<td>Returns the number of bytes of input currently available for reading.</td>
</tr>
<tr>
<td>void close( )</td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>void mark(int readBytes)</td>
<td>Places a mark at the current point in the input stream that will remain valid until readBytes bytes are read.</td>
</tr>
<tr>
<td>boolean markSupported( )</td>
<td>Returns true if mark( ) / reset( ) are supported by the invoking stream.</td>
</tr>
<tr>
<td>int read( )</td>
<td>Returns an integer representation of the next available byte of input. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>int read(byte[] buffer)</td>
<td>Attempts to read up to buffer.length bytes into buffer and returns the actual number of bytes that were successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>int read(byte[] buffer, int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buffer starting at buffer[offset], returning the number of bytes successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>void reset( )</td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td>long skip(long markBytes)</td>
<td>Ignores (that is, skips) markBytes bytes of input, returning the number of bytes actually ignored.</td>
</tr>
</tbody>
</table>

FileInputStream

The FileInputStream class creates an InputStream that you can use to read bytes from a file. Two commonly used constructors are shown here:

FileInputStream(String filePath)
FileInputStream(File fileObj)

Either can throw a FileNotFoundException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file.

The following example creates two FileInputStreams that use the same disk file and each of the two constructors:

Table 20-2  The Methods Defined by OutputStream

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close( )</td>
<td>Closes the output stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td>void flush( )</td>
<td>Finalizes the output state so that any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td>void write(int b)</td>
<td>Writes a single byte to an output stream. Note that the parameter is an int, which allows you to call write( ) with an expression without having to cast it (back to byte).</td>
</tr>
<tr>
<td>void write(byte[] buffer)</td>
<td>Writes a complete array of bytes to an output stream.</td>
</tr>
<tr>
<td>void write(byte[] buffer, int offset, int numBytes)</td>
<td>Writes a subrange of numBytes bytes from the array buffer beginning at buffer[offset].</td>
</tr>
</tbody>
</table>
Although the first constructor is probably more commonly used, the second allows you to closely examine the file using the **File** methods, before attaching it to an input stream. When a **FileInputStream** is created, it is also opened for reading. **FileInputStream** overrides six of the methods in the abstract class **InputStream**. The **mark()** and **reset()** methods are not overridden, and any attempt to use **reset()** on a **FileInputStream** will generate an **IOException**.

The next example shows how to read a single byte, an array of bytes, and a subrange of an array of bytes. It also illustrates how to use **available()** to determine the number of bytes remaining and how to use the **skip()** method to skip over unwanted bytes. The program reads its own source file, which must be in the current directory. Notice that it uses the **try-with-resources** statement to automatically close the file when it is no longer needed.

```java
FileInputStream f0 = new FileInputStream("/autoexec.bat");
File f = new File("/autoexec.bat");
FileInputStream f1 = new FileInputStream(f);
```
// Demonstrate FileInputStream.
// This program uses try-with-resources. It requires JDK 7 or later.

import java.io.*;

class FileInputStreamDemo {
    public static void main(String args[]) {
        int size;

        // Use try-with-resources to close the stream.
        try (FileInputStream f =
            new FileInputStream("FileInputStreamDemo.java") ) {

            System.out.println("Total Available Bytes: "+
            (size = f.available()));

            int n = size/40;
            System.out.println("First " + n +
            " bytes of the file one read() at a time");
            for (int i=0; i < n; i++) {
                System.out.print((char) f.read());
            }

            System.out.println("\nStill Available: " + f.available());
            System.out.println("Reading the next " + n +
            " with one read(b[])");
            byte b[] = new byte[n];
            if (f.read(b) != n) {
                System.err.println("couldn't read " + n + " bytes.");
            }

            System.out.println(new String(b, 0, n));
            System.out.println("\nStill Available: " + (size - f.available()));
            System.out.println("skipping half of remaining bytes with skip()");
            f.skip(size/2);
            System.out.println("Still Available: " + f.available());

            System.out.println("Reading " + n/2 + " into the end of array");
            if (f.read(b, n/2, n/2) != n/2) {
                System.err.println("couldn't read " + n/2 + " bytes.");
            }

            System.out.println(new String(b, 0, b.length));
            System.out.println("\nStill Available: " + f.available());
        } catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
This somewhat contrived example demonstrates how to read three ways, to skip input, and to inspect the amount of data available on a stream.

NOTE  The preceding example and the other examples in this chapter handle any I/O exceptions that might occur as described in Chapter 13. See Chapter 13 for details and alternatives.

FileOutputStream

FileOutputStream creates an OutputStream that you can use to write bytes to a file. It implements the AutoCloseable, Closeable, and Flushable interfaces. Four of its constructors are shown here:

FileOutputStream(String filePath)
FileOutputStream(File fileObj)
FileOutputStream(String filePath, boolean append)
FileOutputStream(File fileObj, boolean append)

They can throw a FileNotFoundException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file. If append is true, the file is opened in append mode.

Creation of a FileOutputStream is not dependent on the file already existing. FileOutputStream will create the file before opening it for output when you create the object. In the case where you attempt to open a read-only file, an exception will be thrown.
The following example creates a sample buffer of bytes by first making a `String` and then using the `getBytes()` method to extract the byte array equivalent. It then creates three files. The first, `file1.txt`, will contain every other byte from the sample. The second, `file2.txt`, will contain the entire set of bytes. The third and last, `file3.txt`, will contain only the last quarter.

```java
// Demonstrate FileOutputStream.
// This program uses the traditional approach to closing a file.

import java.io.*;

class FileOutputStreamDemo {
    public static void main(String[] args) {
        String source = "Now is the time for all good men
+ to come to the aid of their country!
+ and pay their due taxes."
        byte[] buf = source.getBytes();
        FileOutputStream f0 = null;
        FileOutputStream f1 = null;
        FileOutputStream f2 = null;
        try {
            f0 = new FileOutputStream("file1.txt");
            f1 = new FileOutputStream("file2.txt");
            f2 = new FileOutputStream("file3.txt");
            // write to first file
            for (int i = 0; i < buf.length; i += 2) f0.write(buf[i]);
            // write to second file
            f1.write(buf);
            // write to third file
            f2.write(buf, buf.length - buf.length/4, buf.length/4);
        } catch (IOException e) {
            System.out.println("An I/O Error Occurred");
        }
        finally {
            try {
                if(f0 != null) f0.close();
            } catch (IOException e) {
                System.out.println("Error Closing file1.txt");
            }
            try {
                if(f1 != null) f1.close();
            } catch (IOException e) {
                System.out.println("Error Closing file2.txt");
            }
            try {
                if(f2 != null) f2.close();
            } catch (IOException e) {
                System.out.println("Error Closing file3.txt");
            }
        }
    }
}
```
Here are the contents of each file after running this program. First, \texttt{file1.txt}:

```
With effect

to cut in half.
```

Next, \texttt{file2.txt}:

```
Now is the time for all good men
to come to the aid of their country
and pay their due taxes.
```

Finally, \texttt{file3.txt}:

```
nd pay their due taxes.
```

As the comment at the top of the program states, the preceding program shows an example that uses the traditional approach to closing a file when it is no longer needed. This approach is required by all versions of Java prior to JDK 7 and is widely used in legacy code. As you can see, quite a bit of rather awkward code is required to explicitly call \texttt{close()} because each call could generate an \texttt{IOException} if the close operation fails. This program can be substantially improved by using the new \texttt{try-with-resources} statement. For comparison, here is the revised version. Notice that it is much shorter and streamlined:
ByteArrayInputStream

ByteArrayInputStream is an implementation of an input stream that uses a byte array as the source. This class has two constructors, each of which requires a byte array to provide the data source:

ByteArrayInputStream(byte array [])
ByteArrayInputStream(byte array [], int start, int numBytes)

Here, array is the input source. The second constructor creates an InputStream from a subset of the byte array that begins with the character at the index specified by start and is numBytes long.

The close() method has no effect on a ByteArrayInputStream. Therefore, it is not necessary to call close() on a ByteArrayInputStream, but doing so is not an error.

The following example creates a pair of ByteArrayInputStreams, initializing them with the byte representation of the alphabet:
The `input1` object contains the entire lowercase alphabet, whereas `input2` contains only the first three letters.

A `ByteArrayInputStream` implements both `mark()` and `reset()`. However, if `mark()` has not been called, then `reset()` sets the stream pointer to the start of the stream—which, in this case, is the start of the byte array passed to the constructor. The next example shows how to use the `reset()` method to read the same input twice. In this case, the program reads and prints the letters "abc" once in lowercase and then again in uppercase.

```
import java.io.*;

class ByteArrayInputStreamReset {
    public static void main(String args[]) {
        String tmp = "abc";
        byte b[] = tmp.getBytes();
        ByteArrayInputStream in = new ByteArrayInputStream(b);
        for (int i=0; i<2; i++) {
            int c;
            while ((c = in.read()) != -1) {
                if (i == 0) {
                    System.out.print((char) c);
                } else {
                    System.out.print(Character.toUpperCase((char) c));
                }
            }
            System.out.println();
            in.reset();
        }
    }
}
```

This example first reads each character from the stream and prints it as-is in lowercase. It then resets the stream and begins reading again, this time converting each character to uppercase before printing. Here’s the output:
ByteArrayOutputStream

ByteArrayOutputStream is an implementation of an output stream that uses a byte array as the destination. ByteArrayOutputStream has two constructors, shown here:

ByteArrayOutputStream()
ByteArrayOutputStream(int numBytes)

In the first form, a buffer of 32 bytes is created. In the second, a buffer is created with a size equal to that specified by numBytes. The buffer is held in the protected buf field of ByteArrayOutputStream. The buffer size will be increased automatically, if needed. The number of bytes held by the buffer is contained in the protected count field of ByteArrayOutputStream.

The close() method has no effect on a ByteArrayOutputStream. Therefore, it is not necessary to call close() on a ByteArrayOutputStream, but doing so is not an error. The following example demonstrates ByteArrayOutputStream:
When you run the program, you will create the following output. Notice how after the call to
`reset()`, the three X's end up at the beginning.
This example uses the `writeTo()` convenience method to write the contents of `f` to `test.txt`. Examining the contents of the `test.txt` file created in the preceding example shows the result we expected:

```
This should end up in the array
```

**Filtered Byte Streams**
Filtered streams are simply wrappers around underlying input or output streams that transparently provide some extended level of functionality. These streams are typically accessed by methods that are expecting a generic stream, which is a superclass of the filtered streams. Typical extensions are buffering, character translation, and raw data translation. The filtered byte streams are `FilterInputStream` and `FilterOutputStream`. Their constructors are shown here:

```
FilterOutputStream(OutputStream os)
FilterInputStream(InputStream is)
```

The methods provided in these classes are identical to those in `InputStream` and `OutputStream`.

**Buffered Byte Streams**
For the byte-oriented streams, a buffered stream extends a filtered stream class by attaching a memory buffer to the I/O stream. This buffer allows Java to do I/O operations on more than a byte at a time, thereby improving performance. Because the buffer is available, skipping, marking, and resetting of the stream become possible. The buffered byte stream classes are `BufferedInputStream` and `BufferedOutputStream`. `PushbackInputStream` also implements a buffered stream.

**BufferedInputStream**
Buffering I/O is a very common performance optimization. Java's `BufferedInputStream` class allows you to "wrap" any `InputStream` into a buffered stream to improve performance. `BufferedInputStream` has two constructors:

```
BufferedInputStream(InputStream inputStream)
BufferedInputStream(InputStream inputStream, int bufSize)
```

The first form creates a buffered stream using a default buffer size. In the second,
the size of the buffer is passed in \textit{bufSize}. Use of sizes that are multiples of a memory page, a disk block, and so on, can have a significant positive impact on performance. This is, however, implementation-dependent. An optimal buffer size is generally dependent on the host operating system, the amount of memory available, and how the machine is configured. To make good use of buffering doesn’t necessarily require quite this degree of sophistication. A good guess for a size is around 8,192 bytes, and attaching even a rather small buffer to an I/O stream is always a good idea. That way, the low-level system can read blocks of data from the disk or network and store the results in your buffer. Thus, even if you are reading the data a byte at a time out of the \texttt{InputStream}, you will be manipulating fast memory most of the time.

Buffering an input stream also provides the foundation required to support moving backward in the stream of the available buffer. Beyond the \texttt{read( )} and \texttt{skip( )} methods implemented in any \texttt{InputStream}, \texttt{BufferedInputStream} also supports the \texttt{mark( )} and \texttt{reset( )} methods. This support is reflected by \texttt{BufferedInputStream.markSupported( )} returning \texttt{true}.

The following example contrives a situation where we can use \texttt{mark( )} to remember where we are in an input stream and later use \texttt{reset( )} to get back there. This example is parsing a stream for the HTML entity reference for the copyright symbol. Such a reference begins with an ampersand (\&) and ends with a semicolon (;) without any intervening whitespace. The sample input has two ampersands to show the case where the \texttt{reset( )} happens and where it does not.
Notice that this example uses `mark(32)`, which preserves the mark for the next 32 bytes read (which is enough for all entity references). Here is the output produced by this program:

```
This is a (c) copyright symbol but this is &copy not.
```
BufferedOutputStream

A BufferedOutputStream is similar to any OutputStream with the exception that the flush() method is used to ensure that data buffers are written to the stream being buffered. Since the point of a BufferedOutputStream is to improve performance by reducing the number of times the system actually writes data, you may need to call flush() to cause any data that is in the buffer to be immediately written.

Unlike buffered input, buffering output does not provide additional functionality. Buffers for output in Java are there to increase performance. Here are the two available constructors:

BufferedOutputStream(OutputStream outputStream)
BufferedOutputStream(OutputStream outputStream, int bufSize)

The first form creates a buffered stream using the default buffer size. In the second form, the size of the buffer is passed in bufSize.

PushbackInputStream

One of the novel uses of buffering is the implementation of pushback. Pushback is used on an input stream to allow a byte to be read and then returned (that is, "pushed back") to the stream. The PushbackInputStream class implements this idea. It provides a mechanism to "peek" at what is coming from an input stream without disrupting it.

PushbackInputStream has the following constructors:

PushbackInputStream(InputStream inputStream)
PushbackInputStream(InputStream inputStream, int numBytes)

The first form creates a stream object that allows one byte to be returned to the input stream. The second form creates a stream that has a pushback buffer that is numBytes long. This allows multiple bytes to be returned to the input stream.

Beyond the familiar methods of InputStream, PushbackInputStream provides unread( ), shown here:

void unread(int b)
void unread(byte buffer [ ])
void unread(byte buffer, int offset, int numBytes)

The first form pushes back the low-order byte of b. This will be the next byte returned by a subsequent call to read(). The second form pushes back the bytes in buffer. The third form pushes back numBytes bytes beginning at offset from buffer. An IOException will be thrown if there is an attempt to push back a byte when the pushback buffer is full.

Here is an example that shows how a programming language parser might use a PushbackInputStream and unread() to deal with the difference between the == operator for comparison and the = operator for assignment:
// Demonstrate unread().
// This program uses try-with-resources. It requires JDK 7 or later.
import java.io.*;

class PushbackInputStreamDemo {
    public static void main(String args[]) {
        String s = "if (a == 4) a = 0; \n";
        byte buf[] = s.getBytes();
        ByteArrayInputStream in = new ByteArrayInputStream(buf);
        int c;
        try (PushbackInputStream f = new PushbackInputStream(in)) {
            while ((c = f.read()) != -1) {
                switch(c) {
                case '-':
                    if ((c = f.read()) == '=')
                        System.out.print("\ .eq.\n");
                    else {
                        System.out.print("\<\-
");
                        f.unread(c);
                    }
                break;
                default:
                    System.out.print((char) c);
                break;
                }
            } catch(IOException e) {
                System.out.println("I/O Error: " + e);
            }
        }
    }
}

Here is the output for this example. Notice that == was replaced by ",.eq," and = was replaced by ",<\-".

if (a .eq. 4) a <\- 0;

---

**CAUTION** PushbackInputStream has the side effect of invalidating the mark() or reset() methods of the InputStream used to create it. Use markSupported() to check any stream on which you are going to use mark() / reset().

**SequenceInputStream**
The `SequenceInputStream` class allows you to concatenate multiple `InputStreams`. The construction of a `SequenceInputStream` is different from any other `InputStream`. A `SequenceInputStream` constructor uses either a pair of `InputStreams` or an `Enumeration` of `InputStreams` as its argument:

```
SequenceInputStream(InputStream first, InputStream second)
SequenceInputStream(Enumeration <? extends InputStream> streamEnum)
```

Operationally, the class fulfills read requests from the first `InputStream` until it runs out and then switches over to the second one. In the case of an `Enumeration`, it will continue through all of the `InputStreams` until the end of the last one is reached. When the end of each file is reached, its associated stream is closed. Closing the stream created by `SequenceInputStream` causes all unclosed streams to be closed.

Here is a simple example that uses a `SequenceInputStream` to output the contents of two files. For demonstration purposes, this program uses the traditional technique used to close a file. As an exercise, you might want to try changing it to use the `try-with-resources` statement.
This example creates a Vector and then adds three filenames to it. It passes that vector of names to the InputStreamEnumerator class, which is designed to provide a wrapper on the vector where the elements returned are not the filenames but, rather, open FileInputStreams on those names. The SequenceInputStream opens each file in turn, and this example prints the contents of the files.
Notice in `nextElement()` that if a file cannot be opened, `null` is returned. This results in a `NullPointerException`, which is caught in `main()`.

**PrintStream**
The `PrintStream` class provides all of the output capabilities we have been using from the `System` file handle, `System.out`, since the beginning of the book. This makes `PrintStream` one of Java's most often used classes. It implements the `Appendable`, `AutoCloseable`, `Closeable`, and `Flushable` interfaces.

`PrintStream` defines several constructors. The ones shown next have been specified from the start:

```java
PrintStream(OutputStream outputStream)
PrintStream(OutputStream outputStream, boolean autoFlushingOn)
PrintStream(OutputStream outputStream, boolean autoFlushingOn String charSet)  
    throws UnsupportedEncodingException
```

Here, `outputStream` specifies an open `OutputStream` that will receive output. The `autoFlushingOn` parameter controls whether the output buffer is automatically flushed every time a newline (`\n`) character or a byte array is written or when `println()` is called. If `autoFlushingOn` is `true`, flushing automatically takes place. If it is `false`, flushing is not automatic. The first constructor does not automatically flush. You can specify a character encoding by passing its name in `charSet`.

The next set of constructors gives you an easy way to construct a `PrintStream` that writes its output to a file:

```java
PrintStream(File outputFile) throws FileNotFoundException
PrintStream(File outputFile, String charSet)  
    throws FileNotFoundException, UnsupportedEncodingException
PrintStream(String outputFileName) throws FileNotFoundException
PrintStream(String outputFileName, String charSet) throws FileNotFoundException,  
    UnsupportedEncodingException
```

These allow a `PrintStream` to be created from a `File` object or by specifying the name of a file. In either case, the file is automatically created. Any preexisting file by the same name is destroyed. Once created, the `PrintStream` object directs all output to the specified file. You can specify a character encoding by passing its name in `charSet`. 

---
If a security manager is present, some PrintStream constructors will throw a SecurityException if a security violation occurs.

PrintStream supports the print() and println() methods for all types, including Object. If an argument is not a primitive type, the PrintStream methods will call the object’s toString() method and then display the result.

Somewhat recently (with the release of JDK 5), the printf() method was added to PrintStream. It allows you to specify the precise format of the data to be written. The printf() method uses the Formatter class (described in Chapter 19) to format data. It then writes this data to the invoking stream. Although formatting can be done manually, by using Formatter directly, printf() streamlines the process. It also parallels the C/C++ printf() function, which makes it easy to convert existing C/C++ code into Java. Frankly, printf() was a much welcome addition to the Java API because it greatly simplified the output of formatted data to the console.

The printf() method has the following general forms:

```java
PrintStream printf(String fmtString, Object ... args)
PrintStream printf(Locale loc, String fmtString, Object ... args)
```

The first version writes args to standard output in the format specified by fmtString, using the default locale. The second lets you specify a locale. Both return the invoking PrintStream.

In general, printf() works in a manner similar to the format() method specified by Formatter. The fmtString consists of two types of items. The first type is composed of characters that are simply copied to the output buffer. The second type contains format specifiers that define the way the subsequent arguments, specified by args, are displayed. For complete information on formatting output, including a description of the format specifiers, see the Formatter class in Chapter 19.

Because System.out is a PrintStream, you can call printf() on System.out. Thus, printf() can be used in place of println() when writing to the console whenever formatted output is desired. For example, the following program uses printf() to output numeric values in various formats. Prior to JDK 5, such formatting required a bit of work. With the addition of printf(), this is now an easy task.
PrintStream also defines the `format()` method. It has these general forms:

PrintStream format(String fmtString, Object ... args)
PrintStream format(Locale loc, String fmtString, Object ... args)

It works exactly like `printf()`.
DataOutputStream and DataInputStream

DataOutputStream and DataInputStream enable you to write or read primitive data to or from a stream. They implement the DataOutput and DataInput interfaces, respectively. These interfaces define methods that convert primitive values to or from a sequence of bytes. These streams make it easy to store binary data, such as integers or floating-point values, in a file. Each is examined here.

DataOutputStream extends FilterOutputStream, which extends OutputStream. In addition to implementing DataOutput, DataOutputStream also implements AutoCloseable, Closeable, and Flushable. DataOutputStream defines the following constructor:

```
DataOutputStream(OutputStream outputStream)
```

Here, outputStream specifies the output stream to which data will be written. When a DataOutputStream is closed (by calling close()), the underlying stream specified by outputStream is also closed automatically.

DataOutputStream supports all of the methods defined by its superclasses. However, it is the methods defined by the DataOutput interface, which it implements, that make it interesting. DataOutput defines methods that convert values of a primitive type into a byte sequence and then writes it to the underlying stream. Here is a sampling of these methods:

```
final void writeDouble(double value) throws IOException
final void writeBoolean(boolean value) throws IOException
final void writeInt(int value) throws IOException
```

Here, value is the value written to the stream.

DataInputStream is the complement of DataOutputStream. It extends FilterInputStream, which extends InputStream. In addition to implementing the DataInput interface, DataInputStream also implements AutoCloseable and Closeable. Here is its only constructor:

```
DataInputStream(InputStream inputStream)
```

Here, inputStream specifies the input stream from which data will be read. When a DataInputStream is closed (by calling close()), the underlying stream specified by inputStream is also closed automatically.

Like DataOutputStream, DataInputStream supports all of the methods of its superclasses, but it is the methods defined by the DataInput interface that make it unique. These methods read a sequence of bytes and convert them into values of a primitive type. Here is a sampling of these methods:

```
final double readDouble() throws IOException
final boolean readBoolean() throws IOException
final int readInt() throws IOException
```

The following program demonstrates the use of DataOutputStream and
DataInputStream:

```java
// Demonstrate DataInputStream and DataOutputStream.
// This program uses try-with-resources. It requires JDK 7 or later.

import java.io.*;

class DataIODemo {
    public static void main(String args[]) throws IOException {

        // First, write the data.
        try {
            DataOutputStream dout =
                new DataOutputStream(new FileOutputStream("Test.dat"));
        }
        catch (FileNotFoundException e) {
            System.out.println("Cannot Open Output File");
            return;
        }
        catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }

        // Now, read the data back.
        try {
            DataInputStream din =
                new DataInputStream(new FileInputStream("Test.dat"));
        }
        catch (FileNotFoundException e) {
            System.out.println("Cannot Open Input File");
            return;
        }
        catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```

The output is shown here:

```
Here are the values: 98.6 1000 true
```

RandomAccessFile

RandomAccessFile encapsulates a random-access file. It is not derived from InputStream or OutputStream. Instead, it implements the interfaces DataInput and DataOutput, which define the basic I/O methods. It also implements the AutoCloseable
RandomAccessFile is special because it supports positioning requests—that is, you can position the file pointer within the file. It has these two constructors:

```java
RandomAccessFile(File fileObj, String access)
throws FileNotFoundException
RandomAccessFile(String filename, String access)
throws FileNotFoundException
```

In the first form, `fileObj` specifies the file to open as a `File` object. In the second form, the name of the file is passed in `filename`. In both cases, `access` determines what type of file access is permitted. If it is "r", then the file can be read, but not written. If it is "rw", then the file is opened in read-write mode. If it is "rws", the file is opened for read-write operations and every change to the file’s data or metadata will be immediately written to the physical device. If it is "rwd", the file is opened for read-write operations and every change to the file’s data will be immediately written to the physical device.

The method `seek()`, shown here, is used to set the current position of the file pointer within the file:

```java
void seek(long newPos) throws IOException
```

Here, `newPos` specifies the new position, in bytes, of the file pointer from the beginning of the file. After a call to `seek()`, the next read or write operation will occur at the new file position.

`RandomAccessFile` implements the standard input and output methods, which you can use to read and write to random access files. It also includes some additional methods. One is `setLength()`. It has this signature:

```java
void setLength(long len) throws IOException
```

This method sets the length of the invoking file to that specified by `len`. This method can be used to lengthen or shorten a file. If the file is lengthened, the added portion is undefined.

**The Character Streams**

While the byte stream classes provide sufficient functionality to handle any type of I/O operation, they cannot work directly with Unicode characters. Since one of the main purposes of Java is to support the "write once, run anywhere" philosophy, it was necessary to include direct I/O support for characters. In this section, several of the character I/O classes are discussed. As explained earlier, at the top of the character stream hierarchies are the `Reader` and `Writer` abstract classes. We will begin with them.
Reader is an abstract class that defines Java's model of streaming character input. It implements the AutoCloseable, Closeable, and Readable interfaces. All of the methods in this class (except for markSupported( )) will throw an IOException on error conditions. Table 20-3 provides a synopsis of the methods in Reader.

Writer

Writer is an abstract class that defines streaming character output. It implements the AutoCloseable, Closeable, Flushable, and Appendable interfaces. All of the methods in this class throw an IOException in the case of errors. Table 20-4 shows a synopsis of the methods in Writer.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>close()</td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>mark(int numChars)</td>
<td>Places a mark at the current point in the input stream that will remain valid until numChars characters are read.</td>
</tr>
<tr>
<td>markSupported()</td>
<td>Returns true if mark(), reset() are supported on this stream.</td>
</tr>
<tr>
<td>read()</td>
<td>Returns an integer representation of the next available character from the invoking input stream. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>read(char[] buf)</td>
<td>Attempts to read up to buf.length characters into buf and returns the actual number of characters that were successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>readable()</td>
<td>Returns true if the next input request will not wait. Otherwise, it returns false.</td>
</tr>
<tr>
<td>reset()</td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td>skip(long numChars)</td>
<td>Skips over numChars characters of input, returning the number of characters actually skipped.</td>
</tr>
</tbody>
</table>

Table 20-3 The Methods Defined by Reader

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>append(char c)</td>
<td>Appends c to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td>append(CharSequence chars)</td>
<td>Appends chars to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td>append(CharSequence chars, int begin, int end)</td>
<td>Appends the subrange of chars specified by begin and end-1 to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td>close()</td>
<td>Closes the output stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td>flush()</td>
<td>Finalizes the output state so that any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
</tbody>
</table>
Table 20-4  The Methods Defined by Writer

FileReader

The FileReader class creates a Reader that you can use to read the contents of a file. Two commonly used constructors are shown here:

FileReader(String filePath)
FileReader(File fileObj)

Either can throw a FileNotFoundException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file.

The following example shows how to read lines from a file and display them on the standard output device. It reads its own source file, which must be in the current directory.

```java
// Demonstrate FileReader.
// This program uses try-with-resources. It requires JDK 7 or later.
import java.io.*;

class FileReaderDemo {
    public static void main(String args[]) {
        try (FileReader fr = new FileReader("FileReaderDemo.java")) {
            int c;
            // read and display the file.
            while ((c = fr.read()) != -1) System.out.print((char) c);
        } catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```

FileWriter

FileWriter creates a Writer that you can use to write to a file. Four commonly used
constructors are shown here:

FileWriter(String filePath)
FileWriter(String filePath, boolean append)
FileWriter(File fileObj)
FileWriter(File fileObj, boolean append)

They can all throw an IOException. Here, filePath is the full path name of a file, and fileObj is a File object that describes the file. If append is true, then output is appended to the end of the file.

Creation of a FileWriter is not dependent on the file already existing. FileWriter will create the file before opening it for output when you create the object. In the case where you attempt to open a read-only file, an IOException will be thrown.

The following example is a character stream version of an example shown earlier when FileOutputStream was discussed. This version creates a sample buffer of characters by first making a String and then using the getChars( ) method to extract the character array equivalent. It then creates three files. The first, file1.txt, will contain every other character from the sample. The second, file2.txt, will contain the entire set of characters. Finally, the third, file3.txt, will contain only the last quarter.
CharArrayReader

CharArrayReader is an implementation of an input stream that uses a character array as the source. This class has two constructors, each of which requires a character array to provide the data source:

```
CharArrayReader(char array [])
CharArrayReader(char array [], int start, int numChars)
```

Here, `array` is the input source. The second constructor creates a Reader from a subset of your character array that begins with the character at the index specified by `start` and is `numChars` long.

The `close()` method implemented by CharArrayReader does not throw any exceptions. This is because it cannot fail.

The following example uses a pair of CharArrayReaders:
The **input1** object is constructed using the entire lowercase alphabet, whereas **input2** contains only the first five letters. Here is the output:

```
input1 is:
abcdefgijklmnopqrstuvwxyz
input2 is:
abcdefghijklmnopqrstuvwxyz
```

**CharArrayWriter**

**CharArrayWriter** is an implementation of an output stream that uses an array as the destination. **CharArrayWriter** has two constructors, shown here:

```
CharArrayWriter()
```
CharArrayWriter(int numChars)

In the first form, a buffer with a default size is created. In the second, a buffer is created with a size equal to that specified by numChars. The buffer is held in the buf field of CharArrayWriter. The buffer size will be increased automatically, if needed. The number of characters held by the buffer is contained in the count field of CharArrayWriter. Both buf and count are protected fields.

The close( ) method has no effect on a CharArrayWriter.

The following example demonstrates CharArrayWriter by reworking the sample program shown earlier for ByteArrayOutputStream. It produces the same output as the previous version.
BufferedReader

BufferedReader improves performance by buffering input. It has two constructors:

BufferedReader(Reader inputStream)
BufferedReader(Reader inputStream, int bufSize)

The first form creates a buffered character stream using a default buffer size. In the
second, the size of the buffer is passed in `bufSize`.

Closing a `BufferedReader` also causes the underlying stream specified by `inputStream` to be closed.

As is the case with the byte-oriented stream, buffering an input character stream also provides the foundation required to support moving backward in the stream within the available buffer. To support this, `BufferedReader` implements the `mark()` and `reset()` methods, and `BufferedReader.markSupported()` returns `true`. JDK 8 adds a new method to `BufferedReader` called `lines()`. It returns a `Stream` reference to the sequence of lines read by the reader. (`Stream` is part of the new stream API discussed in Chapter 29.)

The following example reworks the `BufferedInputStream` example, shown earlier, so that it uses a `BufferedReader` character stream rather than a buffered byte stream. As before, it uses the `mark()` and `reset()` methods to parse a stream for the HTML entity reference for the copyright symbol. Such a reference begins with an ampersand (&) and ends with a semicolon (;) without any intervening whitespace. The sample input has two ampersands to show the case where the `reset()` happens and where it does not. Output is the same as that shown earlier.
BufferedWriter

A **BufferedWriter** is a **Writer** that buffers output. Using a **BufferedWriter** can improve performance by reducing the number of times data is actually physically written to the output device.

A **BufferedWriter** has these two constructors:
BufferedWriter(Writer outputStream)
BufferedWriter(Writer outputStream, int bufSize)

The first form creates a buffered stream using a buffer with a default size. In the second, the size of the buffer is passed in bufSize.

**PushbackReader**
The **PushbackReader** class allows one or more characters to be returned to the input stream. This allows you to look ahead in the input stream. Here are its two constructors:

PushbackReader(Reader inputStream)
PushbackReader(Reader inputStream, int bufSize)

The first form creates a buffered stream that allows one character to be pushed back. In the second, the size of the pushback buffer is passed in bufSize.

Closing a **PushbackReader** also closes the underlying stream specified by inputStream. **PushbackReader** provides `unread()`, which returns one or more characters to the invoking input stream. It has the three forms shown here:

```java
void unread(int ch) throws IOException
void unread(char buffer []) throws IOException
void unread(char buffer [], int offset, int numChars) throws IOException
```

The first form pushes back the character passed in ch. This will be the next character returned by a subsequent call to `read()`. The second form returns the characters in buffer. The third form pushes back numChars characters beginning at offset from buffer. An IOException will be thrown if there is an attempt to return a character when the pushback buffer is full.

The following program reworks the earlier **PushbackInputStream** example by replacing **PushbackInputStream** with **PushbackReader**. As before, it shows how a programming language parser can use a pushback stream to deal with the difference between the `==` operator for comparison and the `=` operator for assignment.
**PrintWriter**

PrintWriter is essentially a character-oriented version of PrintStream. It implements the Appendable, AutoCloseable, Closeable, and Flushable interfaces. PrintWriter has several constructors. The following have been supplied by PrintWriter from the start:

PrintWriter(OutputStream outputStream)
PrintWriter(OutputStream outputStream, boolean autoFlushingOn)
PrintWriter(Writer outputStream)
PrintWriter(Writer outputStream, boolean autoFlushingOn)

Here, outputStream specifies an open OutputStream that will receive output. The autoFlushingOn parameter controls whether the output buffer is automatically flushed every time println(), printf(), or format() is called. If autoFlushingOn is true, flushing automatically takes place. If false, flushing is not automatic. Constructors that do not specify the autoFlushingOn parameter do
not automatically flush.
The next set of constructors gives you an easy way to construct a PrintWriter that writes its output to a file.

```java
PrintWriter(File output) throws FileNotFoundException
PrintWriter(File output, String charset)
  throws FileNotFoundException, UnsupportedEncodingException
PrintWriter(String outputFileName) throws FileNotFoundException
PrintWriter(String outputFileName, String charset)
  throws FileNotFoundException, UnsupportedEncodingException
```

These allow a PrintWriter to be created from a File object or by specifying the name of a file. In either case, the file is automatically created. Any preexisting file by the same name is destroyed. Once created, the PrintWriter object directs all output to the specified file. You can specify a character encoding by passing its name in charset.

PrintWriter supports the `print()` and `println()` methods for all types, including Object. If an argument is not a primitive type, the PrintWriter methods will call the object’s `toString()` method and then output the result.

PrintWriter also supports the `printf()` method. It works the same way it does in the PrintStream class described earlier: It allows you to specify the precise format of the data. Here is how `printf()` is declared in PrintWriter:

```java
PrintWriter printf(String fmtString, Object ... args)
PrintWriter printf(Locale loc, String fmtString, Object ... args)
```

The first version writes `args` to standard output in the format specified by `fmtString`, using the default locale. The second lets you specify a locale. Both return the invoking PrintWriter.

The `format()` method is also supported. It has these general forms:

```java
PrintWriter format(String fmtString, Object ... args)
PrintWriter format(Locale loc, String fmtString, Object ... args)
```

It works exactly like `printf()`.

The Console Class

The Console class was added to java.io by JDK 6. It is used to read from and write to the console, if one exists. It implements the Flushable interface. Console is primarily a convenience class because most of its functionality is available through System.in and System.out. However, its use can simplify some types of console interactions, especially when reading strings from the console.

Console supplies no constructors. Instead, a Console object is obtained by calling System.console(), which is shown here:
static Console console()

If a console is available, then a reference to it is returned. Otherwise, null is returned. A console will not be available in all cases. Thus, if null is returned, no console I/O is possible.

**Console** defines the methods shown in Table 20-5. Notice that the input methods, such as `readLine()`, throw `IOException` if an input error occurs. `IOException` is a subclass of `Error`. It indicates an I/O failure that is beyond the control of your program. Thus, you will not normally catch an `IOException`. Frankly, if an `IOException` is thrown while accessing the console, it usually means there has been a catastrophic system failure.

Also notice the `readPassword()` methods. These methods let your application read a password without echoing what is typed. When reading passwords, you should "zero-out" both the array that holds the string entered by the user and the array that holds the password that the string is tested against. This reduces the chance that a malicious program will be able to obtain a password by scanning memory.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void flush()</code></td>
<td>Causes buffered output to be written physically to the console.</td>
</tr>
<tr>
<td><code>Console format(String format, Object... arg)</code></td>
<td>Writes args to the console using the format specified by <code>format</code>.</td>
</tr>
<tr>
<td><code>Console printf(String format, Object... arg)</code></td>
<td>Writes args to the console using the format specified by <code>format</code>.</td>
</tr>
<tr>
<td><code>Reader reader()</code></td>
<td>Returns a reference to a <code>Reader</code> connected to the console.</td>
</tr>
<tr>
<td><code>String readLine()</code></td>
<td>Reads and returns a string entered at the keyboard. Input stops when the user presses ENTER. If the end of the console input stream has been reached, null is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>String readLine(String format, Object... arg)</code></td>
<td>Displays a prompting string formatted as specified by <code>format</code> and args, and then reads and returns a string entered at the keyboard. Input stops when the user presses ENTER. If the end of the console input stream has been reached, null is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>char[] readPassword()</code></td>
<td>Reads a string entered at the keyboard. Input stops when the user presses ENTER. The string is not displayed. If the end of the console input stream has been reached, null is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>char[] readPassword(String format, Object... arg)</code></td>
<td>Displays a prompting string formatted as specified by <code>format</code> and args, and then reads a string entered at the keyboard. Input stops when the user presses ENTER. The string is not displayed. If the end of the console input stream has been reached, null is returned. An <code>IOException</code> is thrown on failure.</td>
</tr>
<tr>
<td><code>PrintWriter writer()</code></td>
<td>Returns a reference to a <code>Writer</code> connected to the console.</td>
</tr>
</tbody>
</table>

**Table 20-5** The Methods Defined by **Console**

Here is an example that demonstrates the **Console** class:
Serialization

Serialization is the process of writing the state of an object to a byte stream. This is useful when you want to save the state of your program to a persistent storage area, such as a file. At a later time, you may restore these objects by using the process of deserialization. Serialization is also needed to implement Remote Method Invocation (RMI). RMI allows a Java object on one machine to invoke a method of a Java object on a different machine. An object may be supplied as an argument to that remote method. The sending machine serializes the object and transmits it. The receiving machine deserializes it. (More information about RMI appears in Chapter 30.)

Assume that an object to be serialized has references to other objects, which, in turn, have references to still more objects. This set of objects and the relationships among them form a directed graph. There may also be circular references within this object graph. That is, object X may contain a reference to object Y, and object Y may contain a reference back to object X. Objects may also contain references to themselves. The object serialization and deserialization facilities have been designed to work correctly in these scenarios. If you attempt to serialize an object at the top of an object graph, all of the other referenced objects are recursively located and serialized. Similarly, during the process of deserialization, all of these objects and their references are correctly restored.
An overview of the interfaces and classes that support serialization follows.

**Serializable**

Only an object that implements the *Serializable* interface can be saved and restored by the serialization facilities. The *Serializable* interface defines no members. It is simply used to indicate that a class may be serialized. If a class is serializable, all of its subclasses are also serializable.

Variables that are declared as *transient* are not saved by the serialization facilities. Also, *static* variables are not saved.

**Externalizable**

The Java facilities for serialization and deserialization have been designed so that much of the work to save and restore the state of an object occurs automatically. However, there are cases in which the programmer may need to have control over these processes. For example, it may be desirable to use compression or encryption techniques. The *Externalizable* interface is designed for these situations.

The *Externalizable* interface defines these two methods:

```java
void readExternal(ObjectInput inStream) throws IOException, ClassNotFoundException;
void writeExternal(ObjectOutput outStream) throws IOException;
```

In these methods, *inStream* is the byte stream from which the object is to be read, and *outStream* is the byte stream to which the object is to be written.

**ObjectOutput**

The *ObjectOutput* interface extends the *DataOutput* and *AutoCloseable* interfaces and supports object serialization. It defines the methods shown in Table 20-6. Note especially the *writeObject( )* method. This is called to serialize an object. All of these methods will throw an *IOException* on error conditions.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void close( )</code></td>
<td>Closes the invoking stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td><code>void flush( )</code></td>
<td>Finalizes the output state so any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td><code>void write(byte[] b, int offset, int numBytes)</code></td>
<td>Writes a subrange of <em>numBytes</em> bytes from the array <em>b</em> beginning at <em>offset</em>.</td>
</tr>
<tr>
<td><code>void write(int b)</code></td>
<td>Writes a single byte to the invoking stream. The byte written is the low-order byte of <em>b</em>.</td>
</tr>
<tr>
<td><code>void writeObject(Object obj)</code></td>
<td>Writes object <em>obj</em> to the invoking stream.</td>
</tr>
</tbody>
</table>
ObjectOutputStream

The **ObjectOutputStream** class extends the **OutputStream** class and implements the **ObjectOutput** interface. It is responsible for writing objects to a stream. One constructor of this class is shown here:

```
ObjectOutputStream(OutputStream outStream) throws IOException
```

The argument `outStream` is the output stream to which serialized objects will be written. Closing an **ObjectOutputStream** automatically closes the underlying stream specified by `outStream`.

Several commonly used methods in this class are shown in Table 20-7. They will throw an **IOException** on error conditions. There is also an inner class to **ObjectOutputStream** called **PutField**. It facilitates the writing of persistent fields, and its use is beyond the scope of this book.

---

**Table 20-6**  The Methods Defined by **ObjectOutput**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close()</td>
<td>Closes the invoking stream. Further write attempts will generate an IOException. The underlying stream is also closed.</td>
</tr>
<tr>
<td>void flush()</td>
<td>Finalizes the output state so any buffers are cleared. That is, it flushes the output buffers.</td>
</tr>
<tr>
<td>void write(byte[])</td>
<td>Writes an array of bytes to the invoking stream.</td>
</tr>
<tr>
<td>void write(byte[], int offset, int numbytes)</td>
<td>Writes a subrange of <code>numbytes</code> bytes from the array buffer, beginning at <code>offset</code>.</td>
</tr>
<tr>
<td>void write(int b)</td>
<td>Writes a single byte to the invoking stream. The byte written is the low-order byte of <code>b</code>.</td>
</tr>
<tr>
<td>void writeBoolean(boolean b)</td>
<td>Writes a boolean to the invoking stream.</td>
</tr>
<tr>
<td>void writeByte(int b)</td>
<td>Writes a byte to the invoking stream. The byte written is the low-order byte of <code>b</code>.</td>
</tr>
<tr>
<td>void writeBytes(String str)</td>
<td>Writes the bytes representing <code>str</code> to the invoking stream.</td>
</tr>
<tr>
<td>void writeChar(int c)</td>
<td>Writes a char to the invoking stream.</td>
</tr>
<tr>
<td>void writeChars(String str)</td>
<td>Writes the characters in <code>str</code> to the invoking stream.</td>
</tr>
<tr>
<td>void writeDouble(double d)</td>
<td>Writes a double to the invoking stream.</td>
</tr>
<tr>
<td>void writeFloat(float f)</td>
<td>Writes a float to the invoking stream.</td>
</tr>
<tr>
<td>void writeInt(int i)</td>
<td>Writes an int to the invoking stream.</td>
</tr>
<tr>
<td>void writeLong(long l)</td>
<td>Writes a long to the invoking stream.</td>
</tr>
<tr>
<td>final void writeObject(Object obj)</td>
<td>Writes <code>obj</code> to the invoking stream.</td>
</tr>
<tr>
<td>void writeShort(int i)</td>
<td>Writes a short to the invoking stream.</td>
</tr>
</tbody>
</table>

---

**Table 20-7**  A Sampling of Commonly Used Methods Defined by **ObjectOutputStream**

---

ObjectInput
The `ObjectInput` interface extends the `DataInput` and `AutoCloseable` interfaces and defines the methods shown in Table 20-8. It supports object serialization. Note especially the `readObject()` method. This is called to deserialize an object. All of these methods will throw an `IOException` on error conditions. The `readObject()` method can also throw `ClassNotFoundException`.

**ObjectInputStream**

The `ObjectInputStream` class extends the `InputStream` class and implements the `ObjectInput` interface. `ObjectInputStream` is responsible for reading objects from a stream. One constructor of this class is shown here:

```java
ObjectInputStream(InputStream inStream) throws IOException
```

The argument `inStream` is the input stream from which serialized objects should be read. Closing an `ObjectInputStream` automatically closes the underlying stream specified by `inStream`.

Several commonly used methods in this class are shown in Table 20-9. They will throw an `IOException` on error conditions. The `readObject()` method can also throw `ClassNotFoundException`. There is also an inner class to `ObjectInputStream` called `GetField`. It facilitates the reading of persistent fields, and its use is beyond the scope of this book.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int available()</code></td>
<td>Returns the number of bytes that are now available in the input buffer.</td>
</tr>
<tr>
<td><code>void close()</code></td>
<td>Closes the invoking stream. Further read attempts will generate an <code>IOException</code>.</td>
</tr>
<tr>
<td><code>int read()</code></td>
<td>Returns an integer representation of the next available byte of input. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td><code>int read(byte[] buf)</code></td>
<td>Attempts to read up to <code>buf.length</code> bytes into <code>buf</code>, returning the number of bytes that were successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td><code>int read(byte[] buf, int offset, int numBytes)</code></td>
<td>Attempts to read up to <code>numBytes</code> bytes into <code>buf</code> starting at <code>offset</code>, returning the number of bytes that were successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td><code>Object readObject()</code></td>
<td>Reads an object from the invoking stream.</td>
</tr>
<tr>
<td><code>long skip(long numBytes)</code></td>
<td>Ignores (that is, skips) <code>numBytes</code> bytes in the invoking stream, returning the number of bytes actually ignored.</td>
</tr>
</tbody>
</table>

Table 20-8  The Methods Defined by `ObjectInput`
A Serialization Example

The following program illustrates how to use object serialization and deserialization. It begins by instantiating an object of class MyClass. This object has three instance variables that are of types String, int, and double. This is the information we want to save and restore.

A FileOutputStream is created that refers to a file named "serial", and an ObjectOutputStream is created for that file stream. The writeObject() method of ObjectOutputStream is then used to serialize our object. The object output stream is flushed and closed.

A FileInputStream is then created that refers to the file named "serial", and an ObjectInputStream is created for that file stream. The readObject() method of ObjectInputStream is then used to deserialize our object. The object input stream is then closed.

Note that MyClass is defined to implement the Serializable interface. If this is not done, a NotSerializableException is thrown. Try experimenting with this program by declaring some of the MyClass instance variables to be transient. That data is then not saved during serialization.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>int available()</td>
<td>Returns the number of bytes that are now available in the input buffer.</td>
</tr>
<tr>
<td>void close()</td>
<td>Closes the invoking stream. Further read attempts will generate an IOException. The underlying stream is also closed.</td>
</tr>
<tr>
<td>int read()</td>
<td>Returns an integer representation of the next available byte of input. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>int read(byte buf[], int offset, int numBytes)</td>
<td>Attempts to read up to numBytes bytes into buf starting at buf[offset], returning the number of bytes successfully read. -1 is returned when the end of the file is encountered.</td>
</tr>
<tr>
<td>boolean readBoolean()</td>
<td>Reads and returns a boolean from the invoking stream.</td>
</tr>
<tr>
<td>byte readByte()</td>
<td>Reads and returns a byte from the invoking stream.</td>
</tr>
<tr>
<td>char readChar()</td>
<td>Reads and returns a char from the invoking stream.</td>
</tr>
<tr>
<td>double readDouble()</td>
<td>Reads and returns a double from the invoking stream.</td>
</tr>
<tr>
<td>float readFloat()</td>
<td>Reads and returns a float from the invoking stream.</td>
</tr>
<tr>
<td>void readFully(byte buf[])</td>
<td>Reads bytes into buf. Returns only when all bytes have been read.</td>
</tr>
<tr>
<td>void readFully(byte buf[], int offset, int numBytes)</td>
<td>Reads numBytes bytes into buf starting at buf[offset]. Returns only when numBytes have been read.</td>
</tr>
<tr>
<td>int readInt()</td>
<td>Reads and returns an int from the invoking stream.</td>
</tr>
<tr>
<td>long readLong()</td>
<td>Reads and returns a long from the invoking stream.</td>
</tr>
<tr>
<td>final Object readObject()</td>
<td>Reads and returns an object from the invoking stream.</td>
</tr>
<tr>
<td>short readShort()</td>
<td>Reads and returns a short from the invoking stream.</td>
</tr>
<tr>
<td>int readUnsignedByte()</td>
<td>Reads and returns an unsigned byte from the invoking stream.</td>
</tr>
<tr>
<td>int readUnsignedShort()</td>
<td>Reads and returns an unsigned short from the invoking stream.</td>
</tr>
</tbody>
</table>

Table 20-9  Commonly Used Methods Defined by ObjectInputStream
This program demonstrates that the instance variables of object1 and object2 are identical. The output is shown here:

object1: s=Hello; i=-7; d=2.7E10
object2: s=Hello; i=-7; d=2.7E10
Stream Benefits
The streaming interface to I/O in Java provides a clean abstraction for a complex and often cumbersome task. The composition of the filtered stream classes allows you to dynamically build the custom streaming interface to suit your data transfer requirements. Java programs written to adhere to the abstract, high-level **InputStream**, **OutputStream**, **Reader**, and **Writer** classes will function properly in the future even when new and improved concrete stream classes are invented. As you will see in Chapter 22, this model works very well when we switch from a file system–based set of streams to the network and socket streams. Finally, serialization of objects plays an important role in many types of Java programs. Java’s serialization I/O classes provide a portable solution to this sometimes tricky task.
Beginning with version 1.4, Java has provided a second I/O system called NIO (which is short for New I/O). It supports a buffer-oriented, channel-based approach to I/O operations. With the release of JDK 7, the NIO system was greatly expanded, providing enhanced support for file-handling and file system features. In fact, so significant were the changes that the term NIO.2 is often used. Because of the capabilities supported by the NIO file classes, NIO is expected to become an increasingly important approach to file handling. This chapter explores several of the key features of the NIO system.

**The NIO Classes**

The NIO classes are contained in the packages shown here:

<table>
<thead>
<tr>
<th>Package</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.nio</td>
<td>Top-level package for the NIO system. Encapsulates various types of buffers that contain data operated upon by the NIO system.</td>
</tr>
<tr>
<td>java.nio.channels</td>
<td>Supports channels, which are essentially open I/O connections.</td>
</tr>
<tr>
<td>java.nio.channels.spi</td>
<td>Supports service providers for channels.</td>
</tr>
<tr>
<td>java.nio.charset</td>
<td>Encapsulates character sets. Also supports encoders and decoders that convert characters to bytes and bytes to characters, respectively.</td>
</tr>
<tr>
<td>java.nio.charset.spi</td>
<td>Supports service providers for character sets.</td>
</tr>
<tr>
<td>java.nio.file</td>
<td>Provides support for files.</td>
</tr>
<tr>
<td>java.nio.file.attribute</td>
<td>Provides support for file attributes.</td>
</tr>
<tr>
<td>java.nio.file.spi</td>
<td>Supports service providers for file systems.</td>
</tr>
</tbody>
</table>

Before we begin, it is important to emphasize that the NIO subsystem does not replace the stream-based I/O classes found in java.io, which are discussed in Chapter 20, and good
working knowledge of the stream-based I/O in `java.io` is helpful to understanding NIO.

**NOTE** This chapter assumes that you have read the overview of I/O given in Chapter 13 and the discussion of stream-based I/O supplied in Chapter 20.

**NIO Fundamentals**

The NIO system is built on two foundational items: buffers and channels. A buffer holds data. A channel represents an open connection to an I/O device, such as a file or a socket. In general, to use the NIO system, you obtain a channel to an I/O device and a buffer to hold data. You then operate on the buffer, inputting or outputting data as needed. The following sections examine buffers and channels in more detail.

**Buffers**

Buffers are defined in the `java.nio` package. All buffers are subclasses of the `Buffer` class, which defines the core functionality common to all buffers: current position, limit, and capacity. The current position is the index within the buffer at which the next read or write operation will take place. The current position is advanced by most read or write operations. The limit is the index value one past the last valid location in the buffer. The capacity is the number of elements that the buffer can hold. Often the limit equals the capacity of the buffer. `Buffer` also supports mark and reset. `Buffer` defines several methods, which are shown in Table 21-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract Object array()</td>
<td>If the invoking buffer is backed by an array, returns a reference to the array. Otherwise, an <code>UnsupportedOperationException</code> is thrown. If the array is read-only, a <code>ReadOnlyBufferException</code> is thrown.</td>
</tr>
<tr>
<td>abstract int arrayOffset()</td>
<td>If the invoking buffer is backed by an array, returns the index of the first element. Otherwise, an <code>UnsupportedOperationException</code> is thrown. If the array is read-only, a <code>ReadOnlyBufferException</code> is thrown.</td>
</tr>
<tr>
<td>final int capacity()</td>
<td>Returns the number of elements that the invoking buffer is capable of holding.</td>
</tr>
<tr>
<td>final Buffer clear()</td>
<td>Clears the invoking buffer and returns a reference to the buffer.</td>
</tr>
<tr>
<td>final Buffer flip()</td>
<td>Sets the invoking buffer’s limit to the current position and resets the current position to 0. Returns a reference to the buffer.</td>
</tr>
<tr>
<td>abstract boolean hasArray()</td>
<td>Returns true if the invoking buffer is backed by a read/write array and false otherwise.</td>
</tr>
<tr>
<td>final boolean hasRemaining()</td>
<td>Returns true if there are elements remaining in the invoking buffer. Returns false otherwise.</td>
</tr>
</tbody>
</table>
From Buffer, the following specific buffer classes are derived, which hold the type of data that their names imply:

<table>
<thead>
<tr>
<th>Buffer Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>ByteBuffer</td>
</tr>
<tr>
<td>MappedByteBuffer</td>
</tr>
<tr>
<td>IntBuffer</td>
</tr>
<tr>
<td>LongBuffer</td>
</tr>
<tr>
<td>DoubleBuffer</td>
</tr>
<tr>
<td>FloatBuffer</td>
</tr>
<tr>
<td>ShortBuffer</td>
</tr>
</tbody>
</table>

**MappedByteBuffer** is a subclass of **ByteBuffer** and is used to map a file to a buffer. All of the aforementioned buffers provide various **get()** and **put()** methods, which allow you to get data from a buffer or put data into a buffer. (Of course, if a buffer is read-only, then **put()** operations are not available.) Table 21-2 shows the **get()** and **put()** methods defined by **ByteBuffer**. The other buffer classes have similar methods. All buffer classes also support methods that perform various buffer operations. For example, you can allocate a buffer manually using **allocate()**. You can wrap an array inside a buffer using **wrap()**. You can create a subsequence of a buffer using **slice()**.

**Channels**

Channels are defined in **java.nio.channels**. A channel represents an open connection to an I/O source or destination. Channels implement the **Channel** interface. It extends **Closeable**, and it extends **AutoCloseable**. By implementing **AutoCloseable**, channels can be managed with a **try**-with-resources statement. When used in a **try**-with-resources block, a channel is closed automatically when it is no longer needed. (See Chapter 13 for a discussion of **try**-with-resources.)
One way to obtain a channel is by calling `getChannel()` on an object that supports channels. For example, `getChannel()` is supported by the following I/O classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Channel Type</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>DatagramSocket</code></td>
<td><code>DatagramSocketChannel</code></td>
</tr>
<tr>
<td><code>FileInputStream</code></td>
<td><code>FileChannel</code></td>
</tr>
<tr>
<td><code>FileOutputStream</code></td>
<td><code>FileChannel</code></td>
</tr>
<tr>
<td><code>RandomAccessFile</code></td>
<td><code>FileChannel</code></td>
</tr>
<tr>
<td><code>ServerSocket</code></td>
<td><code>ServerSocketChannel</code></td>
</tr>
<tr>
<td><code>Socket</code></td>
<td><code>SocketChannel</code></td>
</tr>
</tbody>
</table>

The specific type of channel returned depends upon the type of object `getChannel()` is called on. For example, when called on a `FileInputStream`, `FileOutputStream`, or `RandomAccessFile`, `getChannel()` returns a channel of type `FileChannel`. When called on a `Socket`, `getChannel()` returns a `SocketChannel`.

Another way to obtain a channel is to use one of the `static` methods defined by the `Files` class. For example, using `Files`, you can obtain a byte channel by calling `newByteChannel()`. It returns a `SeekableByteChannel`, which is an interface implemented by `FileChannel`. (The `Files` class is examined in detail later in this chapter.) Channels such as `FileChannel` and `SocketChannel` support various `read()` and `write()` methods that enable you to perform I/O operations through the channel. For example, here are a few of the `read()` and `write()` methods defined for `FileChannel`.

---

### Table 21-2 The `get()` and `put()` Methods Defined for `ByteBuffer`

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>abstract byte get()</code></td>
<td>Returns the byte at the current position.</td>
</tr>
<tr>
<td><code>ByteBuffer get(byte value[])</code></td>
<td>Copies the invoking buffer into the array referred to by <code>value</code>. Returns a reference to the buffer. If there are not <code>value.length</code> elements remaining in the buffer, a <code>BufferUnderflowException</code> is thrown.</td>
</tr>
<tr>
<td><code>ByteBuffer get(byte value[], int start, int num)</code></td>
<td>Copies <code>num</code> elements from the invoking buffer into the array referred to by <code>value</code>, beginning at the index specified by <code>start</code>. Returns a reference to the buffer. If there are not <code>num</code> elements remaining in the buffer, a <code>BufferUnderflowException</code> is thrown.</td>
</tr>
<tr>
<td><code>abstract byte get(int index)</code></td>
<td>Returns the byte at the index specified by <code>index</code> within the invoking buffer.</td>
</tr>
<tr>
<td><code>abstract ByteBuffer put(byte b)</code></td>
<td>Copies <code>b</code> into the invoking buffer at the current position. Returns a reference to the buffer. If the buffer is full, a <code>BufferOverflowException</code> is thrown.</td>
</tr>
<tr>
<td><code>final ByteBuffer put(byte value[])</code></td>
<td>Copies all elements of <code>value</code> into the invoking buffer, beginning at the current position. Returns a reference to the buffer. If the buffer cannot hold all of the elements, a <code>BufferOverflowException</code> is thrown.</td>
</tr>
<tr>
<td><code>ByteBuffer put(byte value[], int start, int num)</code></td>
<td>Copies <code>num</code> elements from <code>value</code>, beginning at <code>start</code>, into the invoking buffer. Returns a reference to the buffer. If the buffer cannot hold all of the elements, a <code>BufferOverflowException</code> is thrown.</td>
</tr>
<tr>
<td><code>ByteBuffer put(ByteBuffer bb)</code></td>
<td>Copies the elements in <code>bb</code> to the invoking buffer, beginning at the current position. If the buffer cannot hold all of the elements, a <code>BufferOverflowException</code> is thrown. Returns a reference to the buffer.</td>
</tr>
<tr>
<td><code>abstract ByteBuffer put(int index, byte b)</code></td>
<td>Copies <code>b</code> into the invoking buffer at the location specified by <code>index</code>. Returns a reference to the buffer.</td>
</tr>
</tbody>
</table>
All channels support additional methods that give you access to and control over the channel. For example, **FileChannel** supports methods to get or set the current position, transfer information between file channels, obtain the current size of the channel, and lock the channel, among others. **FileChannel** provides a **static** method called **open()**, which opens a file and returns a channel to it. This provides another way to obtain a channel. **FileChannel** also provides the **map()** method, which lets you map a file to a buffer.

**Charsets and Selectors**

Two other entities used by NIO are charsets and selectors. A **charset** defines the way that bytes are mapped to characters. You can encode a sequence of characters into bytes using an **encoder**. You can decode a sequence of bytes into characters using a **decoder**. Charsets, encoders, and decoders are supported by classes defined in the **java.nio.charset** package. Because default encoders and decoders are provided, you will not often need to work explicitly with charsets.

A **selector** supports key-based, non-blocking, multiplexed I/O. In other words, selectors enable you to perform I/O through multiple channels. Selectors are supported by classes defined in the **java.nio.channels** package. Selectors are most applicable to socket-backed channels.

We will not use charsets or selectors in this chapter, but you might find them useful in your own applications.

**Enhancements Added to NIO by JDK 7**

Beginning with JDK 7, the NIO system was substantially expanded and enhanced. In addition to support for the **try-with-resources** statement (which provides automatic resource management), the improvements included three new packages (**java.nio.file**,** java.nio.file.attribute**, and **java.nio.file.spi**); several new classes, interfaces, and methods; and direct support for stream-based I/O. The additions have greatly expanded the ways in which NIO can be used, especially with files. Several of the key additions are

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract int read(ByteBuffer bb) throws IOException</td>
<td>Reads bytes from the invoking channel into bb until the buffer is full or there is no more input. Returns the number of bytes actually read. Returns -1 at end-of-stream.</td>
</tr>
<tr>
<td>abstract int read(ByteBuffer bb, long start) throws IOException</td>
<td>Beginning at the file location specified by start, reads bytes from the invoking channel into bb until the buffer is full or there is no more input. The current position is unchanged. Returns the number of bytes actually read or -1 if start is beyond the end of the file.</td>
</tr>
<tr>
<td>abstract int write(ByteBuffer bb) throws IOException</td>
<td>Writes the contents of bb to the invoking channel, starting at the current position. Returns the number of bytes written.</td>
</tr>
<tr>
<td>abstract int write(ByteBuffer bb, long start) throws IOException</td>
<td>Beginning at the file location specified by start, writes the contents of bb to the invoking channel. The current position is unchanged. Returns the number of bytes written.</td>
</tr>
</tbody>
</table>
The Path Interface

Perhaps the single most important addition to the NIO system is the Path interface because it encapsulates a path to a file. As you will see, Path is the glue that binds together many of the NIO.2 file-based features. It describes a file’s location within the directory structure. Path is packaged in java.nio.file, and it inherits the following interfaces: Watchable, Iterable<Path>, and Comparable<Path>. Watchable describes an object that can be monitored for changes. The Iterable and Comparable interfaces were described earlier in this book.

Path declares a number of methods that operate on the path. A sampling is shown in Table 21-3. Pay special attention to the getName( ) method. It is used to obtain an element in a path. It works using an index. At index zero is the part of the path nearest the root, which is the leftmost element in a path. Subsequent indexes specify elements to the right of the root. The number of elements in a path can be obtained by calling getNameCount( ). If you want to obtain a string representation of the entire path, simply call toString( ). Notice that you can resolve a relative path into an absolute path by using the resolve( ) method.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean endsWith(String path)</td>
<td>Returns true if the invoking Path ends with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean endsWith(Path path)</td>
<td>Returns true if the invoking Path ends with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path getFilePrefix()</td>
<td>Returns the filename associated with the invoking Path.</td>
</tr>
<tr>
<td>Path getName(int index)</td>
<td>Returns a Path object that contains the name of the path element specified by index within the invoking object. The leftmost element is at index 0. This is the element nearest the root. The rightmost element is at getNameCount() - 1.</td>
</tr>
<tr>
<td>int getNameCount()</td>
<td>Returns the number of elements beyond the root directory in the invoking Path.</td>
</tr>
<tr>
<td>Path getParent()</td>
<td>Returns a Path that contains the entire path except for the name of the file specified by the invoking Path.</td>
</tr>
<tr>
<td>Path getRoot()</td>
<td>Returns the root of the invoking Path.</td>
</tr>
<tr>
<td>boolean isAbsolute()</td>
<td>Returns true if the invoking Path is absolute. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path resolve(Path path)</td>
<td>If path is absolute, path is returned. Otherwise, if path does not contain a root, path is prefixed by the root specified by the invoking Path and the result is returned. If path is empty, the invoking Path is returned. Otherwise, the behavior is unspecified.</td>
</tr>
<tr>
<td>Path resolve(String path)</td>
<td>If path is absolute, path is returned. Otherwise, if path does not contain a root, path is prefixed by the root specified by the invoking Path and the result is returned. If path is empty, the invoking Path is returned. Otherwise, the behavior is unspecified.</td>
</tr>
<tr>
<td>boolean startsWith(String path)</td>
<td>Returns true if the invoking Path starts with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean startsWith(Path path)</td>
<td>Returns true if the invoking Path starts with the path specified by path. Otherwise, returns false.</td>
</tr>
<tr>
<td>Path toAbsolutePath()</td>
<td>Returns the invoking Path as an absolute path.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns a string representation of the invoking Path.</td>
</tr>
</tbody>
</table>
One other point: When updating legacy code that uses the `File` class defined by `java.io`, it is possible to convert a `File` instance into a `Path` instance by calling `toPath()` on the `File` object. Furthermore, it is possible to obtain a `File` instance by calling the `toFile()` method defined by `Path`.

**The Files Class**

Many of the actions that you perform on a file are provided by static methods within the `Files` class. The file to be acted upon is specified by its `Path`. Thus, the `Files` methods use a `Path` to specify the file that is being operated upon. `Files` contains a wide array of functionality. For example, it has methods that let you open or create a file that has the specified path. You can obtain information about a `Path`, such as whether it is executable, hidden, or read-only. `Files` also supplies methods that let you copy or move files. A sampling is shown in Table 21-4. In addition to `IOException`, several other exceptions are possible. JDK 8 adds these four methods to `Files`: `list()`, `walk()`, `lines()`, and `find()`. All return a `Stream` object. These methods help integrate NIO with the new stream API defined by JDK 8 and described in Chapter 29.

Notice that several of the methods in Table 21-4 take an argument of type `OpenOption`. This is an interface that describes how to open a file. It is implemented by the `StandardOpenOption` class, which defines an enumeration that has the values shown in Table 21-5.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>static Path copy(Path src, Path dest, CopyOption ... how)</code> throws IOException</td>
<td>Copies the file specified by <code>src</code> to the location specified by <code>dest</code>. The <code>how</code> parameter specifies how the copy will take place.</td>
</tr>
<tr>
<td><code>static Path createDirectory(Path path, FileAttribute&lt;? ... attribute&gt;) throws IOException</code></td>
<td>Creates the directory whose path is specified by <code>path</code>. The directory attributes are specified by <code>attribute</code>.</td>
</tr>
<tr>
<td><code>static Path createFile(Path path, FileAttribute&lt;? ... attribute&gt;) throws IOException</code></td>
<td>Creates the file whose path is specified by <code>path</code>. The file attributes are specified by <code>attribute</code>.</td>
</tr>
<tr>
<td><code>static void delete(Path path)</code> throws IOException</td>
<td>Deletes the file whose path is specified by <code>path</code>.</td>
</tr>
<tr>
<td><code>static boolean exists(Path path, LinkOption ... options)</code></td>
<td>Returns true if the file specified by <code>path</code> exists and false otherwise. If <code>options</code> is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass <code>NOFOLLOW_LINKS</code> to <code>options</code>.</td>
</tr>
<tr>
<td><code>static boolean isDirectory(Path path, LinkOption ... options)</code></td>
<td>Returns true if <code>path</code> specifies a directory and false otherwise. If <code>options</code> is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass <code>NOFOLLOW_LINKS</code> to <code>options</code>.</td>
</tr>
<tr>
<td><code>static boolean isExecutable(Path path)</code></td>
<td>Returns true if the file specified by <code>path</code> is executable and false otherwise.</td>
</tr>
<tr>
<td><code>static boolean isHidden(Path path)</code> throws IOException</td>
<td>Returns true if the file specified by <code>path</code> is hidden and false otherwise.</td>
</tr>
<tr>
<td><code>static boolean isReadable(Path path)</code></td>
<td>Returns true if the file specified by <code>path</code> can be read from and false otherwise.</td>
</tr>
<tr>
<td><code>static boolean isRegularFile(Path path, LinkOption ... options)</code></td>
<td>Returns true if <code>path</code> specifies a file and false otherwise. If <code>options</code> is not specified, then symbolic links are followed. To prevent the following of symbolic links, pass <code>NOFOLLOW_LINKS</code> to <code>options</code>.</td>
</tr>
<tr>
<td><code>static boolean isWritable(Path path)</code></td>
<td>Returns true if the file specified by <code>path</code> can be written to and false otherwise.</td>
</tr>
<tr>
<td><code>static Path move(Path src, Path dest, CopyOption ... how)</code> throws IOException</td>
<td>Moves the file specified by <code>src</code> to the location specified by <code>dest</code>. The <code>how</code> parameter specifies how the move will take place.</td>
</tr>
<tr>
<td><code>static SeekableByteChannel newByteChannel(Path path, OpenOption ... options)</code> throws IOException</td>
<td>Opens the file specified by <code>path</code>, as specified by <code>options</code>. Returns a <code>SeekableByteChannel</code> to the file. This is a byte channel whose current position can be changed. <code>SeekableByteChannel</code> is implemented by <code>FileChannel</code>.</td>
</tr>
<tr>
<td><code>static DirectoryStream&lt;Path&gt; newDirectoryStream(Path path)</code> throws IOException</td>
<td>Opens the directory specified by <code>path</code>. Returns a <code>DirectoryStream</code> linked to the directory.</td>
</tr>
</tbody>
</table>
The Paths Class

Because Path is an interface, not a class, you can’t create an instance of Path directly through the use of a constructor. Instead, you obtain a Path by calling a method that returns one. Frequently, you do this by using the get() method defined by the Paths class. There are two forms of get(). The one used in this chapter is shown here:

```
static Path get(String pathname, String ... parts)
```

It returns a Path that encapsulates the specified path. The path can be specified in two ways. First, if parts is not used, then the path must be specified in its entirety by pathname. Alternatively, you can pass the path in pieces, with the first part
passed in `pathname` and the subsequent elements specified by the `parts` varargs parameter. In either case, if the path specified is syntactically invalid, `get()` will throw an `InvalidPathException`.

The second form of `get()` creates a `Path` from a `URI`. It is shown here:

```java
static Path get(URI uri)
```

The `Path` corresponding to `uri` is returned.

It is important to understand that creating a `Path` to a file does not open or create a file. It simply creates an object that encapsulates the file's directory path.

### The File Attribute Interfaces

Associated with a file is a set of attributes. These attributes include such things as the file's time of creation, the time of its last modification, whether the file is a directory, and its size. NIO organizes file attributes into several different interfaces. Attributes are represented by a hierarchy of interfaces defined in `java.nio.file.attribute`. At the top is `BasicFileAttributes`. It encapsulates the set of attributes that are commonly found in a variety of file systems. The methods defined by `BasicFileAttributes` are shown in Table 21-6.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>FileTime createTime()</code></td>
<td>Returns the time at which the file was created. If the creation time is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td><code>Object FileKey()</code></td>
<td>Returns the file key. If not supported, <code>null</code> is returned.</td>
</tr>
<tr>
<td><code>boolean isDirectory()</code></td>
<td>Returns <code>true</code> if the file represents a directory.</td>
</tr>
<tr>
<td><code>boolean isOther()</code></td>
<td>Returns <code>true</code> if the file is not a file, symbolic link, or a directory.</td>
</tr>
<tr>
<td><code>boolean isRegularFile()</code></td>
<td>Returns <code>true</code> if the file is a normal file, rather than a directory or symbolic link.</td>
</tr>
<tr>
<td><code>boolean isSymbolicLink()</code></td>
<td>Returns <code>true</code> if the file is a symbolic link.</td>
</tr>
<tr>
<td><code>FileTime lastAccessTime()</code></td>
<td>Returns the time at which the file was last accessed. If the time of last access is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td><code>FileTime lastModifiedTime()</code></td>
<td>Returns the time at which the file was last modified. If the time of last modification is not provided by the file system, then an implementation-dependent value is returned.</td>
</tr>
<tr>
<td><code>long size()</code></td>
<td>Returns the size of the file.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean isArchive()</code></td>
<td>Returns <code>true</code> if the file is flagged for archiving and <code>false</code> otherwise.</td>
</tr>
</tbody>
</table>

From `BasicFileAttributes` two interfaces are derived: `DosFileAttributes` and `PosixFileAttributes`. `DosFileAttributes` describes those attributes related to the FAT file system as first defined by DOS. It defines the methods shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean isArchive()</code></td>
<td>Returns <code>true</code> if the file is flagged for archiving and <code>false</code> otherwise.</td>
</tr>
</tbody>
</table>
### boolean isHidden()
Returns **true** if the file is hidden and **false** otherwise.

### boolean isReadOnly()
Returns **true** if the file is read-only and **false** otherwise.

### boolean isSystem()
Returns **true** if the file is flagged as a system file and **false** otherwise.

---

**PosixFileAttributes** encapsulates attributes defined by the POSIX standards. (POSIX stands for *Portable Operating System Interface.*) It defines the methods shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>GroupPrincipal group()</td>
<td>Returns the file’s group owner.</td>
</tr>
<tr>
<td>UserPrincipal owner()</td>
<td>Returns the file’s owner.</td>
</tr>
<tr>
<td>Set&lt;PosixFilePermission&gt; permissions()</td>
<td>Returns the file’s permissions.</td>
</tr>
</tbody>
</table>

There are various ways to access a file’s attributes. First, you can obtain an object that encapsulates a file’s attributes by calling **readAttributes()**, which is a **static** method defined by **Files**. One of its forms is shown here:

```java
static <A extends BasicFileAttributes>
    A readAttributes(Path path, Class<A> attrType, LinkOption... opts)
    throws IOException
```

This method returns a reference to an object that specifies the attributes associated with the file passed in *path*. The specific type of attributes is specified as a **Class** object in the *attrType* parameter. For example, to obtain the basic file attributes, pass **BasicFileAttributes.class** to *attrType*. For DOS attributes, use **DosFileAttributes.class**, and for POSIX attributes, use **PosixFileAttributes.class**.

Optional link options are passed via *opts*. If not specified, symbolic links are followed. The method returns a reference to requested attributes. If the requested attribute type is not available, **UnsupportedOperationException** is thrown. Using the object returned, you can access the file’s attributes.

A second way to gain access to a file’s attributes is to call **getFileAttributeView()** defined by **Files**. NIO defines several attribute view interfaces, including **AttributeView**, **BasicFileAttributeView**, **DosFileAttributeView**, and **PosixFileAttributeView**, among others. Although we won’t be using attribute views in this chapter, they are a feature that you may find helpful in some situations.

In some cases, you won’t need to use the file attribute interfaces directly because the **Files** class offers **static** convenience methods that access several of the attributes. For example,
Files includes methods such as `isHidden()` and `isWritable()`.

It is important to understand that not all file systems support all possible attributes. For example, the DOS file attributes apply to the older FAT file system as first defined by DOS. The attributes that will apply to a wide variety of file systems are described by `BasicFileAttributes`. For this reason, these attributes are used in the examples in this chapter.

**The FileSystem, FileSystems, and FileStore Classes**

You can easily access the file system through the `FileSystem` and `FileSystems` classes packaged in `java.nio.file`. In fact, by using the `newFileSystem()` method defined by `FileSystems`, it is even possible to obtain a new file system. The `FileStore` class encapsulates the file storage system. Although these classes are not used directly in this chapter, you may find them helpful in your own applications.

**Using the NIO System**

This section illustrates how to apply the NIO system to a variety of tasks. Before beginning, it is important to emphasize that with the release of JDK 7, the NIO subsystem was greatly expanded. As a result, its uses have also been greatly expanded. As mentioned, the enhanced version is sometimes referred to as NIO.2. Because the features added by NIO.2 are so substantial, they have changed the way that much NIO-based code is written and have increased the types of tasks to which NIO can be applied. Because of its importance, most of the remaining discussion and examples in this chapter utilize NIO.2 features and, therefore, require JDK 7, JDK 8, or later. However, at the end of the chapter is a brief description of pre-JDK 7 code. This will be of aid to those programmers working in pre-JDK 7 environments or maintaining older code.

---

**REMEMBER** Most of the examples in this chapter require JDK 7 or later.

In the past, the primary purpose of NIO was channel-based I/O, and this is still a very important use. However, you can now use NIO for stream-based I/O and for performing file-system operations. As a result, the discussion of using NIO is divided into three parts:

- Using NIO for channel-based I/O
- Using NIO for stream-based I/O
- Using NIO for path and file system operations

Because the most common I/O device is the disk file, the rest of this chapter uses
disk files in the examples. Because all file channel operations are byte-based, the type of buffers that we will be using are of type ByteBuffer. Before you can open a file for access via the NIO system, you must obtain a Path that describes the file. One way to do this is to call the Paths.get() factory method, which was described earlier. The form of get() used in the examples is shown here:

```java
static Path get(String pathname, String ... parts)
```

Recall that the path can be specified in two ways. It can be passed in pieces, with the first part passed in pathname and the subsequent elements specified by the parts varargs parameter. Alternatively, the entire path can be specified in pathname and parts is not used. This is the approach used by the examples.

### Use NIO for Channel-Based I/O

An important use of NIO is to access a file via a channel and buffers. The following sections demonstrate some techniques that use a channel to read from and write to a file.

#### Reading a File via a Channel

There are several ways to read data from a file using a channel. Perhaps the most common way is to manually allocate a buffer and then perform an explicit read operation that loads that buffer with data from the file. It is with this approach that we begin.

Before you can read from a file, you must open it. To do this, first create a Path that describes the file. Then use this Path to open the file. There are various ways to open the file depending on how it will be used. In this example, the file will be opened for byte-based input via explicit input operations. Therefore, this example will open the file and establish a channel to it by calling Files.newByteChannel(). The newByteChannel() method has this general form:

```java
static SeekableByteChannel newByteChannel(Path path, OpenOption ... how)
```

It returns a SeekableByteChannel object, which encapsulates the channel for file operations. The Path that describes the file is passed in path. The how parameter specifies how the file will be opened. Because it is a varargs parameter, you can specify zero or more comma-separated arguments. (The valid values were discussed earlier and shown in Table 21-5.) If no arguments are specified, the file is opened for input operations. SeekableByteChannel is an interface that describes a channel that can be used for file operations. It is implemented by the FileChannel class. When the default file system is used, the returned object can be cast to FileChannel. You must close the channel after you have finished with it. Since all channels, including FileChannel, implement AutoCloseable, you can use a try-with-resources statement to close the file automatically instead of calling close() explicitly. This approach is used in the examples.

Next, you must obtain a buffer that will be used by the channel either by wrapping an
existing array or by allocating the buffer dynamically. The examples use allocation, but the choice is yours. Because file channels operate on byte buffers, we will use the `allocate()` method defined by `ByteBuffer` to obtain the buffer. It has this general form:

```java
static ByteBuffer allocate(int cap)
```

Here, `cap` specifies the capacity of the buffer. A reference to the buffer is returned. After you have created the buffer, call `read()` on the channel, passing a reference to the buffer. The version of `read()` that we will use is shown next:

```java
int read(ByteBuffer buf) throws IOException
```

Each time it is called, `read()` fills the buffer specified by `buf` with data from the file. The reads are sequential, meaning that each call to `read()` reads the next buffer’s worth of bytes from the file. The `read()` method returns the number of bytes actually read. It returns –1 when there is an attempt to read at the end of the file.

The following program puts the preceding discussion into action by reading a file called `test.txt` through a channel using explicit input operations:

```java
// Use Channel I/O to read a file. Requires JDK 7 or later.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;
```
Here is how the program works. First, a Path object is obtained that contains the relative path to a file called test.txt. A reference to this object is assigned to filepath. Next, a channel connected to the file is obtained by calling newByteChannel(), passing in filepath. Because no open option is specified, the file is opened for reading. Notice that this channel is the object managed by the try-with-resources statement. Thus, the channel is automatically closed when the block ends. The program then calls the allocate() method of ByteBuffer to allocate a buffer that will hold the contents of the file when it is read. A reference to this buffer is stored in mBuf. The contents of the file are then read, one buffer at a time, into mBuf through a call to read(). The number of bytes read is stored in count. Next, the buffer is rewound through a call to rewind(). This call is necessary because the current position is at the end of the buffer after the call to read(). It must be
reset to the start of the buffer in order for the bytes in `mBuf` to be read by calling `get()`.
(Recall that `get()` is defined by `ByteBuffer`.) Because `mBuf` is a byte buffer, the values returned by `get()` are bytes. They are cast to `char` so the file can be displayed as text.
(Alternatively, it is possible to create a buffer that encodes the bytes into characters and then read that buffer.) When the end of the file has been reached, the value returned by `read()` will be –1. When this occurs, the program ends, and the channel is automatically closed.

As a point of interest, notice that the program obtains the `Path` within one `try` block and then uses another `try` block to obtain and manage a channel linked to that path. Although there is nothing wrong, per se, with this approach, in many cases, it can be streamlined so that only one `try` block is needed. In this approach, the calls to `Paths.get()` and `newByteChannel()` are sequenced together. For example, here is a reworked version of the program that uses this approach:

```java
// A more compact way to open a channel. Requires JDK 7 or later.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class ExplicitChannelRead {
    public static void main(String args[]) {
        int count;

        // Here, the channel is opened on the Path returned by Paths.get().
        // There is no need for the filepath variable.
        try (SeekableByteChannel fChan =
            Files.newByteChannel(Paths.get("test.txt")))
        {
            // Allocate a buffer.
            ByteBuffer mBuf = ByteBuffer.allocate(128);

            do {
                // Read a buffer.
                count = fChan.read(mBuf);

                // Stop when end of file is reached.
                if(count != -1) {

                    // Rewind the buffer so that it can be read.
                    mBuf.rewind();

                    // Read bytes from the buffer and show
                    // them on the screen as characters.
                    for(int i=0; i < count; i++)
                        System.out.print((char)mBuf.get());
                }
            } while(count != -1);
        }
    }
}
```
In this version, the variable `filepath` is not needed and both exceptions are handled by the same `try` statement. Because this approach is more compact, it is the approach used in the rest of the examples in this chapter. Of course, in your own code, you may encounter situations in which the creation of a `Path` object needs to be separate from the acquisition of a channel. In these cases, the previous approach can be used.

Another way to read a file is to map it to a buffer. The advantage is that the buffer automatically contains the contents of the file. No explicit read operation is necessary. To map and read the contents of a file, follow this general procedure. First, obtain a `Path` object that encapsulates the file as previously described. Next, obtain a channel to that file by calling `Files.newByteChannel()`, passing in the `Path` and casting the returned object to `FileChannel`. As explained, `newByteChannel()` returns a `SeekableByteChannel`. When using the default file system, this object can be cast to `FileChannel`. Then, map the channel to a buffer by calling `map()` on the channel. The `map()` method is defined by `FileChannel`. This is why the cast to `FileChannel` is needed. The `map()` function is shown here:

```java
MappedByteBuffer map(FileChannel.MapMode how, long pos, long size) throws IOException
```

The `map()` method causes the data in the file to be mapped into a buffer in memory. The value in `how` determines what type of operations are allowed. It must be one of these values:

<table>
<thead>
<tr>
<th>MapMode.READ_ONLY</th>
<th>MapMode.READ_WRITE</th>
<th>MapMode.PRIVATE</th>
</tr>
</thead>
</table>

For reading a file, use `MapMode.READ_ONLY`. To read and write, use `MapMode.READ_WRITE`. `MapMode.PRIVATE` causes a private copy of the file to be made, and changes to the buffer do not affect the underlying file. The location within the file to begin mapping is specified by `pos`, and the number of bytes to map are specified by `size`. A reference to this buffer is returned as a `MappedByteBuffer`, which is a subclass of `ByteBuffer`. Once the file has been mapped to a buffer, you can read the file from that buffer. Here is an example that illustrates this approach:
In the program, a Path to the file is created and then opened via newByteChannel().  
The channel is cast to FileChannel and stored in fChan. Next, the size of the file is
obtained by calling size() on the channel. Then, the entire file is mapped into memory by
calling map() on fChan and a reference to the buffer is stored in mBuf. Notice that
mBuf is declared as a reference to a MappedByteBuffer. The bytes in mBuf are read by
calling get().

Writing to a File via a Channel
As is the case when reading from a file, there are also several ways to write data to a file
using a channel. We will begin with one of the most common. In this approach, you
manually allocate a buffer, write data to that buffer, and then perform an explicit write
operation to write that data to a file.
Before you can write to a file, you must open it. To do this, first obtain a Path that describes
the file and then use this Path to open the file. In this example, the file will be opened for
byte-based output via explicit output operations. Therefore, this example will open the file
and establish a channel to it by calling Files.newByteChannel(). As shown in the
previous section, the newByteChannel() method has this general form:

    static SeekableByteChannel newByteChannel(Path path, OpenOption ... how)
throws IOException

It returns a **SeekableByteChannel** object, which encapsulates the channel for file operations. To open a file for output, the *how* parameter must specify **StandardOpenOption.WRITE**. If you want to create the file if it does not already exist, then you must also specify **StandardOpenOption.CREATE**. (Other options, which are shown in Table 21-5, are also available.) As explained in the previous section, **SeekableByteChannel** is an interface that describes a channel that can be used for file operations. It is implemented by the **FileChannel** class. When the default file system is used, the return object can be cast to **FileChannel**. You must close the channel after you have finished with it.

Here is one way to write to a file through a channel using explicit calls to **write( )**. First, obtain a **Path** to the file and then open it with a call to **newByteChannel( )**, casting the result to **FileChannel**. Next, allocate a byte buffer and write data to that buffer. Before the data is written to the file, call **rewind( )** on the buffer to set its current position to zero. (Each output operation on the buffer increases the current position. Thus, it must be reset prior to writing to the file.) Then, call **write( )** on the channel, passing in the buffer. The following program demonstrates this procedure. It writes the alphabet to a file called **test.txt**.
It is useful to emphasize an important aspect of this program. As mentioned, after data is written to mBuf, but before it is written to the file, a call to rewind() on mBuf is made. This is necessary in order to reset the current position to zero after data has been written to mBuf. Remember, each call to put() on mBuf advances the current position. Therefore, it is necessary for the current position to be reset to the start of the buffer before calling write(). If this is not done, write() will think that there is no data in the buffer.

Another way to handle the resetting of the buffer between input and output operations is to call flip() instead of rewind(). The flip() method sets the value of the current position to zero and the limit to the previous current position. In the preceding example, because the capacity of the buffer equals its limit, flip() could have been used instead of rewind(). However, the two methods are not interchangeable in all cases.

In general, you must reset the buffer between read and write operations. For example, assuming the preceding example, the following loop will write the alphabet to the file three
times. Pay special attention to the calls to `rewind()`.

```java
for(int h=0; h<3; h++) {
    // Write some bytes to the buffer.
    for(int i=0; i<26; i++)
        mBuf.put((byte) ('A' + i));

    // Rewind the buffer so that it can be written.
    mBuf.rewind();

    // Write the buffer to the output file.
    fChan.write(mBuf);

    // Rewind the buffer so that it can be written to again.
    mBuf.rewind();
}
```

Notice that `rewind()` is called between each read and write operation.

One other thing about the program warrants mentioning: When the buffer is written to the file, the first 26 bytes in the file will contain the output. If the file `test.txt` was preexisting, then after the program executes, the first 26 bytes of `test.txt` will contain the alphabet, but the remainder of the file will remain unchanged.

Another way to write to a file is to map it to a buffer. The advantage to this approach is that the data written to the buffer will automatically be written to the file. No explicit write operation is necessary. To map and write the contents of a file, we will use this general procedure. First, obtain a `Path` object that encapsulates the file and then create a channel to that file by calling `Files.newByteChannel()`, passing in the `Path`. Cast the reference returned by `newByteChannel()` to `FileChannel`. Next, map the channel to a buffer by calling `map()` on the channel. The `map()` method was described in detail in the previous section. It is summarized here for your convenience. Here is its general form:

```
MappedByteBuffer map(FileChannel fc, MapMode how, long pos, long size) throws IOException
```

The `map()` method causes the data in the file to be mapped into a buffer in memory. The value in `how` determines what type of operations are allowed. For writing to a file, `how` must be `MapMode.READ_WRITE`. The location within the file to begin mapping is specified by `pos`, and the number of bytes to map are specified by `size`. A reference to this buffer is returned. Once the file has been mapped to a buffer, you can write data to that buffer, and it will automatically be written to the file. Therefore, no explicit write operations to the channel are necessary.

Here is the preceding program reworked so that a mapped file is used. Notice that in the call to `newByteChannel()`, the open option `StandardOpenOption.READ` has been
added. This is because a mapped buffer can either be read-only or read/write. Thus, to write to the mapped buffer, the channel must be opened as read/write.

```java
// Write to a mapped file. Requires JDK 7 or later.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class MappedChannelWrite {
    public static void main(String args[]) {
        // Obtain a channel to a file within a try-with-resources block.
        try (FileChannel fChan = FileChannel.open(Paths.get("test.txt"),
            StandardOpenOption.WRITE,
            StandardOpenOption.READ,
            StandardOpenOption.CREATE)) {
            // Then, map the file into a buffer.
            MappedByteBuffer mBuf = fChan.map(FileChannel.MapMode.READ_WRITE, 0, 26);

            // Write some bytes to the buffer.
            for (int i = 0; i < 26; i++)
                mBuf.put((byte)('A' + i));

            // catch(InvalidPathException e) {
            System.out.println("Path Error " + e);
            // catch (IOException e) {
            System.out.println("I/O Error " + e);
        }
    }
}
```

As you can see, there are no explicit write operations to the channel itself. Because `mBuf` is mapped to the file, changes to `mBuf` are automatically reflected in the underlying file.

**Copying a File Using NIO**

NIO simplifies several types of file operations. Although we can’t examine them all, an example will give you an idea of what is available. The following program copies a file using a call to a single NIO method: `copy()`, which is a `static` method defined by `Files`. It has several forms. Here is the one we will be using:

```
static Path copy(Path src, Path dest, CopyOption ... how) throws IOException
```

The file specified by `src` is copied to the file specified by `dest`. How the copy is performed is specified by `how`. Because it is a varargs parameter, it can be missing. If specified, it can be one or more of these values, which are valid for all file systems:
Other options may be supported, depending on the implementation.
The following program demonstrates `copy()` function. The source and destination files are specified on the command line, with the source file specified first. Notice how short the program is.
You might want to compare this version of the file copy program to the one found in Chapter 13. As you will find, the part of the program that actually copies the file is substantially shorter in the NIO version shown here.

```java
// Copy a file using NIO. Requires JDK 7 or later.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;
import java.nio.file.*;

public class NIOCopy {
    public static void main(String[] args) {
        if (args.length != 2) {
            System.out.println("Usage: Copy from to");
            return;
        }

        try {
            Path source = Paths.get(args[0]);
            Path target = Paths.get(args[1]);

            // Copy the file.
            Files.copy(source, target, StandardCopyOption.REPLACE_EXISTING);
        } catch (InvalidPathException e) {
            System.out.println("Path Error " + e);
        } catch (IOException e) {
            System.out.println("I/O Error " + e);
        }
    }
}
```

**Use NIO for Stream-Based I/O**
Beginning with NIO.2, you can use NIO to open an I/O stream. Once you have a `Path`, open a file by calling `newInputStream()` or `newOutputStream()`, which are static methods defined by `Files`. These methods return a stream connected to the specified file. In either case, the stream can then be operated on in the way described in Chapter 20, and the same techniques apply. The advantage of using `Path` to open a file is that all of the features defined by NIO are available for your use.
To open a file for stream-based input, use `Files.newInputStream()`.

```java
static InputStream newInputStream(Path path, OpenOption ... how)
    throws IOException
```

Here, `path` specifies the file to open and `how` specifies how the file will be opened. It must be one or more of the values defined by `StandardOpenOption`, described earlier. (Of course, only those options that relate to an input stream will apply.) If no options are specified, then the file is opened as if `StandardOpenOption.READ` were passed.

Once opened, you can use any of the methods defined by `InputStream`. For example, you can use `read()` to read bytes from the file.

The following program demonstrates the use of NIO-based stream I/O. It reworks the `ShowFile` program from Chapter 13 so that it uses NIO features to open the file and obtain a stream. As you can see, it is very similar to the original, except for the use of `Path` and `newInputStream()`.
Because the stream returned by `newInputStream()` is a normal stream, it can be used like any other stream. For example, you can wrap the stream inside a buffered stream, such as a `BufferedInputStream`, to provide buffering, as shown here:

```java
new BufferedInputStream(Files.newInputstream(Paths.get(args[0])))
```

Now, all reads will be automatically buffered.

To open a file for output, use `Files.newOutputStream()`. It is shown here:

```java
static OutputStream newOutputStream(Path path, OpenOption ... how)
    throws IOException
```

Here, `path` specifies the file to open and `how` specifies how the file will be opened.
It must be one or more of the values defined by `StandardOpenOption`, described earlier. (Of course, only those options that relate to an output stream will apply.) If no options are specified, then the file is opened as if `StandardOpenOption.WRITE`, `StandardOpenOption.CREATE`, and `StandardOpenOption.TRUNCATE_EXISTING` were passed.

The methodology for using `newOutputStream()` is similar to that shown previously for `newInputStream()`. Once opened, you can use any of the methods defined by `OutputStream`. For example, you can use `write()` to write bytes to the file. You can also wrap the stream inside a `BufferedOutputStream` to buffer the stream.

The following program shows `newOutputStream()` in action. It writes the alphabet to a file called `test.txt`. Notice the use of buffered I/O.

```java
// Demonstrate NIO-based, stream output. Requires JDK 7 or later.
import java.io.*;
import java.nio.*;

class NIOStreamWrite {
    public static void main(String[] args) {
        // Open the file and obtain a stream linked to it.
        try (OutputStream fout =
            new BufferedOutputStream(
                Files.newOutputStream(Paths.get("test.txt")))) {
            // Write some bytes to the stream.
            for (int i = 0; i < 26; i++)
                fout.write((byte) ('A' + i));
        } catch (InvalidPathException e) {
            System.out.println("Path Error " + e);
        } catch (IOException e) {
            System.out.println("I/O Error: " + e);
        }
    }
}
```

**Use NIO for Path and File System Operations**

At the beginning of Chapter 20, the `File` class in the `java.io` package was examined. As explained there, the `File` class deals with the file system and with the various attributes associated with a file, such as whether a file is read-only, hidden, and so on. It was also used to obtain information about a file's path. Although the `File` class is still perfectly acceptable, the interfaces and classes defined by NIO.2 offer a better way to perform these functions. The benefits include support for symbolic links, better support for directory tree traversal, and improved handling of metadata, among others. The following sections show samples of two common file system operations: obtaining information about a path and file and getting
the contents of a directory.

REMEMBER If you want to update older code that uses java.io.File to the new Path interface, you can use the toPath( ) method to obtain a Path instance from a File instance.

Obtain Information About a Path and a File
Information about a path can be obtained by using methods defined by Path. Some attributes associated with the file described by a Path (such as whether or not the file is hidden) are obtained by using methods defined by Files. The Path methods used here are getName( ), getParent( ), and toAbsolutePath( ). Those provided by Files are isExecutable( ), isHidden( ), isReadable( ), isWritable( ), and exists( ). These are summarized in Tables 21-3 and 21-4, shown earlier.

CAUTION Methods such as isExecutable( ), isReadable( ), isWritable( ), and exists( ) must be used with care because the state of the file system may change after the call, in which case a program malfunction could occur. Such a situation could have security implications.

Other file attributes are obtained by requesting a list of attributes by calling Files.readAttributes( ). In the program, this method is called to obtain the BasicFileAttributes associated with a file, but the general approach applies to other types of attributes.
The following program demonstrates several of the Path and Files methods, along with several methods provided by BasicFileAttributes. This program assumes that a file called test.txt exists in a directory called examples, which must be a subdirectory of the current directory.
// Obtain information about a path and a file.
// Requires JDK 7 or later.

import java.io.*;
import java.nio.file.*;
import java.nio.file.attribute.*;

class PathDemo {
    public static void main(String args[]) {
        Path filepath = Paths.get("examples\test.txt");
    }
}
If you execute this program from a directory called MyDir, which has a subdirectory called examples, and the examples directory contains the test.txt file, then you will see output similar to that shown here. (Of course, the information you see will differ.)
If you are using a computer that supports the FAT file system (i.e., the DOS file system), then you might want to try using the methods defined by `DosFileAttributes`. If you are using a POSIX-compatible system, then try using `PosixFileAttributes`.

### List the Contents of a Directory

If a path describes a directory, then you can read the contents of that directory by using static methods defined by `Files`. To do this, you first obtain a directory stream by calling `newDirectoryStream()`, passing in a `Path` that describes the directory. One form of `newDirectoryStream()` is shown here:

```java
static DirectoryStream<Path> newDirectoryStream(Path dirPath)
    throws IOException
```

Here, `dirPath` encapsulates the path to the directory. The method returns a `DirectoryStream<Path>` object that can be used to obtain the contents of the directory. It will throw an `IOException` if an I/O error occurs and a `NotDirectoryException` (which is a subclass of `IOException`) if the specified path is not a directory. A `SecurityException` is also possible if access to the directory is not permitted.

`DirectoryStream<Path>` implements `AutoCloseable`, so it can be managed by a `try-with-resources` statement. It also implements `Iterable<Path>`. This means that you can obtain the contents of the directory by iterating over the `DirectoryStream` object. When iterating, each directory entry is represented by a `Path` instance. An easy way to iterate over a `DirectoryStream` is to use a for-each style `for` loop. It is important to understand, however, that the iterator implemented by `DirectoryStream<Path>` can be obtained only once for each instance. Thus, the `iterator()` method can be called only once, and a for-each loop can be executed only once.

The following program displays the contents of a directory called `MyDir`:
Here is sample output from the program:

```
Directory of \MyDir
    DirList.class
    DirList.java
    <DIR> examples
        Test.txt
```

You can filter the contents of a directory in two ways. The easiest is to use this version of `newDirectoryStream( )`:

```java
    static DirectoryStream<Path> newDirectoryStream(Path dirPath, String wildcard)
    throws IOException
```

In this version, only files that match the wildcard filename specified by `wildcard` will be
obtained. For wildcard, you can specify either a complete filename or a glob. A glob is a string that defines a general pattern that will match one or more files using the familiar * and ? wildcard characters. These match zero or more of any character and any one character, respectively. The following are also recognized within a glob.

<table>
<thead>
<tr>
<th>**</th>
<th>Matches zero or more of any character across directories.</th>
</tr>
</thead>
<tbody>
<tr>
<td>[chars]</td>
<td>Matches any one character in chars. A * or ? within chars will be treated as a normal character, not a wildcard. A range can be specified by use of a hyphen, such as [x-z].</td>
</tr>
<tr>
<td>{globlist}</td>
<td>Matches any one of the globs specified in a comma-separated list of globs in globlist.</td>
</tr>
</tbody>
</table>

You can specify a * or ? character, using \* and \?. To specify a \, use \\.

You can experiment with a glob by substituting this call to `newDirectoryStream()` into the previous program:

```java
Files.newDirectoryStream(Paths.get(dirname), "{Path,Dir}*.{java,class}"
```

This obtains a directory stream that contains only those files whose names begin with either "Path" or "Dir" and use either the "java" or "class" extension. Thus, it would match names like `DirList.java` and `PathDemo.java`, but not `MyPathDemo.java`, for example.

Another way to filter a directory is to use this version of `newDirectoryStream()`:

```java
```

Here, `DirectoryStream.Filter` is an interface that specifies the following method:

```java
boolean accept(T entry) throws IOException
```

In this case, T will be Path. If you want to include entry in the list, return true. Otherwise, return false. This form of `newDirectoryStream( )` offers the advantage of being able to filter a directory based on something other than a filename. For example, you can filter based on size, creation date, modification date, or attribute, to name a few.

The following program demonstrates the process. It will list only those files that are writable.
Use `walkFileTree()` to List a Directory Tree

The preceding examples have obtained the contents of only a single directory. However, sometimes you will want to obtain a list of the files in a directory tree. In the past, this was quite a chore, but NIO.2 makes it easy because now you can use the `walkFileTree()` method defined by `Files` to process a directory tree. It has two forms. The one used in this chapter is shown here:

```java
// Display a directory of only those files that are writable.
import java.io.*;
import java.nio.file.*;
import java.nio.file.attribute.*;

class DirList {
    public static void main(String[] args) {
        String dirname = "\MyDir\";

        // Create a filter that returns true only for writable files.
        DirectoryStream.Filter<Path> how = new DirectoryStream.Filter<Path>() {
            public boolean accept(Path filename) throws IOException {
                if (Files.isWritable(filename)) return true;
                return false;
            }
        };

        // Obtain and manage a directory stream of writable files.
        try (DirectoryStream<Path> dirstrm = Files.newDirectoryStream(Paths.get(dirname), how)) {
            System.out.println("Directory of " + dirname);
            for (Path entry : dirstrm) {
                BasicFileAttributes attrs = Files.readAttributes(entry, BasicFileAttributes.class);
                if (attrs.isDirectory())
                    System.out.print("<DIR> ");
                else
                    System.out.print(" ");

                System.out.println(entry.getName());
            }
            catch (InvalidPathException e) {
                System.out.println("Path Error " + e);
            }
            catch (NotDirectoryException e) {
                System.out.println(dirname + " is not a directory.");
            }
            catch (IOException e) {
                System.out.println("I/O Error: " + e);
            }
        }
    }
}
```
The path to the starting point of the directory walk is passed in `root`. An instance of `FileVisitor` is passed in `fv`. The implementation of `FileVisitor` determines how the directory tree is traversed, and it gives you access to the directory information. If an I/O error occurs, an `IOException` is thrown. A `SecurityException` is also possible.

`FileVisitor` is an interface that defines how files are visited when a directory tree is traversed. It is a generic interface that is declared like this:

```java
interface FileVisitor<T>
```

For use in `walkFileTree()`, `T` will be `Path` (or any type derived from `Path`). `FileVisitor` defines the following methods.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>FileVisitResult postVisitDirectory(T dir, IOException exc)</code></td>
<td>Called after a directory has been visited. The directory is passed in <code>dir</code>, and any <code>IOException</code> is passed in <code>exc</code>. If <code>exc</code> is null, no exception occurred. The result is returned.</td>
</tr>
<tr>
<td><code>FileVisitResult preVisitDirectory(T dir, BasicFileAttributes attrs)</code></td>
<td>Called before a directory is visited. The directory is passed in <code>dir</code>, and the attributes associated with the directory are passed in <code>attrs</code>. The result is returned. To examine the directory, return <code>FileVisitResult.CONTINUE</code>.</td>
</tr>
<tr>
<td><code>FileVisitResult visitFile(T file, BasicFileAttributes attrs)</code></td>
<td>Called when a file is visited. The file is passed in <code>file</code>, and the attributes associated with the file are passed in <code>attrs</code>. The result is returned.</td>
</tr>
<tr>
<td><code>FileVisitResult visitFailed(T file, IOException exc)</code></td>
<td>Called when an attempt to visit a file fails. The file that failed is passed in <code>file</code>, and the <code>IOException</code> is passed in <code>exc</code>. The result is returned.</td>
</tr>
</tbody>
</table>

Notice that each method returns a `FileVisitResult`. This enumeration defines the following values:

```
CONTINUE    SKIP_SIBLINGS    SKIP_SUBTREE    TERMINATE
```

In general, to continue traversing the directory and subdirectories, a method should return `CONTINUE`. For `preVisitDirectory()`, return `SKIP_SIBLINGS` to bypass the directory and its siblings and prevent `postVisitDirectory()` from being called. To bypass just the directory and subdirectories, return `SKIP_SUBTREE`. To stop the directory traversal, return `TERMINATE`.

Although it is certainly possible to create your own visitor class that implements these methods defined by `FileVisitor`, you won’t normally do so because a simple implementation is provided by `SimpleFileVisitor`. You can just override the default implementation of the method or methods in which you are interested. Here is a short example that illustrates the process. It displays all files in the directory tree that has
MyDir as its root. Notice how short this program is.

```java
// A simple example that uses walkFileTree() to display a directory tree.
// Requires JRE 7 or later.
import java.io.*;
import java.nio.file.*;
import java.nio.file.attribute.*;

// Create a custom version of SimpleFileVisitor that overrides
// the visitFile() method.
class MyFileVisitor extends SimpleFileVisitor<Path> {
    public FileVisitResult visitFile(Path path, BasicFileAttributes attr)
        throws IOException {
        System.out.println(path);
        return FileVisitResult.CONTINUE;
    }
}

class DirTreeList {
    public static void main(String args[]) {
        String dirname = "\MyDir";
        System.out.println("Directory tree starting with " + dirname + "\n");
        try {
            Files.walkFileTree(Paths.get(dirname), new MyFileVisitor());
        } catch (IOException exc) {
            System.out.println("I/O Error");
        }
    }
}
```

Here is sample output produced by the program when used on the same MyDir directory shown earlier. In this example, the subdirectory called examples contains one file called MyProgram.java.

```
Directory tree starting with \MyDir:
\MyDir\DirList.class
\MyDir\DirList.java
\MyDir\examples\MyProgram.java
\MyDir\Test.txt
```

In the program, the class MyFileVisitor extends SimpleFileVisitor, overriding only the visitFile() method. In this example, visitFile() simply displays the files, but more sophisticated functionality is easy to achieve. For example, you could filter the files or perform actions on the files, such as copying them to a backup device. For the sake of clarity, a named class was used to override visitFile(), but you could also use an anonymous inner class.
One last point: It is possible to watch a directory for changes by using `java.nio.file.WatchService`.

**Pre-JDK 7 Channel-Based Examples**

Before concluding this chapter, one more aspect of NIO needs to be covered. The preceding sections have used several of the new features added to NIO by JDK 7. However, you may encounter pre-JDK 7 code that will need to be maintained or possibly converted to use the new features. For this reason, the following sections show how to read and write files using the pre-JDK 7 NIO system. They do so by reworking some of the examples shown earlier so that they use the original NIO features, rather than those supported by NIO.2. This means that the examples in this section will work with versions of Java prior to JDK 7.

The key difference between pre-JDK 7 NIO code and newer NIO code is the `Path` interface, which was added by JDK 7. Thus, pre-JDK 7 code does not use `Path` to describe a file or open a channel to it. Also, pre-JDK 7 code does not use `try-with-resource` statements since automatic resource management was also added by JDK 7.

---

**REMEMBER** The examples in this section describe how legacy NIO code works. This section is strictly for the benefit of those programmers working on pre-JDK 7 code or using pre-JDK 7 compilers. New code should take advantage of the NIO features added by JDK 7.

---

**Read a File, Pre-JDK 7**

This section reworks the two channel-based file input examples shown earlier so they use only pre-JDK 7 features. The first example reads a file by manually allocating a buffer and then performing an explicit read operation. The second example uses a mapped file, which automates the process.

When using a pre-JDK 7 version of Java to read a file using a channel and a manually allocated buffer, you first open the file for input using `FileInputStream`, using the same mechanism explained in Chapter 20. Next, obtain a channel to this file by calling `getChannel()` on the `FileInputStream` object. It has this general form:

```java
FileChannel getChannel()
```

It returns a `FileChannel` object, which encapsulates the channel for file operations. Then, call `allocate()` to allocate a buffer. Because file channels operate on byte buffers, you will use the `allocate()` method defined by `ByteBuffer`, which works as previously described.

The following program shows how to read and display a file called `test.txt` through a
channel using explicit input operations for versions of Java prior to JDK 7:

```java
// Use Channels to read a file. Pre-JDK 7 version.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;

public class ExplicitChannelRead {
    public static void main(String args[]) {
        FileInputStream fIn = null;
        FileChannel fChan = null;
        ByteBuffer mBuf;
        int count;

        try {
            // First, open a file for input.
            fIn = new FileInputStream("test.txt");

            // Next, obtain a channel to that file.
            fChan = fIn.getChannel();

            // Allocate a buffer.
            mBuf = ByteBuffer.allocate(128);

            do {
                ...
In this program, notice that the file is opened by using the `FileInputStream` constructor, and a reference to that object is assigned to `fIn`. Next, a channel connected to the file is obtained by calling `getChannel()` on `fIn`. After this point, the program works like the NIO.2 version shown previously. To synopsize: The program then calls the `allocate()` method of `ByteBuffer` to allocate a buffer that will hold the contents of the file when it is read. A byte buffer is used because `FileChannel` operates on bytes. A reference to this buffer is stored in `mBuf`. The contents of the file are then read, one buffer at a time, into `mBuf` through a call to `read()`. The number of bytes read is stored in `count`. Next, the buffer is rewound through a call to `rewind()`. This call is necessary because the current position is at the end of the buffer after the call to `read()`, and it must be reset to the start of the buffer in order for the bytes in `mBuf` to be read by calling `get()`. When the end of
the file has been reached, the value returned by `read()` will be –1. When this occurs, the program ends, explicitly closing the channel and the file.

Another way to read a file is to map it to a buffer. As explained earlier, a principal advantage to this approach is that the buffer automatically contains the contents of the file. No explicit read operation is necessary. To map and read the contents of a file using pre-JDK 7 NIO, first open the file using `FileInputStream`. Next, obtain a channel to that file by calling `getChannel()` on the file object. Then, map the channel to a buffer by calling `map()` on the `FileChannel` object. The `map()` method works as described earlier.

The following program reworks the preceding example so that it uses only pre-JDK 7 features to create a mapped file:
In the program, the file is opened by using the `FileInputStream` constructor, and a reference to that object is assigned to `fIn`. A channel connected to the file is obtained by calling `getChannel()` on `fIn`. Next, the size of the file is obtained. Then, the entire file is mapped into memory by calling `map()`, and a reference to the buffer is stored in `mBuf`. The bytes in `mBuf` are read by calling `get()`.
Write to a File, Pre-JDK 7

This section reworks the two channel-based file output examples shown earlier so that they use only pre-JDK 7 features. The first example writes to a file by manually allocating a buffer and then performing an explicit output operation. The second example uses a mapped file, which automates the process. In both cases, neither Path nor try-with-resources is used. This is because neither were part of Java until JDK 7.

When using a pre-JDK 7 version of Java to write a file using a channel and a manually allocated buffer, first open the file for output. This is done by creating a FileOutputstream, as described in Chapter 20. Next, obtain a channel to the file by calling getChannel() and then allocate a byte buffer by calling allocate(), as described in the previous section. Next, put the data you want to write into that buffer, and then call write() on the channel. The following program demonstrates this procedure. It writes the alphabet to a file called test.txt.

```java
// Write to a file using NIO. Pre-JDK 7 Version.
import java.io.*;
import java.nio.*;
import java.nio.channels.*;

public class ExplicitChannelWrite {
    public static void main(String args[]) {
        FileOutputStream fOut = null;
        FileChannel fChan = null;
        ByteBuffer mBuf = null;

        try {
            // First, open the output file.
            fOut = new FileOutputStream("test.txt");

            // Next, get a channel to the output file.
            fChan = fOut.getChannel();

            // Create a buffer.
            mBuf = ByteBuffer.allocate(26);

            // Write some bytes to the buffer.
            for(int i=0; i<26; i++)
                mBuf.put((byte)('A' + i));

            // Rewind the buffer so that it can be written.
            mBuf.rewind();

            // Write the buffer to the output file.
            fChan.write(mBuf);
        }
    }
}
```
The call to `rewind()` on `mBuf` is necessary in order to reset the current position to zero after data has been written to `mBuf`. Remember, each call to `put()` advances the current position. Therefore, it is necessary for the current position to be reset to the start of the buffer before calling `write()`. If this is not done, `write()` will think that there is no data in the buffer.

When using a pre-JDK 7 version of Java to write to a file using a mapped file, follow these steps. First, open the file for read/write operations by creating a `RandomAccessFile` object. This is necessary to enable the file to be both read from and written to. Next, map that file to a buffer by calling `map()` on that object. Then, write to the buffer. Because the buffer is mapped to the file, any changes to that buffer are automatically reflected in the file. Thus, no explicit write operations to the channel are necessary.

Here is the preceding program reworked so that a mapped file is used:
As you can see, there are no explicit write operations to the channel itself. Because \texttt{mBuf} is mapped to the file, changes to \texttt{mBuf} are automatically reflected in the underlying file.
As all readers know, Java is practically a synonym for Internet programming. There are a number of reasons for this, not the least of which is its ability to generate secure, cross-platform, portable code. However, one of the most important reasons that Java is the premier language for network programming are the classes defined in the `java.net` package. They provide an easy-to-use means by which programmers of all skill levels can access network resources.

This chapter explores the `java.net` package. It is important to emphasize that networking is a very large and at times complicated topic. It is not possible for this book to discuss all of the capabilities contained in `java.net`. Instead, this chapter focuses on several of its core classes and interfaces.

**Networking Basics**

Before we begin, it will be useful to review some key networking concepts and terms. At the core of Java's networking support is the concept of a socket. A socket identifies an endpoint in a network. The socket paradigm was part of the 4.2BSD Berkeley UNIX release in the early 1980s. Because of this, the term *Berkeley socket* is also used. Sockets are at the foundation of modern networking because a socket allows a single computer to serve many different clients at once, as well as to serve many different types of information. This is accomplished through the use of a port, which is a numbered socket on a particular machine. A server process is said to "listen" to a port until a client connects to it. A server is allowed to accept multiple clients connected to the same port number, although each session is unique. To manage multiple client connections, a server process must be multithreaded or have some other means of multiplexing the simultaneous I/O.

Socket communication takes place via a protocol. *Internet Protocol (IP)* is a low-level routing protocol that breaks data into small packets and sends them to an address across a network, which does not guarantee to deliver said packets to the destination. *Transmission Control Protocol (TCP)* is a higher-level protocol that manages to robustly string together these packets, sorting and retransmitting them as necessary to reliably transmit data. A third protocol, *User Datagram Protocol (UDP)*, sits next to TCP and can be used directly to support fast, connectionless, unreliable transport of packets.
Once a connection has been established, a higher-level protocol ensues, which is dependent on which port you are using. TCP/IP reserves the lower 1,024 ports for specific protocols. Many of these will seem familiar to you if you have spent any time surfing the Internet. Port number 21 is for FTP; 23 is for Telnet; 25 is for e-mail; 43 is for whois; 80 is for HTTP; 119 is for netnews—and the list goes on. It is up to each protocol to determine how a client should interact with the port.

For example, HTTP is the protocol that web browsers and servers use to transfer hypertext pages and images. It is a quite simple protocol for a basic page-browsing web server. Here’s how it works. When a client requests a file from an HTTP server, an action known as a hit, it simply sends the name of the file in a special format to a predefined port and reads back the contents of the file. The server also responds with a status code to tell the client whether or not the request can be fulfilled and why.

A key component of the Internet is the address. Every computer on the Internet has one. An Internet address is a number that uniquely identifies each computer on the Net. Originally, all Internet addresses consisted of 32-bit values, organized as four 8-bit values. This address type was specified by IPv4 (Internet Protocol, version 4). However, a new addressing scheme, called IPv6 (Internet Protocol, version 6) has come into play. IPv6 uses a 128-bit value to represent an address, organized into eight 16-bit chunks. Although there are several reasons for and advantages to IPv6, the main one is that it supports a much larger address space than does IPv4. Fortunately, when using Java, you won’t normally need to worry about whether IPv4 or IPv6 addresses are used because Java handles the details for you.

Just as the numbers of an IP address describe a network hierarchy, the name of an Internet address, called its domain name, describes a machine’s location in a name space. For example, www.HerbSchildt.com is in the COM top-level domain (reserved for U.S. commercial sites); it is called HerbSchildt, and www identifies the server for web requests. An Internet domain name is mapped to an IP address by the Domain Naming Service (DNS). This enables users to work with domain names, but the Internet operates on IP addresses.

The Networking Classes and Interfaces
Java supports TCP/IP both by extending the already established stream I/O interface introduced in Chapter 20 and by adding the features required to build I/O objects across the network. Java supports both the TCP and UDP protocol families. TCP is used for reliable stream-based I/O across the network. UDP supports a simpler, hence faster, point-to-point datagram-oriented model. The classes contained in the java.net package are shown here:
The `java.net` package’s interfaces are listed here:

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Interface/Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Authenticator</td>
<td>InetAddress</td>
<td>SocketAddress</td>
</tr>
<tr>
<td>CacheRequest</td>
<td>InetSocketAddress</td>
<td>SocketImpl</td>
</tr>
<tr>
<td>CacheResponse</td>
<td>InterfaceAddress</td>
<td>SocketPermission</td>
</tr>
<tr>
<td>ContentHandler</td>
<td>JarURLConnection</td>
<td>StandardSocketOption</td>
</tr>
<tr>
<td>CookieHandler</td>
<td>MulticastSocket</td>
<td>URI</td>
</tr>
<tr>
<td>CookieManager</td>
<td>NetPermission</td>
<td>URL</td>
</tr>
<tr>
<td>DatagramPacket</td>
<td>NetworkInterface</td>
<td>URLClassLoader</td>
</tr>
<tr>
<td>DatagramSocket</td>
<td>PasswordAuthentication</td>
<td>URLConnection</td>
</tr>
<tr>
<td>DatagramSocketImpl</td>
<td>Proxy</td>
<td>URLEncoder</td>
</tr>
<tr>
<td>HttpCookie</td>
<td>ProxySelector</td>
<td>URLDecoder</td>
</tr>
<tr>
<td>HttpURLConnection</td>
<td>ResponseCache</td>
<td>URLPermission (Added by JDK 8)</td>
</tr>
<tr>
<td>IDN</td>
<td>SecureCacheResponse</td>
<td>URLStreamHandler</td>
</tr>
<tr>
<td>InetAddress</td>
<td>ServerSocket</td>
<td></td>
</tr>
<tr>
<td>InetAddress</td>
<td>Socket</td>
<td></td>
</tr>
</tbody>
</table>

The `java.net` package’s interfaces are listed here:

<table>
<thead>
<tr>
<th>Class Name</th>
<th>Interface/Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ContentHandlerFactory</td>
<td>FileNameMap</td>
<td>SocketOptions</td>
</tr>
<tr>
<td>CookiePolicy</td>
<td>ProtocolFamily</td>
<td>URLStreamHandlerFactory</td>
</tr>
<tr>
<td>CookieStore</td>
<td>SocketImplFactory</td>
<td></td>
</tr>
<tr>
<td>DatagramSocketImplFactory</td>
<td>SocketOption</td>
<td></td>
</tr>
</tbody>
</table>

In the sections that follow, we will examine the main networking classes and show several examples that apply to them. Once you understand these core networking classes, you will be able to easily explore the others on your own.

**InetAddress**

The `InetAddress` class is used to encapsulate both the numerical IP address and the domain name for that address. You interact with this class by using the name of an IP host, which is more convenient and understandable than its IP address. The `InetAddress` class hides the number inside. `InetAddress` can handle both IPv4 and IPv6 addresses.

**Factory Methods**

The `InetAddress` class has no visible constructors. To create an `InetAddress` object, you have to use one of the available factory methods. *Factory methods* are merely a convention whereby static methods in a class return an instance of that class. This is done in lieu of overloading a constructor with various parameter lists when having unique method names makes the results much clearer. Three commonly used `InetAddress` factory methods are shown here:

```java
static InetAddress getLocalHost() throws UnknownHostException
static InetAddress getByName(String hostName)
```
throws UnknownHostException

    static InetAddress[] getAllByName(String hostName)
throws UnknownHostException

The `getLocalHost()` method simply returns the `InetAddress` object that represents the local host. The `getByName()` method returns an `InetAddress` for a host name passed to it. If these methods are unable to resolve the host name, they throw an `UnknownHostException`.

On the Internet, it is common for a single name to be used to represent several machines. In the world of web servers, this is one way to provide some degree of scaling. The `getAllByName()` factory method returns an array of `InetAddress`es that represent all of the addresses that a particular name resolves to. It will also throw an `UnknownHostException` if it can’t resolve the name to at least one address.

`InetAddress` also includes the factory method `getByAddress()`, which takes an IP address and returns an `InetAddress` object. Either an IPv4 or an IPv6 address can be used. The following example prints the addresses and names of the local machine and two Internet web sites:

```java
// Demonstrate InetAddress.
import java.net.*;

class InetAddressTest {
    public static void main(String args[]) throws UnknownHostException {
        InetAddress Address = InetAddress.getLocalHost();
        System.out.println(Address);

        Address = InetAddress.getByName("www.HerbSchltd.com");
        System.out.println(Address);

        InetAddress SW[] = InetAddress.getAllByName("www.nba.com");
        for (int i=0; i<SW.length; i++)
            System.out.println(SW[i]);
    }
}
```

Here is the output produced by this program. (Of course, the output you see may be slightly different.)

```
default/166.203.115.212
www.HerbSchltd.com/216.92.65.4
www.nba.com/216.66.31.161
www.nba.com/216.66.31.179
```
The `InetAddress` class has several other methods, which can be used on the objects returned by the methods just discussed. Here are some of the more commonly used methods:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>boolean equals(Object other)</code></td>
<td>Returns <code>true</code> if this object has the same Internet address as <code>other</code>.</td>
</tr>
<tr>
<td><code>byte[] getAddress()</code></td>
<td>Returns a byte array that represents the object’s IP address in network byte order.</td>
</tr>
<tr>
<td><code>String getHostAddress()</code></td>
<td>Returns a string that represents the host address associated with the <code>InetAddress</code> object.</td>
</tr>
<tr>
<td><code>String getHostName()</code></td>
<td>Returns a string that represents the host name associated with the <code>InetAddress</code> object.</td>
</tr>
<tr>
<td><code>boolean isMulticastAddress()</code></td>
<td>Returns <code>true</code> if this address is a multicast address. Otherwise, it returns <code>false</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns a string that lists the host name and the IP address for convenience.</td>
</tr>
</tbody>
</table>

Internet addresses are looked up in a series of hierarchically cached servers. That means that your local computer might know a particular name-to-IP-address mapping automatically, such as for itself and nearby servers. For other names, it may ask a local DNS server for IP address information. If that server doesn’t have a particular address, it can go to a remote site and ask for it. This can continue all the way up to the root server. This process might take a long time, so it is wise to structure your code so that you cache IP address information locally rather than look it up repeatedly.

**InetAddress and InetAddress**

Java includes support for both IPv4 and IPv6 addresses. Because of this, two subclasses of `InetAddress` were created: `Inet4Address` and `Inet6Address`. `Inet4Address` represents a traditional-style IPv4 address. `Inet6Address` encapsulates a newer IPv6 address. Because they are subclasses of `InetAddress`, an `InetAddress` reference can refer to either. This is one way that Java was able to add IPv6 functionality without breaking existing code or adding many more classes. For the most part, you can simply use `InetAddress` when working with IP addresses because it can accommodate both styles.

**TCP/IP Client Sockets**

TCP/IP sockets are used to implement reliable, bidirectional, persistent, point-to-point, stream-based connections between hosts on the Internet. A socket can be used to connect Java’s I/O system to other programs that may reside either on the local machine or on any
There are two kinds of TCP sockets in Java. One is for servers, and the other is for clients. The `ServerSocket` class is designed to be a “listener,” which waits for clients to connect before doing anything. Thus, `ServerSocket` is for servers. The `Socket` class is for clients. It is designed to connect to server sockets and initiate protocol exchanges. Because client sockets are the most commonly used by Java applications, they are examined here. The creation of a `Socket` object implicitly establishes a connection between the client and server. There are no methods or constructors that explicitly expose the details of establishing that connection. Here are two constructors used to create client sockets:

<table>
<thead>
<tr>
<th>Constructor</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>Socket(String hostName, int port)</code> throws UnknownHostException, IOException</td>
</tr>
<tr>
<td>Creates a socket connected to the named host and port.</td>
</tr>
<tr>
<td><code>Socket(InetAddress ipAddress, int port)</code> throws IOException</td>
</tr>
<tr>
<td>Creates a socket using a preexisting <code>InetAddress</code> object and a port.</td>
</tr>
</tbody>
</table>

`Socket` defines several instance methods. For example, a `Socket` can be examined at any time for the address and port information associated with it, by use of the following methods:

<table>
<thead>
<tr>
<th>Method</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>getInetAddress()</code></td>
</tr>
<tr>
<td>Returns the <code>InetAddress</code> associated with the <code>Socket</code> object. It returns <code>null</code> if the socket is not connected.</td>
</tr>
<tr>
<td><code>getPort()</code></td>
</tr>
<tr>
<td>Returns the remote port to which the invoking <code>Socket</code> object is connected. It returns 0 if the socket is not connected.</td>
</tr>
<tr>
<td><code>getLocalPort()</code></td>
</tr>
<tr>
<td>Returns the local port to which the invoking <code>Socket</code> object is bound. It returns −1 if the socket is not bound.</td>
</tr>
</tbody>
</table>

You can gain access to the input and output streams associated with a `Socket` by use of the `getInputStream()` and `getOutputStream()` methods, as shown here. Each can throw
an IOException if the socket has been invalidated by a loss of connection. These streams are used exactly like the I/O streams described in Chapter 20 to send and receive data.

| **InputStream getInputStream( ) throws IOException** | Returns the **InputStream** associated with the invoking socket. |
| **OutputStream getOutputStream( ) throws IOException** | Returns the **OutputStream** associated with the invoking socket. |

Several other methods are available, including **connect( )**, which allows you to specify a new connection; **isConnected( )**, which returns true if the socket is connected to a server; **isBound( )**, which returns true if the socket is bound to an address; and **isClosed( )**, which returns true if the socket is closed. To close a socket, call **close( )**. Closing a socket also closes the I/O streams associated with the socket. Beginning with JDK 7, **Socket** also implements **AutoCloseable**, which means that you can use a try-with-resources block to manage a socket.

The following program provides a simple **Socket** example. It opens a connection to a "whois" port (port 43) on the InterNIC server, sends the command-line argument down the socket, and then prints the data that is returned. InterNIC will try to look up the argument as a registered Internet domain name, and then send back the IP address and contact information for that site.
If, for example, you obtained information about **MHPprofessional.com**, you'd get something similar to the following:

```
Whois Server Version 2.0

Domain names in the .com and .net domains can now be registered with many different competing registrars. Go to http://www.internic.net for detailed information.

Domain Name: MHPROFESSIONAL.COM
Registrar: CSC CORPORATE DOMAINS, INC.
Whois Server: whois.corporatedomains.com
Referral URL: http://www.cscglobal.com
Name Server: NS1.MHEDU.COM
Name Server: NS2.MHEDU.COM
```

Here is how the program works. First, a **Socket** is constructed that specifies the host name "whois.internic.net" and the port number 43. **Internic.net** is the InterNIC web site that handles whois requests. Port 43 is the whois port. Next, both input and output streams are opened on the socket. Then, a string is constructed that contains the name of the web site you want to obtain information about. In this case, if no web site is specified on the

```java
// Demonstrate Sockets.
import java.net.*;
import java.io.*;

class Whois {
    public static void main(String args[]) throws Exception {
        int c;

        // Create a socket connected to internic.net, port 43.
        Socket s = new Socket("whois.internic.net", 43);

        // Obtain input and output streams.
        InputStream in = s.getInputStream();
        OutputStream out = s.getOutputStream();

        // Construct a request string.
        String str = (args.length == 0) ? "MHPprofessional.com" : args[0] + ";n";
        // Convert to bytes.
        byte buf[] = str.getBytes()

        // Send request.
        out.write(buf);

        // Read and display response.
        while ((c = in.read()) != -1) {
            System.out.print((char) c);
        }
        s.close();
    }
}
```
command line, then "MHProfessional.com" is used. The string is converted into a byte array and then sent out of the socket. The response is read by inputting from the socket, and the results are displayed. Finally, the socket is closed, which also closes the I/O streams.

In the preceding example, the socket was closed manually by calling close(). If you are using JDK 7 or later, then you can use a try-with-resources block to automatically close the socket. For example, here is another way to write the main() method of the previous program:

```java
// Use try-with-resources to close a socket.
public static void main(String[] args) throws Exception {
    int cf;

    // Create a socket connected to internic.net, port 43. Manage this
    // socket with a try-with-resources block.
    try (Socket s = new Socket("Whois.internic.net", 43)) {
        // Obtain input and output streams.
        InputStream in = s.getInputStream();
        OutputStream out = s.getOutputStream();

        // Construct a request string.
        String str = (args.length == 0 ? "MHProfessional.com" : args[0]) + ";n";
        // Convert to bytes.
        byte buf[] = str.getBytes();

        // Send request.
        out.write(buf);

        // Read and display response.
        while ((c = in.read()) != -1) {
            System.out.print((char) c);
        }
    }

    // The socket is now closed.
}
```

In this version, the socket is automatically closed when the try block ends.

So the examples will work with earlier versions of Java and to clearly illustrate when a network resource can be closed, subsequent examples will continue to call close() explicitly. However, in your own code, you should consider using automatic resource management since it offers a more streamlined approach. One other point: In this version, exceptions are still thrown out of main(), but they could be handled by adding catch clauses to the end of the try-with-resources block.

---

**NOTE** For simplicity, the examples in this chapter simply throw all exceptions out of main(). This allows the logic of the network code to be clearly illustrated. However, in real-world code, you will normally need to handle the exceptions in an appropriate way.
URL

The preceding example was rather obscure because the modern Internet is not about the older protocols such as whois, finger, and FTP. It is about WWW, the World Wide Web. The Web is a loose collection of higher-level protocols and file formats, all unified in a web browser. One of the most important aspects of the Web is that Tim Berners-Lee devised a scalable way to locate all of the resources of the Net. Once you can reliably name anything and everything, it becomes a very powerful paradigm. The Uniform Resource Locator (URL) does exactly that.

The URL provides a reasonably intelligible form to uniquely identify or address information on the Internet. URLs are ubiquitous; every browser uses them to identify information on the Web. Within Java’s network class library, the URL class provides a simple, concise API to access information across the Internet using URLs.

All URLs share the same basic format, although some variation is allowed. Here are two examples: http://www.MHProfessional.com/ and http://www.MHProfessional.com:80/index.htm. A URL specification is based on four components. The first is the protocol to use, separated from the rest of the locator by a colon (:). Common protocols are HTTP, FTP, gopher, and file, although these days almost everything is being done via HTTP (in fact, most browsers will proceed correctly if you leave off the “http://” from your URL specification). The second component is the host name or IP address of the host to use; this is delimited on the left by double slashes (//) and on the right by a slash (/) or optionally a colon (:). The third component, the port number, is an optional parameter, delimited on the left from the host name by a colon (:), and on the right by a slash (/). (It defaults to port 80, the predefined HTTP port; thus, “:80” is redundant.) The fourth part is the actual file path. Most HTTP servers will append a file named index.html or index.htm to URLs that refer directly to a directory resource. Thus, http://www.MHProfessional.com/ is the same as http://www.MHProfessional.com/index.htm.

Java’s URL class has several constructors; each can throw a MalformedURLException. One commonly used form specifies the URL with a string that is identical to what you see displayed in a browser:

    URL(String urlSpecifier) throws MalformedURLException

The next two forms of the constructor allow you to break up the URL into its component parts:

    URL(String protocolName, String hostName, int port, String path )
    throws MalformedURLException

    URL(String protocolName, String hostName, String path)
    throws MalformedURLException
Another frequently used constructor allows you to use an existing URL as a reference context and then create a new URL from that context. Although this sounds a little contorted, it's really quite easy and useful.

URL(URL urlObj, String urlSpecifier) throws MalformedURLException

The following example creates a URL to a page on HerbSchildt.com and then examines its properties:

```java
// Demonstrate URL.
import java.net.*;
class URLDemo {
    public static void main(String args[]) throws MalformedURLException {  
        URL hp = new URL("http://www.HerbSchildt.com/WhatsNew");
        System.out.println("Protocol: " + hp.getProtocol());
        System.out.println("Port: " + hp.getPort());
        System.out.println("Host: " + hp.getHost());
        System.out.println("File: " + hp.getFile());
        System.out.println("Ext: " + hp.toExternalForm());
    }
}
```

When you run this, you will get the following output:

```
Protocol: http
Port: -1
Host: www.HerbSchildt.com
File: /WhatsNew
```

Notice that the port is -1; this means that a port was not explicitly set. Given a URL object, you can retrieve the data associated with it. To access the actual bits or content information of a URL, create a URLConnection object from it, using its openConnection() method, like this:

```java
urlc = url.openConnection()
```

openConnection() has the following general form:

```java
URLConnection openConnection() throws IOException
```

It returns a URLConnection object associated with the invoking URL object. Notice that it may throw an IOException.

**URLConnection**

URLConnection is a general-purpose class for accessing the attributes of a remote resource. Once you make a connection to a remote server, you can use URLConnection to inspect the properties of the remote object before actually transporting it locally. These
attributes are exposed by the HTTP protocol specification and, as such, only make sense for URL objects that are using the HTTP protocol.

**URLConnection** defines several methods. Here is a sampling:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>int getContentLength( )</strong></td>
<td>Returns the size in bytes of the content associated with the resource. If the length is unavailable, –1 is returned.</td>
</tr>
<tr>
<td><strong>long getContentLengthLong( )</strong></td>
<td>Returns the size in bytes of the content associated with the resource. If the length is unavailable, –1 is returned.</td>
</tr>
<tr>
<td><strong>String getContentType( )</strong></td>
<td>Returns the type of content found in the resource. This is the value of the <strong>content-type</strong> header field. Returns <strong>null</strong> if the content type is not available.</td>
</tr>
<tr>
<td><strong>long getDate( )</strong></td>
<td>Returns the time and date of the response represented in terms of milliseconds since January 1, 1970 GMT.</td>
</tr>
<tr>
<td><strong>long getExpiration( )</strong></td>
<td>Returns the expiration time and date of the resource represented in terms of milliseconds since January 1, 1970 GMT. Zero is returned if the expiration date is unavailable.</td>
</tr>
<tr>
<td><strong>String getHeaderField(int idx)</strong></td>
<td>Returns the value of the header field at index <strong>idx</strong>. (Header field indexes begin at 0.) Returns <strong>null</strong> if the value of <strong>idx</strong> exceeds the number of fields.</td>
</tr>
<tr>
<td><strong>String getHeaderField(String fieldName)</strong></td>
<td>Returns the value of header field whose name is specified by <strong>fieldName</strong>. Returns <strong>null</strong> if the specified name is not found.</td>
</tr>
<tr>
<td><strong>String getHeaderFieldKey(int idx)</strong></td>
<td>Returns the header field key at index <strong>idx</strong>. (Header field indexes begin at 0.) Returns <strong>null</strong> if the value of <strong>idx</strong> exceeds the number of fields.</td>
</tr>
<tr>
<td><strong>Map&lt;String, List&lt;String&gt;&gt; getHeaderFields( )</strong></td>
<td>Returns a map that contains all of the header fields and values.</td>
</tr>
<tr>
<td><strong>long getLastModified( )</strong></td>
<td>Returns the time and date, represented in terms of milliseconds since January 1, 1970 GMT, of the last modification of the resource. Zero is returned if the last-modified date is unavailable.</td>
</tr>
<tr>
<td><strong>InputStream getInputStream( ) throws IOException</strong></td>
<td>Returns an <strong>InputStream</strong> that is linked to the resource. This stream can be used to obtain the content of the resource.</td>
</tr>
</tbody>
</table>

Notice that **URLConnection** defines several methods that handle header information. A
header consists of pairs of keys and values represented as strings. By using
getHeaderField(), you can obtain the value associated with a header key. By calling
getHeaderFields(), you can obtain a map that contains all of the headers. Several
standard header fields are available directly through methods such as getDate() and
getContentType().

The following example creates a URLConnection using the openConnection() method
of a URL object and then uses it to examine the document’s properties and content:
The program establishes an HTTP connection to **www.internic.net** over port 80. It then displays several header values and retrieves the content. You might find it interesting to try this example, observing the results, and then for comparison purposes try a different web site of your own choosing.

HttpURLConnection
Java provides a subclass of `URLConnection` that provides support for HTTP connections. This class is called `HttpURLConnection`. You obtain an `HttpURLConnection` in the same way just shown, by calling `openConnection()` on a `URL` object, but you must cast the result to `HttpURLConnection`. (Of course, you must make sure that you are actually opening an HTTP connection.) Once you have obtained a reference to an `HttpURLConnection` object, you can use any of the methods inherited from `URLConnection`. You can also use any of the several methods defined by `HttpURLConnection`. Here is a sampling:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static boolean getFollowRedirects( )</td>
<td>Returns <code>true</code> if redirects are automatically followed and <code>false</code> otherwise. This feature is on by default.</td>
</tr>
<tr>
<td>String getRequestMethod( )</td>
<td>Returns a string representing how URL requests are made. The default is GET. Other options, such as POST, are available.</td>
</tr>
<tr>
<td>int getResponseCode( ) throws IOException</td>
<td>Returns the HTTP response code. –1 is returned if no response code can be obtained. An <code>IOException</code> is thrown if the connection fails.</td>
</tr>
<tr>
<td>String getMessage( ) throws IOException</td>
<td>Returns the response message associated with the response code. Returns <code>null</code> if no message is available. An <code>IOException</code> is thrown if the connection fails.</td>
</tr>
<tr>
<td>static void setFollowRedirects(boolean how)</td>
<td>If <code>how</code> is <code>true</code>, then redirects are automatically followed. If <code>how</code> is <code>false</code>, redirects are not automatically followed. By default, redirects are automatically followed.</td>
</tr>
<tr>
<td>void setRequestMethod(String how) throws ProtocolException</td>
<td>Sets the method by which HTTP requests are made to that specified by <code>how</code>. The default method is GET, but other options, such as POST, are available. If <code>how</code> is invalid, a <code>ProtocolException</code> is thrown.</td>
</tr>
</tbody>
</table>

The following program demonstrates `HttpURLConnection`. It first establishes a connection to `www.google.com`. Then it displays the request method, the response code, and the response message. Finally, it displays the keys and values in the response header.
// Demonstrate HttpURLConnection.
import java.net.*;
import java.io.*;
import java.util.*;

class HttpURLConnectionDemo
{
    public static void main(String args[]) throws Exception {
        URL hp = new URL("http://www.google.com");
        HttpURLConnection hpCon = (HttpURLConnection) hp.openConnection();

        // Display request method.
        System.out.println("Request method is " +
               hpCon.getMethod());

        // Display response code.
        System.out.println("Response code is " +
               hpCon.getResponseCode());

        // Display response message.
        System.out.println("Response Message is " +
               hpCon.getResponseMessage());

        // Get a list of the header fields and a set
        // of the header keys.
        Map<String, List<String>> hdrMap = hpCon.getHeaderFields();
        Set<String> hdrField = hdrMap.keySet();
        System.out.println("Here is the header:");

        // Display all header keys and values.
        for(String k : hdrField) {
            System.out.println("Key: " + k + " Value: " + hdrMap.get(k));
        }
    }
}
Notice how the header keys and values are displayed. First, a map of the header keys and values is obtained by calling `getHeaderFields()` (which is inherited from `URLConnection`). Next, a set of the header keys is retrieved by calling `keySet()` on the map. Then, the key set is cycled through by using a for-each style `for` loop. The value associated with each key is obtained by calling `get()` on the map.

**The URI Class**

The `URI` class encapsulates a *Uniform Resource Identifier (URI)*. URIs are similar to URLs. In fact, URLs constitute a subset of URIs. A URI represents a standard way to identify a resource. A URL also describes how to access the resource.

**Cookies**

The `java.net` package includes classes and interfaces that help manage cookies and can be used to create a stateful (as opposed to stateless) HTTP session. The classes are `CookieHandler`, `CookieManager`, and `HttpCookie`. The interfaces are `CookiePolicy` and `CookieStore`. The creation of a stateful HTTP session is beyond the scope of this book.

NOTE For information about using cookies with servlets, see Chapter 38.

**TCP/IP Server Sockets**

As mentioned earlier, Java has a different socket class that must be used for creating server
applications. The **ServerSocket** class is used to create servers that listen for either local or remote client programs to connect to them on published ports. **ServerSockets** are quite different from normal **Sockets**. When you create a **ServerSocket**, it will register itself with the system as having an interest in client connections. The constructors for **ServerSocket** reflect the port number that you want to accept connections on and, optionally, how long you want the queue for said port to be. The queue length tells the system how many client connections it can leave pending before it should simply refuse connections. The default is 50. The constructors might throw an IOException under adverse conditions. Here are three of its constructors:

<table>
<thead>
<tr>
<th>Constructor</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ServerSocket(int <code>port</code>) throws IOException</td>
<td>Creates server socket on the specified port with a queue length of 50.</td>
</tr>
<tr>
<td>ServerSocket(int <code>port</code>, int <code>maxQueue</code>) throws IOException</td>
<td>Creates a server socket on the specified port with a maximum queue length of <code>maxQueue</code>.</td>
</tr>
<tr>
<td>ServerSocket(int <code>port</code>, int <code>maxQueue</code>, InetAddress <code>localAddress</code>) throws IOException</td>
<td>Creates a server socket on the specified port with a maximum queue length of <code>maxQueue</code>. On a multihomed host, <code>localAddress</code> specifies the IP address to which this socket binds.</td>
</tr>
</tbody>
</table>

**ServerSocket** has a method called **accept()**, which is a blocking call that will wait for a client to initiate communications and then return with a normal **Socket** that is then used for communication with the client.

**Datagrams**

TCP/IP-style networking is appropriate for most networking needs. It provides a serialized, predictable, reliable stream of packet data. This is not without its cost, however. TCP includes many complicated algorithms for dealing with congestion control on crowded networks, as well as pessimistic expectations about packet loss. This leads to a somewhat inefficient way to transport data. Datagrams provide an alternative. **Datagrams** are bundles of information passed between machines. They are somewhat like a hard throw from a well-trained but blindfolded catcher to the third baseman. Once the datagram has been released to its intended target, there is no assurance that it will arrive or even that someone will be there to catch it. Likewise, when the datagram is received, there is no assurance that it hasn’t been damaged in transit or that whoever sent it is still there to receive a response.

Java implements datagrams on top of the UDP protocol by using two classes: the **DatagramPacket** object is the data container, while the **DatagramSocket** is the mechanism used to send or receive the **DatagramPackets**. Each is examined here.
DatagramSocket

DatagramSocket defines four public constructors. They are shown here:

DatagramSocket() throws SocketException
DatagramSocket(int port) throws SocketException
DatagramSocket(int port, InetAddress ipAddress) throws SocketException
DatagramSocket(SocketAddress address) throws SocketException

The first creates a DatagramSocket bound to any unused port on the local computer. The second creates a DatagramSocket bound to the port specified by port. The third constructs a DatagramSocket bound to the specified port and InetAddress. The fourth constructs a DatagramSocket bound to the specified SocketAddress. SocketAddress is an abstract class that is implemented by the concrete class InetAddress. InetAddress encapsulates an IP address with a port number. All can throw a SocketException if an error occurs while creating the socket.

DatagramSocket defines many methods. Two of the most important are send() and receive(), which are shown here:

void send(DatagramPacket packet) throws IOException
void receive(DatagramPacket packet) throws IOException

The send() method sends a packet to the port specified by packet. The receive() method waits for a packet to be received and returns the result.

DatagramSocket also defines the close() method, which closes the socket. Beginning with JDK 7, DatagramSocket implements AutoCloseable, which means that a DatagramSocket can be managed by a try-with-resources block.

Other methods give you access to various attributes associated with a DatagramSocket. Here is a sampling:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>InetAddress</td>
<td>If the socket is connected, then the address is returned. Otherwise, null is returned.</td>
</tr>
<tr>
<td>getInetAddress()</td>
<td>Returns the number of the local port.</td>
</tr>
<tr>
<td>int getLocalPort()</td>
<td>Returns the number of the port to which the socket is connected. It returns -1 if the socket is not connected to a port.</td>
</tr>
<tr>
<td>int getPort()</td>
<td>Returns true if the socket is bound to an address. Returns false otherwise.</td>
</tr>
<tr>
<td>boolean isBound()</td>
<td>Returns true if the socket is connected to a server. Returns false otherwise.</td>
</tr>
</tbody>
</table>
void setSoTimeOut(int millis) throws SocketException
Sets the time-out period to the number of milliseconds passed in millis.

DatagramPacket
DatagramPacket defines several constructors. Four are shown here:

DatagramPacket(byte data [], int size)
DatagramPacket(byte data [], int offset, int size)
DatagramPacket(byte data [], int size, InetAddress ipAddress, int port)
DatagramPacket(byte data [], int offset, int size, InetAddress ipAddress, int port)

The first constructor specifies a buffer that will receive data and the size of a packet. It is used for receiving data over a DatagramSocket. The second form allows you to specify an offset into the buffer at which data will be stored. The third form specifies a target address and port, which are used by a DatagramSocket to determine where the data in the packet will be sent. The fourth form transmits packets beginning at the specified offset into the data. Think of the first two forms as building an "in box," and the second two forms as stuffing and addressing an envelope.

DatagramPacket defines several methods, including those shown here, that give access to the address and port number of a packet, as well as the raw data and its length.

InetAddress
getAddress( )
Returns the address of the source (for datagrams being received) or destination (for datagrams being sent).

byte[ ] getData( )
Returns the byte array of data contained in the datagram. Mostly used to retrieve data from the datagram after it has been received.

int getLength( )
Returns the length of the valid data contained in the byte array that would be returned from the getData( ) method. This may not equal the length of the whole byte array.

int getOffset( )
Returns the starting index of the data.

int getPort( )
Returns the port number.

void setAddress(InetAddress ipAddress)
Sets the address to which a packet will be sent. The address is specified by ipAddress.

void setData(byte[ ] data)
Sets the data to data, the offset to zero, and the length to number of bytes in data.

void setData(byte[ ] data, int idx, int size)
Sets the data to data, the offset to idx, and the length to size.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void setLength(int size)</td>
<td>Sets the length of the packet to size.</td>
</tr>
<tr>
<td>void setPort(int port)</td>
<td>Sets the port to port.</td>
</tr>
</tbody>
</table>

**A Datagram Example**

The following example implements a very simple networked communications client and server. Messages are typed into the window at the server and written across the network to the client side, where they are displayed.

```java
// Demonstrate datagrams.
import java.net.*;

class WriteServer {
    public static int serverPort = 998;
    public static int clientPort = 999;
    public static int buffer_size = 1024;
    public static DatagramSocket ds;
    public static byte buffer[] = new byte[buffer_size];

    public static void TheServer() throws Exception {
        int pos=0;
        while (true) {
            int c = System.in.read();
            switch (c) {
                case -1:
                    System.out.println("Server Quits.");
            }
        }
    }
}
```
This sample program is restricted by the `DatagramSocket` constructor to running between two ports on the local machine. To use the program, run

```
java WriteServer
```

in one window; this will be the client. Then run

```
java WriteServer 1
```

This will be the server. Anything that is typed in the server window will be sent to the client window after a newline is received.

**NOTE** The use of datagrams may not be allowed on your computer. (For example, a firewall may prevent their use.) If this is the case, the
preceding example cannot be used. Also, the port numbers used in the program work on the author's system, but may have to be adjusted for your environment.
This chapter examines the Applet class, which provides the foundation for applets. The Applet class is contained in the java.applet package. Applet contains several methods that give you detailed control over the execution of your applet. In addition, java.applet also defines three interfaces: AppletContext, AudioClip, and AppletStub.

Two Types of Applets
It is important to state at the outset that there are two varieties of applets based on Applet. The first are those based directly on the Applet class described in this chapter. These applets use the Abstract Window Toolkit (AWT) to provide the graphical user interface (or use no GUI at all). This style of applet has been available since Java was first created. The second type of applets are those based on the Swing class JApplet, which inherits Applet. Swing applets use the Swing classes to provide the GUI. Swing offers a richer and often easier-to-use user interface than does the AWT. Thus, Swing-based applets are now the most popular. However, traditional AWT-based applets are still used, especially when only a very simple user interface is required. Thus, both AWT- and Swing-based applets are valid.

This chapter describes AWT-based applets. However, because JApplet inherits Applet, all the features of Applet are also available in JApplet, and much of the information in this chapter applies to both types of applets. Therefore, even if you are interested in only Swing applets, the information in this chapter is still relevant and necessary. Understand, however, that when creating Swing-based applets, some additional constraints apply and these are described later in this book, when Swing is covered.

**NOTE** For information on building applets when using Swing, see Chapter 31.
Applet Basics

Chapter 13 introduced the general form of an applet and the steps necessary to compile and run one. Let’s begin by reviewing this information.

AWT-based applets are subclasses of Applet. Applets are not stand-alone programs. Instead, they run within either a web browser or an applet viewer. The illustrations shown in this chapter were created with the standard applet viewer, called appletviewer, provided by the JDK.

Execution of an applet does not begin at main(). Actually, few applets even have main() methods. Instead, execution of an applet is started and controlled with an entirely different mechanism, which will be explained shortly. Output to your applet’s window is not performed by System.out.println(). Rather, in an AWT-based applet, output is handled with various AWT methods, such as drawString(), which outputs a string to a specified X,Y location. Input is also handled differently than in a console application.

Before an applet can be used, a deployment strategy must be chosen. There are two basic approaches. The first is to use the Java Network Launch Protocol (JNLP). This approach offers the most flexibility, especially as it relates to rich Internet applications. For real-world applets that you create, JNLP will often be the best choice. However, a detailed discussion of JNLP is beyond the scope of this book. (See the JDK documentation for the latest details on JNLP.) Fortunately, JNLP is not required for the example applets shown here.

The second basic approach to deploying an applet is to specify the applet directly in an HTML file, without the use of JNLP. This is the original way that applets were launched when Java was created, and it is still used today—especially for simple applets. Furthermore, because of its inherent simplicity, it is the appropriate method for the applet examples described in this book. At the time of this writing, Oracle recommends the APPLET tag for this purpose. Therefore, the APPLET tag is used in this book. (Be aware that the APPLET tag is currently deprecated by the HTML specification. The alternative is the OBJECT tag. You should check the JDK documentation in this regard for the latest recommendations.) When an APPLET tag is encountered in the HTML file, the specified applet will be executed by a Java-enabled web browser.

The use of the APPLET tag offers a secondary advantage when developing applets because it enables you to easily view and test the applet. To do so, simply include a comment at the head of your Java source code file that contains the APPLET tag. This way, your code is documented with the necessary HTML statements needed by your applet, and you can test the compiled applet by starting the applet viewer with your Java source code file specified as the target. Here is an example of such a comment:

```html
/*
<applet code="MyApplet" width=200 height=60>
</applet>
*/
```
This comment contains an APPLET tag that will run an applet called MyApplet in a window that is 200 pixels wide and 60 pixels high. Because the inclusion of an APPLET command makes testing applets easier, all of the applets shown in this book will contain the appropriate APPLET tag embedded in a comment.

**NOTE** As noted in Chapter 13, beginning with the release of Java 7, update 21, Java applets must be signed to prevent security warnings when run in a browser. In fact, in some cases, the applet may be prevented from running. Applets stored in the local file system, such as you would create when compiling the examples in this book, are especially sensitive to this change. You may need to adjust the security settings in the Java Control Panel to run a local applet in a browser. At the time of this writing, Oracle recommends against the use of local applets, recommending instead that applets be executed through a web server. Furthermore, unsigned local applets may be blocked from execution in the future. In general, for applets that will be distributed via the Internet, such as commercial applications, signing is a virtual necessity. The concepts and techniques required to sign applets (and other types of Java programs) are beyond the scope of this book. However, extensive information is found on Oracle's website. Finally, as mentioned, the easiest way to try the applet examples is to use appletviewer.

**The Applet Class**
The Applet class defines the methods shown in Table 23-1. Applet provides all necessary support for applet execution, such as starting and stopping. It also provides methods that load and display images, and methods that load and play audio clips. Applet extends the AWT class Panel. In turn, Panel extends Container, which extends Component. These classes provide support for Java's window-based, graphical interface. Thus, Applet provides all of the necessary support for window-based activities. (An overview of the AWT is presented in subsequent chapters.)
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void destroy()</td>
<td>Called by the browser just before an applet is terminated. Your applet will override this method if it needs to perform any cleanup prior to its destruction.</td>
</tr>
<tr>
<td>AccessibleContext getAccessibleContext()</td>
<td>Returns the accessibility context for the invoking object.</td>
</tr>
<tr>
<td>AppletContext getAppletContext()</td>
<td>Returns the context associated with the applet.</td>
</tr>
<tr>
<td>String getAppInfo()</td>
<td>Overrides of this method should return a string that describes the applet.</td>
</tr>
<tr>
<td>AudioClip getAudioClip(URL url)</td>
<td>Returns an AudioClip object that encapsulates the audio clip found at the location specified by url.</td>
</tr>
<tr>
<td>AudioClip getAudioClip(URL url, String clipName)</td>
<td>Returns an AudioClip object that encapsulates the audio clip found at the location specified by url and having the name specified by clipName.</td>
</tr>
<tr>
<td>URL getCodeBase()</td>
<td>Returns the URL associated with the invoking applet.</td>
</tr>
<tr>
<td>URL getDocumentBase()</td>
<td>Returns the URL of the HTML document that invokes the applet.</td>
</tr>
<tr>
<td>Image getImage(URL url)</td>
<td>Returns an Image object that encapsulates the image found at the location specified by url.</td>
</tr>
<tr>
<td>Image getImage(URL url, String imageName)</td>
<td>Returns an Image object that encapsulates the image found at the location specified by url and having the name specified by imageName.</td>
</tr>
<tr>
<td>Locale getLocale()</td>
<td>Returns a Locale object that is used by various locale-sensitive classes and methods.</td>
</tr>
<tr>
<td>String getParameter(String parameterName)</td>
<td>Returns the parameter associated with parameterName. null is returned if the specified parameter is not found.</td>
</tr>
</tbody>
</table>
Table 23-1  The Methods Defined by Applet

**Applet Architecture**

As a general rule, an applet is a GUI-based program. As such, its architecture is different from the console-based programs shown in the first part of this book. If you are already familiar with GUI programming, you will be right at home writing applets. If not, then there are a few key concepts you must understand.

First, applets are event driven. Although we won’t examine event handling until the following chapter, it is important to understand in a general way how the event-driven architecture impacts the design of an applet. An applet resembles a set of interrupt service routines. Here is how the process works. An applet waits until an event occurs. The run-time system notifies the applet about an event by calling an event handler that has been
provided by the applet. Once this happens, the applet must take appropriate action and then quickly return. This is a crucial point. For the most part, your applet should not enter a "mode" of operation in which it maintains control for an extended period. Instead, it must perform specific actions in response to events and then return control to the run-time system. In those situations in which your applet needs to perform a repetitive task on its own (for example, displaying a scrolling message across its window), you must start an additional thread of execution. (You will see an example later in this chapter.)

Second, the user initiates interaction with an applet—not the other way around. As you know, in a console-based program, when the program needs input, it will prompt the user and then call some input method, such as `readLine()`. This is not the way it works in an applet. Instead, the user interacts with the applet as he or she wants, when he or she wants. These interactions are sent to the applet as events to which the applet must respond. For example, when the user clicks the mouse inside the applet's window, a mouse-clicked event is generated. If the user presses a key while the applet's window has input focus, a keypress event is generated. As you will see in later chapters, applets can contain various controls, such as push buttons and check boxes. When the user interacts with one of these controls, an event is generated.

While the architecture of an applet is not as easy to understand as that of a console-based program, Java makes it as simple as possible. If you have written programs for Windows (or other GUI-based operating systems), you know how intimidating that environment can be. Fortunately, Java provides a much cleaner approach that is more quickly mastered.

**An Applet Skeleton**

All but the most trivial applets override a set of methods that provides the basic mechanism by which the browser or applet viewer interfaces to the applet and controls its execution. Four of these methods, `init()`, `start()`, `stop()`, and `destroy()`, apply to all applets and are defined by `Applet`. Default implementations for all of these methods are provided. Applets do not need to override those methods they do not use. However, only very simple applets will not need to define all of them.

AWT-based applets (such as those discussed in this chapter) will also often override the `paint()` method, which is defined by the AWT `Component` class. This method is called when the applet's output must be redisplayed. (Swing-based applets use a different mechanism to accomplish this task.) These five methods can be assembled into the skeleton shown here:
Although this skeleton does not do anything, it can be compiled and run. When run, it generates the following empty window when viewed with appletviewer. Of course, in this and all subsequent examples, the precise look of the appletviewer frame may differ based on your execution environment. To help illustrate this fact, a variety of environments were used to generate the screen captures shown throughout this book.

```java
// An Applet skeleton.
import java.awt.*;
import java.applet.*;
/**
 <applet code="AppletSkel" width=300 height=100>
 </applet>
 */

public class AppletSkel extends Applet {
    // Called first.
    public void init() {
        // initialization
    }

    /* Called second, after init(). Also called whenever the applet is restarted. */
    public void start() {
        // start or resume execution
    }

    // Called when the applet is stopped.
    public void stop() {
        // suspends execution
    }

    /* Called when applet is terminated. This is the last method executed. */
    public void destroy() {
        // perform shutdown activities
    }

    // Called when an applet’s window must be restored.
    public void paint(Graphics g) {
        // redraw the contents of window
    }
}
Applet Initialization and Termination

It is important to understand the order in which the various methods shown in the skeleton are called. When an applet begins, the following methods are called, in this sequence:

1. init( )
2. start( )
3. paint( )

When an applet is terminated, the following sequence of method calls takes place:

1. stop( )
2. destroy( )

Let’s look more closely at these methods.

init( )
The init( ) method is the first method to be called. This is where you should initialize variables. This method is called only once during the run time of your applet.

start( )
The start( ) method is called after init( ). It is also called to restart an applet after it has been stopped. Whereas init( ) is called once—the first time an applet is loaded—start( ) is called each time an applet’s HTML document is displayed onscreen. So, if a user leaves a web page and comes back, the applet resumes execution at start( ).

paint( )
The paint( ) method is called each time an AWT-based applet’s output must be redrawn. This situation can occur for several reasons. For example, the window in which the applet is running may be overwritten by another window and then uncovered. Or the applet window may be minimized and then restored. paint( ) is also called when the applet begins execution. Whatever the cause, whenever the applet must redraw its output, paint( ) is called. The paint( ) method has one parameter of type Graphics. This parameter will contain the graphics context, which describes the graphics environment in which the applet is running. This context is used whenever output to the applet is required.
stop() method
The stop() method is called when a web browser leaves the HTML document containing the applet—when it goes to another page, for example. When stop() is called, the applet is probably running. You should use stop() to suspend threads that don’t need to run when the applet is not visible. You can restart them when start() is called if the user returns to the page.

destroy() method
The destroy() method is called when the environment determines that your applet needs to be removed completely from memory. At this point, you should free up any resources the applet may be using. The stop() method is always called before destroy().

Overriding update() method
In some situations, an AWT-based applet may need to override another method defined by the AWT, called update(). This method is called when your applet has requested that a portion of its window be redrawn. The default version of update() simply calls paint(). However, you can override the update() method so that it performs more subtle repainting. In general, overriding update() is a specialized technique that is not applicable to all applets, and the examples in this chapter do not override update().

Simple Applet Display Methods
As we’ve mentioned, applets are displayed in a window, and AWT-based applets use the AWT to perform input and output. Although we will examine the methods, procedures, and techniques related to the AWT in subsequent chapters, a few are described here, because we will use them to write sample applets. (Remember, Swing-based applets are described later in this book.)

As described in Chapter 13, to output a string to an applet, use drawString(), which is a member of the Graphics class. Typically, it is called from within either update() or paint(). It has the following general form:

```java
void drawString(String message, int x, int y)
```

Here, message is the string to be output beginning at x,y. In a Java window, the upper-left corner is location 0,0. The drawString() method will not recognize newline characters. If you want to start a line of text on another line, you must do so manually, specifying the precise X,Y location where you want the line to begin. (As you will see in later chapters, there are techniques that make this process easy.)

To set the background color of an applet’s window, use setBackground(). To set the foreground color (the color in which text is shown, for example), use setForeground(). These methods are defined by Component, and they have the following general forms:

```java
void setBackground(Color newColor)
void setForeground(Color newColor)
```
void setForeground(Color newColor)

Here, newColor specifies the new color. The class Color defines the constants shown here that can be used to specify colors:

<table>
<thead>
<tr>
<th>Color</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Color.black</td>
<td>Color.magenta</td>
</tr>
<tr>
<td>Color.blue</td>
<td>Color.orange</td>
</tr>
<tr>
<td>Color.cyan</td>
<td>Color.pink</td>
</tr>
<tr>
<td>Color.darkGray</td>
<td>Color.red</td>
</tr>
<tr>
<td>Color.gray</td>
<td>Color.white</td>
</tr>
<tr>
<td>Color.green</td>
<td>Color.yellow</td>
</tr>
<tr>
<td>Color.lightGray</td>
<td></td>
</tr>
</tbody>
</table>

Uppercase versions of the constants are also defined. The following example sets the background color to green and the text color to red:

```java
setBackground(Color.green);
setForeground(Color.red);
```

A good place to set the foreground and background colors is in the init() method. Of course, you can change these colors as often as necessary during the execution of your applet.

You can obtain the current settings for the background and foreground colors by calling getBackground() and getForeground(), respectively. They are also defined by Component and are shown here:

```java
Color getBackground()
Color getForeground()
```

Here is a very simple applet that sets the background color to cyan, the foreground color to red, and displays a message that illustrates the order in which the init(), start(), and paint() methods are called when an applet starts up:
Sample output is shown here:

![Applet Viewer: Sample](image)

The methods **stop()** and **destroy()** are not overridden, because they are not needed by this simple applet.

**Requesting Repainting**

As a general rule, an applet writes to its window only when its **paint()** method is called by the AWT. This raises an interesting question: How can the applet itself cause its window to
be updated when its information changes? For example, if an applet is displaying a moving
banner, what mechanism does the applet use to update the window each time this banner
scrolls? Remember, one of the fundamental architectural constraints imposed on an applet
is that it must quickly return control to the run-time system. It cannot create a loop inside
paint( ) that repeatedly scrolls the banner, for example. This would prevent control from
passing back to the AWT. Given this constraint, it may seem that output to your applet’s
window will be difficult at best. Fortunately, this is not the case. Whenever your applet
needs to update the information displayed in its window, it simply calls repaint( ).

The repaint( ) method is defined by the AWT. It causes the AWT run-time system to
execute a call to your applet’s update( ) method, which, in its default implementation, calls
paint( ). Thus, for another part of your applet to output to its window, simply store the
output and then call repaint( ). The AWT will then execute a call to paint( ), which can
display the stored information. For example, if part of your applet needs to output a string,

it can store this string in a String variable and then call repaint( ). Inside paint( ), you
will output the string using drawString( ).

The repaint( ) method has four forms. Let’s look at each one, in turn. The simplest version
of repaint( ) is shown here:

    void repaint()

This version causes the entire window to be repainted. The following version
specifies a region that will be repainted:

    void repaint(int left, int top, int width, int height)

Here, the coordinates of the upper-left corner of the region are specified by left and
top, and the width and height of the region are passed in width and height. These
dimensions are specified in pixels. You save time by specifying a region to repaint.

Window updates are costly in terms of time. If you need to update only a small
portion of the window, it is more efficient to repaint only that region.

Calling repaint( ) is essentially a request that your applet be repainted sometime soon.
However, if your system is slow or busy, update( ) might not be called immediately.

Multiple requests for repainting that occur within a short time can be collapsed by the AWT
in a manner such that update( ) is only called sporadically. This can be a problem in many
situations, including animation, in which a consistent update time is necessary. One
solution to this problem is to use the following forms of repaint( ):

    void repaint(long maxDelay)
    void repaint(long maxDelay, int x, int y, int width, int height)

Here, maxDelay specifies the maximum number of milliseconds that can elapse
before update( ) is called. Beware, though. If the time elapses before update( )
can be called, it isn’t called. There’s no return value or exception thrown, so you
must be careful.
NOTE It is possible for a method other than `paint()` or `update()` to output to an applet's window. To do so, it must obtain a graphics context by calling `getGraphics()` (defined by `Component`) and then use this context to output to the window. However, for most applications, it is better and easier to route window output through `paint()` and to call `repaint()` when the contents of the window change.

A Simple Banner Applet
To demonstrate `repaint()`, a simple banner applet is developed. This applet scrolls a message, from right to left, across the applet's window. Since the scrolling of the message is a repetitive task, it is performed by a separate thread, created by the applet when it is initialized. The banner applet is shown here:

```java
/* A simple banner applet.
   
   This applet creates a thread that scrolls
   the message contained in msg right to left
   across the applet's window.
 */
import java.awt.*;
import java.applet.*;

/*
<applet code="SimpleBanner" width=300 height=50>
</applet>
*/

public class SimpleBanner extends Applet implements Runnable {
    String msg = "A Simple Moving Banner:";
    Thread t = null;
    int state;
    volatile boolean stopFlag;

    // Set colors and initialize thread.
    public void init() {
        setBackground(Color.cyan);
        setForeground(Color.red);
    }
```
// Start thread
public void start() {
    t = new Thread(this);
    stopFlag = false;
    t.start();
}

// Entry point for the thread that runs the banner.
public void run() {

    // Redisplay banner
    for( ; ; ) {
        try {
            repaint();
            Thread.sleep(250);
            if(stopFlag)
                break;
        } catch(InterruptedException e) {} 
    }
}

// Pause the banner.
public void stop() {
    stopFlag = true;
    t = null;
}

// Display the banner.
public void paint(Graphics g) {
    char ch;

    ch = msg.charAt(0);
    msg = msg.substring(1, msg.length());
    msg += ch;

    g.drawString(msg, 50, 30);
}

Following is sample output:
Let’s take a close look at how this applet operates. First, notice that SimpleBanner extends Applet, as expected, but it also implements Runnable. This is necessary, since the applet will be creating a second thread of execution that will be used to scroll the banner. Inside init(), the foreground and background colors of the applet are set. After initialization, the run-time system calls start() to start the applet running. Inside start(), a new thread of execution is created and assigned to the Thread variable t. Then, the boolean variable stopFlag, which controls the execution of the applet, is set to false. Next, the thread is started by a call to t.start(). Remember that t.start() calls a method defined by Thread, which causes run() to begin executing. It does not cause a call to the version of start() defined by Applet. These are two separate methods. Inside run(), a call to repaint() is made. This eventually causes the paint() method to be called, and the rotated contents of msg are displayed. Between each iteration, run() sleeps for a quarter of a second. The net effect is that the contents of msg are scrolled right to left in a constantly moving display. The stopFlag variable is checked on each iteration. When it is true, the run() method terminates. If a browser is displaying the applet when a new page is viewed, the stop() method is called, which sets stopFlag to true, causing run() to terminate. This is the mechanism used to stop the thread when its page is no longer in view. When the applet is brought back into view, start() is once again called, which starts a new thread to execute the banner.

Using the Status Window

In addition to displaying information in its window, an applet can also output a message to the status window of the browser or applet viewer on which it is running. To do so, call showStatus() with the string that you want displayed. The status window is a good place to give the user feedback about what is occurring in the applet, suggest options, or possibly report some types of errors. The status window also makes an excellent debugging aid, because it gives you an easy way to output information about your applet. The following applet demonstrates showStatus():
Sample output from this program is shown here:

```
// Using the Status Window.
import java.awt.*;
import java.applet.*;
/

<applet code="StatusWindow" width=300 height=50>
</applet>
*/

public class StatusWindow extends Applet {
    public void init() {
        setBackground(Color.cyan);
    }

    // Display msg in applet window.
    public void paint(Graphics g) {
        g.drawString("This is in the applet window.", 10, 20);
        showStatus("This is shown in the status window.");
    }
}
```

The HTML APPLET Tag

As mentioned earlier, at the time of this writing, Oracle recommends that the APPLET tag be used to manually start an applet when JNLP is not used. An applet viewer will execute each APPLET tag that it finds in a separate window, while web browsers will allow many applets on a single page. So far, we have been using only a simplified form of the APPLET tag. Now it is time to take a closer look at it.

The syntax for a fuller form of the APPLET tag is shown here. Bracketed items are optional.
Let's take a look at each part now.

**CODEBASE**  CODEBASE is an optional attribute that specifies the base URL of the applet code, which is the directory that will be searched for the applet's executable class file (specified by the CODE tag). The HTML document's URL directory is used as the CODEBASE if this attribute is not specified.

**CODE**  CODE is a required attribute that gives the name of the file containing your applet's compiled .class file. This file is relative to the code base URL of the applet, which is the directory that the HTML file was in or the directory indicated by CODEBASE if set.

**ALT**  The ALT tag is an optional attribute used to specify a short text message that should be displayed if the browser recognizes the APPLET tag but can’t currently run Java applets. This is distinct from the alternate HTML you provide for browsers that don’t support applets.

**NAME**  NAME is an optional attribute used to specify a name for the applet instance. Applets must be named in order for other applets on the same page to find them by name and communicate with them. To obtain an applet by name, use `getApplet()` , which is defined by the **AppletContext** interface.

**WIDTH and HEIGHT**  WIDTH and HEIGHT are required attributes that give the size (in pixels) of the applet display area.

**ALIGN**  ALIGN is an optional attribute that specifies the alignment of the applet. This attribute is treated the same as the HTML IMG tag with these possible values: LEFT, RIGHT, TOP, BOTTOM, MIDDLE, BASELINE, TEXTTOP, ABSMIDDLE,
and ABSBOTTOM.

**VSPACE and HSPACE** These attributes are optional. VSPACE specifies the space, in pixels, above and below the applet. HSPACE specifies the space, in pixels, on each side of the applet. They’re treated the same as the IMG tag’s VSPACE and HSPACE attributes.

**PARAM NAME and VALUE** The PARAM tag allows you to specify applet-specific arguments. Applets access their attributes with the `getParameter()` method.

Other valid APPLET attributes include ARCHIVE, which lets you specify one or more archive files, and OBJECT, which specifies a saved version of the applet. In general, an APPLET tag should include only a CODE or an OBJECT attribute, but not both.

**Passing Parameters to Applets**

As just discussed, the APPLET tag allows you to pass parameters to your applet. To retrieve a parameter, use the `getParameter()` method. It returns the value of the specified parameter in the form of a `String` object. Thus, for numeric and boolean values, you will need to convert their string representations into their internal formats. Here is an example that demonstrates passing parameters:

```java
// Use Parameters
import java.awt.*;
import java.applet.*;
/**
 * <applet code="ParamDemo" width=300 height=80>
<param name=fontName value=Courier>
<param name=fontSize value=14>
<param name=leading value=2>
<param name=accountEnabled value=true>
</applet>
*/

public class ParamDemo extends Applet {
    String fontName,
```
```java
int fontSize;
float leading;
boolean active;

// Initialize the string to be displayed.
public void start() {
    String param;

    fontName = getParameter("fontName");
    if (fontName == null)
        fontName = "Not Found";

    param = getParameter("fontSize");
    try {
        if (param != null)
            fontSize = Integer.parseInt(param);
    } catch (NumberFormatException e) {
        fontSize = -1;
    }

    param = getParameter("leading");
    try {
        if (param != null)
            leading = Float.valueOf(param).floatValue();
    } catch (NumberFormatException e) {
        leading = -1;
    }

    param = getParameter("accountEnabled");
    if (param != null)
        active = Boolean.valueOf(param).booleanValue();

    // Display parameters.
    public void paint(Graphics g) {
        g.drawString("Font name: " + fontName, 0, 10);
        g.drawString("Font size: " + fontSize, 0, 26);
        g.drawString("Leading: " + leading, 0, 42);
        g.drawString("Account Active: " + active, 0, 58);
    }
}
```

Sample output from this program is shown here:
As the program shows, you should test the return values from `getParameter()`. If a parameter isn’t available, `getParameter()` will return `null`. Also, conversions to numeric types must be attempted in a `try` statement that catches `NumberFormatException`. Uncaught exceptions should never occur within an applet.

**Improving the Banner Applet**

It is possible to use a parameter to enhance the banner applet shown earlier. In the previous version, the message being scrolled was hard-coded into the applet. However, passing the message as a parameter allows the banner applet to display a different message each time it is executed. This improved version is shown here. Notice that the `APPLET` tag at the top of the file now specifies a parameter called `message` that is linked to a quoted string.
// A parameterized banner
import java.awt.*;
import java.applet.*;
/*
<applet code="ParamBanner" width=300 height=50>
<param name="message" value="Java makes the Web move!">
</applet>
*/

public class ParamBanner extends Applet implements Runnable {
    String msg;
    Thread t = null;
    int state;
    volatile boolean stopFlag;

    // Set colors and initialize thread.
    public void init() {
        setBackground(Color.cyan);
        setForeground(Color.red);
    }

    // Start thread
    public void start() {
        msg = getParameter("message");
        if (msg == null) msg = "Message not found."
        msg = "" + msg;
        t = new Thread(this);
        stopFlag = false;
        t.start();
    }

    // Entry point for the thread that runs the banner.
    public void run() {
        // Redisplay banner
        for (; ; ) {
            try {
                repaint();
                Thread.sleep(250);
                if (stopFlag)
                    break;
            } catch (InterruptedException e) { }
        }
    }
}
getDocumentBase() and getCodeBase()

Often, you will create applets that will need to explicitly load media and text. Java will allow the applet to load data from the directory holding the HTML file that started the applet (the document base) and the directory from which the applet’s class file was loaded (the code base). These directories are returned as URL objects (described in Chapter 22) by getDocumentBase() and getCodeBase(). They can be concatenated with a string that names the file you want to load. To actually load another file, you will use the showDocument() method defined by the AppletContext interface, discussed in the next section.

The following applet illustrates these methods:
AppletContext and showDocument( )

One application of Java is to use active images and animation to provide a graphical means of navigating the Web that is more interesting than simple text-based links. To allow your applet to transfer control to another URL, you must use the showDocument( ) method defined by the AppletContext interface. AppletContext is an interface that lets you get information from the applet’s execution environment. The methods defined by AppletContext are shown in Table 23-2. The context of the currently executing applet is obtained by a call to the getAppletContext( ) method defined by Applet.

Sample output from this program is shown here:
Within an applet, once you have obtained the applet's context, you can bring another document into view by calling `showDocument()`. This method has no return value and throws no exception if it fails, so use it carefully. There are two `showDocument()` methods. The method `showDocument(URL)` displays the document at the specified URL. The method `showDocument(URL, String)` displays the specified document at the specified location within the browser window. Valid arguments for `where` are "_self" (show in current frame), "_parent" (show in parent frame), "_top" (show in topmost frame), and "_blank" (show in new browser window). You can also specify a name, which causes the document to be shown in a new browser window by that name.

The following applet demonstrates `AppletContext` and `showDocument()`. Upon execution, it obtains the current applet context and uses that context to transfer control to a file called `Test.html`. This file must be in the same directory as the applet. `Test.html` can contain any valid hypertext that you like.
The AudioClip Interface
The AudioClip interface defines these methods: play( ) (play a clip from the beginning), stop( ) (stop playing the clip), and loop( ) (play the loop continuously). After you have loaded an audio clip using getAudioClip( ), you can use these methods to play it.

The AppletStub Interface
The AppletStub interface provides the means by which an applet and the browser (or applet viewer) communicate. Your code will not typically implement this interface.

Outputting to the Console
Although output to an applet's window must be accomplished through GUI-based methods, such as drawString( ), it is still possible to use console output in your applet—especially for debugging purposes. In an applet, when you call a method such as System.out.println( ), the output is not sent to your applet's window. Instead, it appears either in the console session in which you launched the applet viewer or in the Java console that is available in some browsers. Use of console output for purposes other than debugging is discouraged, since it violates the design principles of the graphical interface most users will expect.

/* Using an applet context, getCodeBase(),
   and showDocument() to display an HTML file. */

import java.awt.*;
import java.applet.*;
import java.net.*;
/*
<applet code="ACDemo" width=300 height=50>
</applet>
*/

public class ACDemo extends Applet {
    public void start() {
        AppletContext ac = getAppletContext();
        URL url = getCodeBase(); // get url of this applet
        try {
            ac.showDocument(new URL(url + "Test.html"));
        } catch (MalformedURLException e) {
            showStatus("URL not found");
        }
    }
}

The AudioClip Interface
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This chapter examines an important aspect of Java: the event. Event handling is fundamental to Java programming because it is integral to the creation of many kinds of applications, including applets and other types of GUI-based programs. As explained in Chapter 23, applets are event-driven programs that use a graphical user interface to interact with the user. Furthermore, any program that uses a graphical user interface, such as a Java application written for Windows, is event driven. Thus, you cannot write these types of programs without a solid command of event handling. Events are supported by a number of packages, including `java.util`, `java.awt`, and `java.awt.event`.

Most events to which your program will respond are generated when the user interacts with a GUI-based program. These are the types of events examined in this chapter. They are passed to your program in a variety of ways, with the specific method dependent upon the actual event. There are several types of events, including those generated by the mouse, the keyboard, and various GUI controls, such as a push button, scroll bar, or check box.

This chapter begins with an overview of Java’s event handling mechanism. It then examines the main event classes and interfaces used by the AWT and develops several examples that demonstrate the fundamentals of event processing. This chapter also explains how to use adapter classes, inner classes, and anonymous inner classes to streamline event handling code. The examples provided in the remainder of this book make frequent use of these techniques.

**NOTE** This chapter focuses on events related to GUI-based programs. However, events are also occasionally used for purposes not directly related to GUI-based programs. In all cases, the same basic event handling techniques apply.

Two Event Handling Mechanisms
Before beginning our discussion of event handling, an important historical point must be made: The way in which events are handled changed significantly between the original version of Java (1.0) and all subsequent versions of Java, beginning with version 1.1. Although the 1.0 method of event handling is still supported, it is not recommended for new programs. Also, many of the methods that support the old 1.0 event model have been deprecated. The modern approach is the way that events should be handled by all new programs and thus is the method employed by programs in this book.

**The Delegation Event Model**

The modern approach to handling events is based on the **delegation event model**, which defines standard and consistent mechanisms to generate and process events. Its concept is quite simple: a *source* generates an event and sends it to one or more *listeners*. In this scheme, the listener simply waits until it receives an event. Once an event is received, the listener processes the event and then returns. The advantage of this design is that the application logic that processes events is cleanly separated from the user interface logic that generates those events. A user interface element is able to “delegate” the processing of an event to a separate piece of code.

In the delegation event model, listeners must register with a source in order to receive an event notification. This provides an important benefit: notifications are sent only to listeners that want to receive them. This is a more efficient way to handle events than the design used by the original Java 1.0 approach. Previously, an event was propagated up the containment hierarchy until it was handled by a component. This required components to receive events that they did not process, and it wasted valuable time. The delegation event model eliminates this overhead.

The following sections define events and describe the roles of sources and listeners.

**Events**

In the delegation model, an *event* is an object that describes a state change in a source. Among other causes, an event can be generated as a consequence of a person interacting with the elements in a graphical user interface. Some of the activities that cause events to be generated are pressing a button, entering a character via the keyboard, selecting an item in a list, and clicking the mouse. Many other user operations could also be cited as examples. Events may also occur that are not directly caused by interactions with a user interface. For example, an event may be generated when a timer expires, a counter exceeds a value, a software or hardware failure occurs, or an operation is completed. You are free to define events that are appropriate for your application.

**Event Sources**

A *source* is an object that generates an event. This occurs when the internal state of that object changes in some way. Sources may generate more than one type of event. A source must register listeners in order for the listeners to receive notifications about a
specific type of event. Each type of event has its own registration method. Here is the general form:

```
public void addTypeListener (TypeListener el )
```

Here, Type is the name of the event, and el is a reference to the event listener. For example, the method that registers a keyboard event listener is called `addKeyListener()`. The method that registers a mouse motion listener is called `addMouseMotionListener()`. When an event occurs, all registered listeners are notified and receive a copy of the event object. This is known as *multicasting* the event. In all cases, notifications are sent only to listeners that register to receive them.

Some sources may allow only one listener to register. The general form of such a method is this:

```
public void addTypeListener (TypeListener el )
throws java.util.TooManyListenersException
```

Here, Type is the name of the event, and el is a reference to the event listener. When such an event occurs, the registered listener is notified. This is known as *unicasting* the event.

A source must also provide a method that allows a listener to unregister an interest in a specific type of event. The general form of such a method is this:

```
public void removeTypeListener (TypeListener el )
```

Here, Type is the name of the event, and el is a reference to the event listener. For example, to remove a keyboard listener, you would call `removeKeyListener()`. The methods that add or remove listeners are provided by the source that generates events. For example, the `Component` class provides methods to add and remove keyboard and mouse event listeners.

### Event Listeners

A *listener* is an object that is notified when an event occurs. It has two major requirements. First, it must have been registered with one or more sources to receive notifications about specific types of events. Second, it must implement methods to receive and process these notifications.

The methods that receive and process events are defined in a set of interfaces, such as those found in `java.awt.event`. For example, the `MouseMotionListener` interface defines two methods to receive notifications when the mouse is dragged or moved. Any object may receive and process one or both of these events if it provides an implementation of this interface. Other listener interfaces are discussed later in this and other chapters.

### Event Classes

The classes that represent events are at the core of Java’s event handling mechanism. Thus,
a discussion of event handling must begin with the event classes. It is important to understand, however, that Java defines several types of events and that not all event classes can be discussed in this chapter. Arguably, the most widely used events at the time of this writing are those defined by the AWT and those defined by Swing. This chapter focuses on the AWT events. (Most of these events also apply to Swing.) Several Swing-specific events are described in Chapter 31, when Swing is covered.

At the root of the Java event class hierarchy is EventObject, which is in java.util. It is the superclass for all events. Its one constructor is shown here:

```
EventObject(Object src)
```

Here, src is the object that generates this event.

EventObject defines two methods: getSource( ) and toString( ). The getSource( ) method returns the source of the event. Its general form is shown here:

```
Object getSource( )
```

As expected, toString( ) returns the string equivalent of the event.

The class AWTEvent, defined within the java.awt package, is a subclass of EventObject. It is the superclass (either directly or indirectly) of all AWT-based events used by the delegation event model. ItsgetID( ) method can be used to determine the type of the event. The signature of this method is shown here:

```
int getID( )
```

Additional details about AWTEvent are provided at the end of Chapter 26. At this point, it is important to know only that all of the other classes discussed in this section are subclasses of AWTEvent. To summarize:

- EventObject is a superclass of all events.
- AWTEvent is a superclass of all AWT events that are handled by the delegation event model.

The package java.awt.event defines many types of events that are generated by various user interface elements. Table 24-1 shows several commonly used event classes and provides a brief description of when they are generated. Commonly used constructors and methods in each class are described in the following sections.
The ActionEvent Class

An `ActionEvent` is generated when a button is pressed, a list item is double-clicked, or a menu item is selected. The `ActionEvent` class defines four integer constants that can be used to identify any modifiers associated with an action event: `ALT_MASK`, `CTRL_MASK`, `META_MASK`, and `SHIFT_MASK`. In addition, there is an integer constant, `ACTION_PERFORMED`, which can be used to identify action events.

`ActionEvent` has these three constructors:

```java
public ActionEvent(Object src, int type, String cmd)
public ActionEvent(Object src, int type, String cmd, int modifiers)
public ActionEvent(Object src, int type, String cmd, long when, int modifiers)
```

Here, `src` is a reference to the object that generated this event. The type of the event is specified by `type`, and its command string is `cmd`. The argument `modifiers` indicates which modifier keys (`ALT`, `CTRL`, `META`, and/or `SHIFT`) were pressed when the event was generated. The `when` parameter specifies when the event occurred.

You can obtain the command name for the invoking `ActionEvent` object by using the `getActionCommand()` method, shown here:

```java
String getActionCommand()
```

For example, when a button is pressed, an action event is generated that has a command name equal to the label on that button.

The `getModifiers()` method returns a value that indicates which modifier keys (`ALT`, `CTRL`, `META`, and/or `SHIFT`) were pressed when the event was generated. Its form is shown here:

```java
int getModifiers()
```

The method `getWhen()` returns the time at which the event took place. This is
called the event’s timestamp. The `getWhen()` method is shown here:

```java
long getWhen()
```

**The AdjustmentEvent Class**

An `AdjustmentEvent` is generated by a scroll bar. There are five types of adjustment events. The `AdjustmentEvent` class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK_DECREMENT</td>
<td>The user clicked inside the scroll bar to decrease its value.</td>
</tr>
<tr>
<td>BLOCK_INCREMENT</td>
<td>The user clicked inside the scroll bar to increase its value.</td>
</tr>
<tr>
<td>TRACK</td>
<td>The slider was dragged.</td>
</tr>
<tr>
<td>UNIT_DECREMENT</td>
<td>The button at the end of the scroll bar was clicked to decrease its value.</td>
</tr>
<tr>
<td>UNIT_INCREMENT</td>
<td>The button at the end of the scroll bar was clicked to increase its value.</td>
</tr>
</tbody>
</table>

In addition, there is an integer constant, `ADJUSTMENT_VALUE_CHANGED`, that indicates that a change has occurred.

Here is one `AdjustmentEvent` constructor:

```java
AdjustmentEvent(Adjustable src, int id, int type, int val)
```

Here, `src` is a reference to the object that generated this event. The `id` specifies the event. The type of the adjustment is specified by `type`, and its associated value is `val`.

The `getAdjustable()` method returns the object that generated the event. Its form is shown here:

```java
Adjustable getAdjustable()
```

The type of the adjustment event may be obtained by the `getAdjustmentType()` method. It returns one of the constants defined by `AdjustmentEvent`. The general form is shown here:

```java
int getAdjustmentType()
```

The amount of the adjustment can be obtained from the `getValue()` method, shown here:

```java
int getValue()
```

For example, when a scroll bar is manipulated, this method returns the value represented by that change.

**The ComponentEvent Class**
A ComponentEvent is generated when the size, position, or visibility of a component is changed. There are four types of component events. The ComponentEvent class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>COMPONENT_HIDDEN</td>
<td>The component was hidden.</td>
</tr>
<tr>
<td>COMPONENT_MOVED</td>
<td>The component was moved.</td>
</tr>
<tr>
<td>COMPONENT_RESIZED</td>
<td>The component was resized.</td>
</tr>
<tr>
<td>COMPONENT_SHOWN</td>
<td>The component became visible.</td>
</tr>
</tbody>
</table>

ComponentEvent has this constructor:

```
ComponentEvent(Component src, int type)
```

Here, src is a reference to the object that generated this event. The type of the event is specified by type.

ComponentEvent is the superclass either directly or indirectly of ContainerEvent, KeyEvent, MouseEvent, and WindowEvent, among others. The getComponent() method returns the component that generated the event. It is shown here:

```
Component getComponent()
```

The ContainerEvent Class

A ContainerEvent is generated when a component is added to or removed from a container. There are two types of container events. The ContainerEvent class defines int constants that can be used to identify them: COMPONENT_ADDED and COMPONENT_REMOVED. They indicate that a component has been added to or removed from the container.

ContainerEvent is a subclass of ComponentEvent and has this constructor:

```
ContainerEvent(Component src, int type, Component comp)
```

Here, src is a reference to the container that generated this event. The type of the event is specified by type, and the component that has been added to or removed from the container is comp.

You can obtain a reference to the container that generated this event by using the getContainer() method, shown here:

```
Container getContainer()
```

The getChild() method returns a reference to the component that was added to or removed from the container. Its general form is shown here:
The FocusEvent Class

A FocusEvent is generated when a component gains or loses input focus. These events are identified by the integer constants FOCUS_GAINED and FOCUS_LOST. FocusEvent is a subclass of ComponentEvent and has these constructors:

FocusEvent(Component src, int type)
FocusEvent(Component src, int type, boolean temporaryFlag)
FocusEvent(Component src, int type, boolean temporaryFlag, Component other)

Here, src is a reference to the component that generated this event. The type of the event is specified by type. The argument temporaryFlag is set to true if the focus event is temporary. Otherwise, it is set to false. (A temporary focus event occurs as a result of another user interface operation. For example, assume that the focus is in a text field. If the user moves the mouse to adjust a scroll bar, the focus is temporarily lost.)

The other component involved in the focus change, called the opposite component, is passed in other. Therefore, if a FOCUS_GAINED event occurred, other will refer to the component that lost focus. Conversely, if a FOCUS_LOST event occurred, other will refer to the component that gains focus.

You can determine the other component by calling getOppositeComponent(), shown here:

Component getOppositeComponent()  
The opposite component is returned.

The isTemporary() method indicates if this focus change is temporary. Its form is shown here:

boolean isTemporary()  
The method returns true if the change is temporary. Otherwise, it returns false.

The InputEvent Class

The abstract class InputEvent is a subclass of ComponentEvent and is the superclass for component input events. Its subclasses are KeyEvent and MouseEvent. InputEvent defines several integer constants that represent any modifiers, such as the control key being pressed, that might be associated with the event. Originally, the InputEvent class defined the following eight values to represent the modifiers:

<table>
<thead>
<tr>
<th>Modifier</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT_MASK</td>
<td>0</td>
</tr>
<tr>
<td>ALT_GRAPH_MASK</td>
<td>1</td>
</tr>
<tr>
<td>BUTTON0_MASK</td>
<td>2</td>
</tr>
<tr>
<td>BUTTON1_MASK</td>
<td>4</td>
</tr>
<tr>
<td>BUTTON2_MASK</td>
<td>8</td>
</tr>
<tr>
<td>CTRL_MASK</td>
<td>16</td>
</tr>
<tr>
<td>META_MASK</td>
<td>32</td>
</tr>
<tr>
<td>SHIFT_MASK</td>
<td>64</td>
</tr>
</tbody>
</table>
However, because of possible conflicts between the modifiers used by keyboard events and mouse events, and other issues, the following extended modifier values were added:

<table>
<thead>
<tr>
<th>ALT_DOWN_MASK</th>
<th>BUTTON2_DOWN_MASK</th>
<th>META_DOWN_MASK</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALT_GRAPH_DOWN_MASK</td>
<td>BUTTON3_DOWN_MASK</td>
<td>SHIFT_DOWN_MASK</td>
</tr>
<tr>
<td>BUTTON1_DOWN_MASK</td>
<td>CTRL_DOWN_MASK</td>
<td></td>
</tr>
</tbody>
</table>

When writing new code, it is recommended that you use the new, extended modifiers rather than the original modifiers.

To test if a modifier was pressed at the time an event is generated, use the `isAltDown()`, `isAltGraphDown()`, `isControlDown()`, `isMetaDown()`, and `isShiftDown()` methods. The forms of these methods are shown here:

```java
boolean isAltDown()
boolean isAltGraphDown()
boolean isControlDown()
boolean isMetaDown()
boolean isShiftDown()
```

You can obtain a value that contains all of the original modifier flags by calling the `getModifiers()` method. It is shown here:

```java
int getModifiers()
```

You can obtain the extended modifiers by calling `getModifiersEx()`, which is shown here:

```java
int getModifiersEx()
```

**The ItemEvent Class**

An `ItemEvent` is generated when a check box or a list item is clicked or when a checkable menu item is selected or deselected. (Check boxes and list boxes are described later in this book.) There are two types of item events, which are identified by the following integer constants:

<table>
<thead>
<tr>
<th>DESELECTED</th>
<th>The user deselected an item.</th>
</tr>
</thead>
<tbody>
<tr>
<td>SELECTED</td>
<td>The user selected an item.</td>
</tr>
</tbody>
</table>

In addition, `ItemEvent` defines one integer constant, `ITEM_STATE_CHANGED`, that signifies a change of state.

`ItemEvent` has this constructor:

```java
ItemEvent(ItemSelectable src, int type, Object entry, int state)
```

Here, `src` is a reference to the component that generated this event. For example,
this might be a list or choice element. The type of the event is specified by type. The specific item that generated the item event is passed in entry. The current state of that item is in state.

The getItem method can be used to obtain a reference to the item that changed. Its signature is shown here:

Object getItem()

The getItemSelectable method can be used to obtain a reference to the ItemSelectable object that generated an event. Its general form is shown here:

ItemSelectable getItemSelectable()

Lists and choices are examples of user interface elements that implement the ItemSelectable interface.

The getStateChange method returns the state change (that is, SELECTED or DESELECTED) for the event. It is shown here:

int getStateChange()

The KeyEvent Class

A KeyEvent is generated when keyboard input occurs. There are three types of key events, which are identified by these integer constants: KEY_PRESSED, KEY_RELEASED, and KEY_TYPED. The first two events are generated when any key is pressed or released. The last event occurs only when a character is generated. Remember, not all keypresses result in characters. For example, pressing shift does not generate a character.

There are many other integer constants that are defined by KeyEvent. For example, VK_0 through VK_9 and VK_A through VK_Z define the ASCII equivalents of the numbers and letters. Here are some others:

<table>
<thead>
<tr>
<th>VK_ALT</th>
<th>VK_DOWN</th>
<th>VK_LEFT</th>
<th>VK_RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td>VK_CANCEL</td>
<td>VK_ENTER</td>
<td>VK_PAGE_DOWN</td>
<td>VK_SHIFT</td>
</tr>
<tr>
<td>VK_CONTROL</td>
<td>VK_ESCAPE</td>
<td>VK_PAGE_UP</td>
<td>VK_UP</td>
</tr>
</tbody>
</table>

The VK constants specify virtual key codes and are independent of any modifiers, such as control, shift, or alt.

KeyEvent is a subclass of InputEvent. Here is one of its constructors:

KeyEvent(Component src, int type, long when, int modifiers, int code, char ch)

Here, src is a reference to the component that generated the event. The type of the event is specified by type. The system time at which the key was pressed is passed in when. The modifiers argument indicates which modifiers were pressed when this key event occurred. The virtual key code, such as VK_UP, VK_A, and so forth, is passed in code. The character equivalent (if one exists) is passed in ch. If no valid character exists, then ch contains CHAR_UNDEFINED. For
**KEY_TYPED** events, code will contain **VK_UNDEFINED**.
The **KeyEvent** class defines several methods, but probably the most commonly used ones are **getKeyChar()**, which returns the character that was entered, and **getKeyCode()**, which returns the key code. Their general forms are shown here:

```java
char getKeyChar()
int getKeyCode()
```

If no valid character is available, then **getKeyChar()** returns **CHAR_UNDEFINED**. When a **KEY_TYPED** event occurs, **getKeyCode()** returns **VK_UNDEFINED**.

The **MouseEvent** Class

There are eight types of mouse events. The **MouseEvent** class defines the following integer constants that can be used to identify them:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOUSE_CLICKED</td>
<td>The user clicked the mouse.</td>
</tr>
<tr>
<td>MOUSE_DRAGGED</td>
<td>The user dragged the mouse.</td>
</tr>
<tr>
<td>MOUSE_ENTERED</td>
<td>The mouse entered a component.</td>
</tr>
<tr>
<td>MOUSE_EXITED</td>
<td>The mouse exited from a component.</td>
</tr>
<tr>
<td>MOUSE_MOVED</td>
<td>The mouse moved.</td>
</tr>
<tr>
<td>MOUSE_PRESSED</td>
<td>The mouse was pressed.</td>
</tr>
<tr>
<td>MOUSE_RELEASED</td>
<td>The mouse was released.</td>
</tr>
<tr>
<td>MOUSE_WHEEL</td>
<td>The mouse wheel was moved.</td>
</tr>
</tbody>
</table>

**MouseEvent** is a subclass of **InputEvent**. Here is one of its constructors:

```java
MouseEvent(Component src, int type, long when, int modifiers,
            int x, int y, int clicks, boolean triggersPopup)
```

Here, **src** is a reference to the component that generated the event. The type of the event is specified by **type**. The system time at which the mouse event occurred is passed in **when**. The **modifiers** argument indicates which modifiers were pressed when a mouse event occurred. The coordinates of the mouse are passed in **x** and **y**. The click count is passed in **clicks**. The **triggersPopup** flag indicates if this event causes a pop-up menu to appear on this platform.

Two commonly used methods in this class are **getX()** and **getY()**. These return the X and Y coordinates of the mouse within the component when the event occurred. Their forms are shown here:

```java
int getX()
```
int getY()

Alternatively, you can use the **getPoint()** method to obtain the coordinates of the mouse. It is shown here:

Point getPoint()

It returns a **Point** object that contains the X,Y coordinates in its integer members: \(x\) and \(y\).

The **translatePoint()** method changes the location of the event. Its form is shown here:

```java
void translatePoint(int x, int y)
```

Here, the arguments \(x\) and \(y\) are added to the coordinates of the event.

The **getClickCount()** method obtains the number of mouse clicks for this event. Its signature is shown here:

```java
int getClickCount()
```

The **isPopupTrigger()** method tests if this event causes a pop-up menu to appear on this platform. Its form is shown here:

```java
boolean isPopupTrigger()
```

Also available is the **getButton()** method, shown here:

```java
int getButton()
```

It returns a value that represents the button that caused the event. For most cases, the return value will be one of these constants defined by **MouseEvent**:

```
| NOBUTTON     | BUTTON1 | BUTTON2 | BUTTON3 |
```

The **NOBUTTON** value indicates that no button was pressed or released.

Also available are three methods that obtain the coordinates of the mouse relative to the screen rather than the component. They are shown here:

```java
Point getLocationOnScreen()
int getXOnScreen()
int getYOnScreen()
```

The **getLocationOnScreen()** method returns a **Point** object that contains both the X and Y coordinate. The other two methods return the indicated coordinate.

### The MouseWheelEvent Class

The **MouseWheelEvent** class encapsulates a mouse wheel event. It is a subclass of **MouseEvent**. Not all mice have wheels. If a mouse has a wheel, it is typically located between the left and right buttons. Mouse wheels are used for scrolling.

**MouseWheelEvent** defines these two integer constants:
Here is one of the constructors defined by `MouseWheelEvent`:

```java
MouseWheelEvent(Component src, int type, long when, int modifiers,
                 int x, int y, int clicks, boolean triggersPopup,
                 int scrollHow, int amount, int count)
```

Here, `src` is a reference to the object that generated the event. The type of the event is specified by `type`. The system time at which the mouse event occurred is passed in `when`. The `modifiers` argument indicates which modifiers were pressed when the event occurred. The coordinates of the mouse are passed in `x` and `y`. The number of clicks is passed in `clicks`. The `triggersPopup` flag indicates if this event causes a pop-up menu to appear on this platform. The `scrollHow` value must be either `WHEEL_UNIT_SCROLL` or `WHEEL_BLOCK_SCROLL`. The number of units to scroll is passed in `amount`. The `count` parameter indicates the number of rotational units that the wheel moved.

`MouseWheelEvent` defines methods that give you access to the wheel event. To obtain the number of rotational units, call `getWheelRotation()`, shown here:

```java
int getWheelRotation()
```

It returns the number of rotational units. If the value is positive, the wheel moved counterclockwise. If the value is negative, the wheel moved clockwise. JDK 7 added a method called `getPreciseWheelRotation()`, which supports high-resolution wheels. It works like `getWheelRotation()`, but returns a `double`.

To obtain the type of scroll, call `getScrollType()`, shown next:

```java
int getScrollType()
```

It returns either `WHEEL_UNIT_SCROLL` or `WHEEL_BLOCK_SCROLL`. If the scroll type is `WHEEL_UNIT_SCROLL`, you can obtain the number of units to scroll by calling `getScrollAmount()`. It is shown here:

```java
int getScrollAmount()
```

**The TextEvent Class**

Instances of this class describe text events. These are generated by text fields and text areas when characters are entered by a user or program. `TextEvent` defines the integer constant `TEXT_VALUE_CHANGED`.

The one constructor for this class is shown here:

```java
TextEvent(Object src, int type)
```
Here, \( src \) is a reference to the object that generated this event. The type of the event is specified by \( type \).

The \texttt{TextEvent} object does not include the characters currently in the text component that generated the event. Instead, your program must use other methods associated with the text component to retrieve that information. This operation differs from other event objects discussed in this section. Think of a text event notification as a signal to a listener that it should retrieve information from a specific text component.

**The WindowEvent Class**

There are ten types of window events. The \texttt{WindowEvent} class defines integer constants that can be used to identify them. The constants and their meanings are shown here:

<table>
<thead>
<tr>
<th>Constant</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>\texttt{WINDOW_ACTIVATED}</td>
<td>The window was activated.</td>
</tr>
<tr>
<td>\texttt{WINDOW_CLOSED}</td>
<td>The window has been closed.</td>
</tr>
<tr>
<td>\texttt{WINDOW_CLOSING}</td>
<td>The user requested that the window be closed.</td>
</tr>
<tr>
<td>\texttt{WINDOW_DEACTIVATED}</td>
<td>The window was deactivated.</td>
</tr>
<tr>
<td>\texttt{WINDOW_DEICONIFIED}</td>
<td>The window was deiconified.</td>
</tr>
<tr>
<td>\texttt{WINDOW_GAINED_FOCUS}</td>
<td>The window gained input focus.</td>
</tr>
<tr>
<td>\texttt{WINDOW_ICONIFIED}</td>
<td>The window was iconified.</td>
</tr>
<tr>
<td>\texttt{WINDOW_LOST_FOCUS}</td>
<td>The window lost input focus.</td>
</tr>
<tr>
<td>\texttt{WINDOW_OPENED}</td>
<td>The window was opened.</td>
</tr>
<tr>
<td>\texttt{WINDOW_STATE_CHANGED}</td>
<td>The state of the window changed.</td>
</tr>
</tbody>
</table>

\texttt{WindowEvent} is a subclass of \texttt{ComponentEvent}. It defines several constructors. The first is

\begin{verbatim}
WindowEvent(Window src, int type)
\end{verbatim}

Here, \( src \) is a reference to the object that generated this event. The type of the event is \( type \). The next three constructors offer more detailed control:

\begin{verbatim}
WindowEvent(Window src, int type, Window other)
WindowEvent(Window src, int type, int fromState, int toState)
WindowEvent(Window src, int type, Window other, int fromState, int toState)
\end{verbatim}

Here, \( other \) specifies the opposite window when a focus or activation event occurs. The \( fromState \) specifies the prior state of the window, and \( toState \) specifies the new state that the window will have when a window state change occurs.

A commonly used method in this class is \texttt{getWindow( )}. It returns the \texttt{Window} object that generated the event. Its general form is shown here:

\begin{verbatim}
Window getWindow()
\end{verbatim}
WindowEvent also defines methods that return the opposite window (when a focus or activation event has occurred), the previous window state, and the current window state. These methods are shown here:

```java
Window getOppositeWindow()
int getOldState()
int getNewState()
```

Sources of Events
Table 24-2 lists some of the user interface components that can generate the events described in the previous section. In addition to these graphical user interface elements, any class derived from Component, such as Applet, can generate events. For example, you can receive key and mouse events from an applet. (You may also build your own components that generate events.) In this chapter, we will be handling only mouse and keyboard events, but the following two chapters will be handling events from the sources shown in Table 24-2.

<table>
<thead>
<tr>
<th>Event Source</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Button</td>
<td>Generates action events when the button is pressed.</td>
</tr>
<tr>
<td>Check box</td>
<td>Generates item events when the check box is selected or deselected.</td>
</tr>
<tr>
<td>Choice</td>
<td>Generates item events when the choice is changed.</td>
</tr>
<tr>
<td>List</td>
<td>Generates action events when an item is double-clicked; generates item events when an item is selected or deselected.</td>
</tr>
<tr>
<td>Menu item</td>
<td>Generates action events when a menu item is selected; generates item events when a checkable menu item is selected or deselected.</td>
</tr>
<tr>
<td>Scroll bar</td>
<td>Generates adjustment events when the scroll bar is manipulated.</td>
</tr>
<tr>
<td>Text component</td>
<td>Generates text events when the user enters a character.</td>
</tr>
<tr>
<td>Window</td>
<td>Generates window events when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

Table 24-2  Event Source Examples

Event Listener Interfaces
As explained, the delegation event model has two parts: sources and listeners. As it relates to this chapter, listeners are created by implementing one or more of the interfaces defined by the java.awt.event package. When an event occurs, the event source invokes the appropriate method defined by the listener and provides an event object as its argument. Table 24-3 lists several commonly used listener interfaces and provides a brief description of the methods that they define. The following sections examine the specific methods that are contained in each interface.
Table 24-3  Commonly Used Event Listener Interfaces

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActionListener</td>
<td>Defines one method to receive action events.</td>
</tr>
<tr>
<td>AdjustmentListener</td>
<td>Defines one method to receive adjustment events.</td>
</tr>
<tr>
<td>ComponentListener</td>
<td>Defines four methods to recognize when a component is hidden, moved, resized, or shown.</td>
</tr>
<tr>
<td>ContainerListener</td>
<td>Defines two methods to recognize when a component is added to or removed from a container.</td>
</tr>
<tr>
<td>FocusListener</td>
<td>Defines two methods to recognize when a component gains or loses keyboard focus.</td>
</tr>
<tr>
<td>ItemListener</td>
<td>Defines one method to recognize when the state of an item changes.</td>
</tr>
<tr>
<td>KeyListener</td>
<td>Defines three methods to recognize when a key is pressed, released, or typed.</td>
</tr>
<tr>
<td>MouseListener</td>
<td>Defines five methods to recognize when the mouse is clicked, enters a component, exits a component, is pressed, or is released.</td>
</tr>
<tr>
<td>MouseMotionListener</td>
<td>Defines two methods to recognize when the mouse is dragged or moved.</td>
</tr>
<tr>
<td>MouseWheelListener</td>
<td>Defines one method to recognize when the mouse wheel is moved.</td>
</tr>
<tr>
<td>TextListener</td>
<td>Defines one method to recognize when a text value changes.</td>
</tr>
<tr>
<td>WindowFocusListener</td>
<td>Defines two methods to recognize when a window gains or loses input focus.</td>
</tr>
<tr>
<td>WindowListener</td>
<td>Defines seven methods to recognize when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

The ActionListener Interface
This interface defines the `actionPerformed()` method that is invoked when an action event occurs. Its general form is shown here:

```java
void actionPerformed(ActionEvent ae)
```

The AdjustmentListener Interface
This interface defines the `adjustmentValueChanged()` method that is invoked when an adjustment event occurs. Its general form is shown here:

```java
void adjustmentValueChanged(AdjustmentEvent ae)
```

The ComponentListener Interface
This interface defines four methods that are invoked when a component is resized, moved, shown, or hidden. Their general forms are shown here:

```java
void componentResized(ComponentEvent ce)
void componentMoved(ComponentEvent ce)
void componentShown(ComponentEvent ce)
void componentHidden(ComponentEvent ce)
```

The ContainerListener Interface
This interface contains two methods. When a component is added to a container, `componentAdded()` is invoked. When a component is removed from a container, `componentRemoved()` is invoked. Their general forms are shown here:

```java
void componentAdded(ContainerEvent ce)
void componentRemoved(ContainerEvent ce)
```
The FocusListener Interface
This interface defines two methods. When a component obtains keyboard focus, **focusGained( )** is invoked. When a component loses keyboard focus, **focusLost( )** is called. Their general forms are shown here:

```
void focusGained(FocusEvent fe)
void focusLost(FocusEvent fe)
```

The ItemListener Interface
This interface defines the **itemStateChanged( )** method that is invoked when the state of an item changes. Its general form is shown here:

```
void itemStateChanged(ItemEvent ie)
```

The KeyListener Interface
This interface defines three methods. The **keyPressed( )** and **keyReleased( )** methods are invoked when a key is pressed and released, respectively. The **keyTyped( )** method is invoked when a character has been entered.

For example, if a user presses and releases the a key, three events are generated in sequence: key pressed, typed, and released. If a user presses and releases the home key, two key events are generated in sequence: key pressed and released.

The general forms of these methods are shown here:

```
void keyPressed(KeyEvent ke)
void keyReleased(KeyEvent ke)
void keyTyped(KeyEvent ke)
```

The MouseListener Interface
This interface defines five methods. If the mouse is pressed and released at the same point, **mouseClicked( )** is invoked. When the mouse enters a component, the **mouseEntered( )** method is called. When it leaves, **mouseExited( )** is called. The **mousePressed( )** and **mouseReleased( )** methods are invoked when the mouse is pressed and released, respectively.

The general forms of these methods are shown here:

```
void mouseClicked(MouseEvent me)
void mouseEntered(MouseEvent me)
void mouseExited(MouseEvent me)
void mousePressed(MouseEvent me)
void mouseReleased(MouseEvent me)
```

The MouseMotionListener Interface
This interface defines two methods. The **mouseDragged( )** method is called multiple times as the mouse is dragged. The **mouseMoved( )** method is called multiple times as the
mouse is moved. Their general forms are shown here:

```java
void mouseDragged(MouseEvent me)
void mouseMoved(MouseEvent me)
```

**The MouseWheelListener Interface**
This interface defines the `mouseWheelMoved()` method that is invoked when the mouse wheel is moved. Its general form is shown here:

```java
void mouseWheelMoved(MouseWheelEvent mwe)
```

**The TextListener Interface**
This interface defines the `textValueChanged()` method that is invoked when a change occurs in a text area or text field. Its general form is shown here:

```java
void textValueChanged(TextEvent te)
```

**The WindowFocusListener Interface**
This interface defines two methods: `windowGainedFocus()` and `windowLostFocus()`. These are called when a window gains or loses input focus. Their general forms are shown here:

```java
void windowGainedFocus(WindowEvent we)
void windowLostFocus(WindowEvent we)
```

**The WindowListener Interface**
This interface defines seven methods. The `windowActivated()` and `windowDeactivated()` methods are invoked when a window is activated or deactivated, respectively. If a window is iconified, the `windowIconified()` method is called. When a window is deiconified, the `windowDeiconified()` method is called. When a window is opened or closed, the `windowOpened()` or `windowClosed()` methods are called, respectively. The `windowClosing()` method is called when a window is being closed. The general forms of these methods are

```java
void windowActivated(WindowEvent we)
void windowClosed(WindowEvent we)
void windowClosing(WindowEvent we)
void windowDeactivated(WindowEvent we)
void windowDeiconified(WindowEvent we)
void windowIconified(WindowEvent we)
void windowOpened(WindowEvent we)
```

**Using the Delegation Event Model**
Now that you have learned the theory behind the delegation event model and have had an overview of its various components, it is time to see it in practice. Using the delegation event model is actually quite easy. Just follow these two steps:
1. Implement the appropriate interface in the listener so that it can receive the type of event desired.
2. Implement code to register and unregister (if necessary) the listener as a recipient for the event notifications.

Remember that a source may generate several types of events. Each event must be registered separately. Also, an object may register to receive several types of events, but it must implement all of the interfaces that are required to receive these events.

To see how the delegation model works in practice, we will look at examples that handle two commonly used event generators: the mouse and keyboard.

**Handling Mouse Events**

To handle mouse events, you must implement the `MouseListener` and the `MouseMotionListener` interfaces. (You may also want to implement `MouseWheelListener`, but we won’t be doing so, here.) The following applet demonstrates the process. It displays the current coordinates of the mouse in the applet’s status window. Each time a button is pressed, the word "Down" is displayed at the location of the mouse pointer. Each time the button is released, the word "Up" is shown. If a button is clicked, the message "Mouse clicked" is displayed in the upper-left corner of the applet display area.

As the mouse enters or exits the applet window, a message is displayed in the upper-left corner of the applet display area. When dragging the mouse, a * is shown, which tracks with the mouse pointer as it is dragged. Notice that the two variables, `mouseX` and `mouseY`, store the location of the mouse when a mouse pressed, released, or dragged event occurs. These coordinates are then used by `paint()` to display output at the point of these occurrences.
// Demonstrate the mouse event handlers.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/**
   <applet code="MouseEvents" width=300 height=100>
   </applet>
*/

public class MouseEvents extends Applet
   implements MouseListener, MouseMotionListener {

   String msg = "";
   int mouseX = 0, mouseY = 0; // coordinates of mouse

   public void init() {
      addMouseListener(this);
      addMouseMotionListener(this);
   }

   // Handle mouse clicked.
   public void mouseClicked(MouseEvent me) {
      // save coordinates
      mouseX = 0;
      mouseY = 10;
      msg = "Mouse clicked."
      repaint();
   }

   // Handle mouse entered.
   public void mouseEntered(MouseEvent me) {
      // save coordinates
      mouseX = 0;
      mouseY = 10;
      msg = "Mouse entered."
      repaint();
   }

   // Handle mouse exited.
public void mouseExited(MouseEvent me) {
    // save coordinates
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse exited."
    repaint();
}

// Handle button pressed.
public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Down"
    repaint();
}

// Handle button released.
public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Up"
    repaint();
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "";
    showStatus("Dragging mouse at " + mouseX + ", " + mouseY);
    repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    // show status
    showStatus("Moving mouse at " + me.getX() + ", " + me.getY());
}

// Display msg in applet window at current X,Y location.
public void paint(Graphics g) {
    g.drawString(msg, mouseX, mouseY);
}

Sample output from this program is shown here:
Let's look closely at this example. The `MouseEvents` class extends `Applet` and implements both the `MouseListener` and `MouseMotionListener` interfaces. These two interfaces contain methods that receive and process the various types of mouse events. Notice that the applet is both the source and the listener for these events. This works because the `Component` class, which supplies the `addMouseListener( )` and `addMouseMotionListener( )` methods, is a superclass of `Applet`. Being both the source and the listener for events is a common situation for applets.

Inside `init( )`, the applet registers itself as a listener for mouse events. This is done by using `addMouseListener( )` and `addMouseMotionListener( )`, which, as mentioned, are members of `Component`. They are shown here:

```java
void addMouseListener(MouseListener ml)
void addMouseMotionListener(MouseMotionListener mml)
```

Here, `ml` is a reference to the object receiving mouse events, and `mml` is a reference to the object receiving mouse motion events. In this program, the same object is used for both.

The applet then implements all of the methods defined by the `MouseListener` and `MouseMotionListener` interfaces. These are the event handlers for the various mouse events. Each method handles its event and then returns.

**Handling Keyboard Events**

To handle keyboard events, you use the same general architecture as that shown in the mouse event example in the preceding section. The difference, of course, is that you will be implementing the `KeyListener` interface.

Before looking at an example, it is useful to review how key events are generated. When a key is pressed, a `KEY_PRESSED` event is generated. This results in a call to the `keyPressed( )` event handler. When the key is released, a `KEY_RELEASED` event is generated and the `keyReleased( )` handler is executed. If a character is generated by the keystroke, then a `KEY_TYPED` event is sent and the `keyTyped( )` handler is invoked. Thus, each time the user presses a key, at least two and often three events are generated. If all you care about are actual characters, then you can ignore the information passed by the key press and release events. However, if your program needs to handle special keys, such as the arrow or function keys, then it must watch for them through the `keyPressed( )`
The following program demonstrates keyboard input. It echoes keystrokes to the applet window and shows the pressed/released status of each key in the status window.

```
// Demonstrate the key event handlers.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/*
 * <applet code="SimpleKey" width=300 height=100>
 */
 public class SimpleKey extends Applet
 implements KeyListener {
     String msg = ";
     int X = 10, Y = 20; // output coordinates

     public void init() {
         addKeyListener(this);
     }

     public void keyPressed(KeyEvent ke) {
         showStatus("Key Down");
     }

     public void keyReleased(KeyEvent ke) {
         showStatus("Key Up");
     }

     public void keyTyped(KeyEvent ke) {
         msg += ke.getKeyChar();
         repaint();
     }

     // Display keystrokes.
     public void paint(Graphics g) {
         g.drawString(msg, X, Y);
     }
}
```

Sample output is shown here:
If you want to handle the special keys, such as the arrow or function keys, you need to respond to them within the `keyPressed()` handler. They are not available through `keyTyped()`.

To identify the keys, you use their virtual key codes. For example, the next applet outputs the name of a few of the special keys:
// Demonstrate some virtual key codes.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/
  <applet code="KeyEvents" width=300 height=100>
  </applet>
*/

public class KeyEvents extends Applet
implements KeyListener {

    String msg = "";
    int X = 10, Y = 20; // output coordinates

    public void init() {
        addKeyListener(this);
    }

    public void keyPressed(KeyEvent ke) {
        showStatus("Key Down");
        int key = ke.getKeyCode();
        switch(key) {
            case KeyEvent.VK_F1:
                msg += "<F1>";
                break;
            case KeyEvent.VK_F2:
                msg += "<F2>";
                break;
            case KeyEvent.VK_F3:
                msg += "<F3>";
                break;
            case KeyEvent.VK_PAGE_DOWN:
                msg += "<PgDn>";
                break;
            case KeyEvent.VK_PAGE_UP:
                msg += "<PgUp>";
                break;
            case KeyEvent.VK_LEFT:
                msg += "<Left Arrow>";
                break;
            case KeyEvent.VK_RIGHT:
                msg += "<Right Arrow>";
                break;
            }
        repaint();
    }
public void keyReleased(KeyEvent ke) {
    showStatus("Key Up");
}

public void keyTyped(KeyEvent ke) {
    msg += ke.getKeyChar();
    repaint();
}

// Display keystrokes.
public void paint(Graphics g) {
    g.drawString(msg, X, Y);
}

Sample output is shown here:

The procedures shown in the preceding keyboard and mouse event examples can be
generalized to any type of event handling, including those events generated by controls. In
later chapters, you will see many examples that handle other types of events, but they will
all follow the same basic structure as the programs just described.

**Adapter Classes**

Java provides a special feature, called an *adapter class*, that can simplify the creation of
event handlers in certain situations. An adapter class provides an empty implementation of
all methods in an event listener interface. Adapter classes are useful when you want to
receive and process only some of the events that are handled by a particular event listener
interface. You can define a new class to act as an event listener by extending one of the
adapter classes and implementing only those events in which you are interested.

For example, the `MouseMotionAdapter` class has two methods, `mouseDragged()` and
`mouseMoved()`, which are the methods defined by the `MouseMotionListener`
interface. If you were interested in only mouse drag events, then you could simply extend
`MouseMotionAdapter` and override `mouseDragged()`. The empty implementation of
`mouseMoved()` would handle the mouse motion events for you.

Table 24-4 lists several commonly used adapter classes in `java.awt.event` and notes the
interface that each implements.

<table>
<thead>
<tr>
<th>Adapter Class</th>
<th>Listener Interface</th>
</tr>
</thead>
<tbody>
<tr>
<td>ComponentAdapter</td>
<td>ComponentListener</td>
</tr>
<tr>
<td>ContainerAdapter</td>
<td>ContainerListener</td>
</tr>
<tr>
<td>FocusAdapter</td>
<td>FocusListener</td>
</tr>
<tr>
<td>KeyAdapter</td>
<td>KeyListener</td>
</tr>
<tr>
<td>MouseAdapter</td>
<td>MouseListener and (as of JDK 6) MouseMotionListener</td>
</tr>
<tr>
<td>MouseAdapter</td>
<td>MouseMotionListener</td>
</tr>
<tr>
<td>WindowAdapter</td>
<td>WindowListener, WindowFocusListener, and WindowStateListener</td>
</tr>
</tbody>
</table>

Table 24-4 Commonly Used Listener Interfaces Implemented by Adapter Classes

The following example demonstrates an adapter. It displays a message in the status bar of an applet viewer or browser when the mouse is clicked or dragged. However, all other mouse events are silently ignored. The program has three classes. **AdapterDemo** extends **Applet**. Its **init( )** method creates an instance of **MyMouseAdapter** and registers that object to receive notifications of mouse events. It also creates an instance of **MyMouseMotionAdapter** and registers that object to receive notifications of mouse motion events. Both of the constructors take a reference to the applet as an argument. **MyMouseAdapter** extends **MouseAdapter** and overrides the **mouseClicked( )** method. The other mouse events are silently ignored by code inherited from the **MouseAdapter** class. **MyMouseMotionAdapter** extends **MouseMotionAdapter** and overrides the **mouseDragged( )** method. The other mouse motion event is silently ignored by code inherited from the **MouseMotionAdapter** class. (**MouseAdaptor** also provides an empty implementation for **MouseMotionListener**. However, for the sake of illustration, this example handles each separately.)

Note that both of the event listener classes save a reference to the applet. This information is provided as an argument to their constructors and is used later to invoke the **showStatus( )** method.
As you can see by looking at the program, not having to implement all of the methods defined by the \texttt{MouseListener} and \texttt{MouseMotionListener} interfaces saves you a considerable amount of effort and prevents your code from becoming cluttered with empty methods. As an exercise, you might want to try rewriting one of the keyboard input examples shown earlier so that it uses a \texttt{KeyAdapter}.
Inner Classes
In Chapter 7, the basics of inner classes were explained. Here, you will see why they are important. Recall that an inner class is a class defined within another class, or even within an expression. This section illustrates how inner classes can be used to simplify the code when using event adapter classes.

To understand the benefit provided by inner classes, consider the applet shown in the following listing. It does not use an inner class. Its goal is to display the string "Mouse Pressed" in the status bar of the applet viewer or browser when the mouse is pressed. There are two top-level classes in this program. MousePressedDemo extends Applet, and MyMouseAdapter extends MouseAdapter. The init() method of MousePressedDemo instantiates MyMouseAdapter and provides this object as an argument to the addMouseListener() method.

Notice that a reference to the applet is supplied as an argument to the MyMouseAdapter constructor. This reference is stored in an instance variable for later use by the mousePressed() method. When the mouse is pressed, it invokes the showStatus() method of the applet through the stored applet reference. In other words, showStatus() is invoked relative to the applet reference stored by MyMouseAdapter.

```java
// This applet does NOT use an inner class.
import java.applet.*;
import java.awt.event.*;
/*
<applet code="MousePressedDemo" width=200 height=100>
</applet>
*/

class MousePressedDemo extends Applet {
    public void init() {
        addMouseListener(new MyMouseAdapter(this));
    }
}

class MyMouseAdapter extends MouseAdapter {
    MousePressedDemo mousePressedDemo;
    public MyMouseAdapter(MousePressedDemo mousePressedDemo) {
        this.mousePressedDemo = mousePressedDemo;
    }
    public void mousePressed(MouseEvent me) {
        mousePressedDemo.showStatus("Mouse Pressed.");
    }
}
```

The following listing shows how the preceding program can be improved by using an inner class. Here, InnerClassDemo is a top-level class that extends Applet. MyMouseAdapter is an inner class that extends MouseAdapter. Because
**MyMouseAdapter** is defined within the scope of **InnerClassDemo**, it has access to all of the variables and methods within the scope of that class. Therefore, the **mousePressed()** method can call the **showStatus()** method directly. It no longer needs to do this via a stored reference to the applet. Thus, it is no longer necessary to pass **MyMouseAdapter()** a reference to the invoking object.

```java
// Inner class demo.
import java.applet.*;
import java.awt.event.*;
/*
 <applet code="InnerClassDemo" width=200 height=100>
 </applet>
 */

public class InnerClassDemo extends Applet {
    public void init() {
        addMouseListener(new MyMouseAdapter());
    }
    class MyMouseAdapter extends MouseAdapter {
        public void mousePressed(MouseEvent me) {
            showStatus("Mouse Pressed");
        }
    }
}
```

**Anonymous Inner Classes**

An anonymous inner class is one that is not assigned a name. This section illustrates how an anonymous inner class can facilitate the writing of event handlers. Consider the applet shown in the following listing. As before, its goal is to display the string "Mouse Pressed" in the status bar of the applet viewer or browser when the mouse is pressed.
There is one top-level class in this program: **AnonymousInnerClassDemo**. The `init()` method calls the `addMouseListener()` method. Its argument is an expression that defines and instantiates an anonymous inner class. Let's analyze this expression carefully. The syntax `new MouseAdapter(){...}` indicates to the compiler that the code between the braces defines an anonymous inner class. Furthermore, that class extends `MouseAdapter`. This new class is not named, but it is automatically instantiated when this expression is executed.

Because this anonymous inner class is defined within the scope of **AnonymousInnerClassDemo**, it has access to all of the variables and methods within the scope of that class. Therefore, it can call the `showStatus()` method directly.

As just illustrated, both named and anonymous inner classes solve some annoying problems in a simple yet effective way. They also allow you to create more efficient code.
The Abstract Window Toolkit (AWT) was Java’s first GUI framework, and it has been part of Java since version 1.0. It contains numerous classes and methods that allow you to create windows and simple controls. The AWT was introduced in Chapter 23, where it was used in several short, example applets. This chapter begins a more detailed examination. Here, you will learn how to create and manage windows, manage fonts, output text, and utilize graphics. Chapter 26 describes various AWT controls, such as scroll bars and push buttons. It also explains further aspects of Java’s event handling mechanism. Chapter 27 introduces the AWT’s imaging subsystem.

It is important to state at the outset that you will seldom create GUIs based solely on the AWT because more powerful GUI frameworks (Swing and JavaFX) have been developed for Java. Despite this fact, the AWT remains an important part of Java. To understand why, consider the following.

At the time of this writing, the framework that is most widely used is Swing. Because Swing provides a richer, more flexible GUI framework than does the AWT, it is easy to jump to the conclusion that the AWT is no longer relevant—that it has been fully superseded by Swing. This assumption is, however, false. Instead, an understanding of the AWT is still important because the AWT underpins Swing, with many AWT classes being used either directly or indirectly by Swing. As a result, a solid knowledge of the AWT is still required to use Swing effectively.

Java’s newest GUI framework is JavaFX. It is anticipated that, at some point in the future, JavaFX will replace Swing as Java’s most popular GUI. Even when this occurs, however, much legacy code that relies on Swing (and thus, the AWT) will still need to be maintained for some time to come. Finally, for some types of small programs (especially small applets) that make only minimal use of a GUI, using the AWT may still be appropriate. Therefore, even though the AWT constitutes Java’s oldest GUI framework, a basic working knowledge of its fundamentals is still important today.

Although a common use of the AWT is in applets, it is also used to create stand-alone windows that run in a GUI environment, such as Windows. For the sake of convenience, most of the examples in this chapter are contained in applets. The easiest way to run them
is with the applet viewer. A few examples demonstrate the creation of stand-alone, windowed programs, which can be executed directly.

One last point before beginning: The AWT is quite large and a full description would easily fill an entire book. Therefore, it is not possible to describe in detail every AWT class, method, or instance variable. However, this and the following chapters explain the basic techniques needed to use the AWT. From there, you will be able to explore other parts of the AWT on your own. You will also be ready to move on to Swing.

---

**NOTE** If you have not yet read Chapter 24, please do so now. It provides an overview of event handling, which is used by many of the examples in this chapter.

### AWT Classes

The AWT classes are contained in the `java.awt` package. It is one of Java's largest packages. Fortunately, because it is logically organized in a top-down, hierarchical fashion, it is easier to understand and use than you might at first believe. Table 25-1 lists some of the many AWT classes.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AWTEvent</td>
<td>Encapsulates AWT events.</td>
</tr>
<tr>
<td>AWTEventListener</td>
<td>Dispatches events to multiple listeners.</td>
</tr>
<tr>
<td>BorderLayout</td>
<td>The border layout manager. Border layouts use five components: North, South, East, West, and Center.</td>
</tr>
<tr>
<td>Button</td>
<td>Creates a push button control.</td>
</tr>
<tr>
<td>Canvas</td>
<td>A blank, semantics-free window.</td>
</tr>
<tr>
<td>CardLayout</td>
<td>The card layout manager. Card layouts emulate index cards. Only the one on top is showing.</td>
</tr>
<tr>
<td>Checkbox</td>
<td>Creates a check box control.</td>
</tr>
<tr>
<td>CheckboxGroup</td>
<td>Creates a group of check box controls.</td>
</tr>
<tr>
<td>CheckboxMenuItem</td>
<td>Creates on/off menu item.</td>
</tr>
<tr>
<td>Choice</td>
<td>Creates a pop-up list.</td>
</tr>
<tr>
<td>Color</td>
<td>Manages colors in a portable, platform-independent fashion.</td>
</tr>
<tr>
<td>Component</td>
<td>An abstract superclass for various AWT components.</td>
</tr>
<tr>
<td>Container</td>
<td>A subclass of Component that can hold other components.</td>
</tr>
<tr>
<td>Cursor</td>
<td>Encapsulates a bitmapped cursor.</td>
</tr>
<tr>
<td>Dialog</td>
<td>Creates a dialog window.</td>
</tr>
<tr>
<td>Dimension</td>
<td>Specifies the dimensions of an object. The width is stored in width, and the height is stored in height.</td>
</tr>
<tr>
<td>EventQueue</td>
<td>Queues events.</td>
</tr>
<tr>
<td>FileDialog</td>
<td>Creates a window from which a file can be selected.</td>
</tr>
</tbody>
</table>
Although the basic structure of the AWT has been the same since Java 1.0, some of the original methods were deprecated and replaced by new ones. For backward-compatibility, Java still supports all the original 1.0 methods. However, because these methods are not for use with new code, this book does not describe them.
Window Fundamentals

The AWT defines windows according to a class hierarchy that adds functionality and specificity with each level. The two most common windows are those derived from **Panel**, which is used by applets, and those derived from **Frame**, which creates a standard application window. Much of the functionality of these windows is derived from their parent classes. Thus, a description of the class hierarchies relating to these two classes is fundamental to their understanding. Figure 25-1 shows the class hierarchy for **Panel** and **Frame**. Let’s look at each of these classes now.

![Class Hierarchy Diagram]

**Component**

At the top of the AWT hierarchy is the **Component** class. **Component** is an abstract class that encapsulates all of the attributes of a visual component. Except for menus, all user interface elements that are displayed on the screen and that interact with the user are subclasses of **Component**. It defines over a hundred public methods that are responsible for managing events, such as mouse and keyboard input, positioning and sizing the window, and repainting. (You already used many of these methods when you created applets in Chapters 23 and 24.) A **Component** object is responsible for remembering the current foreground and background colors and the currently selected text font.

**Container**

The **Container** class is a subclass of **Component**. It has additional methods that allow other **Component** objects to be nested within it. Other **Container** objects can be stored inside of a **Container** (since they are themselves instances of **Component**). This makes for a multileveled containment system. A container is responsible for laying out (that is, positioning) any components that it contains. It does this through the use of various layout
managers, which you will learn about in Chapter 26.

**Panel**
The **Panel** class is a concrete subclass of **Container**. A **Panel** may be thought of as a recursively nestable, concrete screen component. **Panel** is the superclass for **Applet**. When screen output is directed to an applet, it is drawn on the surface of a **Panel** object. In essence, a **Panel** is a window that does not contain a title bar, menu bar, or border. This is why you don’t see these items when an applet is run inside a browser. When you run an applet using an applet viewer, the applet viewer provides the title and border. Other components can be added to a **Panel** object by its **add**() method (inherited from **Container**). Once these components have been added, you can position and resize them manually using the **setLocation**(), **setSize**(), **setPreferredSize**(), or **setBounds**() methods defined by **Component**.

**Window**
The **Window** class creates a top-level window. A **top-level window** is not contained within any other object; it sits directly on the desktop. Generally, you won’t create **Window** objects directly. Instead, you will use a subclass of **Window** called **Frame**, described next.

**Frame**
**Frame** encapsulates what is commonly thought of as a "window." It is a subclass of **Window** and has a title bar, menu bar, borders, and resizing corners. The precise look of a **Frame** will differ among environments. A number of environments are reflected in the screen captures shown throughout this book.

**Canvas**
Although it is not part of the hierarchy for applet or frame windows, there is one other type of window that you will find valuable: **Canvas**. Derived from **Component**, **Canvas** encapsulates a blank window upon which you can draw. You will see an example of **Canvas** later in this book.

**Working with Frame Windows**
In addition to the applet, the type of AWT-based window you will most often create is derived from **Frame**. You will use it to create child windows within applets, and top-level or child windows for stand-alone applications. As mentioned, it creates a standard-style window.

Here are two of **Frame**’s constructors:

Frame() throws HeadlessException

Frame(String *title*) throws HeadlessException

The first form creates a standard window that does not contain a title. The second form creates a window with the title specified by *title*. Notice that you cannot
specify the dimensions of the window. Instead, you must set the size of the window after it has been created. A **HeadlessException** is thrown if an attempt is made to create a **Frame** instance in an environment that does not support user interaction.

There are several key methods you will use when working with **Frame** windows. They are examined here.

### Setting the Window’s Dimensions

The **setSize( )** method is used to set the dimensions of the window. Its signature is shown here:

```java
void setSize(int newWidth, int newHeight)
void setSize(Dimension newSize)
```

The new size of the window is specified by `newWidth` and `newHeight`, or by the `width` and `height` fields of the **Dimension** object passed in `newSize`. The dimensions are specified in terms of pixels.

The **getSize( )** method is used to obtain the current size of a window. One of its forms is shown here:

```java
Dimension getSize()
```

This method returns the current size of the window contained within the `width` and `height` fields of a **Dimension** object.

### Hiding and Showing a Window

After a frame window has been created, it will not be visible until you call **setVisible( )**. Its signature is shown here:

```java
void setVisible(boolean visibleFlag)
```

The component is visible if the argument to this method is `true`. Otherwise, it is hidden.

### Setting a Window’s Title

You can change the title in a frame window using **setTitle( )**, which has this general form:

```java
void setTitle(String newTitle)
```

Here, `newTitle` is the new title for the window.

### Closing a Frame Window

When using a frame window, your program must remove that window from the screen when it is closed, by calling **setVisible(false)**. To intercept a window-close event, you must implement the **windowClosing( )** method of the **WindowListener** interface. Inside **windowClosing( )**, you must remove the window from the screen. The example in the next section illustrates this technique.
Creating a Frame Window in an AWT-Based Applet

While it is possible to simply create a window by creating an instance of Frame, you will seldom do so, because you will not be able to do much with it. For example, you will not be able to receive or process events that occur within it or easily output information to it. Most of the time, you will create a subclass of Frame. Doing so lets you override Frame's methods and provide event handling.

Creating a new frame window from within an AWT-based applet is actually quite easy. First, create a subclass of Frame. Next, override any of the standard applet methods, such as init(), start(), and stop(), to show or hide the frame as needed. Finally, implement the windowClosing() method of the WindowListener interface, calling setVisible(false) when the window is closed.

Once you have defined a Frame subclass, you can create an object of that class. This causes a frame window to come into existence, but it will not be initially visible. You make it visible by calling setVisible(). When created, the window is given a default height and width. You can set the size of the window explicitly by calling the setSize() method.

The following applet creates a subclass of Frame called SampleFrame. A window of this subclass is instantiated within the init() method of AppletFrame. Notice that SampleFrame calls Frame's constructor. This causes a standard frame window to be created with the title passed in title. This example overrides the applet's start() and stop() methods so that they show and hide the child window, respectively. This causes the window to be removed automatically when you terminate the applet, when you close the window, or, if using a browser, when you move to another page. It also causes the child window to be shown when the browser returns to the applet.

```
// Create a child frame window from within an applet.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/**
   * <applet code="AppletFrame" width=300 height=50>
   * </applet>
   */

// Create a subclass of Frame.
class SampleFrame extends Frame {
    SampleFrame(String title) {
        super(title);

        // create an object to handle window events
        MyWindowAdapter adapter = new MyWindowAdapter(this);
```
```java
// register it to receive those events
addWindowListener(adapter);
}
public void paint(Graphics g) {
    g.drawString("This is in frame window", 10, 40);
}
}
class MyWindowAdapter extends WindowAdapter {
    SampleFrame sampleFrame;
    public MyWindowAdapter(SampleFrame sampleFrame) {
        this.sampleFrame = sampleFrame;
    }
    public void windowClosing(WindowEvent we) {
        sampleFrame.setVisible(false);
    }
}
// Create frame window.
public class AppletFrame extends Applet {
    Frame f;
    public void init() {
        f = new SampleFrame("A Frame Window");
        f.setSize(250, 250);
        f.setVisible(true);
    }
    public void start() {
        f.setVisible(true);
    }
    public void stop() {
        f.setVisible(false);
    }
    public void paint(Graphics g) {
        g.drawString("This is in applet window", 10, 20);
    }
}
```

Sample output from this program is shown here:
Handling Events in a Frame Window

Since Frame is a subclass of Component, it inherits all the capabilities defined by Component. This means that you can use and manage a frame window just like you manage an applet's main window, as described earlier in this book. For example, you can override paint( ) to display output, call repaint( ) when you need to restore the window, and add event handlers. Whenever an event occurs in a window, the event handlers defined by that window will be called. Each window handles its own events. For example, the following program creates a window that responds to mouse events. The main applet window also responds to mouse events. When you experiment with this program, you will see that mouse events are sent to the window in which the event occurs.
// Handle mouse events in both child and applet windows.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/
  <applet code="WindowEvents" width=300 height=50>
</applet>
*/

// Create a subclass of Frame.
class SampleFrame extends Frame
  implements MouseListener, MouseMotionListener {

  String msg = "";
  int mouseX=10, mouseY=40;
  int movX=0, movY=0;

  SampleFrame(String title) {
    super(title);
    // register this object to receive its own mouse events
    addMouseListener(this);
    addMouseMotionListener(this);
    // create an object to handle window events
    MyWindowAdapter adapter = new MyWindowAdapter(this);
    // register it to receive those events
    addWindowListener(adapter);
  }

  // Handle mouse clicked.
  public void mouseClicked(MouseEvent me) {
  }

  // Handle mouse entered.
  public void mouseEntered(MouseEvent e) {
    // save coordinates
    mouseX = 10;
    mouseY = 54;
    msg = "Mouse just entered child."
    repaint();
  }
public void mouseExited(MouseEvent me) {
    // save coordinates
    mouseX = 10;
    mouseY = 54;
    msg = "Mouse just left child window."
    repaint();
}

// Handle mouse pressed.
public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Down"
    repaint();
}

// Handle mouse released.
public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Up"
    repaint();
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    moveX = me.getX();
    moveY = me.getY();
    msg = "Drag";
    repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    // save coordinates
    moveX = me.getX();
    moveY = me.getY();
    repaint(0, 0, 100, 60);
}

public void paint(Graphics g) {
    g.drawString(msg, mouseX, mouseY);
    g.drawString("Mouse at " + moveX + ", " + moveY, 10, 40);
}

class MyWindowAdapter extends WindowAdapter {
    SampleFrame sampleFrame;
public MyWindowAdapter(SampleFrame sampleFrame) {
    this.sampleFrame = sampleFrame;
}

public void windowClosing(WindowEvent we) {
    sampleFrame.setVisible(false);
}

// Applet window.
public class WindowEvents extends Applet
    implements MouseListener, MouseMotionListener {
    SampleFrame f;
    String msg = "";
    int mouseX=0, mouseY=10;
    int moveX=0, moveY=0;
    // Create a frame window.
    public void init() {
        f = new SampleFrame("Handle Mouse Events");
        f.setSize(300, 200);
        f.setVisible(true);
        // register this object to receive its own mouse events
        addMouseListener(this);
        addMouseMotionListener(this);
    }
    // Remove frame window when stopping applet.
    public void stop() {
        f.setVisible(false);
    }
    // Show frame window when starting applet.
    public void start() {
        f.setVisible(true);
    }
    // Handle mouse clicked.
    public void mouseClicked(MouseEvent me) {
    }
    // Handle mouse entered.
    public void mouseEntered(MouseEvent me) {
        // save coordinates
        mouseX = 0;
        mouseY = 24;
        msg = "Mouse just entered applet window."
        repaint();
    }
}
// Handle mouse exited.
public void mouseExited(MouseEvent me) {
    // save coordinates
    mouseX = 0;
    mouseY = 24;
    msg = "Mouse just left applet window."
    repaint();
}

// Handle button pressed.
public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Down"
    repaint();
}

// Handle button released.
public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Up"
    repaint();
}

// Handle mouse dragged.
public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    movX = me.getX();
    movY = me.getY();
    msg = "*"
    repaint();
}

// Handle mouse moved.
public void mouseMoved(MouseEvent me) {
    // save coordinates
    movX = me.getX();
    movY = me.getY();
    repaint(0, 0, 100, 20);
}

// Display msg in applet window.
public void paint(Graphics g) {
    g.drawString(msg, mouseX, mouseY);
    g.drawString("Mouse at " + movX + ", " + movY, 0, 10);
    }

Sample output from this program is shown here:
Creating a Windowed Program
Although creating applets is a common use for Java’s AWT, it is also possible to create stand-alone AWT-based applications. To do this, simply create an instance of the window or windows you need inside `main()`. For example, the following program creates a frame window that responds to mouse clicks and keystrokes:
// Create an AWT-based application.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

// Create a frame window.
public class AppWindow extends Frame {
  String keymsg = "This is a test."
  String mousemsg = "";
  int mouseX=30, mouseY=30;

  public AppWindow() {
    addKeyListener(new MyKeyAdapter(this));
    addMouseListener(new MyMouseListener(this));
    addWindowListener(new MyWindowAdapter());
  }

  public void paint(Graphics g) {
    g.drawString(keymsg, 10, 40);
    g.drawString(mousemsg, mouseX, mouseY);
  }

  // Create the window.
  public static void main(String args[]) {
    AppWindow appwin = new AppWindow();

    appwin.setSize(new Dimension(300, 200));
    appwin.setTitle("An AWT-Based Application");
    appwin.setVisible(true);
  }
}
Sample output from this program is shown here:

Once created, a frame window takes on a life of its own. Notice that **main()** ends with the
call to `appwin.setVisible(true)`. However, the program keeps running until you close the window. In essence, when creating a windowed application, you will use `main()` to launch its top-level window. After that, your program will function as a GUI-based application, not like the console-based programs used earlier.

**Displaying Information Within a Window**

In the most general sense, a window is a container for information. Although we have already output small amounts of text to a window in the preceding examples, we have not begun to take advantage of a window's ability to present high-quality text and graphics. Indeed, much of the power of the AWT comes from its support for these items. For this reason, the remainder of this chapter introduces the AWT's text-, graphics-, and font-handling capabilities. As you will see, they are both powerful and flexible.

**Introducing Graphics**

The AWT includes several methods that support graphics. All graphics are drawn relative to a window. This can be the main window of an applet, a child window of an applet, or a stand-alone application window. (These methods are also supported by Swing-based windows.) The origin of each window is at the top-left corner and is 0,0. Coordinates are specified in pixels. All output to a window takes place through a *graphics context*.

A graphics context is encapsulated by the `Graphics` class. Here are two ways in which a graphics context can be obtained:

- It is passed to a method, such as `paint()` or `update()`, as an argument.
- It is returned by the `getGraphics()` method of `Component`.

Among other things, the `Graphics` class defines a number of methods that draw various types of objects, such as lines, rectangles, and arcs. In several cases, objects can be drawn edge-only or filled. Objects are drawn and filled in the currently selected color, which is black by default. When a graphics object is drawn that exceeds the dimensions of the window, output is automatically clipped. A sampling of the drawing methods supported by `Graphics` is presented here.

---

**NOTE** With the release of version 1.2, the graphics capabilities of Java were expanded by the inclusion of several new classes. One of these is `Graphics2D`, which extends `Graphics`. `Graphics2D` supports several powerful enhancements to the basic capabilities provided by `Graphics`. To gain access to this extended functionality, you must cast the graphics context obtained from a method such as `paint()`, to `Graphics2D`. Although the basic graphics functions supported by `Graphics` are
adequate for the purposes of this book, Graphics2D is a class that you will want to explore fully on your own if you will be programming sophisticated graphics applications.

Drawing Lines

Lines are drawn by means of the `drawLine()` method, shown here:

```java
void drawLine(int startX, int startY, int endX, int endY)
```

`drawLine()` displays a line in the current drawing color that begins at `startX, startY` and ends at `endX, endY`.

Drawing Rectangles

The `drawRect()` and `fillRect()` methods display an outlined and filled rectangle, respectively. They are shown here:

```java
void drawRect(int left, int top, int width, int height)
void fillRect(int left, int top, int width, int height)
```

The upper-left corner of the rectangle is at `left, top`. The dimensions of the rectangle are specified by `width` and `height`.

To draw a rounded rectangle, use `drawRoundRect()` or `fillRoundRect()`, both shown here:

```java
void drawRoundRect(int left, int top, int width, int height,
                    int xDiam, int yDiam)
void fillRoundRect(int left, int top, int width, int height,
                   int xDiam, int yDiam)
```

A rounded rectangle has rounded corners. The upper-left corner of the rectangle is at `left, top`. The dimensions of the rectangle are specified by `width` and `height`. The diameter of the rounding arc along the X axis is specified by `xDiam`. The diameter of the rounding arc along the Y axis is specified by `yDiam`.

Drawing Ellipses and Circles

To draw an ellipse, use `drawOval()`. To fill an ellipse, use `fillOval()`. These methods are shown here:

```java
void drawOval(int left, int top, int width, int height)
void fillOval(int left, int top, int width, int height)
```

The ellipse is drawn within a bounding rectangle whose upper-left corner is specified by `left, top` and whose width and height are specified by `width` and `height`. To draw a circle, specify a square as the bounding rectangle.
**Drawing Arcs**

Arcs can be drawn with `drawArc()` and `fillArc()`, shown here:

```java
void drawArc(int left, int top, int width, int height, int startAngle,
            int sweepAngle)
void fillArc(int left, int top, int width, int height, int startAngle,
            int sweepAngle)
```

The arc is bounded by the rectangle whose upper-left corner is specified by `left, top` and whose width and height are specified by `width` and `height`. The arc is drawn from `startAngle` through the angular distance specified by `sweepAngle`. Angles are specified in degrees. Zero degrees is on the horizontal, at the three o’clock position. The arc is drawn counterclockwise if `sweepAngle` is positive, and clockwise if `sweepAngle` is negative. Therefore, to draw an arc from twelve o’clock to six o’clock, the start angle would be 90 and the sweep angle 180.

**Drawing Polygons**

It is possible to draw arbitrarily shaped figures using `drawPolygon()` and `fillPolygon()`, shown here:

```java
void drawPolygon(int x[], int y[], int numPoints)
void fillPolygon(int x[], int y[], int numPoints)
```

The polygon’s endpoints are specified by the coordinate pairs contained within the `x` and `y` arrays. The number of points defined by these arrays is specified by `numPoints`. There are alternative forms of these methods in which the polygon is specified by a `Polygon` object.

**Demonstrating the Drawing Methods**

The following program demonstrates the drawing methods just described.
// Draw graphics elements.
import java.awt.*;
import java.applet.*/
/**
 <applet code="GraphicsDemo" width=350 height=700>
 </applet>
 */
public class GraphicsDemo extends Applet {
    public void paint(Graphics g) {

        // Draw lines.
        g.drawLine(0, 0, 100, 90);
        g.drawLine(0, 90, 100, 10);
        g.drawLine(40, 25, 250, 80);

        // Draw rectangles.
        g.drawRect(10, 150, 60, 50);
        g.fillRect(100, 150, 60, 50);
        g.drawRectRoundRect(190, 150, 60, 50, 15, 15);
        g.fillRectRoundRect(280, 150, 60, 50, 30, 40);

        // Draw Ellipses and Circles
        g.drawOval(10, 250, 50, 50);
        g.fillOval(90, 250, 75, 50);
        g.drawOval(190, 260, 100, 40);

        // Draw Arcs
        g.drawArc(10, 350, 70, 70, 0, 180);
        g.fillArc(60, 350, 70, 70, 0, 75);

        // Draw a polygon
        int xpoints[] = {10, 200, 10, 200, 10};
        int ypoints[] = {450, 450, 650, 650, 450};
        int num = 5;
        g.drawPolygon(xpoints, ypoints, num);
    }
}

Sample output is shown in Figure 25-2.
Sizing Graphics

Often, you will want to size a graphics object to fit the current size of the window in which it is drawn. To do so, first obtain the current dimensions of the window by calling `getSize()` on the window object. It returns the dimensions of the window encapsulated within a `Dimension` object. Once you have the current size of the window, you can scale your graphical output accordingly.

To demonstrate this technique, here is an applet that will start as a 200×200-pixel square and grow by 25 pixels in width and height with each mouse click until the applet gets larger than 500×500. At that point, the next click will return it to 200×200, and the process starts over.
Within the window, a rectangle is drawn around the inner border of the window; within that rectangle, an X is drawn so that it fills the window. This applet works in appletviewer, but it may not work in a browser window.

```java
// Resizing output to fit the current size of a window.
import java.applet.*;
import java.awt.*;
import java.awt.event.*;
/**
<applet code="ResizeMe" width=200 height=200>
</applet>
*/

public class ResizeMe extends Applet {
    final int inc = 25;
    int max = 500;
    int mln = 200;
    Dimension d;

    public ResizeMe() {
        addMouseListener(new MouseAdapter() {
            public void mouseReleased(MouseEvent me) {
                int w = (d.width + inc) > max?min : (d.width + inc);
                int h = (d.height + inc) > max?min : (d.height + inc);
                setSize(new Dimension(w, h));
            }
        });
    }

    public void paint(Graphics g) {
        d = getSize();
        g.drawLine(0, 0, d.width-1, d.height-1);
        g.drawLine(0, d.height-1, d.width-1, 0);
        g.drawRect(0, 0, d.width-1, d.height-1);
    }
}
```

**Working with Color**

Java supports color in a portable, device-independent fashion. The AWT color system allows you to specify any color you want. It then finds the best match for that color, given the limits of the display hardware currently executing your program or applet. Thus, your code does not need to be concerned with the differences in the way color is supported by various hardware devices. Color is encapsulated by the `Color` class.

As you saw in Chapter 23, `Color` defines several constants (for example, `Color.black`) to specify a number of common colors. You can also create your own colors, using one of the color constructors. Three commonly used forms are shown here:
Color(int red, int green, int blue)
Color(int rgbValue)
Color(float red, float green, float blue)

The first constructor takes three integers that specify the color as a mix of red, green, and blue. These values must be between 0 and 255, as in this example:

```java
new Color(255, 100, 100); // light red
```

The second color constructor takes a single integer that contains the mix of red, green, and blue packed into an integer. The integer is organized with red in bits 16 to 23, green in bits 8 to 15, and blue in bits 0 to 7. Here is an example of this constructor:

```java
int newRed = (0xff000000 | (0x00 << 16) | (0x00 << 8) | 0x00);
Color darkRed = new Color(newRed);
```

The final constructor, `Color(float, float, float)`, takes three `float` values (between 0.0 and 1.0) that specify the relative mix of red, green, and blue.

Once you have created a color, you can use it to set the foreground and/or background color by using the `setForeground()` and `setBackground()` methods described in Chapter 23. You can also select it as the current drawing color.

**Color Methods**
The `Color` class defines several methods that help manipulate colors. Several are examined here.

**Using Hue, Saturation, and Brightness**
The hue-saturation-brightness (HSB) color model is an alternative to red-green-blue (RGB) for specifying particular colors. Figuratively, hue is a wheel of color. The hue can be specified with a number between 0.0 and 1.0, which is used to obtain an angle into the color wheel. (The principal colors are approximately red, orange, yellow, green, blue, indigo, and violet.) Saturation is another scale ranging from 0.0 to 1.0, representing light pastels to intense hues. Brightness values also range from 0.0 to 1.0, where 1 is bright white and 0 is black. `Color` supplies two methods that let you convert between RGB and HSB. They are shown here:

```java
static int HSBtoRGB(float hue, float saturation, float brightness)
static float[] RGBtoHSB(int red, int green, int blue, float values[])
```

`HSBtoRGB()` returns a packed RGB value compatible with the `Color(int)` constructor. `RGBtoHSB()` returns a `float` array of HSB values corresponding to RGB integers. If `values` is not `null`, then this array is given the HSB values and returned. Otherwise, a new array is created and the HSB values are returned in it. In either case, the array contains the hue at index 0, saturation at index 1, and
brightness at index 2.

getRed(), getGreen(), getBlue()
You can obtain the red, green, and blue components of a color independently using getRed(), getGreen(), and getBlue(), shown here:

```java
int getRed()
int getGreen()
int getBlue()
```

Each of these methods returns the RGB color component found in the invoking Color object in the lower 8 bits of an integer.

getRGB()
To obtain a packed, RGB representation of a color, use getRGB(), shown here:

```java
int getRGB()
```

The return value is organized as described earlier.

**Setting the Current Graphics Color**

By default, graphics objects are drawn in the current foreground color. You can change this color by calling the Graphics method setColor() :

```java
void setColor(Color newColor)
```

Here, newColor specifies the new drawing color.

You can obtain the current color by calling getColor(), shown here:

```java
Color getColor()
```

**A Color Demonstration Applet**

The following applet constructs several colors and draws various objects using these colors:
Setting the Paint Mode

The paint mode determines how objects are drawn in a window. By default, new output to a window overwrites any preexisting contents. However, it is possible to have new objects XORed onto the window by using `setXORMode()`, as follows:

```java
void setXORMode(Color xorColor)
```

Here, `xorColor` specifies the color that will be XORed to the window when an
object is drawn. The advantage of XOR mode is that the new object is always
guaranteed to be visible no matter what color the object is drawn over.

To return to overwrite mode, call \texttt{setPaintMode()} , shown here:

\begin{verbatim}
void setPaintMode()

In general, you will want to use overwrite mode for normal output, and XOR mode
for special purposes. For example, the following program displays cross hairs that
track the mouse pointer. The cross hairs are XORed onto the window and are
always visible, no matter what the underlying color is.
Sample output from this program is shown here:
Working with Fonts

The AWT supports multiple type fonts. Years ago, fonts emerged from the domain of traditional typesetting to become an important part of computer-generated documents and displays. The AWT provides flexibility by abstracting font-manipulation operations and allowing for dynamic selection of fonts.

Fonts have a family name, a logical font name, and a face name. The family name is the general name of the font, such as Courier. The logical name specifies a name, such as Monospaced, that is linked to an actual font at runtime. The face name specifies a specific font, such as Courier Italic.

Fonts are encapsulated by the **Font** class. Several of the methods defined by **Font** are listed in Table 25-2.
Table 25-2  A Sampling of Methods Defined by Font

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static Font decode(String str)</td>
<td>Returns a font given its name.</td>
</tr>
<tr>
<td>boolean equals(Object FontObj)</td>
<td>Returns true if the invoking object contains the same font as that specified by FontObj. Otherwise, it returns false.</td>
</tr>
<tr>
<td>String getFamily()</td>
<td>Returns the name of the font family to which the invoking font belongs.</td>
</tr>
<tr>
<td>static Font getFont(String property)</td>
<td>Returns the font associated with the system property specified by property. null is returned if property does not exist.</td>
</tr>
<tr>
<td>static Font getFont(String property, Font defaultFont)</td>
<td>Returns the font associated with the system property specified by property. The font specified by defaultFont is returned if property does not exist.</td>
</tr>
<tr>
<td>String getFontName()</td>
<td>Returns the face name of the invoking font.</td>
</tr>
<tr>
<td>String getName()</td>
<td>Returns the logical name of the invoking font.</td>
</tr>
<tr>
<td>int getSize()</td>
<td>Returns the size, in points, of the invoking font.</td>
</tr>
<tr>
<td>int getStyle()</td>
<td>Returns the style values of the invoking font.</td>
</tr>
<tr>
<td>int hashCode()</td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td>boolean isBold()</td>
<td>Returns true if the font includes the BOLD style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>boolean isItalic()</td>
<td>Returns true if the font includes the ITALIC style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>boolean isPlain()</td>
<td>Returns true if the font includes the PLAIN style value. Otherwise, false is returned.</td>
</tr>
<tr>
<td>String toString()</td>
<td>Returns the string equivalent of the invoking font.</td>
</tr>
</tbody>
</table>

The **Font** class defines these protected variables:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>String name</td>
<td>Name of the font</td>
</tr>
<tr>
<td>float pointSize</td>
<td>Size of the font in points</td>
</tr>
<tr>
<td>int size</td>
<td>Size of the font in points</td>
</tr>
<tr>
<td>int style</td>
<td>Font style</td>
</tr>
</tbody>
</table>

Several static fields are also defined.

**Determining the Available Fonts**

When working with fonts, often you need to know which fonts are available on your machine. To obtain this information, you can use the `getAvailableFontFamilyNames()` method defined by the **GraphicsEnvironment** class. It is shown here:

```java
String[] getAvailableFontFamilyNames()
```

This method returns an array of strings that contains the names of the available font families.
In addition, the `getAllFonts()` method is defined by the `GraphicsEnvironment` class. It is shown here:

```java
Font[] getAllFonts()
```

This method returns an array of `Font` objects for all of the available fonts. Since these methods are members of `GraphicsEnvironment`, you need a `GraphicsEnvironment` reference to call them. You can obtain this reference by using the `getLocalGraphicsEnvironment()` static method, which is defined by `GraphicsEnvironment`. It is shown here:

```java
static GraphicsEnvironment getLocalGraphicsEnvironment()
```

Here is an applet that shows how to obtain the names of the available font families:

```java
// Display Fonts
/*
<applet code="ShowFonts" width=550 height=60>
</applet>
*/
import java.applet.*;
import java.awt.*;

public class ShowFonts extends Applet {
    public void paint(Graphics g) {
        String msg = "";
        String FontList[];

        GraphicsEnvironment ge =
            GraphicsEnvironment.getLocalGraphicsEnvironment();
        FontList = ge.getAvailableFontFamilyNames();
        for(int i = 0; i < FontList.length; i++)
            msg += FontList[i] + " ";

        g.drawString(msg, 4, 16);
    }
}
```

Sample output from this program is shown next. However, when you run this program, you may see a different list of fonts than the one shown in this illustration.
Creating and Selecting a Font

To create a new font, construct a **Font** object that describes that font. One **Font** constructor has this general form:

```
Font(String fontName, int fontStyle, int pointSize)
```

Here, `fontName` specifies the name of the desired font. The name can be specified using either the logical or face name. All Java environments will support the following fonts: Dialog, DialogInput, SansSerif, Serif, and Monospaced. Dialog is the font used by your system’s dialog boxes. Dialog is also the default if you don’t explicitly set a font. You can also use any other fonts supported by your particular environment, but be careful—these other fonts may not be universally available.

The style of the font is specified by `fontStyle`. It may consist of one or more of these three constants: **Font.PLAIN**, **Font.BOLD**, and **Font.ITALIC**. To combine styles, OR them together. For example, **Font.BOLD | Font.ITALIC** specifies a bold, italics style.

The size, in points, of the font is specified by `pointSize`.

To use a font that you have created, you must select it using `setFont()`, which is defined by **Component**. It has this general form:

```
void setFont(Font fontObj)
```

Here, `fontObj` is the object that contains the desired font.

The following program outputs a sample of each standard font. Each time you click the mouse within its window, a new font is selected and its name is displayed.

```java
// Show fonts.
import java.applet.*;
import java.awt.*;
import java.awt.event.*;
/*
 <applet code="SampleFonts" width=200 height=100>
 */
public class SampleFonts extends Applet {
    int next = 0;
    Font f;
    String msg;
```
public void init() {
    f = new Font("Dialog", Font.PLAIN, 12);
    msg = "Dialog";
    setFont(f);
    addMouseListener(new MyMouseAdapter(this));
}

public void paint(Graphics g) {
    g.drawString(msg, 4, 20);
}

class MyMouseAdapter extends MouseAdapter {
    SampleFonts sampleFonts;

    public MyMouseAdapter(SampleFonts sampleFonts) {
        this.sampleFonts = sampleFonts;
    }

    public void mousePressed(MouseEvent me) {
        // Switch fonts with each mouse click.
        sampleFonts.next++;
        switch(sampleFonts.next) {
        case 0:
            sampleFonts.f = new Font("Dialog", Font.PLAIN, 12);
            sampleFonts.msg = "Dialog";
            break;
        case 1:
            sampleFonts.f = new Font("DialogInput", Font.PLAIN, 12);
            sampleFonts.msg = "DialogInput";
            break;
        case 2:
            sampleFonts.f = new Font("SansSerif", Font.PLAIN, 12);
            sampleFonts.msg = "SansSerif";
            break;
        case 3:
            sampleFonts.f = new Font("Serif", Font.PLAIN, 12);
            sampleFonts.msg = "Serif";
            break;
        case 4:
            sampleFonts.f = new Font("Monospaced", Font.PLAIN, 12);
            sampleFonts.msg = "Monospaced";
            break;
        }
        if(sampleFonts.next == 4) sampleFonts.next = -1;
        sampleFonts.setFont(sampleFonts.f);
        sampleFonts.repaint();
    }
}

Sample output from this program is shown here:
Obtaining Font Information

Suppose you want to obtain information about the currently selected font. To do this, you must first get the current font by calling `getFont()`. This method is defined by the `Graphics` class, as shown here:

```java
Font getFont()
```

Once you have obtained the currently selected font, you can retrieve information about it using various methods defined by `Font`. For example, this applet displays the name, family, size, and style of the currently selected font:
Managing Text Output Using FontMetrics

As just explained, Java supports a number of fonts. For most fonts, characters are not all the same dimension—most fonts are proportional. Also, the height of each character, the length of *descenders* (the hanging parts of letters, such as *y*), and the amount of space between horizontal lines vary from font to font. Further, the point size of a font can be changed. That these (and other) attributes are variable would not be of too much consequence except that Java demands that you, the programmer, manually manage virtually all text output.

Given that the size of each font may differ and that fonts may be changed while your program is executing, there must be some way to determine the dimensions and various other attributes of the currently selected font. For example, to write one line of text after another implies that you have some way of knowing how tall the font is and how many pixels are needed between lines. To fill this need, the AWT includes the *FontMetrics* class, which encapsulates various information about a font. Let’s begin by defining the common terminology used when describing fonts:

```java
// Display font info.
import java.applet.*;
import java.awt.*;
/*
<applet code="FontInfo" width=350 height=60>
</applet>
*/

public class FontInfo extends Applet {
    public void paint(Graphics g) {
        Font f = g.getFont();
        String fontName = f.getName();
        String fontFamily = f.getFontFamily();
        int fontSize = f.getSize();
        int fontStyle = f.getStyle();

        String msg = "Family: "+fontName;
        msg += ", Font: " + fontFamily;
        msg += ", Size: " + fontSize + ", Style: ";
        if((fontStyle & Font.BOLD) == Font.BOLD)
            msg += "Bold ";
        if((fontStyle & Font.ITALIC) == Font.ITALIC)
            msg += "Italic ";
        if((fontStyle & Font.PLAIN) == Font.PLAIN)
            msg += "Plain ";

        g.drawString(msg, 4, 16);
    }
}
```
As you know, we have used the `drawString()` method in many of the previous examples. It paints a string in the current font and color, beginning at a specified location. However, this location is at the left edge of the baseline of the characters, not at the upper-left corner as is usual with other drawing methods. It is a common error to draw a string at the same coordinate that you would draw a box. For example, if you were to draw a rectangle at coordinate 0,0, you would see a full rectangle. If you were to draw the string “Typesetting” at 0,0, you would only see the tails (or descenders) of the y, p, and g. As you will see, by using font metrics, you can determine the proper placement of each string that you display. **FontMetrics** defines several methods that help you manage text output. Several commonly used ones are listed in Table 25-3. These methods help you properly display text in a window. Let’s look at some examples.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>int byteWidth(byte b, int start, int numBytes)</code></td>
<td>Returns the width of <code>numBytes</code> characters held in array A beginning at <code>start</code>.</td>
</tr>
<tr>
<td><code>int charWidth(char c, int start, int numChars)</code></td>
<td>Returns the width of <code>numChars</code> characters held in array C beginning at <code>start</code>.</td>
</tr>
<tr>
<td><code>int charWidth(char c)</code></td>
<td>Returns the width of <code>c</code>.</td>
</tr>
<tr>
<td><code>int charWidth(int c)</code></td>
<td>Returns the width of <code>c</code>.</td>
</tr>
<tr>
<td><code>int getAscent()</code></td>
<td>Returns the ascent of the font.</td>
</tr>
<tr>
<td><code>int getDescent()</code></td>
<td>Returns the descent of the font.</td>
</tr>
<tr>
<td><code>Font getFont()</code></td>
<td>Returns the font.</td>
</tr>
<tr>
<td><code>int getHeight()</code></td>
<td>Returns the height of a line of text. This value can be used to output multiple lines of text in a window.</td>
</tr>
<tr>
<td><code>int getLeading()</code></td>
<td>Returns the space between lines of text.</td>
</tr>
<tr>
<td><code>int getMaxAdvance()</code></td>
<td>Returns the width of the widest character. −1 is returned if this value is not available.</td>
</tr>
<tr>
<td><code>int getMaxAscent()</code></td>
<td>Returns the maximum ascent.</td>
</tr>
<tr>
<td><code>int getMaxDescent()</code></td>
<td>Returns the maximum descent.</td>
</tr>
<tr>
<td><code>int[] getWeights()</code></td>
<td>Returns the widths of the first 256 characters.</td>
</tr>
<tr>
<td><code>int stringWidth(String str)</code></td>
<td>Returns the width of the string specified by <code>str</code>.</td>
</tr>
<tr>
<td><code>String toString()</code></td>
<td>Returns the string equivalent of the invoking object.</td>
</tr>
</tbody>
</table>

**Table 25-3** A Sampling of Methods Defined by **FontMetrics**

**Displaying Multiple Lines of Text**
Perhaps the most common use of **FontMetrics** is to determine the spacing between lines of
text. The second most common use is to determine the length of a string that is being displayed. Here, you will see how to accomplish these tasks.

In general, to display multiple lines of text, your program must manually keep track of the current output position. Each time a newline is desired, the Y coordinate must be advanced to the beginning of the next line. Each time a string is displayed, the X coordinate must be set to the point at which the string ends. This allows the next string to be written so that it begins at the end of the preceding one.

To determine the spacing between lines, you can use the value returned by `getLeading()`.

To determine the total height of the font, add the value returned by `getAscent()` to the value returned by `getDescent()`. You can then use these values to position each line of text you output. However, in many cases, you will not need to use these individual values. Often, all that you will need to know is the total height of a line, which is the sum of the leading space and the font’s ascent and descent values. The easiest way to obtain this value is to call `getHeight()`. Simply increment the Y coordinate by this value each time you want to advance to the next line when outputting text.

To start output at the end of previous output on the same line, you must know the length, in pixels, of each string that you display. To obtain this value, call `stringWidth()`. You can use this value to advance the X coordinate each time you display a line.

The following applet shows how to output multiple lines of text in a window. It also displays multiple sentences on the same line. Notice the variables `curX` and `curY`. They keep track of the current text output position.
Sample output from this program is shown here:
Centering Text

Here is an example that centers text, left to right, top to bottom, in a window. It obtains the ascent, descent, and width of the string and computes the position at which it must be displayed to be centered.

```java
// Center text.
import java.applet.*;
import java.awt.*;
/*
 <applet code="CenterText" width=200 height=100>
</applet>
*/

public class CenterText extends Applet {
    final Font f = new Font("SansSerif", Font.BOLD, 16);
    public void paint(Graphics g) {
        Dimension d = this.getSize();
        g.setColor(Color.white);
        g.fillRect(0, 0, d.width, d.height);
        g.setColor(Color.black);
        g.setFont(f);
        drawCenteredString("This is centered.", d.width, d.height, g);
        g.drawRect(0, 0, d.width-1, d.height-1);
    }

    public void drawCenteredString(String s, int w, int h, Graphics g) {
        FontMetrics fm = g.getFontMetrics();
        int x = (w - fm.stringWidth(s)) / 2;
        int y = (h - (fm.getAscent() + fm.getDescent()))/2;
        g.drawString(s, x, y);
    }
}
```

Following is a sample output from this program:
Multiline Text Alignment
When using a word processor, it is common for text to be aligned so that one or more of the
dges of the text make a straight line. For example, most word processors can left-justify
and/or right-justify text. Most can also center text. In the following program, you will see
how to accomplish these actions.
In the program, the string to be justified is broken into individual words. For each word, the
program keeps track of its length in the current font and automatically advances to the next
line if the word will not fit on the current line. Each completed line is displayed in the
window in the currently selected alignment style. Each time you click the mouse in the
applet’s window, the alignment style is changed. Sample output from this program is shown
here:
// Demonstrate text alignment.
import java.applet.*;
import java.awt.*;
import java.awt.event.*;
import java.util.*;
/*<title>Text Layout</title>
<applet code="TextLayout" width=200 height=200>
<param name="text" value="Output to a Java window is actually quite easy."
As you have seen, the AWT provides support for fonts, colors, text, and graphics. <p>Of course, you must effectively utilize these items if you are to achieve professional results."/>
<param name="fontname" value="Serif"/>
<param name="fontsize" value="14"/>
</applet>
*/
public class TextLayout extends Applet {
    final int LEFT = 0;
    final int RIGHT = 1;
    final int CENTER = 2;
    final int LEFTRIGHT = 3;
    int align;
Dimension d;
Font f;
FontMetrics fm;
int fontSize;
int fh, bl;
int space;
String text;

public void init() {
    setBackground(Color.white);
    text = getParameter("text");
    try {
        fontSize = Integer.parseInt(getParameter("fontSize"));
    } catch (NumberFormatException e) {
        fontSize=14;
    }
    align = LEFT;
    addMouseListener(new MyMouseListener(this));
}

public void paint(Graphics g) {
    update(g);
}

public void update(Graphics g) {
    d = getSize();
    g.setColor(getBackground());
    g.fillRect(0,0,d.width, d.height);
    if(f==null) f = new Font(getParameter("fontName"),
                              Font.PLAIN, fontSize);
    g.setFont(f);
    if(fm==null) {
        fm = g.getFontMetrics();
        bl = fm.getAscent();
        fh = bl + fm.getDescent();
        space = fm.stringWidth(" ");
    }
    g.setColor(Color.black);
    StringTokenizer st = new StringTokenizer(text);
    int x = 0;
    int nextx;
    int y = 0;
    String word, sp;
    int wordCount = 0;
    String line = " ",
    while (st.hasMoreTokens()) {
        word = st.nextToken();
        if(word.equals("<p>")) {
            drawString(g, line, wordCount,
                       fm.stringWidth(line), y+bl);
            line = " ";
            wordCount = 0;
        } else { wordCount ++; 
            String w;
            if (word.length() > fh) {
                w = word.substring(0, fh);
            } else {
                w = word;
            }
            drawString(g, w, wordCount,
                       fm.stringWidth(w), y+bl);
            line = line + w + " ";
            wordCount ++;
        }
    }
}
```java
public void drawString(Graphics g, String line,
   int wc, int lineW, int y) {
   switch (align) {
      case LEFT: g.drawString(line, 0, y); break;
      case RIGHT: g.drawString(line, d.width-lineW, y); break;
      case CENTER: g.drawString(line, (d.width-lineW)/2, y); break;
      case LEFTRIGHT:
         if(lineW < (int)(d.width*.75)) {
            g.drawString(line, 0, y);
         } else {
            int toFill = (d.width - lineW)/wc;
            int nudge = d.width - lineW - (toFill*wc);
            int a = fm.stringWidth(" ");
            StringTokenizer st = new StringTokenizer(line);
            int x = 0;
            while(st.hasMoreTokens()) {
               String word = st.nextToken();
               g.drawString(word, x, y);
               if(nudge>0) {
                  x = x + fm.stringWidth(word) + space + toFill + 1;
                  nudge--;
               } else {
                  x = x + fm.stringWidth(word) + space + toFill;
               }
            }
         }
   }
}```
Let’s take a closer look at how this applet works. The applet first creates several constants that will be used to determine the alignment style, and then declares several variables. The `init()` method obtains the text that will be displayed. It then initializes the font size in a `try-catch` block, which will set the font size to 14 if the `fontSize` parameter is missing from the HTML. The `text` parameter is a long string of text, with the HTML tag `<P>` as a paragraph separator.

The `update()` method is the engine for this example. It sets the font and gets the baseline and font height from a font metrics object. Next, it creates a `StringTokenizer` and uses it to retrieve the next token (a string separated by whitespace) from the string specified by `text`. If the next token is `<P>`, it advances the vertical spacing. Otherwise, `update()` checks to see if the length of this token in the current font will go beyond the width of the column. If the line is full of text or if there are no more tokens, the line is output by a custom version of `drawString()`.

The first three cases in `drawString()` are simple. Each aligns the string that is passed in `line` to the left or right edge or to the center of the column, depending upon the alignment style. The `LEFTRIGHT` case aligns both the left and right sides of the string. This means that we need to calculate the remaining whitespace (the difference between the width of the string and the width of the column) and distribute that space between each of the words.

The last method in this class advances the alignment style each time you click the mouse on the applet’s window.
This chapter continues our overview of the Abstract Window Toolkit (AWT). It begins with a look at several of the AWT's controls and layout managers. It then discusses menus and the menu bar. The chapter also includes a discussion of two high-level components: the dialog box and the file dialog box. It concludes with another look at event handling.

Controls are components that allow a user to interact with your application in various ways—for example, a commonly used control is the push button. A layout manager automatically positions components within a container. Thus, the appearance of a window is determined by a combination of the controls that it contains and the layout manager used to position them.

In addition to the controls, a frame window can also include a standard-style menu bar. Each entry in a menu bar activates a drop-down menu of options from which the user can choose. This constitutes the main menu of an application. As a general rule, a menu bar is positioned at the top of a window. Although different in appearance, menu bars are handled in much the same way as are the other controls.

While it is possible to manually position components within a window, doing so is quite tedious. The layout manager automates this task. For the first part of this chapter, which introduces various controls, the default layout manager will be used. This displays components in a container using left-to-right, top-to-bottom organization. Once the controls have been covered, several layout managers will be examined. There, you will see ways to better manage the positioning of controls.

Before continuing, it is important to emphasize that today you will seldom create GUIs based solely on the AWT because more powerful GUI frameworks (Swing and JavaFX) have been developed for Java. However, the material presented here remains important for the following reasons. First, much of the information and many of the techniques related to controls and event handling are generalizable to the other Java GUI frameworks. (As mentioned in the previous chapter, Swing is built upon the AWT.) Second, the layout managers described here can also be used by Swing. Third, for some small applications, the AWT components might be the appropriate choice. Finally, and perhaps most importantly, you may need to maintain or upgrade legacy code that uses the AWT. Therefore, a basic
understanding of the AWT is important for all Java programmers.

**AWT Control Fundamentals**

The AWT supports the following types of controls:

- Labels
- Push buttons
- Check boxes
- Choice lists
- Lists
- Scroll bars
- Text Editing

These controls are subclasses of **Component**. Although this is not a particularly rich set of controls, it is sufficient for simple applications. (Note that both Swing and JavaFX provide a substantially larger, more sophisticated set of controls.)

**Adding and Removing Controls**

To include a control in a window, you must add it to the window. To do this, you must first create an instance of the desired control and then add it to a window by calling **add()**, which is defined by **Container**. The **add()** method has several forms. The following form is the one that is used for the first part of this chapter:

```
Component add(Component compRef)
```

Here, **compRef** is a reference to an instance of the control that you want to add. A reference to the object is returned. Once a control has been added, it will automatically be visible whenever its parent window is displayed.

Sometimes you will want to remove a control from a window when the control is no longer needed. To do this, call **remove()**. This method is also defined by **Container**. Here is one of its forms:

```
void remove(Component compRef)
```

Here, **compRef** is a reference to the control you want to remove. You can remove all controls by calling **removeAll()**.

**Responding to Controls**

Except for labels, which are passive, all other controls generate events when they are accessed by the user. For example, when the user clicks on a push button, an event is sent that identifies the push button. In general, your program simply implements the appropriate interface and then registers an event listener for each control that you need to monitor. As explained in Chapter 24, once a listener has been installed, events are automatically sent to it. In the sections that follow, the appropriate interface for each control is specified.
**The HeadlessException**

Most of the AWT controls described in this chapter have constructors that can throw a **HeadlessException** when an attempt is made to instantiate a GUI component in a non-interactive environment (such as one in which no display, mouse, or keyboard is present). You can use this exception to write code that can adapt to non-interactive environments. (Of course, this is not always possible.) This exception is not handled by the programs in this chapter because an interactive environment is required to demonstrate the AWT controls.

**Labels**

The easiest control to use is a label. A *label* is an object of type **Label**, and it contains a string, which it displays. Labels are passive controls that do not support any interaction with the user. **Label** defines the following constructors:

- `Label()` throws HeadlessException
- `Label(String str)` throws HeadlessException
- `Label(String str, int how)` throws HeadlessException

The first version creates a blank label. The second version creates a label that contains the string specified by `str`. This string is left-justified. The third version creates a label that contains the string specified by `str` using the alignment specified by `how`. The value of `how` must be one of these three constants: **Label.LEFT**, **Label.RIGHT**, or **Label.CENTER**.

You can set or change the text in a label by using the `setText()` method. You can obtain the current label by calling `getText()`. These methods are shown here:

- `void setText(String str)`
- `String getText()`

For `setText()`, `str` specifies the new label. For `getText()`, the current label is returned.

You can set the alignment of the string within the label by calling `setAlignment()`. To obtain the current alignment, call `getAlignment()`. The methods are as follows:

- `void setAlignment(int how)`
- `int getAlignment()`

Here, `how` must be one of the alignment constants shown earlier.

The following example creates three labels and adds them to an applet window:
Here is sample output from the **LabelDemo** applet. Notice that the labels are organized in the window by the default layout manager. Later, you will see how to control more precisely the placement of the labels.

```java
// Demonstrate Labels
import java.awt.*;
import java.applet.*;
/**
<applet code="LabelDemo" width=300 height=200>
</applet>
*/

class LabelDemo extends Applet {
    public void init() {
        Label one = new Label("One");
        Label two = new Label("Two");
        Label three = new Label("Three");
        // add labels to applet window
        add(one);
        add(two);
        add(three);
    }
}

Here is sample output from the **LabelDemo** applet. Notice that the labels are organized in the window by the default layout manager. Later, you will see how to control more precisely the placement of the labels.

**Using Buttons**

Perhaps the most widely used control is the push button. A push button is a component that contains a label and that generates an event when it is pressed. Push buttons are objects of type **Button**. **Button** defines these two constructors:

- `Button()` throws `HeadlessException`
- `Button(String str)` throws `HeadlessException`

The first version creates an empty button. The second creates a button that contains `str` as a label.

After a button has been created, you can set its label by calling `setLabel()`. You can retrieve its label by calling `getLabel()`. These methods are as follows:
void setLabel(String str)
String getLabel()

Here, `str` becomes the new label for the button.

**Handling Buttons**

Each time a button is pressed, an action event is generated. This is sent to any listeners that previously registered an interest in receiving action event notifications from that component. Each listener implements the `ActionListener` interface. That interface defines the `actionPerformed()` method, which is called when an event occurs. An `ActionEvent` object is supplied as the argument to this method. It contains both a reference to the button that generated the event and a reference to the action command string associated with the button. By default, the action command string is the label of the button. Either the button reference or the action command string can be used to identify the button. (You will soon see examples of each approach.)

Here is an example that creates three buttons labeled "Yes", "No", and "Undecided". Each time one is pressed, a message is displayed that reports which button has been pressed. In this version, the action command of the button (which, by default, is its label) is used to determine which button has been pressed. The label is obtained by calling the `getActionCommand()` method on the `ActionEvent` object passed to `actionPerformed()`. 
Sample output from the *ButtonDemo* program is shown in Figure 26-1.
As mentioned, in addition to comparing button action command strings, you can also determine which button has been pressed by comparing the object obtained from the `getSource()` method to the button objects that you added to the window. To do this, you must keep a list of the objects when they are added. The following applet shows this approach:
In this version, the program stores each button reference in an array when the buttons are added to the applet window. (Recall that the `add()` method returns a reference to the button when it is added.) Inside `actionPerformed()`, this array is then used to determine which button has been pressed.

For simple programs, it is usually easier to recognize buttons by their labels. However, in situations in which you will be changing the label inside a button during the execution of your program, or using buttons that have the same label, it may be easier to determine which button has been pushed by using its object reference. It is also possible to set the action command string associated with a button to something other than its label by calling...
**setActionCommand()**. This method changes the action command string, but does not affect the string used to label the button. Thus, setting the action command enables the action command and the label of a button to differ.

In some cases, you can handle the action events generated by a button (or some other type of control) by use of an anonymous inner class (as described in Chapter 24) or a lambda expression (discussed in Chapter 15). For example, assuming the previous programs, here is a set of action event handlers that use lambda expressions:

```java
// Use lambda expressions to handle action events.
yes.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});

no.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});

maybe.addActionListener((ae) -> {
    msg = "You pressed " + ae.getActionCommand();
    repaint();
});
```

This code works because **ActionListener** defines a functional interface, which is an interface with exactly one abstract method. Thus, it can be used by a lambda expression. In general, you can use a lambda expression to handle an AWT event when its listener defines a functional interface. For example, **ItemListener** is also a functional interface. Of course, whether you use the traditional approach, an anonymous inner class, or a lambda expression will be determined by the precise nature of your application. The remaining examples in this chapter use the traditional approach to event handling so that they can be compiled by nearly any version of Java. However, you might find it interesting to try converting the event handlers to lambda expressions or anonymous inner classes, where appropriate.

**Applying Check Boxes**

A **check box** is a control that is used to turn an option on or off. It consists of a small box that can either contain a check mark or not. There is a label associated with each check box that describes what option the box represents. You change the state of a check box by clicking on it. Check boxes can be used individually or as part of a group. Check boxes are objects of the **Checkbox** class.

**Checkbox** supports these constructors:

```
Checkbox() throws HeadlessException
```
Checkbox(String str) throws HeadlessException
Checkbox(String str, boolean on) throws HeadlessException
Checkbox(String str, boolean on, CheckboxGroup cbGroup) throws HeadlessException
Checkbox(String str, CheckboxGroup cbGroup, boolean on) throws HeadlessException

The first form creates a check box whose label is initially blank. The state of the check box is unchecked. The second form creates a check box whose label is specified by str. The state of the check box is unchecked. The third form allows you to set the initial state of the check box. If on is true, the check box is initially checked; otherwise, it is cleared. The fourth and fifth forms create a check box whose label is specified by str and whose group is specified by cbGroup. If this check box is not part of a group, then cbGroup must be null. (Check box groups are described in the next section.) The value of on determines the initial state of the check box.

To retrieve the current state of a check box, call getState(). To set its state, call setState(). You can obtain the current label associated with a check box by calling getLabel(). To set the label, call setLabel(). These methods are as follows:

    boolean getState()
    void setState(boolean on)
    String getLabel()
    void setLabel(String str)

Here, if on is true, the box is checked. If it is false, the box is cleared. The string passed in str becomes the new label associated with the invoking check box.

Handling Check Boxes
Each time a check box is selected or deselected, an item event is generated. This is sent to any listeners that previously registered an interest in receiving item event notifications from that component. Each listener implements the ItemListener interface. That interface defines the itemStateChanged() method. An ItemEvent object is supplied as the argument to this method. It contains information about the event (for example, whether it was a selection or deselection).

The following program creates four check boxes. The initial state of the first box is checked. The status of each check box is displayed. Each time you change the state of a check box, the status display is updated.
// Demonstrate check boxes.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

/**<applet code="CheckboxDemo" width=240 height=200>
</applet>
*/

public class CheckboxDemo extends Applet implements ItemListener {
    String msg = "";
    Checkbox windows, android, solaris, mac;

    public void init() {
        windows = new Checkbox("Windows", null, true);
        android = new Checkbox("Android");
        solaris = new Checkbox("Solaris");
        mac = new Checkbox("Mac OS");

        add(windows);
        add(android);
        add(solaris);
        add(mac);

        windows.addItemListener(this);
        android.addItemListener(this);
        solaris.addItemListener(this);
        mac.addItemListener(this);
    }

    public void itemStateChanged(ItemEvent ie) {
        repaint();
    }

    // Display current state of the check boxes.
    public void paint(Graphics g) {
        msg = "Current state: ";
        g.drawString(msg, 6, 80);
        msg = " Windows: " + windows.getState();
        g.drawString(msg, 6, 100);
        msg = " Android: " + android.getState();
        g.drawString(msg, 6, 120);
        msg = " Solaris: " + solaris.getState();
        g.drawString(msg, 6, 140);
        msg = " Mac OS: " + mac.getState();
        g.drawString(msg, 6, 160);
    }
}

Sample output is shown in Figure 26-2.
CheckboxGroup

It is possible to create a set of mutually exclusive check boxes in which one and only one check box in the group can be checked at any one time. These check boxes are often called radio buttons, because they act like the station selector on a car radio—only one station can be selected at any one time. To create a set of mutually exclusive check boxes, you must first define the group to which they will belong and then specify that group when you construct the check boxes. Check box groups are objects of type CheckboxGroup. Only the default constructor is defined, which creates an empty group.

You can determine which check box in a group is currently selected by calling getSelectedCheckbox(). You can set a check box by calling setSelectedCheckbox(). These methods are as follows:

Checkbox getSelectedCheckbox()

void setSelectedCheckbox(Checkbox which)

Here, which is the check box that you want to be selected. The previously selected check box will be turned off.

Here is a program that uses check boxes that are part of a group:
Sample output generated by the CBGroup applet is shown in Figure 26-3. Notice that the check boxes are now circular in shape.
Choice Controls

The Choice class is used to create a pop-up list of items from which the user may choose. Thus, a Choice control is a form of menu. When inactive, a Choice component takes up only enough space to show the currently selected item. When the user clicks on it, the whole list of choices pops up, and a new selection can be made. Each item in the list is a string that appears as a left-justified label in the order it is added to the Choice object. Choice defines only the default constructor, which creates an empty list.

To add a selection to the list, call add(). It has this general form:

```
void add(String name)
```

Here, name is the name of the item being added. Items are added to the list in the order in which calls to add() occur.

To determine which item is currently selected, you may call either getSelectedItem() or getSelectedIndex(). These methods are shown here:

```
String getSelectedItem()
int getSelectedIndex()
```

The getSelectedItem() method returns a string containing the name of the item. getSelectedIndex() returns the index of the item. The first item is at index 0.

By default, the first item added to the list is selected.

To obtain the number of items in the list, call getItemCount(). You can set the currently selected item using the select() method with either a zero-based integer index or a string that will match a name in the list. These methods are shown here:

```
int getItemCount()
void select(int index)
void select(String name)
```
Given an index, you can obtain the name associated with the item at that index by calling `getItem()`, which has this general form:

```java
String getItem(int index)
```

Here, `index` specifies the index of the desired item.

**Handling Choice Lists**

Each time a choice is selected, an item event is generated. This is sent to any listeners that previously registered an interest in receiving item event notifications from that component. Each listener implements the `ItemListener` interface. That interface defines the `itemStateChanged()` method. An `ItemEvent` object is supplied as the argument to this method.

Here is an example that creates two `Choice` menus. One selects the operating system. The other selects the browser.

```java
    // Demonstrate Choice lists.
    import java.awt.*;
    import java.awt.event.*;
```
import java.applet.*;
/
 *<applet code="ChoiceDemo" width=300 height=180>
 */

public class ChoiceDemo extends Applet implements ItemListener {
    Choice os, browser;
    String msg = "";

    public void init() {
        os = new Choice();
        browser = new Choice();

        // add items to os list
        os.add("Windows");
        os.add("Android");
        os.add("Solaris");
        os.add("Mac OS");

        // add items to browser list
        browser.add("Internet Explorer");
        browser.add("Firefox");
        browser.add("Chrome");

        // add choice lists to window
        add(os);
        add(browser);

        // register to receive item events
        os.addItemListener(this);
        browser.addItemListener(this);
    }

    public void itemStateChanged(ItemEvent ie) {
        repaint();
    }

    // Display current selections.
    public void paint(Graphics g) {
        msg = "Current OS: ";
        msg += os.getSelectedItem();
        g.drawString(msg, 6, 120);
        msg = "Current Browser: ";
        msg += browser.getSelectedItem();
        g.drawString(msg, 6, 140);
    }
}

Sample output is shown in Figure 26-4.
Using Lists

The **List** class provides a compact, multiple-choice, scrolling selection list. Unlike the **Choice** object, which shows only the single selected item in the menu, a **List** object can be constructed to show any number of choices in the visible window. It can also be created to allow multiple selections. **List** provides these constructors:

- `List()` throws `HeadlessException`
- `List(int numRows)` throws `HeadlessException`
- `List(int numRows, boolean multipleSelect)` throws `HeadlessException`

The first version creates a **List** control that allows only one item to be selected at any one time. In the second form, the value of `numRows` specifies the number of entries in the list that will always be visible (others can be scrolled into view as needed). In the third form, if `multipleSelect` is `true`, then the user may select two or more items at a time. If it is `false`, then only one item may be selected.

To add a selection to the list, call `add()`. It has the following two forms:

- `void add(String name)`
- `void add(String name, int index)`

Here, `name` is the name of the item added to the list. The first form adds items to the end of the list. The second form adds the item at the index specified by `index`. Indexing begins at zero. You can specify −1 to add the item to the end of the list.

For lists that allow only single selection, you can determine which item is currently selected by calling either `getSelectedString()` or `getSelectedIndex()`. These methods are shown here:

- `String getSelectedString()`
- `int getSelectedIndex()`
The `getSelectedItem()` method returns a string containing the name of the item. If more than one item is selected, or if no selection has yet been made, `null` is returned. `getSelectedIndex()` returns the index of the item. The first item is at index 0. If more than one item is selected, or if no selection has yet been made, −1 is returned.

For lists that allow multiple selection, you must use either `getSelectedItems()` or `getSelectedIndexes()`, shown here, to determine the current selections:

```java
String[] getSelectedItems()
int[] getSelectedIndexes()
```

`getSelectedItems()` returns an array containing the names of the currently selected items. `getSelectedIndexes()` returns an array containing the indexes of the currently selected items.

To obtain the number of items in the list, call `getItemCount()`. You can set the currently selected item by using the `select()` method with a zero-based integer index. These methods are shown here:

```java
int getItemCount()
void select(int index)
```

Given an index, you can obtain the name associated with the item at that index by calling `getItem()`, which has this general form:

```java
String getItem(int index)
```

Here, `index` specifies the index of the desired item.

### Handling Lists

To process list events, you will need to implement the `ActionListener` interface. Each time a `List` item is double-clicked, an `ActionEvent` object is generated. Its `getActionCommand()` method can be used to retrieve the name of the newly selected item. Also, each time an item is selected or deselected with a single click, an `ItemEvent` object is generated. Its `getStateChange()` method can be used to determine whether a selection or deselection triggered this event. `getItemSelectable()` returns a reference to the object that triggered this event.

Here is an example that converts the `Choice` controls in the preceding section into `List` components, one multiple choice and the other single choice:
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

public class ListDemo extends Applet implements ActionListener {
    List os, browser;
    String msg = "";

    public void init() {
        os = new List(4, true);
        browser = new List(4, false);

        // add items to os list
        os.add("Windows");
    }
}
Sample output generated by the **ListDemo** applet is shown in Figure 26-5.
Managing Scroll Bars

Scroll bars are used to select continuous values between a specified minimum and maximum. Scroll bars may be oriented horizontally or vertically. A scroll bar is actually a composite of several individual parts. Each end has an arrow that you can click to move the current value of the scroll bar one unit in the direction of the arrow. The current value of the scroll bar relative to its minimum and maximum values is indicated by the slider box (or thumb) for the scroll bar. The slider box can be dragged by the user to a new position. The scroll bar will then reflect this value. In the background space on either side of the thumb, the user can click to cause the thumb to jump in that direction by some increment larger than 1. Typically, this action translates into some form of page up and page down. Scroll bars are encapsulated by the Scrollbar class.

Scrollbar defines the following constructors:

- Scrollbar() throws HeadlessException
- Scrollbar(int style) throws HeadlessException
- Scrollbar(int style, int initialValue, int thumbSize, int min, int max),
  throws HeadlessException

The first form creates a vertical scroll bar. The second and third forms allow you to specify the orientation of the scroll bar. If style is Scrollbar.VERTICAL, a vertical scroll bar is created. If style is Scrollbar.HORIZONTAL, the scroll bar is horizontal. In the third form of the constructor, the initial value of the scroll bar is passed in initialValue. The number of units represented by the height of the thumb is passed in thumbSize. The minimum and maximum values for the scroll bar are specified by min and max.

If you construct a scroll bar by using one of the first two constructors, then you need to set its parameters by using setValues(), shown here, before it can be used:

void setValues(int initialValue, int thumbSize, int min, int max)
The parameters have the same meaning as they have in the third constructor just described.
To obtain the current value of the scroll bar, call `getValue()`. It returns the current setting.
To set the current value, call `setValue()`. These methods are as follows:

```java
int getValue()
void setValue(int newValue)
```

Here, `newValue` specifies the new value for the scroll bar. When you set a value, the slider box inside the scroll bar will be positioned to reflect the new value.

You can also retrieve the minimum and maximum values via `getMinimum()` and `getMaximum()`, shown here:

```java
int getMinimum()
int getMaximum()
```

They return the requested quantity.

By default, 1 is the increment added to or subtracted from the scroll bar each time it is scrolled up or down one line. You can change this increment by calling `setUnitIncrement()`. By default, page-up and page-down increments are 10. You can change this value by calling `setBlockIncrement()`. These methods are shown here:

```java
void setUnitIncrement(int newIncr)
void setBlockIncrement(int newIncr)
```

### Handling Scroll Bars

To process scroll bar events, you need to implement the `AdjustmentListener` interface.

Each time a user interacts with a scroll bar, an `AdjustmentEvent` object is generated. Its `getAdjustmentType()` method can be used to determine the type of the adjustment. The types of adjustment events are as follows:

<table>
<thead>
<tr>
<th>Adjustment Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BLOCK_DECREMENT</td>
<td>A page-down event has been generated.</td>
</tr>
<tr>
<td>BLOCK_INCREMENT</td>
<td>A page-up event has been generated.</td>
</tr>
<tr>
<td>TRACK</td>
<td>An absolute tracking event has been generated.</td>
</tr>
<tr>
<td>UNIT_DECREMENT</td>
<td>The line-down button in a scroll bar has been pressed.</td>
</tr>
<tr>
<td>UNIT_INCREMENT</td>
<td>The line-up button in a scroll bar has been pressed.</td>
</tr>
</tbody>
</table>

The following example creates both a vertical and a horizontal scroll bar. The current settings of the scroll bars are displayed. If you drag the mouse while inside the window, the coordinates of each drag event are used to update the scroll bars. An asterisk is displayed at the current drag position. Notice the use of `setPreferredSize()` to set the size of the scrollbars.
// Demonstrate scroll bars.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/**
   <applet code="SBDemo" width=300 height=200>
   </applet>
*/

class SBDemo extends Applet
   implements AdjustmentListener, MouseMotionListener {
   String msg = "";
   Scrollbar vertSB, horzSB;

   public void init() {
      int width = Integer.parseInt(getParameter("width"));
      int height = Integer.parseInt(getParameter("height"));

      vertSB = new Scrollbar(Scrollbar.VERTICAL,
         0, 1, 0, height);
      vertSB.setPreferredSize(new Dimension(20, 100));

      horzSB = new Scrollbar(Scrollbar.HORIZONTAL,
         0, 1, 0, width);
      horzSB.setPreferredSize(new Dimension(100, 20));

      add(vertSB);
      add(horzSB);

      // register to receive adjustment events
Sample output from the **SBDemo** applet is shown in Figure 26-6.
Using a TextField

The TextField class implements a single-line text-entry area, usually called an edit control. Text fields allow the user to enter strings and to edit the text using the arrow keys, cut and paste keys, and mouse selections. TextField is a subclass of TextComponent. TextField defines the following constructors:

TextField( ) throws HeadlessException
TextField(int numChars) throws HeadlessException
TextField(String str) throws HeadlessException
TextField(String str, int numChars) throws HeadlessException

The first version creates a default text field. The second form creates a text field that is numChars characters wide. The third form initializes the text field with the string contained in str. The fourth form initializes a text field and sets its width.

TextField (and its superclass TextComponent) provides several methods that allow you to utilize a text field. To obtain the string currently contained in the text field, call getText( ). To set the text, call setText( ). These methods are as follows:

String getText( )
void setText(String str)

Here, str is the new string.

The user can select a portion of the text in a text field. Also, you can select a portion of text under program control by using select( ). Your program can obtain the currently selected text by calling getSelectedText( ). These methods are shown here:

String getSelectedText( )
void select(int startIndex, int endIndex)
**getSelectedText()** returns the selected text. The **select()** method selects the characters beginning at **startIndex** and ending at **endIndex** -1.

You can control whether the contents of a text field may be modified by the user by calling **setEditable()**. You can determine editability by calling **isEditable()**. These methods are shown here:

```java
boolean isEditable()
void setEditable(boolean canEdit)
```

**isEditable()** returns true if the text may be changed and false if not. In **setEditable()**, if canEdit is true, the text may be changed. If it is false, the text cannot be altered.

There may be times when you will want the user to enter text that is not displayed, such as a password. You can disable the echoing of the characters as they are typed by calling **setEchoChar()**. This method specifies a single character that the TextField will display when characters are entered (thus, the actual characters typed will not be shown). You can check a text field to see if it is in this mode with the **echoCharIsSet()** method. You can retrieve the echo character by calling the **getEchoChar()** method. These methods are as follows:

```java
void setEchoChar(char ch)
boolean echoCharIsSet()
char getEchoChar()
```

Here, ch specifies the character to be echoed. If ch is zero, then normal echoing is restored.

**Handling a TextField**

Since text fields perform their own editing functions, your program generally will not respond to individual key events that occur within a text field. However, you may want to respond when the user presses ENTER. When this occurs, an action event is generated. Here is an example that creates the classic user name and password screen:
Sample output from the **TextFieldDemo** applet is shown in Figure 26-7.
Using a TextArea

Sometimes a single line of text input is not enough for a given task. To handle these situations, the AWT includes a simple multiline editor called TextArea. Following are the constructors for TextArea:

TextArea( ) throws HeadlessException
TextArea(int numLines, int numChars) throws HeadlessException
TextArea(String str) throws HeadlessException
TextArea(String str, int numLines, int numChars) throws HeadlessException
TextArea(String str, int numLines, int numChars, int sBars) throws HeadlessException

Here, numLines specifies the height, in lines, of the text area, and numChars specifies its width, in characters. Initial text can be specified by str. In the fifth form, you can specify the scroll bars that you want the control to have. sBars must be one of these values:

<table>
<thead>
<tr>
<th>SCROLLBARS_BOTH</th>
<th>SCROLLBARS_NONE</th>
</tr>
</thead>
<tbody>
<tr>
<td>SCROLLBARS_HORIZONTAL_ONLY</td>
<td>SCROLLBARS_VERTICAL_ONLY</td>
</tr>
</tbody>
</table>

TextArea is a subclass of TextComponent. Therefore, it supports the getText(), setText(), getSelectedText(), select(), isEditable(), and setEditable() methods described in the preceding section.

TextArea adds the following editing methods:

void append(String str)
void insert(String str, int index)
void replaceRange(String str, int startIndex, int endIndex)

The append() method appends the string specified by str to the end of the
current text. **insert( )** inserts the string passed in *str* at the specified index. To replace text, call **replaceRange( )**. It replaces the characters from *startIndex* to *endIndex−1*, with the replacement text passed in *str*.

Text areas are almost self-contained controls. Your program incurs virtually no management overhead. Normally, your program simply obtains the current text when it is needed. You can, however, listen for **TextEvents**, if you choose.

The following program creates a **TextArea** control:

```java
// Demonstrate TextArea.
import java.awt.*;
import java.applet.*;
/*
<applet code="TextAreaDemo" width=100 height=250>
</applet>
*/

public class TextAreaDemo extends Applet {
    public void init() {
        String val = "Java 8 is the latest version of the most\n" + "widely-used computer language for Internet programming.\n" + "Building on a rich heritage, Java has advanced both\n" + "the art and science of computer language design.\n" + "One of the reasons for Java's ongoing success is its\n" + "constant, steady rate of evolution. Java has never stood\n" + "still. Instead, Java has consistently adapted to the\n" + "rapidly changing landscape of the networked world.\n" + "Moreover, Java has often led the way, charting the\n" + "course for others to follow."
        TextArea text = new TextArea(val, 10, 30);
        add(text);
    }
}
```

Here is sample output from the **TextAreaDemo** applet:
Understanding Layout Managers

All of the components that we have shown so far have been positioned by the default layout manager. As we mentioned at the beginning of this chapter, a layout manager automatically arranges your controls within a window by using some type of algorithm. If you have programmed for other GUI environments, such as Windows, then you may have laid out your controls by hand. While it is possible to lay out Java controls by hand, too, you generally won’t want to, for two main reasons. First, it is very tedious to manually lay out a large number of components. Second, sometimes the width and height information is not yet available when you need to arrange some control, because the native toolkit components haven’t been realized. This is a chicken-and-egg situation; it is pretty confusing to figure out when it is okay to use the size of a given component to position it relative to another.

Each Container object has a layout manager associated with it. A layout manager is an instance of any class that implements the LayoutManager interface. The layout manager is set by the setLayout() method. If no call to setLayout() is made, then the default layout manager is used. Whenever a container is resized (or sized for the first time), the layout manager is used to position each of the components within it.

The setLayout() method has the following general form:

```java
void setLayout(LayoutManager layoutObj)
```

Here, layoutObj is a reference to the desired layout manager. If you wish to disable the layout manager and position components manually, pass null for layoutObj. If you do this, you will need to determine the shape and position of each component manually, using the setBounds() method defined by Component. Normally, you will want to use a layout manager.

Each layout manager keeps track of a list of components that are stored by their names. The layout manager is notified each time you add a component to a container. Whenever the
container needs to be resized, the layout manager is consulted via its
minimumLayoutSize() and preferredLayoutSize() methods. Each component that is
being managed by a layout manager contains the getPreferredSize() and
getMinimumSize() methods. These return the preferred and minimum size required to
display each component. The layout manager will honor these requests if at all possible,
while maintaining the integrity of the layout policy. You may override these methods for
controls that you subclass. Default values are provided otherwise.
Java has several predefined LayoutManager classes, several of which are described next.
You can use the layout manager that best fits your application.

FlowLayout

FlowLayout is the default layout manager. This is the layout manager that the preceding
examples have used. FlowLayout implements a simple layout style, which is similar to
how words flow in a text editor. The direction of the layout is governed by the container’s
component orientation property, which, by default, is left to right, top to bottom. Therefore,
by default, components are laid out line-by-line beginning at the upper-left corner. In all
cases, when a line is filled, layout advances to the next line. A small space is left between
each component, above and below, as well as left and right. Here are the constructors for
FlowLayout:

FlowLayout( )
FlowLayout(int how)
FlowLayout(int how, int horz, int vert)

The first form creates the default layout, which centers components and leaves five
pixels of space between each component. The second form lets you specify how
each line is aligned. Valid values for how are as follows:

FlowLayout.LEFT
FlowLayout.CENTER
FlowLayout.RIGHT
FlowLayout.LEADING
FlowLayout.TRAILING

These values specify left, center, right, leading edge, and trailing edge alignment,
respectively. The third constructor allows you to specify the horizontal and vertical
space left between components in horz and vert, respectively.

Here is a version of the CheckboxDemo applet shown earlier in this chapter, modified so
that it uses left-aligned flow layout:
// Use left-aligned flow layout.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/*
   <applet code="FlowLayoutDemo" width=240 height=200>
</applet>
*/

public classFlowLayoutDemo extends Applet
   implements ItemListener {
   String msg = "";
   Checkbox windows, android, solaris, mac;

   public void init() {
      // set left-aligned flow layout
   setLayout(new FlowLayout(FlowLayout.LEFT));

      windows = new Checkbox("Windows", null, true);
      android = new Checkbox("Android");
      solaris = new Checkbox("Solaris");
      mac = new Checkbox("Mac OS");

      add(windows);
      add(android);
      add(solaris);
      add(mac);

      // register to receive item events
   windows.addItemListener(this);
   android.addItemListener(this);
   solaris.addItemListener(this);
   mac.addItemListener(this);
   }
}
Here is sample output generated by the **FlowLayoutDemo** applet. Compare this with the output from the **CheckboxDemo** applet, shown earlier in Figure 26-2.

---

Here are the constructors defined by **BorderLayout**:

- `BorderLayout()`
- `BorderLayout(int horz, int vert)`

The first form creates a default border layout. The second allows you to specify the...
horizontal and vertical space left between components in horz and vert, respectively. 

**BorderLayout** defines the following constants that specify the regions:

<table>
<thead>
<tr>
<th>BorderLayout.CENTER</th>
<th>BorderLayout.SOUTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>BorderLayout.EAST</td>
<td>BorderLayout.WEST</td>
</tr>
<tr>
<td>BorderLayout.NORTH</td>
<td></td>
</tr>
</tbody>
</table>

When adding components, you will use these constants with the following form of `add()`, which is defined by **Container**:

```java
void add(Component compRef, Object region)
```

Here, `compRef` is a reference to the component to be added, and `region` specifies where the component will be added.

Here is an example of a **BorderLayout** with a component in each layout area:
public class BorderLayoutDemo extends Applet {
    public void init() {
        setLayout(new BorderLayout());
        add(new Button("This is across the top."), BorderLayout.NORTH);
        add(new Label("The footer message might go here."), BorderLayout.SOUTH);
        add(new Button("Right"), BorderLayout.EAST);
        add(new Button("Left"), BorderLayout.WEST);

        String msg = "The reasonable man adapts " + "himself to the world;\n" + "the unreasonable one persists in " + "trying to adapt the world to himself.\n" + "Therefore all progress depends " + "on the unreasonable man.\n" + "- George Bernard Shaw\n";

        add(new TextArea(msg), BorderLayout.CENTER);
    }
}

Sample output from the BorderLayoutDemo applet is shown here:
Using Insets

Sometimes you will want to leave a small amount of space between the container that holds your components and the window that contains it. To do this, override the `getInsets()` method that is defined by `Container`. This method returns an `Insets` object that contains the top, bottom, left, and right inset to be used when the container is displayed. These values are used by the layout manager to inset the components when it lays out the window.

The constructor for `Insets` is shown here:

```java
Insets(int top, int left, int bottom, int right)
```

The values passed in `top`, `left`, `bottom`, and `right` specify the amount of space between the container and its enclosing window.

The `getInsets()` method has this general form:

```java
Insets getInsets()
```

When overriding this method, you must return a new `Insets` object that contains the inset spacing you desire.

Here is the preceding `BorderLayout` example modified so that it insets its components ten pixels from each border. The background color has been set to cyan to help make the insets more visible.
Sample output from the **InsetsDemo** applet is shown here:
GridLayout

GridLayout lays out components in a two-dimensional grid. When you instantiate a GridLayout, you define the number of rows and columns. The constructors supported by GridLayout are shown here:

    GridLayout( )
    GridLayout(int numRows, int numColumns)
    GridLayout(int numRows, int numColumns, int horz, int vert)

    The first form creates a single-column grid layout. The second form creates a grid layout with the specified number of rows and columns. The third form allows you to specify the horizontal and vertical space left between components in horz and vert, respectively. Either numRows or numColumns can be zero. Specifying numRows as zero allows for unlimited-length columns. Specifying numColumns as zero allows for unlimited-length rows.

Here is a sample program that creates a 4×4 grid and fills it in with 15 buttons, each labeled with its index:
Following is sample output generated by the **GridLayoutDemo** applet:

```
// Demonstrate GridLayout
import java.awt.*;
import java.applet.*;
/**
 <applet code="GridLayoutDemo" width=300 height=200>
 </applet>
 */
public class GridLayoutDemo extends Applet {
    static final int n = 4;
    public void init() {
        setLayout (new GridLayout(n, n));

        setFont(new Font("SansSerif", Font.BOLD, 24));

        for(int i = 0; i < n; i++) {
            for(int j = 0; j < n; j++) {
                int k = i * n + j;
                if(k > 0)
                    add(new Button("" + k));
            }
        }
    }
}
```

**TIP** You might try using this example as the starting point for a 15-square puzzle.
**CardLayout**

The **CardLayout** class is unique among the other layout managers in that it stores several different layouts. Each layout can be thought of as being on a separate index card in a deck that can be shuffled so that any card is on top at a given time. This can be useful for user interfaces with optional components that can be dynamically enabled and disabled upon user input. You can prepare the other layouts and have them hidden, ready to be activated when needed.

**CardLayout** provides these two constructors:

```java
CardLayout()
CardLayout(int horz, int vert)
```

The first form creates a default card layout. The second form allows you to specify the horizontal and vertical space left between components in *horz* and *vert*, respectively.

Use of a card layout requires a bit more work than the other layouts. The cards are typically held in an object of type **Panel**. This panel must have **CardLayout** selected as its layout manager. The cards that form the deck are also typically objects of type **Panel**. Thus, you must create a panel that contains the deck and a panel for each card in the deck. Next, you add to the appropriate panel the components that form each card. You then add these panels to the panel for which **CardLayout** is the layout manager. Finally, you add this panel to the window. Once these steps are complete, you must provide some way for the user to select between cards. One common approach is to include one push button for each card in the deck.

When card panels are added to a panel, they are usually given a name. Thus, most of the time, you will use this form of **add** when adding cards to a panel:

```java
void add(Component panelRef, Object name)
```

Here, *name* is a string that specifies the name of the card whose panel is specified by *panelRef*.

After you have created a deck, your program activates a card by calling one of the following methods defined by **CardLayout**:

```java
void first(Container deck)
void last(Container deck)
void next(Container deck)
void previous(Container deck)
void show(Container deck, String cardName)
```

Here, *deck* is a reference to the container (usually a panel) that holds the cards, and *cardName* is the name of a card. Calling **first()** causes the first card in the deck to be shown. To show the last card, call **last()**. To show the next card, call **next()**. To show the previous card, call **previous()**. To show a specific card, call **show()** and specify the name of the card.
next( ). To show the previous card, call previous( ). Both next( ) and previous( ) automatically cycle back to the top or bottom of the deck, respectively. The show( ) method displays the card whose name is passed in cardName.

The following example creates a two-level card deck that allows the user to select an operating system. Windows-based operating systems are displayed in one card. Mac OS and Solaris are displayed in the other card.

```java
// Demonstrate CardLayout.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/*
   <applet code="CardLayoutDemo" width=300 height=100>
   </applet>
*/

public class CardLayoutDemo extends Applet
   implements ActionListener, MouseListener {
```
public void init()
{
    Win = new Button("Windows");
    Other = new Button("Other");
    add(Win);
    add(Other);

    cardLO = new CardLayout();
    osCards = new Panel();
    osCards.setLayout(cardLO); // set panel layout to card layout

    windowsXP = new CheckBox("Windows XP", null, true);
    windows7 = new CheckBox("Windows 7", null, false);
    windows8 = new CheckBox("Windows 8", null, false);
    android = new CheckBox("Android");
    solaris = new CheckBox("Solaris");
    mac = new CheckBox("Mac OS");

    // add Windows check boxes to a panel
    Panel winPan = new Panel();
    winPan.add(windowsXP);
    winPan.add(windows7);
    winPan.add(windows8);

    // add other OS check boxes to a panel
    Panel otherPan = new Panel();
    otherPan.add(android);
    otherPan.add(solaris);
    otherPan.add(mac);

    // add panels to card deck panel
    osCards.add(winPan, "Windows");
    osCards.add(otherPan, "Other");

    // add panels to main applet panel
    add(osCards);

    // register to receive action events
    Win.addActionListener(this);
    Other.addActionListener(this);

    // register mouse events
    addMouseListener(this);
}

// cycle through panels.
public void mousePressed(MouseEvent me)
{
    cardLO.next(osCards);
}
Here is sample output generated by the `CardLayoutDemo` applet. Each card is activated by pushing its button. You can also cycle through the cards by clicking the mouse.

GridBagLayout
Although the preceding layouts are perfectly acceptable for many uses, some situations will require that you take a bit more control over how the components are arranged. A good way to do this is to use a grid bag layout, which is specified by the `GridBagLayout` class. What makes the grid bag useful is that you can specify the relative placement of components by specifying their positions within cells inside a grid. The key to the grid bag is that each
component can be a different size, and each row in the grid can have a different number of columns. This is why the layout is called a grid bag. It's a collection of small grids joined together.

The location and size of each component in a grid bag are determined by a set of constraints linked to it. The constraints are contained in an object of type GridBagConstraints. Constraints include the height and width of a cell, and the placement of a component, its alignment, and its anchor point within the cell.

The general procedure for using a grid bag is to first create a new GridBagLayout object and to make it the current layout manager. Then, set the constraints that apply to each component that will be added to the grid bag. Finally, add the components to the layout manager. Although GridBagLayout is a bit more complicated than the other layout managers, it is still quite easy to use once you understand how it works.

GridBagLayout defines only one constructor, which is shown here:

```
GridBagLayout()
```

GridBagLayout defines several methods, of which many are protected and not for general use. There is one method, however, that you must use: setConstraints( ). It is shown here:

```
void setConstraints(Component comp, GridBagConstraints cons)
```

Here, comp is the component for which the constraints specified by cons apply. This method sets the constraints that apply to each component in the grid bag.

The key to successfully using GridBagLayout is the proper setting of the constraints, which are stored in a GridBagConstraints object. GridBagConstraints defines several fields that you can set to govern the size, placement, and spacing of a component. These are shown in Table 26-1. Several are described in greater detail in the following discussion.
GridBagConstraints also defines several static fields that contain standard constraint values, such as GridBagConstraints.CENTER and GridBagConstraints.VERTICAL. When a component is smaller than its cell, you can use the anchor field to specify where within the cell the component’s top-left corner will be located. There are three types of values that you can give to anchor. The first are absolute:

<table>
<thead>
<tr>
<th>Field</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>int anchor</td>
<td>Specifies the location of a component within a cell. The default is GridBagConstraints.CENTER</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>Specifies how a component is resized if the component is smaller than</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>its cell. Valid values are GridBagConstraints.NONE (the default),</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>GridBagConstraints.HORIZONTAL, GridBagConstraints.VERTICAL,</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>GridBagConstraints.BOTH.</td>
</tr>
<tr>
<td>int gridheight</td>
<td>Specifies the height of component in terms of cells. The default is 1.</td>
</tr>
<tr>
<td>int gridwidth</td>
<td>Specifies the width of component in terms of cells. The default is 1.</td>
</tr>
<tr>
<td>int gridx</td>
<td>Specifies the X coordinate of the cell to which the component will be</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>added. The default value is GridBagConstraints.RELATIVE.</td>
</tr>
<tr>
<td>int gridy</td>
<td>Specifies the Y coordinate of the cell to which the component will be</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>added. The default value is GridBagConstraints.RELATIVE.</td>
</tr>
<tr>
<td>Insets insets</td>
<td>Specifies the insets. Default insets are all zero.</td>
</tr>
<tr>
<td>int ipadx</td>
<td>Specifies extra horizontal space that surrounds a component within a</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>cell. The default is 0.</td>
</tr>
<tr>
<td>int ipady</td>
<td>Specifies extra vertical space that surrounds a component within a</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>cell. The default is 0.</td>
</tr>
<tr>
<td>double weights</td>
<td>Specifies a weight value that determines the horizontal spacing between</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>cells and the edges of the container that holds them. The default value</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>is 0.0. The greater the weight, the more space that is allocated. If all</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>values are 0.0, extra space is distributed evenly between the edges of</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>the window.</td>
</tr>
<tr>
<td>double weighly</td>
<td>Specifies a weight value that determines the vertical spacing between</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>cells and the edges of the container that holds them. The default value</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>is 0.0. The greater the weight, the more space that is allocated. If all</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>values are 0.0, extra space is distributed evenly between the edges of</td>
</tr>
<tr>
<td>GridBagConstraints</td>
<td>the window.</td>
</tr>
</tbody>
</table>

Table 26-1  Constraint Fields Defined by GridBagConstraints

As their names imply, these values cause the component to be placed at the specific locations.

The second type of values that can be given to anchor is relative, which means the values are relative to the container's orientation, which might differ for non-Western languages. The relative values are shown here:

<table>
<thead>
<tr>
<th>GridBagConstraints.CENTER</th>
<th>GridBagConstraints.SOUTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>GridBagConstraints.EAST</td>
<td>GridBagConstraints.SOUTHEAST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTH</td>
<td>GridBagConstraints.SOUTHWEST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTHEAST</td>
<td>GridBagConstraints.WEST</td>
</tr>
<tr>
<td>GridBagConstraints.NORTHWEST</td>
<td></td>
</tr>
</tbody>
</table>

As their names imply, these values cause the component to be placed at the specific locations.

The second type of values that can be given to anchor is relative, which means the values are relative to the container’s orientation, which might differ for non-Western languages. The relative values are shown here:
Their names describe the placement.
The third type of values that can be given to anchor allows you to position components relative to the baseline of the row. These values are shown here:

<table>
<thead>
<tr>
<th>GridBagConstraints.BASELINE</th>
<th>GridBagConstraints.BASELINE.LEADING</th>
</tr>
</thead>
<tbody>
<tr>
<td>GridBagConstraints.BASELINE_TRAILING</td>
<td>GridBagConstraints.ABOVE_BASELINE</td>
</tr>
<tr>
<td>GridBagConstraints.ABOVE_BASELINE.LEADING</td>
<td>GridBagConstraints.ABOVE_BASELINE_TRAILING</td>
</tr>
<tr>
<td>GridBagConstraints.BELOW_BASELINE</td>
<td>GridBagConstraints.BELOW_BASELINE.LEADING</td>
</tr>
</tbody>
</table>

The horizontal position can be either centered, against the leading edge (LEADING), or against the trailing edge (TRAILING).

The **weightx** and **weighty** fields are both quite important and quite confusing at first glance. In general, their values determine how much of the extra space within a container is allocated to each row and column. By default, both these values are zero. When all values within a row or a column are zero, extra space is distributed evenly between the edges of the window. By increasing the weight, you increase that row or column’s allocation of space proportional to the other rows or columns. The best way to understand how these values work is to experiment with them a bit.

The **gridwidth** variable lets you specify the width of a cell in terms of cell units. The default is 1. To specify that a component use the remaining space in a row, use **GridBagConstraints.REMAINDER**. To specify that a component use the next-to-last cell in a row, use **GridBagConstraints.RELATIVE**. The **gridheight** constraint works the same way, but in the vertical direction.

You can specify a padding value that will be used to increase the minimum size of a cell. To pad horizontally, assign a value to **ipadx**. To pad vertically, assign a value to **ipady**.

Here is an example that uses **GridBagLayout** to demonstrate several of the points just discussed:
// Use GridBagLayout.
import java.awt.*;
import java.awt.event.*;
import java.applet.UpDown.*;
/**<applet code="GridBagDemo" width=250 height=200>
</applet> */

public class GridBagDemo extends Applet
    implements ItemListener {

    String msg = "";
    Checkbox windows, android, solaris, mac;

    public void init() {
        GridBagLayout gbag = new GridBagLayout();
        GridBagConstraints gbc = new GridBagConstraints();
        setLayout(gbag);

        // Define check boxes.
        windows = new Checkbox("Windows ", null, true);
        android = new Checkbox("Android");
        solaris = new Checkbox("Solaris");
        mac = new Checkbox("Mac OS");

        // Define the grid bag.

        // Use default row weight of 0 for first row.
        gbc.weightx = 1.0; // use a column weight of 1
Sample output produced by the program is shown here.
In this layout, the operating system check boxes are positioned in a 2×2 grid. Each cell has a horizontal padding of 200. Each component is inset slightly (by 4 units) from the top left. The column weight is set to 1, which causes any extra horizontal space to be distributed evenly between the columns. The first row uses a default weight of 0; the second has a weight of 1. This means that any extra vertical space is added to the second row.

**GridBagLayout** is a powerful layout manager. It is worth taking some time to experiment with and explore. Once you understand what the various settings do, you can use **GridBagLayout** to position components with a high degree of precision.

### Menu Bars and Menus

A top-level window can have a menu bar associated with it. A menu bar displays a list of top-level menu choices. Each choice is associated with a drop-down menu. This concept is implemented in the AWT by the following classes: **MenuBar**, **Menu**, and **MenuItem**. In general, a menu bar contains one or more **Menu** objects. Each **Menu** object contains a list of **MenuItem** objects. Each **MenuItem** object represents something that can be selected by the user. Since **Menu** is a subclass of **MenuItem**, a hierarchy of nested submenus can be created. It is also possible to include checkable menu items. These are menu options of type **CheckboxMenuItem** and will have a check mark next to them when they are selected.

To create a menu bar, first create an instance of **MenuBar**. This class defines only the default constructor. Next, create instances of **Menu** that will define the selections displayed on the bar. Following are the constructors for **Menu**:

- **Menu()** throws **HeadlessException**
- **Menu(String optionName)** throws **HeadlessException**
- **Menu(String optionName, boolean removable)** throws **HeadlessException**

Here, **optionName** specifies the name of the menu selection. If **removable** is **true**, the menu can be removed and allowed to float free. Otherwise, it will remain
attached to the menu bar. (Removable menus are implementation-dependent.) The
first form creates an empty menu. Individual menu items are of type **MenuItem**.
It defines these constructors:

    MenuItem() throws HeadlessException
    MenuItem(String itemName) throws HeadlessException
    MenuItem(String itemName, MenuShortcut keyAccel) throws HeadlessException

Here, *itemName* is the name shown in the menu, and *keyAccel* is the menu
shortcut for this item.

You can disable or enable a menu item by using the **setEnabled( )** method. Its form is
shown here:

    void setEnabled(boolean enabledFlag)

If the argument *enabledFlag* is true, the menu item is enabled. If false, the menu
item is disabled.

You can determine an item’s status by calling **isEnabled( )**. This method is shown here:

    boolean isEnabled( )

**isEnabled( )** returns true if the menu item on which it is called is enabled.
Otherwise, it returns false.

You can change the name of a menu item by calling **setLabel( )**. You can retrieve the
current name by using **getLabel( )**. These methods are as follows:

    void setLabel(String newName)
    String getLabel( )

Here, *newName* becomes the new name of the invoking menu item. **getLabel( )**
returns the current name.

You can create a checkable menu item by using a subclass of **MenuItem** called
**CheckboxMenuItem**. It has these constructors:

    CheckboxMenuItem() throws HeadlessException
    CheckboxMenuItem(String itemName) throws HeadlessException
    CheckboxMenuItem(String itemName, boolean on) throws HeadlessException

Here, *itemName* is the name shown in the menu. Checkable items operate as
toggles. Each time one is selected, its state changes. In the first two forms, the
checkable entry is unchecked. In the third form, if *on* is true, the checkable entry
is initially checked. Otherwise, it is cleared.

You can obtain the status of a checkable item by calling **getState( )**. You can set it to a
known state by using **setState( )**. These methods are shown here:

    boolean getState( )
    void setState(boolean checked)
If the item is checked, `getState()` returns `true`. Otherwise, it returns `false`. To check an item, pass `true` to `setState()`. To clear an item, pass `false`.

Once you have created a menu item, you must add the item to a `Menu` object by using `add()`, which has the following general form:

```java
MenuItem add(MenuItem item)
```

Here, `item` is the item being added. Items are added to a menu in the order in which the calls to `add()` take place. The `item` is returned.

Once you have added all items to a `Menu` object, you can add that object to the menu bar by using this version of `add()` defined by `MenuBar`:

```java
Menu add(Menu menu)
```

Here, `menu` is the menu being added. The `menu` is returned.

Menus generate events only when an item of type `MenuItem` or `CheckboxMenuItem` is selected. They do not generate events when a menu bar is accessed to display a drop-down menu, for example. Each time a menu item is selected, an `ActionEvent` object is generated. By default, the action command string is the name of the menu item. However, you can specify a different action command string by calling `setActionCommand()` on the menu item. Each time a check box menu item is checked or unchecked, an `ItemEvent` object is generated. Thus, you must implement the `ActionListener` and/or `ItemListener` interfaces in order to handle these menu events.

The `getItem()` method of `ItemEvent` returns a reference to the item that generated this event. The general form of this method is shown here:

```java
Object getItem()
```

Following is an example that adds a series of nested menus to a pop-up window. The item selected is displayed in the window. The state of the two check box menu items is also displayed.
// Illustrate menus.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;
/*/  
<applet code="MenuDemo" width=250 height=250>
  </applet>
*/

// Create a subclass of Frame.
class MenuFrame extends Frame {
  String msg = "";
  CheckboxMenuItem debug, test;

  MenuFrame(String title) {
    super(title);

    // create menu bar and add it to frame
    MenuBar mbar = new MenuBar();
    setMenuBar(mbar);

    // create the menu items
    Menu file = new Menu("File");
    Menu file1, file2, file3, file4, file5;
    file.add(file1 = new MenuItem("New..."));
    file.add(file2 = new MenuItem("Open..."));
    file.add(file3 = new MenuItem("Close"));
    file.add(file4 = new MenuItem("-"));
    file.add(file5 = new MenuItem("Quit..."));
    mbar.add(file);

    Menu edit = new Menu("Edit");
    Menu edit1, edit2, edit3, edit4;
    edit.add(edit1 = new MenuItem("Cut"));
    edit.add(edit2 = new MenuItem("Copy"));
    edit.add(edit3 = new MenuItem("Paste"));
    edit.add(edit4 = new MenuItem("Undo"));
    mbar.add(edit);
```java
edit.add(item8 = new Menuitem("Paste"));
edit.add(item9 = new Menuitem("-"));

Menu sub = new Menu("Special");
Menuitem item10, item11, item12;
sub.add(item10 = new Menuitem("First"));
sub.add(item11 = new Menuitem("Second"));
sub.add(item12 = new Menuitem("Third"));
edit.add(sub);

// these are checkable menu items
debug = new CheckboxMenuItem("Debug");
edit.add(debug);
test = new CheckboxMenuItem("Testing");
edit.add(test);

mbar.add(edit);

// create an object to handle action and item events
MyMenuHandler handler = new MyMenuHandler(this);
// register it to receive those events
item1.addActionListener(handler);
item2.addActionListener(handler);
item3.addActionListener(handler);
item4.addActionListener(handler);
item5.addActionListener(handler);
item6.addActionListener(handler);
item7.addActionListener(handler);
item8.addActionListener(handler);
item9.addActionListener(handler);
item0.addActionListener(handler);
item11.addActionListener(handler);
item12.addActionListener(handler);
debug.addActionListener(handler);
test.addActionListener(handler);

// create an object to handle window events
MyWindowAdapter adapter = new MyWindowAdapter(this);
// register it to receive those events
addWindowListener(adapter);

public void paint(Graphics g) {
    g.drawString(msg, 10, 200);
    if(debug.getState())
        g.drawString("Debug is on.", 10, 220);
    else
        g.drawString("Debug is off.", 10, 220);
    if(test.getState())
        g.drawString("Testing is on.", 10, 240);
    else
```
g.drawString("Testing is off.", 10, 240);
}

class MyWindowAdapter extends WindowAdapter {
    MenuFrame menuFrame;

    public MyWindowAdapter(MenuFrame menuFrame) {
        this.menuFrame = menuFrame;
    }

    public void windowClosing(WindowEvent ev) {
        menuFrame.setVisible(false);
    }
}

class MyMenuHandler implements ActionListener, ItemListener {
    MenuFrame menuFrame;

    public MyMenuHandler(MenuFrame menuFrame) {
        this.menuFrame = menuFrame;
    }

    // Handle action events.
    public void actionPerformed(ActionEvent ae) {
        String msg = "You selected ";
        String arg = ae.getActionCommand();
        if (arg.equals("New..."))
            msg += "New."
        else if (arg.equals("Open..."))
            msg += "Open."
        else if (arg.equals("Close"))
            msg += "Close."
        else if (arg.equals("Quit..."))
            msg += "Quit."
        else if (arg.equals("Edit"))
            msg += "Edit."
        else if (arg.equals("Cut"))
            msg += "Cut."
        else if (arg.equals("Copy"))
            msg += "Copy."
        else if (arg.equals("Paste"))
            msg += "Paste."
        else if (arg.equals("First"))
            msg += "First."
        else if (arg.equals("Second"))
            msg += "Second."
        else if (arg.equals("Third"))
            msg += "Third."
        else if (arg.equals("Debug"))
            msg += "Debug."
        else if (arg.equals("Testing"))
            msg += "Testing.");
    }
}
Sample output from the **MenuDemo** applet is shown in Figure 26-8.
There is one other menu-related class that you might find interesting: `PopupMenu`. It works just like `Menu`, but produces a menu that can be displayed at a specific location. `PopupMenu` provides a flexible, useful alternative for some types of menuing situations.

**Dialog Boxes**

Often, you will want to use a *dialog box* to hold a set of related controls. Dialog boxes are primarily used to obtain user input and are often child windows of a top-level window. Dialog boxes don’t have menu bars, but in other respects, they function like frame windows. (You can add controls to them, for example, in the same way that you add controls to a frame window.) Dialog boxes may be modal or modeless. When a *modal* dialog box is active, all input is directed to it until it is closed. This means that you cannot access other parts of your program until you have closed the dialog box. When a *modeless* dialog box is active, input focus can be directed to another window in your program. Thus, other parts of your program remain active and accessible. In the AWT, dialog boxes are of type `Dialog`. Two commonly used constructors are shown here:

```
Dialog(Frame parentWindow, boolean mode)
Dialog(Frame parentWindow, String title, boolean mode)
```

Here, `parentWindow` is the owner of the dialog box. If `mode` is `true`, the dialog box is modal. Otherwise, it is modeless. The title of the dialog box can be passed in `title`. Generally, you will subclass `Dialog`, adding the functionality required by your application.

Following is a modified version of the preceding menu program that displays a modeless dialog box when the New option is chosen. Notice that when the dialog box is closed, `dispose()` is called. This method is defined by `Window`, and it frees all system resources associated with the dialog box window.
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

/*
<applet code="DialogDemo" width=250 height=250>
</applet>
*/

// Demonstrate Dialog box.

// Create a subclass of Dialog.

class SampleDialog extends Dialog implements ActionListener {
    SampleDialog(Frame parent, String title) {
        super(parent, title, false);
        setLayout(new FlowLayout());
        setSize(300, 200);

        add(new Label("Press this button:");
    Button b;
    add/b = new Button("Cancel");
    b.addActionListener(this);
    
}
public void actionPerformed(ActionEvent ae) {
    dispose();
}

public void paint(Graphics g) {
    g.drawString("This is in the dialog box", 10, 70);
}

// Create a subclass of Frame.
class MenuFrame extends Frame {
    String msg = " ";
    CheckboxMenuItem debug, test;

    MenuFrame(String title) {
        super(title);

        // create menu bar and add it to frame
        MenuBar mbar = new MenuBar();
        setMenuBar(mbar);

        // create the menu items
        Menu file = new Menu("File");
        MenuItem item1, item2, item3, item4;
        file.add(item1 = new MenuItem("New...")));
        file.add(item2 = new MenuItem("Open...")));
        file.add(item3 = new MenuItem("Close");
        file.add(new MenuItem("-"));
        file.add(item4 = new MenuItem("Quit..."));
        mbar.add(file);

        Menu edit = new Menu("Edit");
        MenuItem item5, item6, item7;
        edit.add(item5 = new MenuItem("Cut"));
        edit.add(item6 = new MenuItem("Copy"));
        edit.add(item7 = new MenuItem("Paste"));
        edit.add(new MenuItem("-"));

        Menu sub = new Menu("Special", true);
        MenuItem item8, item9, item10;
        sub.add(item8 = new MenuItem("First"));
        sub.add(item9 = new MenuItem("Second"));
        sub.add(item10 = new MenuItem("Third"));
        edit.add(sub);

        // these are checkable menu items
        debug = new CheckboxMenuItem("Debug");
        edit.add(debug);
        test = new CheckboxMenuItem("Testing");
        edit.add(test);

        mbar.add(edit);
// create an object to handle action and item events
MyMenuHandler handler = new MyMenuHandler(this);

// register it to receive those events
item1.addActionListener(handler);
item2.addActionListener(handler);
item3.addActionListener(handler);
item4.addActionListener(handler);
item5.addActionListener(handler);
item6.addActionListener(handler);
item7.addActionListener(handler);
item8.addActionListener(handler);
item9.addActionListener(handler);
item10.addActionListener(handler);
debug.addItemListener(handler);
test.addItemListener(handler);

// create an object to handle window events
MyWindowAdapter adapter = new MyWindowAdapter(this);

// register it to receive those events
addWindowListener(adapter);
}

public void paint(Graphics g) {
    g.drawString(msg, 10, 200);
    if (debug.getState())
        g.drawString("Debug is on.", 10, 220);
    else
        g.drawString("Debug is off.", 10, 220);

    if (test.getState())
        g.drawString("Testing is on.", 10, 240);
    else
        g.drawString("Testing is off.", 10, 240);
}

class MyWindowAdapter extends WindowAdapter {
    MenuFrame menuFrame;

    public MyWindowAdapter(MenuFrame menuFrame) {
        this.menuFrame = menuFrame;
    }

    public void windowClosing(WindowEvent we) {
        menuFrame.dispose();
    }
}

class MyMenuHandler implements ActionListener, ItemListener {
    MenuFrame menuFrame;
public MyMenuHandler(MenuFrame menuFrame) {
    this.menuFrame = menuFrame;
}

// Handle action events.
public void actionPerformed(ActionEvent ae) {
    String msg = "You selected ";
    String arg = ae.getActionCommand();
    // Activate a dialog box when New is selected.
    if(arg.equals("New...")) {
        msg += "New."
        SampleDialog d = new
        SampleDialog(menuFrame, "New Dialog Box")
        d.setVisible(true);
    }
    // Try defining other dialog boxes for these options
    else if(arg.equals("Open..."))
        msg += "Open."
    else if(arg.equals("Close"))
        msg += "Close."
    else if(arg.equals("Quit..."))
        msg += "Quit."
    else if(arg.equals("Edit"))
        msg += "Edit."
    else if(arg.equals("Cut"))
        msg += "Cut."
    else if(arg.equals("Copy"))
        msg += "Copy."
    else if(arg.equals("Paste"))
        msg += "Paste."
    else if(arg.equals("First"))
        msg += "First."
    else if(arg.equals("Second"))
        msg += "Second."
    else if(arg.equals("Third"))
        msg += "Third."
    else if(arg.equals("Debug"))
        msg += "Debug."
    else if(arg.equals("Testing"))
        msg += "Testing."
    menuFrame.msg = msg;
    menuFrame.repaint();
}

public void itemStateChanged(ItemEvent ie) {
    menuFrame.repaint();
}

// Create frame window.
public static class DialogDemo extends Applet {
    Frame f;
public void init() {
    f = new MenuFrame("Menu Demo");
    int width = Integer.parseInt(getParameter("width"));
    int height = Integer.parseInt(getParameter("height"));

    setSize(width, height);

    f.setSize(width, height);
    f.setVisible(true);
}

public void start() {
    f.setVisible(true);
}

public void stop() {
    f.setVisible(false);
}

Here is sample output from the DialogDemo applet:

TIP On your own, try defining dialog boxes for the other options
**FileDialog**

Java provides a built-in dialog box that lets the user specify a file. To create a file dialog box, instantiate an object of type **FileDialog**. This causes a file dialog box to be displayed. Usually, this is the standard file dialog box provided by the operating system. Here are three **FileDialog** constructors:

FileDialog(Frame *parent*)
FileDialog(Frame *parent*, String *boxName*)
FileDialog(Frame *parent*, String *boxName*, int *how*)

Here, *parent* is the owner of the dialog box. The *boxName* parameter specifies the name displayed in the box’s title bar. If *boxName* is omitted, the title of the dialog box is empty. If *how* is **FileDialog.LOAD**, then the box is selecting a file for reading. If *how* is **FileDialog.SAVE**, the box is selecting a file for writing. If *how* is omitted, the box is selecting a file for reading.

**FileDialog** provides methods that allow you to determine the name of the file and its path as selected by the user. Here are two examples:

String getDirectory( )
String getFile( )

These methods return the directory and the filename, respectively.

The following program activates the standard file dialog box:
/* Demonstrate File Dialog box.

   This is an application, not an applet.
*/
import java.awt.*;
import java.awt.event.*;

// Create a subclass of Frame.
class SampleFrame extends Frame {
   SampleFrame(String title) {
      super(title);

      // remove the window when closed
      addWindowListener(new WindowAdapter() {
         public void windowClosing(WindowEvent we) {
            System.exit(0);
         }
      });
   }
}

// Demonstrate FileDialog.
class FileDialogDemo {
   public static void main(String args[]) {
      // create a frame that owns the dialog
      Frame f = new SampleFrame("File Dialog Demo");
      f.setVisible(true);
      f.setSize(100, 100);

      FileDialog fd = new FileDialog(f, "File Dialog");

      fd.setVisible(true);
   }
}

The output generated by this program is shown here. (The precise configuration of the dialog box may vary.)
One last point: Beginning with JDK 7, you can use `FileDialog` to select a list of files. This functionality is supported by the `setMultipleMode()`, `isMultipleMode()`, and `getFiles()` methods.

A Word About Overriding `paint()`

Before concluding our examination of AWT controls, a short word about overriding `paint()` is in order. Although not relevant to the simple AWT examples shown in this book, when overriding `paint()`, there are times when it is necessary to call the superclass implementation of `paint()`. Therefore, for some programs, you will need to use this `paint()` skeleton:

```java
public void paint(Graphics g) {
   // code to repaint this window
   // Call superclass paint()
   super.paint(g);
}
```

In Java, there are two general types of components: heavyweight and lightweight. A heavyweight component has its own native window, which is called its peer. A lightweight component is implemented completely in Java code and uses the window provided by an ancestor. The AWT controls described and used in this chapter are all heavyweight. However, if a container holds any lightweight components (that is, has lightweight child
components), your override of `paint()` for that container must call `super.paint()`. By calling `super.paint()`, you ensure that any lightweight child components, such as lightweight controls, get properly painted. If you are unsure of a child component’s type, you can call `isLightweight()`, defined by `Component`, to find out. It returns `true` if the component is lightweight, and `false` otherwise.
CHAPTER 27: Images

This chapter examines the `Image` class and the `java.awt.image` package. Together, they provide support for imaging (the display and manipulation of graphical images). An `image` is simply a rectangular graphical object. Images are a key component of web design. In fact, the inclusion of the `<img>` tag in the Mosaic browser at NCSA (National Center for Supercomputer Applications) is what caused the Web to begin to grow explosively in 1993. This tag was used to include an image inline with the flow of hypertext. Java expands upon this basic concept, allowing images to be managed under program control. Because of its importance, Java provides extensive support for imaging.

Images are objects of the `Image` class, which is part of the `java.awt` package. Images are manipulated using the classes found in the `java.awt.image` package. There are a large number of imaging classes and interfaces defined by `java.awt.image`, and it is not possible to examine them all. Instead, we will focus on those that form the foundation of imaging. Here are the `java.awt.image` classes discussed in this chapter:

<table>
<thead>
<tr>
<th>CropImageFilter</th>
<th>MemoryImageSource</th>
</tr>
</thead>
<tbody>
<tr>
<td>FilteredImageSource</td>
<td>PixelGrabber</td>
</tr>
<tr>
<td>ImageFilter</td>
<td>RGBImageFilter</td>
</tr>
</tbody>
</table>

These are the interfaces that we will use:

| ImageConsumer | ImageObserver | ImageProducer |

Also examined is the `MediaTracker` class, which is part of `java.awt`.

**File Formats**

Originally, web images could only be in GIF format. The GIF image format was created by CompuServe in 1987 to make it possible for images to be viewed while online, so it was well suited to the Internet. GIF images can have only up to 256 colors each. This limitation
caused the major browser vendors to add support for JPEG images in 1995. The JPEG format was created by a group of photographic experts to store full-color-spectrum, continuous-tone images. These images, when properly created, can be of much higher fidelity as well as more highly compressed than a GIF encoding of the same source image. Another file format is PNG. It too is an alternative to GIF. In almost all cases, you will never care or notice which format is being used in your programs. The Java image classes abstract the differences behind a clean interface.

**Image Fundamentals: Creating, Loading, and Displaying**

There are three common operations that occur when you work with images: creating an image, loading an image, and displaying an image. In Java, the `Image` class is used to refer to images in memory and to images that must be loaded from external sources. Thus, Java provides ways for you to create a new image object and ways to load one. It also provides a means by which an image can be displayed. Let’s look at each.

**Creating an Image Object**

You might expect that you create a memory image using something like the following:

```
Image test = new Image(200, 100); // Error -- won't work
```

Not so. Because images must eventually be painted on a window to be seen, the `Image` class doesn’t have enough information about its environment to create the proper data format for the screen. Therefore, the `Component` class in `java.awt` has a factory method called `createImage()` that is used to create `Image` objects. (Remember that all of the AWT components are subclasses of `Component`, so all support this method.)

The `createImage()` method has the following two forms:

```
Image createImage(ImageProducer imgProd)
Image createImage(int width, int height)
```

The first form returns an image produced by `imgProd`, which is an object of a class that implements the `ImageProducer` interface. (We will look at image producers later.) The second form returns a blank (that is, empty) image that has the specified width and height. Here is an example:

```
Canvas c = new Canvas();
Image test = c.createImage(200, 100);
```

This creates an instance of `Canvas` and then calls the `createImage()` method to actually make an `Image` object. At this point, the image is blank. Later, you will see how to write data to it.

**Loading an Image**

The other way to obtain an image is to load one. One way to do this is to use the `getImage()`
method defined by the Applet class. It has the following forms:

    Image getImage(URL url)
    Image getImage(URL url, String imageName)

The first version returns an Image object that encapsulates the image found at the location specified by url. The second version returns an Image object that encapsulates the image found at the location specified by url and having the name specified by imageName.

Displaying an Image
Once you have an image, you can display it by using drawImage(), which is a member of the Graphics class. It has several forms. The one we will be using is shown here:

    boolean drawImage(Image imgObj, int left, int top, ImageObserver imgOb)

This displays the image passed in imgObj with its upper-left corner specified by left and top. imgOb is a reference to a class that implements the ImageObserver interface. This interface is implemented by all AWT (and Swing) components. An image observer is an object that can monitor an image while it loads.

ImageObserver is described in the next section.

With getImage() and drawImage(), it is actually quite easy to load and display an image. Here is a sample applet that loads and displays a single image. The file Lilies.jpg is loaded, but you can substitute any GIF, JPG, or PNG file you like (just make sure it is available in the same directory with the HTML file that contains the applet).

```java
/*
 * <applet code="SimpleImageLoad" width=400 height=345>
 * <param name="img" value="Lilies.jpg">
 * </applet>
 */
import java.awt.*;
import java.applet.*;

public class SimpleImageLoad extends Applet {
    Image img;

    public void init() {
        img = getImage(getDocumentBase(), getParameter("img"));
    }

    public void paint(Graphics g) {
        g.drawImage(img, 0, 0, this);
    }
}
```
In the `init()` method, the `img` variable is assigned to the image returned by `getImage()` method. The `getImage()` method uses the string returned by `getParameter("img")` as the filename for the image. This image is loaded from a URL that is relative to the result of `getDocumentBase()`, which is the URL of the HTML page this applet tag was in. The filename returned by `getParameter("img")` comes from the applet tag `<param name="img" value="Lilies.jpg">`. This is the equivalent, if a little slower, of using the HTML tag `<img src="Lilies.jpg" width=400 height=345>`. Figure 27-1 shows what it looks like when you run the program.

[Image: applet viewer window showing a lily flower]

Figure 27-1   Sample output from SimpleImageLoad

When this applet runs, it starts loading `img` in the `init()` method. Onscreen you can see the image as it loads from the network, because Applet’s implementation of the `ImageObserver` interface calls `paint()` every time more image data arrives. Seeing the image load is somewhat informative, but it might be better if you use the time it takes to load the image to do other things in parallel. That way, the fully formed image can simply appear on the screen in an instant, once it is fully loaded. You can use `ImageObserver`, described next, to monitor loading an image while you paint the screen with other information.
**ImageObserver** is an interface used to receive notification as an image is being generated, and it defines only one method: `imageUpdate()`. Using an image observer allows you to perform other actions, such as show a progress indicator or an attract screen, as you are informed of the progress of the download. This kind of notification is very useful when an image is being loaded over a slow network.

The `imageUpdate()` method has this general form:

```java
boolean imageUpdate(Image imgObj, int flags, int left, int top,
                   int width, int height)
```

Here, `imgObj` is the image being loaded, and `flags` is an integer that communicates the status of the update report. The four integers `left`, `top`, `width`, and `height` represent a rectangle that contains different values depending on the values passed in `flags`.

`imageUpdate()` should return `false` if it has completed loading, and `true` if there is more image to process.

The `flags` parameter contains one or more bit flags defined as static variables inside the `ImageObserver` interface. These flags and the information they provide are listed in Table 27-1.

<table>
<thead>
<tr>
<th>Flag</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>WIDTH</td>
<td>The <code>width</code> parameter is valid and contains the width of the image.</td>
</tr>
<tr>
<td>HEIGHT</td>
<td>The <code>height</code> parameter is valid and contains the height of the image.</td>
</tr>
<tr>
<td>PROPERTIES</td>
<td>The properties associated with the image can now be obtained using <code>imgObj.getProperty()</code>.</td>
</tr>
<tr>
<td>SOMEBITS</td>
<td>More pixels needed to draw the image have been received. The parameters <code>left</code>, <code>top</code>, <code>width</code>, and <code>height</code> define the rectangle containing the new pixels.</td>
</tr>
<tr>
<td>FRAMEBITS</td>
<td>A complete frame that is part of a multiframe image, which was previously drawn, has been received. This frame can be displayed. The <code>left</code>, <code>top</code>, <code>width</code>, and <code>height</code> parameters are not used.</td>
</tr>
<tr>
<td>ALLBITS</td>
<td>The image is now complete. The <code>left</code>, <code>top</code>, <code>width</code>, and <code>height</code> parameters are not used.</td>
</tr>
<tr>
<td>ERROR</td>
<td>An error has occurred to an image that was being tracked asynchronously. The image is incomplete and cannot be displayed. No further image information will be received. The <code>ABORT</code> flag will also be set to indicate that the image production was aborted.</td>
</tr>
<tr>
<td>ABORT</td>
<td>An image that was being tracked asynchronously was aborted before it was complete. However, if an error has not occurred, accessing any part of the image's data will restart the production of the image.</td>
</tr>
</tbody>
</table>

Table 27-1  Bit Flags of the `imageUpdate()` flags Parameter

The **Applet** class has an implementation of the `imageUpdate()` method for the `ImageObserver` interface that is used to repaint images as they are loaded. You can override this method in your class to change that behavior.

Here is a simple example of an `imageUpdate()` method:
Double Buffering

Not only are images useful for storing pictures, as we’ve just shown, but you can also use them as offscreen drawing surfaces. This allows you to render any image, including text and graphics, to an offscreen buffer that you can display at a later time. The advantage to doing this is that the image is seen only when it is complete. Drawing a complicated image could take several milliseconds or more, which can be seen by the user as flashing or flickering. This flashing is distracting and causes the user to perceive your rendering as slower than it actually is. Use of an offscreen image to reduce flicker is called double buffering, because the screen is considered a buffer for pixels, and the offscreen image is the second buffer, where you can prepare pixels for display.

Earlier in this chapter, you saw how to create a blank `Image` object. Now you will see how to draw on that image rather than the screen. As you recall from earlier chapters, you need a `Graphics` object in order to use any of Java’s rendering methods. Conveniently, the `Graphics` object that you can use to draw on an `Image` is available via the `getGraphics()` method. Here is a code fragment that creates a new image, obtains its graphics context, and fills the entire image with red pixels:

```java
Canvas c = new Canvas();
Image test = c.createImage(200, 100);
Graphics gc = test.getGraphics();
gc.setColor(Color.red);
gc.fillRect(0, 0, 200, 100);
```

Once you have constructed and filled an offscreen image, it will still not be visible. To actually display the image, call `drawImage()`. Here is an example that draws a time-consuming image to demonstrate the difference that double buffering can make in perceived drawing time:

```java
public boolean imageUpdate(Image img, int flags, int x, int y, int w, int h) {
    if ((flags & ALLBITS) == 0) {
        System.out.println("Still processing the image.");
        return true;
    } else {
        System.out.println("Done processing the image.");
        return false;
    }
}
```
import java.awt.*;
import java.awt.event.*;
import java.applet.*;

public class DoubleBuffer extends Applet {
    int gap = 3;
    int mx, my;
    boolean flicker = true;
    Image buffer = null;
    int w, h;

    public void init() {
        Dimension d = getSize();
        w = d.width;
        h = d.height;
        buffer = createImage(w, h);
        addMouseMotionListener(new MouseMotionAdapter() {
            public void mouseDragged(MouseEvent me) {
                mx = me.getX();
                my = me.getY();
                flicker = false;
                repaint();
            }
            public void mouseMoved(MouseEvent me) {
                mx = me.getX();
                my = me.getY();
                flicker = true;
            }
        });
    }
}
This simple applet has a complicated `paint()` method. It fills the background with blue and then draws a red moiré pattern on top of that. It paints some black text on top of that and then paints a yellow circle centered at the coordinates `mx, my`. The `mouseMoved()` and `mouseDragged()` methods are overridden to track the mouse position. These methods are identical, except for the setting of the `flicker` Boolean variable. `mouseMoved()` sets `flicker` to `true`, and `mouseDragged()` sets it to `false`. This has the effect of calling `repaint()` with `flicker` set to `true` when the mouse is moved (but no button is pressed) and set to `false` when the mouse is dragged with any button pressed.

When `paint()` gets called with `flicker` set to `true`, we see each drawing operation as it is executed on the screen. In the case where a mouse button is pressed and `paint()` is called with `flicker` set to `false`, we see quite a different picture. The `paint()` method swaps the `Graphics` reference `g` with the graphics context that refers to the offscreen canvas, `buffer`,
which we created in `init()`. Then all of the drawing operations are invisible. At the end of `paint()`, we simply call `drawImage()` to show the results of these drawing methods all at once.

Notice that it is okay to pass in a `null` as the fourth parameter to `drawImage()`. This is the parameter used to pass an `ImageObserver` object that receives notification of image events. Since this is an image that is not being produced from a network stream, we have no need for notification. The left snapshot in Figure 27-2 is what the applet looks like with the mouse button not pressed. As you can see, the image was in the middle of repainting when this snapshot was taken. The right snapshot shows how, when a mouse button is pressed, the image is always complete and clean due to double buffering.

![Figure 27-2](image.png)

Figure 27-2  Output from `DoubleBuffer` without (left) and with (right) double buffering

**MediaTracker**

A `MediaTracker` is an object that will check the status of an arbitrary number of images in parallel. To use `MediaTracker`, you create a new instance and use its `addImage()` method to track the loading status of an image. `addImage()` has the following general forms:

- `void addImage(Image imgObj, int imgID)`
- `void addImage(Image imgObj, int imgID, int width, int height)`

Here, `imgObj` is the image being tracked. Its identification number is passed in `imgID`. ID numbers do not need to be unique. You can use the same number with several images as a means of identifying them as part of a group. Furthermore, images with lower IDs are given priority over those with higher IDs when loading. In the second form, `width` and `height` specify the dimensions of the object when it is displayed.

Once you’ve registered an image, you can check whether it’s loaded, or you can wait for it to
completely load. To check the status of an image, call `checkID( )`. The version used in this chapter is shown here:

```java
boolean checkID(int imgID)
```

Here, `imgID` specifies the ID of the image you want to check. The method returns `true` if all images that have the specified ID have been loaded (or if an error or user-abort has terminated loading). Otherwise, it returns `false`. You can use the `checkAll( )` method to see if all images being tracked have been loaded.

You should use `MediaTracker` when loading a group of images. If all of the images that you’re interested in aren’t downloaded, you can display something else to entertain the user until they all arrive.

---

**CAUTION** If you use `MediaTracker` once you’ve called `addImage( )` on an image, a reference in `MediaTracker` will prevent the system from garbage collecting it. If you want the system to be able to garbage collect images that were being tracked, make sure it can collect the `MediaTracker` instance as well.

Here’s an example that loads a three-image slide show and displays a nice bar chart of the loading progress:
/*
 * <applet code="TrackedImageLoad" width=400 height=345>
 * <param name="img" value="Lilies+SunFlower+ConeFlowers">
 * </applet>
 */
import java.util.*;
import java.applet.*;
import java.awt.*;

public class TrackedImageLoad extends Applet implements Runnable {
    MediaTracker tracker;
    int tracked;
    int frame_rate = 5;
    int current_img = 0;
    Thread timer;
    static final int MAXIMAGES = 10;
    Image img[] = new Image[MAXIMAGES];
    String name[] = new String[MAXIMAGES];
    volatile boolean stopFlag;

    public void init() {
        tracker = new MediaTracker(this);
        StringTokenizer st = new StringTokenizer(getParameter("img"), "+");

        while (st.hasMoreTokens() && tracked <= MAXIMAGES) {
            name[tracked] = st.nextToken();
            img[tracked] = getImage(getDocumentBase(), name[tracked] + ".jpg");
            tracker.addImage(img[tracked], tracked);
            tracked++;
        }
    }

    public void paint(Graphics g) {
        String loaded = ""
        int donecount = 0;

        for(int i=0; i<tracked; i++) {
            if (tracker.checkID(i, true)) {

            }
        }
    }
}
This example creates a new MediaTracker in the init() method and then adds each of the named images as a tracked image with addImage(). In the paint() method, it calls checkID() on each of the images that we’re tracking. If all of the images are loaded, they are displayed. If not, a simple bar chart of the number of images loaded is shown, with the names of the fully loaded images displayed underneath the bar.
ImageProducer

ImageProducer is an interface for objects that want to produce data for images. An object that implements the ImageProducer interface will supply integer or byte arrays that represent image data and produce Image objects. As you saw earlier, one form of the createImage() method takes an ImageProducer object as its argument. There are two image producers contained in java.awt.image: MemoryImageSource and FilteredImageSource. Here, we will examine MemoryImageSource and create a new Image object from data generated in an applet.

MemoryImageSource

MemoryImageSource is a class that creates a new Image from an array of data. It defines several constructors. Here is the one we will be using:

```
MemoryImageSource(int width, int height, int[] pixel, int offset, int scanLineWidth)
```

The MemoryImageSource object is constructed out of the array of integers specified by pixel, in the default RGB color model to produce data for an Image object. In the default color model, a pixel is an integer with Alpha, Red, Green, and Blue (0xAARRGGBB). The Alpha value represents a degree of transparency for the pixel. Fully transparent is 0 and fully opaque is 255. The width and height of the resulting image are passed in width and height. The starting point in the pixel array to begin reading data is passed in offset. The width of a scan line (which is often the same as the width of the image) is passed in scanLineWidth.

The following short example generates a MemoryImageSource object using a variation on a simple algorithm (a bitwise-exclusive-OR of the x and y address of each pixel) from the book Beyond Photography, The Digital Darkroom by Gerard J. Holzmann (Prentice Hall, 1988).
The data for the new `MemoryImageSource` is created in the `init()` method. An array of integers is created to hold the pixel values; the data is generated in the nested `for` loops where the `r`, `g`, and `b` values get shifted into a pixel in the `pixels` array. Finally, `createImage()` is called with a new instance of a `MemoryImageSource` created from the raw pixel data as its parameter. Figure 27-3 shows the image when we run the applet. (It looks much nicer in color.)
ImageConsumer

ImageConsumer is an interface for objects that want to take pixel data from images and supply it as another kind of data. This, obviously, is the opposite of ImageProducer, described earlier. An object that implements the ImageConsumer interface is going to create int or byte arrays that represent pixels from an Image object. We will examine the PixelGrabber class, which is a simple implementation of the ImageConsumer interface.

PixelGrabber

The PixelGrabber class is defined within java.lang.image. It is the inverse of the MemoryImageSource class. Rather than constructing an image from an array of pixel values, it takes an existing image and grabs the pixel array from it. To use PixelGrabber, you first create an array of ints big enough to hold the pixel data, and then you create a PixelGrabber instance passing in the rectangle that you want to grab. Finally, you call grabPixels() on that instance.

The PixelGrabber constructor that is used in this chapter is shown here:

```
PixelGrabber(Image imgObj, int left, int top, int width, int height, int pixel | []
int offset, int scanLineWidth)
```

Here, imgObj is the object whose pixels are being grabbed. The values of left and top specify the upper-left corner of the rectangle, and width and height specify the dimensions of the rectangle from which the pixels will be obtained. The pixels will be stored in pixel beginning at offset. The width of a scan line (which is often the same as the width of the image) is passed in scanLineWidth.

grabPixels( ) is defined like this:
Both methods return **true** if successful and **false** otherwise. In the second form, **milliseconds** specifies how long the method will wait for the pixels. Both throw **InterruptedException** if execution is interrupted by another thread.

Here is an example that grabs the pixels from an image and then creates a histogram of pixel brightness. The **histogram** is simply a count of pixels that are a certain brightness for all brightness settings between 0 and 255. After the applet paints the image, it draws the histogram over the top.

```java
/*
 * <applet code=HistGrab width=400 height=345>
 * <param name=img value=Lilies.jpg>
 * </applet> */
import java.applet.*;
import java.awt.*;
import java.awt.image.*;
```
Figure 27-4 shows an example image and its histogram.

**ImageFilter**

Given the `ImageProducer` and `ImageConsumer` interface pair—and their concrete classes `MemoryImageSource` and `PixelGrabber”—you can create an arbitrary set of translation filters that takes a source of pixels, modifies them, and passes them on to an
arbitrary consumer. This mechanism is analogous to the way concrete classes are created from the abstract I/O classes InputStream, OutputStream, Reader, and Writer (described in Chapter 20). This stream model for images is completed by the introduction of the ImageFilter class. Some subclasses of ImageFilter in the java.awt.image package are AreaAveragingScaleFilter, CropImageFilter, ReplicateScaleFilter, and RGBImageFilter. There is also an implementation of ImageProducer called FilteredImageSource, which takes an arbitrary ImageFilter and wraps it around an ImageProducer to filter the pixels it produces. An instance of FilteredImageSource can be used as an ImageProducer in calls to createImage(), in much the same way that BufferedInputStreams can be passed off as InputStreams.

In this chapter, we examine two filters: CropImageFilter and RGBImageFilter.

CropImageFilter
CropImageFilter filters an image source to extract a rectangular region. One situation in which this filter is valuable is where you want to use several small images from a single, larger source image. Loading twenty 2K images takes much longer than loading a single 40K image that has many frames of an animation tiled into it. If every subimage is the same size, then you can easily extract these images by using CropImageFilter to disassemble the...
block once your program starts. Here is an example that creates 16 images taken from a single image. The tiles are then scrambled by swapping a random pair from the 16 images 32 times.

```java
/*
* <applet code=TileImage width=400 height=345>
* <param name=img value=Lilies.jpg>
* </applet>
*/
import java.applet.*;
import java.awt.*;
import java.awt.image.*;

public class TileImage extends Applet {
    Image img;
    Image cell[] = new Image[4*4];
    int iw, ih;
    int tw, th;

    public void init() {
        try {
            img = getImage(getDocumentBase(), getParameter("img"));
            MediaTracker t = new MediaTracker(this);
            t.addImage(img, 0);
            t.waitForID(0);
            iw = img.getWidth(null);
            ih = img.getHeight(null);
            tw = iw / 4;
            th = ih / 4;
            CropImageFilter f;
            FilteredImageSource fis;
            t = new MediaTracker(this);
            for (int y=0; y<4; y++) {
                for (int x=0; x<4; x++) {
                    f = new CropImageFilter(tw*x, th*y, tw, th);
                    fis = new FilteredImageSource(img.getSource(), f);
                    int i = y*4+x;
                    cell[i] = createImage(fis);
                    t.addImage(cell[i], i);
                }
            }
        }
    }
```
Figure 27-5 shows the flowers image scrambled by the **TileImage** applet.
**RGBImageFilter**
The **RGBImageFilter** is used to convert one image to another, pixel by pixel, transforming the colors along the way. This filter could be used to brighten an image, to increase its contrast, or even to convert it to grayscale.

To demonstrate **RGBImageFilter**, we have developed a somewhat complicated example that employs a dynamic plug-in strategy for image-processing filters. We’ve created an interface for generalized image filtering so that an applet can simply load these filters based on `<param>` tags without having to know about all of the **ImageFilter**s in advance. This example consists of the main applet class called **ImageFilterDemo**, the interface called **PlugInFilter**, and a utility class called **LoadedImage**, which encapsulates some of the **MediaTracker** methods we’ve been using in this chapter. Also included are three filters—**Grayscale**, **Invert**, and **Contrast**—which simply manipulate the color space of the source image using **RGBImageFilter**s, and two more classes—**Blur** and **Sharpen**—which do more complicated “convolution” filters that change pixel data based on the pixels surrounding each pixel of source data. **Blur** and **Sharpen** are subclasses of an abstract helper class called **Convolver**. Let’s look at each part of our example.

**ImageFilterDemo.java**
The **ImageFilterDemo** class is the applet framework for our sample image filters. It employs a simple **BorderLayout**, with a **Panel** at the **South** position to hold the buttons.
that will represent each filter. A Label object occupies the North slot for informational messages about filter progress. The Center is where the image (which is encapsulated in the LoadedImage Canvas subclass, described later) is put. We parse the buttons/filters out of the filters <param> tag, separating them with +’s using a StringTokenizer.

The actionPerformed() method is interesting because it uses the label from a button as the name of a filter class that it tries to load with (PlugInFilter) Class.forName(a).newInstance(). This method is robust and takes appropriate action if the button does not correspond to a proper class that implements PlugInFilter.

```java
/*
 * <applet code=ImageFilterDemo width=400 height=345>
 * <param name=img value=Lilies.jpg>
 * <param name=filters value="Grayscale+Invert+Contrast+Blur+Sharpen">
 * </applet>
 */
import java.applet.*;
import java.awt.*;
import java.util.*;
import java.util.*;
import java.awt.event.*;
import java.awt.*;

public class ImageFilterDemo extends Applet implements ActionListener {
    Image img;
    PlugInFilter pf;
    Image fin;
    Image curImg;
    LoadedImage lim;
    Label lab;
    Button reset;
```
Figure 27-6 shows what the applet looks like when it is first loaded using the applet tag shown at the top of this source file.
PlugInFilter.java
PlugInFilter is a simple interface used to abstract image filtering. It has only one method, filter( ), which takes the applet and the source image and returns a new image that has been filtered in some way.

```java
interface PlugInFilter {
    java.awt.Image filter(java.awt.Applet a, java.awt.Image in);
}
```

LoadedImage.java
LoadedImage is a convenient subclass of Canvas, which takes an image at construction time and synchronously loads it using MediaTracker. LoadedImage then behaves properly inside of LayoutManager control, because it overrides the getPreferredSize( ) and getMinimumSize( ) methods. Also, it has a method called set( ) that can be used to set a new Image to be displayed in this Canvas. That is how the filtered image is displayed after the plug-in is finished.
Grayscale.java

The Grayscale filter is a subclass of RGBImageFilter, which means that Grayscale can use itself as the ImageFilter parameter to FilteredImageSource’s constructor. Then all it needs to do is override filterRGB() to change the incoming color values. It takes the red, green, and blue values and computes the brightness of the pixel, using the NTSC (National Television Standards Committee) color-to-brightness conversion factor. It then simply returns a gray pixel that is the same brightness as the color source.
Invert.java

The Invert filter is also quite simple. It takes apart the red, green, and blue channels and then inverts them by subtracting them from 255. These inverted values are packed back into a pixel value and returned.

```java
import java.awt.*;
import java.awt.image.*;

class Invert extends RGBImageFilter implements PlugInFilter {
    public ImageFilter(Applet a, Image in) {
        return a.createImage(new FilteredImageSource(in.getSource(), this));
    }

    public int filterRGB(int x, int y, int rgb) {
        int r = (rgb >> 16) & 0xff;
        int g = (rgb >> 8) & 0xff;
        int b = rgb & 0xff;
        int k = (int) (.56 * g + .33 * r + .11 * b);
        return (0xff000000 | r << 16 | g << 8 | b);
    }
}
```

Figure 27-7 shows the image after it has been run through the Invert filter.
Contrast.java

The Contrast filter is very similar to Grayscale, except its override of filterRGB() is slightly more complicated. The algorithm it uses for contrast enhancement takes the red, green, and blue values separately and boosts them by 1.2 times if they are already brighter than 128. If they are below 128, then they are divided by 1.2. The boosted values are properly clamped at 255 by the multclamp() method.
Figure 27-8 shows the image after **Contrast** is pressed.

**Convolver.java**
The abstract class **Convolver** handles the basics of a convolution filter by implementing the **ImageConsumer** interface to move the source pixels into an array called **imgpixels**. It also creates a second array called **newimgpixels** for the filtered data. Convolution filters sample a small rectangle of pixels around each pixel in an image, called the **convolution kernel**. This area, 3 x 3 pixels in this demo, is used to decide how to change the center pixel in the area.

![](image)

**NOTE** The reason that the filter can’t modify the **imgpixels** array in place is that the next pixel on a scan line would try to use the original value for the previous pixel, which would have just been filtered away.
The two concrete subclasses, shown in the next section, simply implement the `convolve()` method, using `imgpixels` for source data and `newimgpixels` to store the result.
import java.applet.*;
import java.awt.*;
import java.awt.image.*;

abstract class Convolver implements ImageConsumer, PlugInFilter {
    int width, height;
    int imgpixels[], newimgpixels[];
    boolean imageReady = false;

    abstract void convolve(); // filter goes here...

    public Image filter(Applet a, Image in) {
        imageReady = false;
        in.getSource().startProduction(this);
        waitForImage();
        newimgpixels = new int[width*height];

        try {
            convolve();
        } catch (Exception e) {
            System.out.println("Convolver failed: "+ e);
            e.printStackTrace();
        }
    }
}
return a.createImage(
    new MemoryImageSource(width, height, newimgpixels, 0, width));
}

synchronized void waitForImage() {
    try {
        while(!imageReady) wait();
    } catch (Exception e) {
        System.out.println("Interrupted");
    }
}

public void setProperties(java.util.Hashtable<?, ?> dummy) {}
public void setColorModel(ColorModel dummy) {}
public void setHints(int dummy) {}

public synchronized void imageComplete(int dummy) {
    imageReady = true;
    notifyAll();
}

public void setDimensions(int x, int y) {
    width = x;
    height = y;
    imgpixels = new int[x*y];
}

public void setPixels(int x1, int y1, int x, int h,
    ColorModel model, byte pixels[]), int off, int scansize) {
    int pix, x, y, x2, y2, sx, sy;
    x2 = x1+w;
    y2 = y1+h;
    sy = off;
    for(y=y1; y<y2; y++) {
        sx = sy;
        for(x=x1; x<x2; x++) {
            pix = model.getRGB(pixels[sx++]);
            if((pix & 0xff000000) == 0)
                pix = 0xff000000;
            imgpixels[y*width+x] = pix;
        }
        sy += scansize;
    }
}

public void setPixels(int x1, int y1, int x, int h,
    ColorModel model, int pixels[], int off, int scansize) {
    int pix, x, y, x2, y2, sx, sy;
    x2 = x1+w;
    y2 = y1+h;
    sy = off;
}
A built-in convolution filter called `ConvolveOp` is provided by `java.awt.image`. You may want to explore its capabilities on your own.

**Blur.java**

The `Blur` filter is a subclass of `Convolver` and simply runs through every pixel in the source image array, `imgpixels`, and computes the average of the 3 x 3 box surrounding it. The corresponding output pixel in `newimgpixels` is that average value.
public class Blur extends Convolver {
    public void convolve() {
        for (int y=1; y<height-1; y++) {
            for (int x=1; x<width-1; x++) {
                int rs = 0;
                int gs = 0;
                int bs = 0;

                for (int k=-1; k<=1; k++) {
                    for (int j=-1; j<=1; j++) {
                        int rgb = imgPixels[(y+k)*width+x+j];
                        int r = (rgb >> 16) & 0xff;
                        int g = (rgb >> 8) & 0xff;
                        int b = rgb & 0xff;
                        rs += r;
                        gs += g;
                        bs += b;
                    }
                }
                rs /= 9;
                gs /= 9;
                bs /= 9;

                newImgPixels[y*width+x] = (0xff000000 |
                    rs << 16 | gs << 8 | bs);
            }
        }
    }
}

Figure 27-9 shows the applet after **Blur**.
Figure 27-9  Using the Blur filter with ImageFilterDemo

Sharpen.java
The Sharpen filter is also a subclass of Convolver and is (more or less) the inverse of Blur. It runs through every pixel in the source image array, imgpixels, and computes the average of the 3 x 3 box surrounding it, not counting the center. The corresponding output pixel in newimgpixels has the difference between the center pixel and the surrounding average added to it. This basically says that if a pixel is 30 brighter than its surroundings, make it another 30 brighter. If, however, it is 10 darker, then make it another 10 darker. This tends to accentuate edges while leaving smooth areas unchanged.
Figure 27-10 shows the applet after **Sharpen**.
Additional Imaging Classes

In addition to the imaging classes described in this chapter, `java.awt.image` supplies several others that offer enhanced control over the imaging process and that support advanced imaging techniques. Also available is the imaging package called `javax.imageio`. This package supports plug-ins that handle various image formats. If sophisticated graphical output is of special interest to you, then you will want to explore the additional classes found in `java.awt.image` and `javax.imageio`. 
From the start, Java has provided built-in support for multithreading and synchronization. For example, new threads can be created by implementing Runnable or by extending Thread; synchronization is available by use of the synchronized keyword; and interthread communication is supported by the wait() and notify() methods that are defined by Object. In general, this built-in support for multithreading was one of Java’s most important innovations and is still one of its major strengths. However, as conceptually pure as Java’s original support for multithreading is, it is not ideal for all applications—especially those that make intensive use of multiple threads. For example, the original multithreading support does not provide several high-level features, such as semaphores, thread pools, and execution managers, that facilitate the creation of intensively concurrent programs.

It is important to explain at the outset that many Java programs make use of multithreading and are, therefore, “concurrent.” For example, many applets and servlets use multithreading. However, as it is used in this chapter, the term concurrent program refers to a program that makes extensive, integral use of concurrently executing threads. An example of such a program is one that uses separate threads to simultaneously compute the partial results of a larger computation. Another example is a program that coordinates the activities of several threads, each of which seeks access to information in a database. In this case, read-only accesses might be handled differently from those that require read/write capabilities.

To begin to handle the needs of a concurrent program, JDK 5 added the concurrency utilities, also commonly referred to as the concurrent API. The original set of concurrency utilities supplied many features that had long been wanted by programmers who develop concurrent applications. For example, it offered synchronizers (such as the semaphore), thread pools, execution managers, locks, several concurrent collections, and a streamlined way to use threads to obtain computational results.

Although the original concurrent API was impressive in its own right, it was significantly expanded by JDK 7. The most important addition was the Fork/Join Framework. The Fork/Join Framework facilitates the creation of programs that make use of multiple
processors (such as those found in multicore systems). Thus, it streamlines the development of programs in which two or more pieces execute with true simultaneity (that is, true parallel execution), not just time-slicing. As you can easily imagine, parallel execution can dramatically increase the speed of certain operations. Because multicore systems are now commonplace, the inclusion of the Fork/Join Framework was as timely as it was powerful. With the release of JDK 8, the Fork/Join Framework was further enhanced.

In addition, JDK 8 included some new features related to other parts of the concurrent API. Thus, the concurrent API continues to evolve and expand to meet the needs of the contemporary computing environment.

The original concurrent API was quite large, and the additions made by JDK 7 and JDK 8 have increased its size substantially. As you might expect, many of the issues surrounding the concurrency utilities are quite complex. It is beyond the scope of this book to discuss all of its facets. The preceding notwithstanding, it is important for all programmers to have a general, working knowledge of key aspects of the concurrent API. Even in programs that are not intensively parallel, features such as synchronizers, callable threads, and executors, are applicable to a wide variety of situations. Perhaps most importantly, because of the rise of multicore computers, solutions involving the Fork/Join Framework are becoming more common. For these reasons, this chapter presents an overview of several core features defined by the concurrency utilities and shows a number of examples that demonstrate their use. It concludes with an introduction to the Fork/Join Framework.

### The Concurrent API Packages

The concurrency utilities are contained in the `java.util.concurrent` package and in its two subpackages: `java.util.concurrent.atomic` and `java.util.concurrent.locks`. A brief overview of their contents is given here.

#### java.util.concurrent

`java.util.concurrent` defines the core features that support alternatives to the built-in approaches to synchronization and interthread communication. It defines the following key features:

- Synchronizers
- Executors
- Concurrent collections
- The Fork/Join Framework

*Synchronizers* offer high-level ways of synchronizing the interactions between multiple threads. The synchronizer classes defined by `java.util.concurrent` are

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semaphore</td>
<td>Implements the classic semaphore.</td>
</tr>
<tr>
<td>CountDownLatch</td>
<td>Waits until a specified number of events have occurred.</td>
</tr>
</tbody>
</table>
CyclicBarrier Enables a group of threads to wait at a predefined execution point.

Exchanger Exchanges data between two threads.

Phaser Synchronizes threads that advance through multiple phases of an operation.

Notice that each synchronizer provides a solution to a specific type of synchronization problem. This enables each synchronizer to be optimized for its intended use. In the past, these types of synchronization objects had to be crafted by hand. The concurrent API standardizes them and makes them available to all Java programmers.

Executors manage thread execution. At the top of the executor hierarchy is the Executor interface, which is used to initiate a thread. ExecutorService extends Executor and provides methods that manage execution. There are three implementations of ExecutorService: ThreadPoolExecutor, ScheduledThreadPoolExecutor, and ForkJoinPool. Java.util.concurrent also defines the Executors utility class, which includes a number of static methods that simplify the creation of various executors.

Related to executors are the Future and Callable interfaces. A Future contains a value that is returned by a thread after it executes. Thus, its value becomes defined “in the future,” when the thread terminates. Callable defines a thread that returns a value.

Java.util.concurrent defines several concurrent collection classes, including ConcurrentHashMap, ConcurrentLinkedQueue, and CopyOnWriteArrayList. These offer concurrent alternatives to their related classes defined by the Collections Framework.


Finally, to better handle thread timing, Java.util.concurrent defines the TimeUnit enumeration.

Java.util.concurrent.atomic

Java.util.concurrent.atomic facilitates the use of variables in a concurrent environment. It provides a means of efficiently updating the value of a variable without the use of locks. This is accomplished through the use of classes, such as AtomicInteger and AtomicLong, and methods, such as compareAndSet(), decrementAndGet(), and getAndSet(). These methods execute as a single, non-interruptible operation.

Java.util.concurrent.locks

Java.util.concurrent.locks provides an alternative to the use of synchronized methods. At the core of this alternative is the Lock interface, which defines the basic mechanism used to acquire and relinquish access to an object. The key methods are lock(), tryLock(), and unlock(). The advantage to using these methods is greater control over synchronization.
The remainder of this chapter takes a closer look at the constituents of the concurrent API.

**Using Synchronization Objects**

Synchronization objects are supported by the *Semaphore, CountDownLatch, CyclicBarrier, Exchanger*, and *Phaser* classes. Collectively, they enable you to handle several formerly difficult synchronization situations with ease. They are also applicable to a wide range of programs—even those that contain only limited concurrency. Because the synchronization objects will be of interest to nearly all Java programs, each is examined here in some detail.

**Semaphore**

The synchronization object that many readers will immediately recognize is *Semaphore*, which implements a classic semaphore. A semaphore controls access to a shared resource through the use of a counter. If the counter is greater than zero, then access is allowed. If it is zero, then access is denied. What the counter is counting are *permits* that allow access to the shared resource. Thus, to access the resource, a thread must be granted a permit from the semaphore.

In general, to use a semaphore, the thread that wants access to the shared resource tries to acquire a permit. If the semaphore’s count is greater than zero, then the thread acquires a permit, which causes the semaphore’s count to be decremented. Otherwise, the thread will be blocked until a permit can be acquired. When the thread no longer needs access to the shared resource, it releases the permit, which causes the semaphore’s count to be incremented. If there is another thread waiting for a permit, then that thread will acquire a permit at that time. Java’s *Semaphore* class implements this mechanism.

*Semaphore* has the two constructors shown here:

```java
Semaphore(int num)
Semaphore(int num, boolean how)
```

Here, *num* specifies the initial permit count. Thus, *num* specifies the number of threads that can access a shared resource at any one time. If *num* is one, then only one thread can access the resource at any one time. By default, waiting threads are granted a permit in an undefined order. By setting *how* to *true*, you can ensure that waiting threads are granted a permit in the order in which they requested access.

To acquire a permit, call the `acquire()` method, which has these two forms:

```java
void acquire() throws InterruptedException
void acquire(int num) throws InterruptedException
```

The first form acquires one permit. The second form acquires *num* permits. Most often, the first form is used. If the permit cannot be granted at the time of the call, then the invoking thread suspends until the permit is available.

To release a permit, call `release()`, which has these two forms:
void release( )
void release(int num)

The first form releases one permit. The second form releases the number of permits specified by num.

To use a semaphore to control access to a resource, each thread that wants to use that resource must first call acquire( ) before accessing the resource. When the thread is done with the resource, it must call release( ). Here is an example that illustrates the use of a semaphore:
// A simple semaphore example.
import java.util.concurrent.*;

class SemDemo {
    public static void main(String args[]) {
        Semaphore sem = new Semaphore(1);
        new IncThread(sem, "A");
        new DecThread(sem, "B");
    }
}

// A shared resource.
class Shared {
    static int count = 0;
}

// A thread of execution that increments count.
class IncThread implements Runnable {
    String name;
    Semaphore sem;

    IncThread(Semaphore s, String n) {
        sem = s;
        name = n;
        new Thread(this).start();
    }

    public void run() {
        System.out.println("Starting " + name);
        try {
            // First, get a permit.
            System.out.println(name + " is waiting for a permit.");
            sem.acquire();
            System.out.println(name + " gets a permit.");

            // Now, access shared resource.
            for(int i=0; i < 5; i++) {
                Shared.count++;
                System.out.println(name + ": " + Shared.count);

                // Now, allow a context switch -- if possible.
                Thread.sleep(10);
            }
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }

        // Release the permit.
        System.out.println(name + " releases the permit.");
        sem.release();
    }
}
The output from the program is shown here. (The precise order in which the threads execute may vary.)
The program uses a semaphore to control access to the `count` variable, which is a static variable within the `Shared` class. `Shared.count` is incremented five times by the `run()` method of `IncThread` and decremented five times by `DecThread`. To prevent these two threads from accessing `Shared.count` at the same time, access is allowed only after a permit is acquired from the controlling semaphore. After access is complete, the permit is released. In this way, only one thread at a time will access `Shared.count`, as the output shows.

In both `IncThread` and `DecThread`, notice the call to `sleep()` within `run()`. It is used to “prove” that accesses to `Shared.count` are synchronized by the semaphore. In `run()`, the call to `sleep()` causes the invoking thread to pause between each access to `Shared.count`. This would normally enable the second thread to run. However, because of the semaphore, the second thread must wait until the first has released the permit, which happens only after all accesses by the first thread are complete. Thus, `Shared.count` is first incremented five times by `IncThread` and then decremented five times by `DecThread`. The increments and decrements are not intermixed.

Without the use of the semaphore, accesses to `Shared.count` by both threads would have occurred simultaneously, and the increments and decrements would be intermixed. To confirm this, try commenting out the calls to `acquire()` and `release()`. When you run the program, you will see that access to `Shared.count` is no longer synchronized, and each thread accesses it as soon as it gets a timeslice.

Although many uses of a semaphore are as straightforward as that shown in the preceding program, more intriguing uses are also possible. Here is an example. The following program reworks the producer/consumer program shown in Chapter 11 so that it uses two semaphores to regulate the producer and consumer threads, ensuring that each call to `put()`
is followed by a corresponding call to `get()`:

```java
// An implementation of a producer and consumer
// that use semaphores to control synchronization.

import java.util.concurrent.Semaphore;

class Q {
    int n;

    // Start with consumer semaphore unavailable.
    static Semaphore semCon = new Semaphore(0);
    static Semaphore semProd = new Semaphore(1);

    void get() {
        try {
            semCon.acquire();
        } catch(InterruptedException e) {
            System.out.println("InterruptedException caught");
        }
    }
```
```java
System.out.println("Got: " + n);
semProd.release();
}

void put(int n) {
    try {
        semProd.acquire();
    } catch (InterruptedException e) {
        System.out.println("InterruptedException caught");
    }
    this.n = n;
    System.out.println("Put: " + n);
    semCon.release();
}

class Producer implements Runnable {
    Q q;

    Producer(Q q) {
        this.q = q;
        new Thread(this, "Producer").start();
    }

    public void run() {
        for (int i = 0; i < 20; i++) q.put(i);
    }
}

class Consumer implements Runnable {
    Q q;

    Consumer(Q q) {
        this.q = q;
        new Thread(this, "Consumer").start();
    }

    public void run() {
        for (int i = 0; i < 20; i++) q.get();
    }
}

class ProdCon {
    public static void main(String args[]) {
        Q q = new Q();
        new Consumer(q);
        new Producer(q);
    }
}
```

A portion of the output is shown here:

```
Put: 0
Got: 0
Put: 1
Got: 1
Put: 2
Got: 2
```
As you can see, the calls to `put()` and `get()` are synchronized. That is, each call to `put()` is followed by a call to `get()` and no values are missed. Without the semaphores, multiple calls to `put()` would have occurred without matching calls to `get()`, resulting in values being missed. (To prove this, remove the semaphore code and observe the results.)

The sequencing of `put()` and `get()` calls is handled by two semaphores: `semProd` and `semCon`. Before `put()` can produce a value, it must acquire a permit from `semProd`. After it has set the value, it releases `semCon`. Before `get()` can consume a value, it must acquire a permit from `semCon`. After it consumes the value, it releases `semProd`. This “give and take” mechanism ensures that each call to `put()` must be followed by a call to `get()`.

Notice that `semCon` is initialized with no available permits. This ensures that `put()` executes first. The ability to set the initial synchronization state is one of the more powerful aspects of a semaphore.

**CountDownLatch**

Sometimes you will want a thread to wait until one or more events have occurred. To handle such a situation, the concurrent API supplies `CountDownLatch`. A `CountDownLatch` is initially created with a count of the number of events that must occur before the latch is released. Each time an event happens, the count is decremented. When the count reaches zero, the latch opens.

`CountDownLatch` has the following constructor:

```java
CountDownLatch(int num)
```

Here, `num` specifies the number of events that must occur in order for the latch to open.

To wait on the latch, a thread calls `await()`, which has the forms shown here:

```java
void await( ) throws InterruptedException
boolean await(long wait, TimeUnit tu) throws InterruptedException
```

The first form waits until the count associated with the invoking `CountDownLatch` reaches zero. The second form waits only for the period of time specified by `wait`. The units represented by `wait` are specified by `tu`, which is
an object the **TimeUnit** enumeration. (**TimeUnit** is described later in this chapter.) It returns **false** if the time limit is reached and **true** if the countdown reaches zero.

To signal an event, call the **countDown** method, shown next:

```java
void countDown()
```

Each call to **countDown** decrements the count associated with the invoking object.

The following program demonstrates **CountDownLatch**. It creates a latch that requires five events to occur before it opens.
// An example of CountDownLatch.

import java.util.concurrent.CountDownLatch;

class CDLDemo {
    public static void main(String args[]) {
        CountDownLatch cdl = new CountDownLatch(5);

        System.out.println("Starting");
        new MyThread(cdl);

        try {
            cdl.await();
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }

        System.out.println("Done");
    }
}

class MyThread implements Runnable {
    CountDownLatch latch;

    MyThread(CountDownLatch c) {
        latch = c;
        new Thread(this).start();
    }

    public void run() {
        for(int i = 0; i<5; i++) {
            System.out.println(i);
            latch.countDown(); // decrement count
        }
    }
}

The output produced by the program is shown here:

Starting
0
1
2
3
4
Done
Inside `main()` a `CountDownLatch` called `cdl` is created with an initial count of five. Next, an instance of `MyThread` is created, which begins execution of a new thread. Notice that `cdl` is passed as a parameter to `MyThread`’s constructor and stored in the `latch` instance variable. Then, the main thread calls `await()` on `cdl`, which causes execution of the main thread to pause until `cdl`’s count has been decremented five times. Inside the `run()` method of `MyThread`, a loop is created that iterates five times. With each iteration, the `countDown()` method is called on `latch`, which refers to `cdl` in `main()` . After the fifth iteration, the latch opens, which allows the main thread to resume. `CountDownLatch` is a powerful yet easy-to-use synchronization object that is appropriate whenever a thread must wait for one or more events to occur.

**CyclicBarrier**

A situation not uncommon in concurrent programming occurs when a set of two or more threads must wait at a predetermined execution point until all threads in the set have reached that point. To handle such a situation, the concurrent API supplies the `CyclicBarrier` class. It enables you to define a synchronization object that suspends until the specified number of threads has reached the barrier point. `CyclicBarrier` has the following two constructors:

```
CyclicBarrier(int numThreads)
CyclicBarrier(int numThreads, Runnable action)
```

Here, `numThreads` specifies the number of threads that must reach the barrier before execution continues. In the second form, `action` specifies a thread that will be executed when the barrier is reached.

Here is the general procedure that you will follow to use `CyclicBarrier`. First, create a `CyclicBarrier` object, specifying the number of threads that you will be waiting for. Next, when each thread reaches the barrier, have it call `await()` on that object. This will pause execution of the thread until all of the other threads also call `await()`. Once the specified number of threads has reached the barrier, `await()` will return and execution will resume. Also, if you have specified an action, then that thread is executed.

The `await()` method has the following two forms:

```
int await() throws InterruptedException, BrokenBarrierException
int await(long wait, TimeUnit tu)
    throws InterruptedException, BrokenBarrierException, TimeoutException
```

The first form waits until all the threads have reached the barrier point. The second form waits only for the period of time specified by `wait`. The units represented by `wait` are specified by `tu`. Both forms return a value that indicates the order that the threads arrive at the barrier point. The first thread returns a value equal to the number of threads waited upon minus one. The last thread returns zero.

Here is an example that illustrates `CyclicBarrier`. It waits until a set of three threads has
reached the barrier. When that occurs, the thread specified by **BarAction** executes.

```java
import java.util.concurrent.*;

class BarDemo {
    public static void main(String args[]) {
        CyclicBarrier cb = new CyclicBarrier(3, new BarAction());
        System.out.println("Starting");
        new MyThread(cb, "A");
        new MyThread(cb, "B");
        new MyThread(cb, "C");
    }
}

// A thread of execution that uses a CyclicBarrier.

class MyThread implements Runnable {
    CyclicBarrier cb;
    String name;
    MyThread(CyclicBarrier c, String n) {
        cb = c;
        name = n;
        new Thread(this).start();
    }
    public void run() {
        System.out.println(name);
        try {
            cb.await();
        } catch (BrokenBarrierException exc) {
            System.out.println(exc);
        } catch (InterruptedException exc) {
            System.out.println(exc);
        }
    }
}

// An object of this class is called when the CyclicBarrier ends.
class BarAction implements Runnable {
    public void run() {
        System.out.println("Barrier Reached");
    }
}
```

The output is shown here. (The precise order in which the threads execute may vary.)
A CyclicBarrier can be reused because it will release waiting threads each time the specified number of threads calls await(). For example, if you change main() in the preceding program so that it looks like this:

```java
public static void main(String args[]) {
    CyclicBarrier cb = new CyclicBarrier(3, new BarAction());
    System.out.println("Starting");
    new MyThread(cb, "A");
    new MyThread(cb, "B");
    new MyThread(cb, "C");
    new MyThread(cb, "D");
    new MyThread(cb, "E");
    new MyThread(cb, "F");
}
```

the following output will be produced. (The precise order in which the threads execute may vary.)

```
Starting
A
B
C
Barrier Reached:
X
Y
Z
Barrier Reached:
```

As the preceding example shows, the CyclicBarrier offers a streamlined solution to what was previously a complicated problem.

**Exchanger**

Perhaps the most interesting of the synchronization classes is Exchanger. It is designed to simplify the exchange of data between two threads. The operation of an Exchanger is astoundingly simple: it simply waits until two separate threads call its exchange() method. When that occurs, it exchanges the data supplied by the threads. This mechanism is both elegant and easy to use. Uses for Exchanger are easy to imagine. For example, one
thread might prepare a buffer for receiving information over a network connection. Another thread might fill that buffer with the information from the connection. The two threads work together so that each time a new buffer is needed, an exchange is made. **Exchanger** is a generic class that is declared as shown here:

```
Exchanger<V>
```

Here, \( V \) specifies the type of the data being exchanged.

The only method defined by **Exchanger** is **exchange()**, which has the two forms shown here:

```
V exchange(V objRef) throws InterruptedException

V exchange(V objRef, long wait, TimeUnit tu)
    throws InterruptedException, TimeoutException
```

Here, \( objRef \) is a reference to the data to exchange. The data received from the other thread is returned. The second form of **exchange()** allows a time-out period to be specified. The key point about **exchange()** is that it won’t succeed until it has been called on the same **Exchanger** object by two separate threads. Thus, **exchange()** synchronizes the exchange of the data.

Here is an example that demonstrates **Exchanger**. It creates two threads. One thread creates an empty buffer that will receive the data put into it by the second thread. In this case, the data is a string. Thus, the first thread exchanges an empty string for a full one.
// An example of Exchanger.

import java.util.concurrent.Exchanger;

class ExchangerDemo {
    public static void main(String args[]) {
        Exchanger<String> exgr = new Exchanger<String>();

        new UseString(exgr);
        new MakeString(exgr);
    }
}

// A Thread that constructs a string.
class MakeString implements Runnable {
    Exchanger<String> ex;
    String str;

    MakeString(Exchanger<String> c) {
        ex = c;
        str = new String();

        new Thread(this).start();
    }

    public void run() {
        char ch = 'A';

        for(int i = 0; i < 3; i++) {

            // Fill Buffer
            for(int j = 0; j < 5; j++)
        }
Here is the output produced by the program:

Got: ABCDE
Got: FGHIJ
Got: KLMNO

In the program, the `main()` method creates an `Exchanger` for strings. This object is then used to synchronize the exchange of strings between the `MakeString` and `UseString` classes. The `MakeString` class fills a string with data. The `UseString` exchanges an empty string for a full one. It then displays the contents of the newly constructed string. The exchange of empty and full buffers is synchronized by the `exchange()` method, which is called by both classes’ `run()` method.
Phaser
Another synchronization class is called Phaser. Its primary purpose is to enable the synchronization of threads that represent one or more phases of activity. For example, you might have a set of threads that implement three phases of an order-processing application. In the first phase, separate threads are used to validate customer information, check inventory, and confirm pricing. When that phase is complete, the second phase has two threads that compute shipping costs and all applicable tax. After that, a final phase confirms payment and determines estimated shipping time. In the past, to synchronize the multiple threads that comprise this scenario would require a bit of work on your part. With the inclusion of Phaser, the process is now much easier.

To begin, it helps to know that a Phaser works a bit like a CyclicBarrier, described earlier, except that it supports multiple phases. As a result, Phaser lets you define a synchronization object that waits until a specific phase has completed. It then advances to the next phase, again waiting until that phase concludes. It is important to understand that Phaser can also be used to synchronize only a single phase. In this regard, it acts much like a CyclicBarrier. However, its primary use is to synchronize multiple phases.

Phaser defines four constructors. Here are the two used in this section:

    Phaser()
    Phaser(int numParties)

The first creates a phaser that has a registration count of zero. The second sets the registration count to numParties. The term party is often applied to the objects that register with a phaser. Although often there is a one-to-correspondence between the number of registrants and the number of threads being synchronized, this is not required. In both cases, the current phase is zero. That is, when a Phaser is created, it is initially at phase zero.

In general, here is how you use Phaser. First, create a new instance of Phaser. Next, register one or more parties with the phaser, either by calling register( ) or by specifying the number of parties in the constructor. For each registered party, have the phaser wait until all registered parties complete a phase. A party signals this by calling one of a variety of methods supplied by Phaser, such as arrive( ) or arriveAndAwaitAdvance( ). After all parties have arrived, the phase is complete, and the phaser can move on to the next phase (if there is one), or terminate. The following sections explain the process in detail.

To register parties after a Phaser has been constructed, call register( ). It is shown here:

    int register()

It returns the phase number of the phase to which it is registered.

To signal that a party has completed a phase, it must call arrive( ) or some variation of arrive( ). When the number of arrivals equals the number of registered parties, the phase is completed and the Phaser moves on to the next phase (if there is one).
method has this general form:

```java
int arrive()
```

This method signals that a party (normally a thread of execution) has completed some task (or portion of a task). It returns the current phase number. If the phaser has been terminated, then it returns a negative value. The `arrive()` method does not suspend execution of the calling thread. This means that it does not wait for the phase to be completed. This method should be called only by a registered party.

If you want to indicate the completion of a phase and then wait until all other registrants have also completed that phase, use `arriveAndAwaitAdvance()`. It is shown here:

```java
int arriveAndAwaitAdvance()
```

It waits until all parties have arrived. It returns the next phase number or a negative value if the phaser has been terminated. This method should be called only by a registered party.

A thread can arrive and then deregister itself by calling `arriveAndDeregister()`. It is shown here:

```java
int arriveAndDeregister()
```

It returns the current phase number or a negative value if the phaser has been terminated. It does not wait until the phase is complete. This method should be called only by a registered party.

To obtain the current phase number, call `getPhase()`, which is shown here:

```java
final int getPhase()
```

When a Phaser is created, the first phase will be 0, the second phase 1, the third phase 2, and so on. A negative value is returned if the invoking Phaser has been terminated.

Here is an example that shows Phaser in action. It creates three threads, each of which have three phases. It uses a Phaser to synchronize each phase.
// An example of Phaser.

import java.util.concurrent.*;

class PhaserDemo {
    public static void main(String args[]) {
        Phaser phsr = new Phaser(1);
        int curPhase;

        System.out.println("Starting");

        new MyThread(phsr, "A");
        new MyThread(phsr, "B");
        new MyThread(phsr, "C");

        // Wait for all threads to complete phase one.
        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");

        // Wait for all threads to complete phase two.
        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");

        curPhase = phsr.getPhase();
        phsr.arriveAndAwaitAdvance();
        System.out.println("Phase " + curPhase + " Complete");
    }
}

// Deregister the main thread.
phsr.arriveAndDeregister();

if(phsr.isTerminated())
    System.out.println("The Phaser is terminated");
}

// A thread of execution that uses a Phaser.
class MyThread implements Runnable {
    Phaser phsr;
    String name;

    MyThread(Phaser p, String n) {
        phsr = p;
        name = n;
        phsr.register();
        new Thread(this).start();
    }

    public void run() {
        System.out.println("Thread " + name + " Beginning Phase One");
        phsr.arriveAndAwaitAdvance(); // Signal arrival.

        // Pause a bit to prevent jumbled output. This is for illustration
        // only. It is not required for the proper operation of the phaser.
        try {
            Thread.sleep(10);
        } catch(InterruptedException e) {
            System.out.println(e);
        }

        System.out.println("Thread " + name + " Beginning Phase Two");
        phsr.arriveAndAwaitAdvance(); // Signal arrival.

        // Pause a bit to prevent jumbled output. This is for illustration
        // only. It is not required for the proper operation of the phaser.
        try {
            Thread.sleep(10);
        } catch(InterruptedException e) {
            System.out.println(e);
        }

        System.out.println("Thread " + name + " Beginning Phase Three");
        phsr.arriveAndDeregister(); // Signal arrival and deregister.
    }
}
Starting
Thread A Beginning Phase One
Thread C Beginning Phase One
Thread B Beginning Phase One
Phase 0 Complete
Thread B Beginning Phase Two
Thread C Beginning Phase Two
Thread A Beginning Phase Two
Phase 1 Complete
Thread C Beginning Phase Three
Thread B Beginning Phase Three
Thread A Beginning Phase Three
Phase 2 Complete
The Phaser is terminated

Let's look closely at the key sections of the program. First, in `main()`, a Phaser called `phsr` is created with an initial party count of 1 (which corresponds to the main thread). Then three threads are started by creating three `MyThread` objects. Notice that `MyThread` is passed a reference to `phsr` (the phaser). The `MyThread` objects use this phaser to synchronize their activities. Next, `main()` calls `getPhase()` to obtain the current phase number (which is initially zero) and then calls `arriveAndAwaitAdvance()`. This causes `main()` to suspend until phase zero has completed. This won’t happen until all `MyThreads` also call `arriveAndAwaitAdvance()`. When this occurs, `main()` will resume execution, at which point it displays that phase zero has completed, and it moves on to the next phase. This process repeats until all three phases have finished. Then, `main()` calls `arriveAndDeregister()`. At that point, all three `MyThreads` have also deregistered. Since this results in there being no registered parties when the phaser advances to the next phase, the phaser is terminated.

Now look at `MyThread`. First, notice that the constructor is passed a reference to the phaser that it will use and then registers with the new thread as a party on that phaser. Thus, each new `MyThread` becomes a party registered with the passed-in phaser. Also notice that each thread has three phases. In this example, each phase consists of a placeholder that simply displays the name of the thread and what it is doing. Obviously, in real-world code, the thread would be performing more meaningful actions. Between the first two phases, the thread calls `arriveAndAwaitAdvance()`. Thus, each thread waits until all threads have completed the phase (and the main thread is ready). After all threads have arrived (including the main thread), the phaser moves on to the next phase. After the third phase, each thread deregisters itself with a call to `arriveAndDeregister()`. As the comments in `MyThread` explain, the calls to `sleep()` are used for the purposes of illustration to ensure that the output is not jumbled because of the multithreading. They are not needed to make the phaser work properly. If you remove them, the output may look a bit jumbled, but the phases will still be synchronized correctly.

One other point: Although the preceding example used three threads that were all of the
same type, this is not a requirement. Each party that uses a phaser can be unique, with each performing some separate task.

It is possible to take control of precisely what happens when a phase advance occurs. To do this, you must override the `onAdvance()` method. This method is called by the run time when a `Phaser` advances from one phase to the next. It is shown here:

```java
protected boolean onAdvance(int phase, int numParties)
```

Here, `phase` will contain the current phase number prior to being incremented and `numParties` will contain the number of registered parties. To terminate the phaser, `onAdvance()` must return `true`. To keep the phaser alive, `onAdvance()` must return `false`.

The default version of `onAdvance()` returns `true` (thus terminating the phaser) when there are no registered parties. As a general rule, your override should also follow this practice.

One reason to override `onAdvance()` is to enable a phaser to execute a specific number of phases and then stop. The following example gives you the flavor of this usage. It creates a class called `MyPhaser` that extends `Phaser` so that it will run a specified number of phases. It does this by overriding the `onAdvance()` method. The `MyPhaser` constructor accepts one argument, which specifies the number of phases to execute. Notice that `MyPhaser` automatically registers one party. This behavior is useful in this example, but the needs of your own applications may differ.
import java.util.concurrent.*;

// Extend Phaser and override onAdvance() so that only a specific
// number of phases are executed.

class MyPhaser extends Phaser {
    int numPhases;

    MyPhaser(int parties, int phaseCount) {
        super(parties);
        numPhases = phaseCount - 1;
    }

    // Override onAdvance() to execute the specified
    // number of phases.
    protected boolean onAdvance(int p, int regParties) {
        // This println() statement is for illustration only.
        // Normally, onAdvance() will not display output.
        System.out.println("Phase "+p+" completed.
");

        // If all phases have completed, return true
        if(p == numPhases || regParties == 0) return true;

        // Otherwise, return false.
        return false;
    }
}

class PhaserDemo2 {
    public static void main(String args[]) {
        MyPhaser phar = new MyPhaser(1, 4);
        System.out.println("Starting\n");
        new MyThread(phar, "A");
        new MyThread(phar, "B");
        new MyThread(phar, "C");

        // Wait for the specified number of phases to complete.
        while(!phar.isTerminated()) {
            // Code...
        }
    }
}
The output from the program is shown here:

```java
    Phaser phsr = new Phaser();
    phsr.arriveAndAwaitAdvance();
    System.out.println("The Phaser is terminated");
}

// A thread of execution that uses a Phaser.
class MyThread implements Runnable {
    Phaser phsr;
    String name;
    MyThread(Phaser p, String n) {
        phsr = p;
        name = n;
        phsr.register();
        new Thread(this).start();
    }
    public void run() {
        while (!phsr.isTerminated()) {
            System.out.println("Thread "+name+" Beginning Phase "+phsr.getPhase());
            phsr.arriveAndAwaitAdvance();
            // Pause a bit to prevent jumbled output. This is for illustration
            // only. It is not required for the proper operation of the phaser.
            try {
                Thread.sleep(10);
            } catch(InterruptedException e) {
                System.out.println(e);
            }
        }
    }
}
```
Inside `main()` , one instance of `Phaser` is created. It is passed 4 as an argument, which means that it will execute four phases and then stop. Next, three threads are created and then the following loop is entered:

```java
    // Wait for the specified number of phases to complete.
    while(!phsr.isTerminated()) {
        phsr.arriveAndAwaitAdvance();
    }
```

This loop simply calls `arriveAndAwaitAdvance()` until the phaser is terminated. The phaser won’t terminate until the specified number of phases have been executed. In this case, the loop continues to execute until four phases have run. Next, notice that the threads also call `arriveAndAwaitAdvance()` within a loop that runs until the phaser is terminated. This means that they will execute until the specified number of phases has been completed.

Now, look closely at the code for `onAdvance()`. Each time `onAdvance()` is called, it is passed the current phase and the number of registered parties. If the current phase equals the specified phase, or if the number of registered parties is zero, `onAdvance()` returns `true`, thus stopping the phaser. This is accomplished with this line of code:

```java
    // If all phases have completed, return true
    if(p == numPhases || regParties == 0) return true;
```
As you can see, very little code is needed to accommodate the desired outcome. Before moving on, it is useful to point out that you don’t necessarily need to explicitly extend Phaser as the previous example does to simply override onAdvance(). In some cases, more compact code can be created by using an anonymous inner class to override onAdvance(). Phaser has additional capabilities that may be of use in your applications. You can wait for a specific phase by calling awaitAdvance(), which is shown here:

```java
int awaitAdvance(int phase)
```

Here, `phase` indicates the phase number on which `awaitAdvance()` will wait until a transition to the next phase takes place. It will return immediately if the argument passed to `phase` is not equal to the current phase. It will also return immediately if the phaser is terminated. However, if `phase` is passed the current phase, then it will wait until the phase increments. This method should be called only by a registered party. There is also an interruptible version of this method called awaitAdvanceInterruptibly().

To register more than one party, call bulkRegister(). To obtain the number of registered parties, call getRegisteredParties(). You can also obtain the number of arrived parties and unarrived parties by calling getArrivedParties() and getUnarrivedParties(), respectively. To force the phaser to enter a terminated state, call forceTermination(). Phaser also lets you create a tree of phasers. This is supported by two additional constructors, which let you specify the parent, and the getParent() method.

**Using an Executor**

The concurrent API supplies a feature called an executor that initiates and controls the execution of threads. As such, an executor offers an alternative to managing threads through the Thread class.

At the core of an executor is the Executor interface. It defines the following method:

```java
void execute(Runnable thread)
```

The thread specified by `thread` is executed. Thus, `execute()` starts the specified thread.

The ExecutorService interface extends Executor by adding methods that help manage and control the execution of threads. For example, ExecutorService defines shutdown(), shown here, which stops the invoking ExecutorService.

```java
void shutdown()
```

ExecutorService also defines methods that execute threads that return results, that execute a set of threads, and that determine the shutdown status. We will look at several of these methods a little later.

Also defined is the interface ScheduledExecutorService, which extends
ExecutorService to support the scheduling of threads.
The concurrent API defines three predefined executor classes: ThreadPoolExecutor and ScheduledThreadPoolExecutor, and ForkJoinPool. ThreadPoolExecutor implements the Executor and ExecutorService interfaces and provides support for a managed pool of threads. ScheduledThreadPoolExecutor also implements the ScheduledExecutorService interface to allow a pool of threads to be scheduled.
ForkJoinPool implements the Executor and ExecutorService interfaces and is used by the Fork/Join Framework. It is described later in this chapter.
A thread pool provides a set of threads that is used to execute various tasks. Instead of each task using its own thread, the threads in the pool are used. This reduces the overhead associated with creating many separate threads. Although you can use ThreadPoolExecutor and ScheduledThreadPoolExecutor directly, most often you will want to obtain an executor by calling one of the following static factory methods defined by the Executors utility class. Here are some examples:

static ExecutorService newCachedThreadPool()
static ExecutorService newFixedThreadPool(int numThreads)
static ScheduledExecutorService newScheduledThreadPool(int numThreads)

newCachedThreadPool() creates a thread pool that adds threads as needed but reuses threads if possible. newFixedThreadPool() creates a thread pool that consists of a specified number of threads. newScheduledThreadPool() creates a thread pool that supports thread scheduling. Each returns a reference to an ExecutorService that can be used to manage the pool.

A Simple Executor Example
Before going any further, a simple example that uses an executor will be of value. The following program creates a fixed thread pool that contains two threads. It then uses that pool to execute four tasks. Thus, four tasks share the two threads that are in the pool. After the tasks finish, the pool is shut down and the program ends.
The output from the program is shown here. (The precise order in which the threads execute may vary.)
As the output shows, even though the thread pool contains only two threads, all four tasks are still executed. However, only two can run at the same time. The others must wait until one of the pooled threads is available for use.

The call to `shutdown()` is important. If it were not present in the program, then the program would not terminate because the executor would remain active. To try this for yourself, simply comment out the call to `shutdown()` and observe the result.

### Using Callable and Future

One of the most interesting features of the concurrent API is the `Callable` interface. This interface represents a thread that returns a value. An application can use `Callable` objects to compute results that are then returned to the invoking thread. This is a powerful mechanism because it facilitates the coding of many types of numerical computations in which partial results are computed simultaneously. It can also be used to run a thread that returns a status code that indicates the successful completion of the thread.

`Callable` is a generic interface that is defined like this:

```java
interface Callable<V>
```

Here, `V` indicates the type of data returned by the task. `Callable` defines only one method, `call()`, which is shown here:

```java
V call() throws Exception
```

Inside `call()`, you define the task that you want performed. After that task
completes, you return the result. If the result cannot be computed, `call()` must throw an exception.

A `Callable` task is executed by an `ExecutorService`, by calling its `submit()` method. There are three forms of `submit()`, but only one is used to execute a `Callable`. It is shown here:

```java
<T> Future<T> submit(Callable<T> task)
```

Here, `task` is the `Callable` object that will be executed in its own thread. The result is returned through an object of type `Future`.

`Future` is a generic interface that represents the value that will be returned by a `Callable` object. Because this value is obtained at some future time, the name `Future` is appropriate. `Future` is defined like this:

```java
interface Future<V>
```

Here, `V` specifies the type of the result.

To obtain the returned value, you will call `Future`’s `get()` method, which has these two forms:

```java
V get()
```

throws `InterruptedException, ExecutionException`

```java
V get(long wait, TimeUnit tu)
```

throws `InterruptedException, ExecutionException, TimeoutException`

The first form waits for the result indefinitely. The second form allows you to specify a timeout period in `wait`. The units of `wait` are passed in `tu`, which is an object of the `TimeUnit` enumeration, described later in this chapter.

The following program illustrates `Callable` and `Future` by creating three tasks that perform three different computations. The first returns the summation of a value, the second computes the length of the hypotenuse of a right triangle given the length of its sides, and the third computes the factorial of a value. All three computations occur simultaneously.
// An example that uses a Callable.

import java.util.concurrent.*;

class CallableDemo {
    public static void main(String args[]) {
        ExecutorService es = Executors.newFixedThreadPool(3);
        Future<Integer> f;
        Future<Double> f2;
        Future<Integer> f3;

        System.out.println("Starting");

        f = es.submit(new Sum(10));
        f2 = es.submit(new Hypot(3, 4));
        f3 = es.submit(new Factorial(5));

        try {
            System.out.println(f.get());
            System.out.println(f2.get());
            System.out.println(f3.get());
        }
    }
}

class Sum {
    private int x; // data

    // Constructor
    public Sum(int x) {
        this.x = x;
    }

    // Method
    public int get() {
        return x;
    }
}

class Hypot {
    private int x; // data
    private int y; // data

    // Constructor
    public Hypot(int x, int y) {
        this.x = x;
        this.y = y;
    }

    // Method
    public double get() {
        return Math.hypot(x, y);
    }
}

class Factorial {
    private int x; // data

    // Constructor
    public Factorial(int x) {
        this.x = x;
    }

    // Method
    public int get() {
        return factorial(x);
    }

    // Helper method
    private int factorial(int n) {
        if (n <= 1) {
            return 1;
        } else {
            return n * factorial(n - 1);
        }
    }
}
```java
// Following are three computational threads.
class Sum implements Callable<Integer> {
    int stop;
    Sum(int v) { stop = v; }
    public Integer call() {
        int sum = 0;
        for(int i = 1; i <= stop; i++) {
            sum += i;
        }
        return sum;
    }
}

class Hypot implements Callable<Double> {
    double side1, side2;
    Hypot(double s1, double s2) {
        side1 = s1;
        side2 = s2;
    }
    public Double call() {
        return Math.sqrt((side1*side1) + (side2*side2));
    }
}

class Factorial implements Callable<Integer> {
    int stop;
    Factorial(int v) { stop = v; }
    public Integer call() {
        int fact = 1;
        for(int i = 2; i <= stop; i++) {
            fact *= i;
        }
        return fact;
    }
}
```

The output is shown here:

Starting
55
5.0
120
Done
The TimeUnit Enumeration

The concurrent API defines several methods that take an argument of type `TimeUnit`, which indicates a time-out period. `TimeUnit` is an enumeration that is used to specify the granularity (or resolution) of the timing. `TimeUnit` is defined within `java.util.concurrent`. It can be one of the following values:

- DAYS
- HOURS
- MINUTES
- SECONDS
- MICROSECONDS
- MILLISECONDS
- NANOSECONDS

Although `TimeUnit` lets you specify any of these values in calls to methods that take a timing argument, there is no guarantee that the system is capable of the specified resolution.

Here is an example that uses `TimeUnit`. The `CallableDemo` class, shown in the previous section, is modified as shown next to use the second form of `get()` that takes a `TimeUnit` argument.

```java
try {
    System.out.println(f1.get(10, TimeUnit.MILLISECONDS));
    System.out.println(f2.get(10, TimeUnit.MILLISECONDS));
    System.out.println(f3.get(10, TimeUnit.MILLISECONDS));
} catch (InterruptedException exc) {
    System.out.println(exc);
}
```

In this version, no call to `get()` will wait more than 10 milliseconds.

The `TimeUnit` enumeration defines various methods that convert between units. These are shown here:

- `long convert(long tval, TimeUnit tu)`
- `long toMicros(long tval)`
- `long toMillis(long tval)`
- `long toNanos(long tval)`
- `long toSeconds(long tval)`
- `long toDays(long tval)`
long toHours(long tval)
long toMinutes(long tval)

The convert() method converts tval into the specified unit and returns the result. The to methods perform the indicated conversion and return the result.

The TimeUnit also defines the following timing methods:

void sleep(long delay) throws InterruptedException
void timedJoin(Thread thrd, long delay) throws InterruptedException
void timedWait(Object obj, long delay) throws InterruptedException

Here, sleep() pauses execution for the specified delay period, which is specified in terms of the invoking enumeration constant. It translates into a call to Thread.sleep(). The timedJoin() method is a specialized version of Thread.join() in which thrd pauses for the time period specified by delay, which is described in terms of the invoking time unit. The timedWait() method is a specialized version of Object.wait() in which obj is waited on for the period of time specified by delay, which is described in terms of the invoking time unit.

The Concurrent Collections
As explained, the concurrent API defines several collection classes that have been engineered for concurrent operation. They include:

ArrayBlockingQueue
ConcurrentHashMap
ConcurrentLinkedDeque
ConcurrentLinkedQueue
ConcurrentSkipListMap
ConcurrentSkipListSet
CopyOnWriteArrayList
CopyOnWriteArraySet
DelayQueue
LinkedBlockingDeque
LinkedBlockingQueue
LinkedTransferQueue
PriorityBlockingQueue
SynchronousQueue

These offer concurrent alternatives to their related classes defined by the Collections Framework. These collections work much like the other collections except that they provide concurrency support. Programmers familiar with the Collections Framework will have no trouble using these concurrent collections.

Locks
The `java.util.concurrent.locks` package provides support for locks, which are objects that offer an alternative to using `synchronized` to control access to a shared resource. In general, here is how a lock works. Before accessing a shared resource, the lock that protects that resource is acquired. When access to the resource is complete, the lock is released. If a second thread attempts to acquire the lock when it is in use by another thread, the second thread will suspend until the lock is released. In this way, conflicting access to a shared resource is prevented.

Locks are particularly useful when multiple threads need to access the value of shared data. For example, an inventory application might have a thread that first confirms that an item is in stock and then decreases the number of items on hand as each sale occurs. If two or more of these threads are running, then without some form of synchronization, it would be possible for one thread to be in the middle of a transaction when the second thread begins its transaction. The result could be that both threads would assume that adequate inventory exists, even if there is only sufficient inventory on hand to satisfy one sale. In this type of situation, a lock offers a convenient means of handling the needed synchronization.

The `Lock` interface defines a lock. The methods defined by `Lock` are shown in Table 28-1. In general, to acquire a lock, call `lock()`. If the lock is unavailable, `lock()` will wait. To release a lock, call `unlock()`. To see if a lock is available, and to acquire it if it is, call `tryLock()`. This method will not wait for the lock if it is unavailable. Instead, it returns `true` if the lock is acquired and `false` otherwise. The `newCondition()` method returns a `Condition` object associated with the lock. Using a `Condition`, you gain detailed control of the lock through methods such as `await()` and `signal()`, which provide functionality similar to `Object.wait()` and `Object.notify()`.

`java.util.concurrent.locks` supplies an implementation of `Lock` called `ReentrantLock`. `ReentrantLock` implements a reentrant lock, which is a lock that can be repeatedly entered by the thread that currently holds the lock. Of course, in the case of a thread reentering a lock, all calls to `lock()` must be offset by an equal number of calls to `unlock()`. Otherwise, a thread seeking to acquire the lock will suspend until the lock is not in use.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void lock()</code></td>
<td>Waits until the invoking lock can be acquired.</td>
</tr>
<tr>
<td><code>void lockInterruptibly()</code></td>
<td>Waits until the invoking lock can be acquired, unless interrupted.</td>
</tr>
<tr>
<td><code>Condition newCondition()</code></td>
<td>Returns a <code>Condition</code> object that is associated with the invoking lock.</td>
</tr>
<tr>
<td><code>boolean tryLock()</code></td>
<td>Attempts to acquire the lock. This method will not wait if the lock is unavailable. Instead, it returns <code>true</code> if the lock has been acquired and <code>false</code> if the lock is currently in use by another thread.</td>
</tr>
<tr>
<td><code>boolean tryLock(long wait, TimeUnit unit)</code> throws InterruptedException</td>
<td>Attempts to acquire the lock. If the lock is unavailable, this method will wait no longer than the period specified by <code>wait</code>, which is in <code>wait</code> units. It returns <code>true</code> if the lock has been acquired and <code>false</code> if the lock cannot be acquired within the specified period.</td>
</tr>
<tr>
<td><code>void unlock()</code></td>
<td>Releases the lock.</td>
</tr>
</tbody>
</table>
The following program demonstrates the use of a lock. It creates two threads that access a shared resource called `Shared.count`. Before a thread can access `Shared.count`, it must obtain a lock. After obtaining the lock, `Shared.count` is incremented and then, before releasing the lock, the thread sleeps. This causes the second thread to attempt to obtain the lock. However, because the lock is still held by the first thread, the second thread must wait until the first thread stops sleeping and releases the lock. The output shows that access to `Shared.count` is, indeed, synchronized by the lock.
import java.util.concurrent.locks.*;

class LockDemo {
    public static void main(String[] args) {
        ReentrantLock lock = new ReentrantLock();
        new LockThread(lock, "A");
        new LockThread(lock, "B");
    }
}

// A shared resource.
class Shared {
    static int count = 0;
}

// A thread of execution that increments count.
class LockThread implements Runnable {
    String name;
    ReentrantLock lock;

    LockThread(ReentrantLock lk, String n) {
        lock = lk;
        name = n;
        new Thread(this).start();
    }

    public void run() {
        System.out.println("Starting " + name);
        try {
            // First, lock count.
            System.out.println(name + " is waiting to lock count.");
            lock.lock();
            System.out.println(name + " is locking count.");
            Shared.count++;
            System.out.println(name + " is locking count.");
            System.out.println(name + " + Shared.count");
            // Now, allow a context switch -- if possible.
            System.out.println(name + " is sleeping.");
            Thread.sleep(1000);
        } catch (InterruptedException exc) {
            System.out.println(exc);
        } finally {
            // Unlock
            System.out.println(name + " is unlocking count.");
            lock.unlock();
        }
    }
}

The output is shown here. (The precise order in which the threads execute may vary.)
java.util.concurrent.locks also defines the ReadWriteLock interface. This interface specifies a lock that maintains separate locks for read and write access. This enables multiple locks to be granted for readers of a resource as long as the resource is not being written. ReentrantReadWriteLock provides an implementation of ReadWriteLock.

NOTE JDK 8 adds a specialized lock called StampedLock. It does not implement the Lock or ReadWriteLock interfaces. It does, however, provide a mechanism that enables aspects of it to be used like a Lock or ReadWriteLock.

Atomic Operations
java.util.concurrent.atomic offers an alternative to the other synchronization features when reading or writing the value of some types of variables. This package offers methods that get, set, or compare the value of a variable in one uninterruptible (that is, atomic) operation. This means that no lock or other synchronization mechanism is required. Atomic operations are accomplished through the use of classes, such as AtomicInteger and AtomicLong, and methods such as get(), set(), compareAndSet(), decrementAndGet(), and getAndSet(), which perform the action indicated by their names.
Here is an example that demonstrates how access to a shared integer can be synchronized by the use of AtomicInteger:
In the program, a static `AtomicInteger` named `ai` is created by `Shared`. Then, three threads of type `AtomThread` are created. Inside `run()`, `Shared.ai` is modified by calling `getAndSet()`. This method returns the previous value and then sets the value to the one passed as an argument. The use of `AtomicInteger` prevents two threads from writing to `ai` at the same time.

In general, the atomic operations offer a convenient (and possibly more efficient) alternative to the other synchronization mechanisms when only a single variable is involved. Beginning with JDK 8, `java.util.concurrent.atomic` also provides four classes that support lock-free cumulative operations. These are `DoubleAccumulator`, `DoubleAdder`, `LongAccumulator`, and `LongAdder`. The accumulator classes support a series of user-
Parallel Programming via the Fork/Join Framework

In recent years, an important new trend has emerged in software development: parallel programming. Parallel programming is the name commonly given to the techniques that take advantage of computers that contain two or more processors (multicore). As most readers will know, multicore computers are becoming commonplace. The advantage that multi-processor environments offer is the ability to significantly increase program performance. As a result, there has been a growing need for a mechanism that gives Java programmers a simple, yet effective way to make use of multiple processors in a clean, scalable manner. To answer this need, JDK 7 added several new classes and interfaces that support parallel programming. They are commonly referred to as the Fork/Join Framework. It is one of the more important additions that has recently been made to the Java class library. The Fork/Join Framework is defined in the java.util.concurrent package.

The Fork/Join Framework enhances multithreaded programming in two important ways. First, it simplifies the creation and use of multiple threads. Second, it automatically makes use of multiple processors. In other words, by using the Fork/Join Framework you enable your applications to automatically scale to make use of the number of available processors. These two features make the Fork/Join Framework the recommended approach to multithreading when parallel processing is desired.

Before continuing, it is important to point out the distinction between traditional multithreading and parallel programming. In the past, most computers had a single CPU and multithreading was primarily used to take advantage of idle time, such as when a program is waiting for user input. Using this approach, one thread can execute while another is waiting. In other words, on a single-CPU system, multithreading is used to allow two or more tasks to share the CPU. This type of multithreading is typically supported by an object of type Thread (as described in Chapter 11). Although this type of multithreading will always remain quite useful, it was not optimized for situations in which two or more CPUs are available (multicore computers).

When multiple CPUs are present, a second type of multithreading capability that supports true parallel execution is required. With two or more CPUs, it is possible to execute portions of a program simultaneously, with each part executing on its own CPU. This can be used to significantly speed up the execution of some types of operations, such as sorting, transforming, or searching a large array. In many cases, these types of operations can be broken down into smaller pieces (each acting on a portion of the array), and each piece can be run on its own CPU. As you can imagine, the gain in efficiency can be enormous. Simply put: Parallel programming will be part of nearly every programmer’s future because it offers a way to dramatically improve program performance.

The Main Fork/Join Classes

specified operations. The adder classes maintain a cumulative sum.
The Fork/Join Framework is packaged in `java.util.concurrent`. At the core of the Fork/Join Framework are the following four classes:

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>ForkJoinTask&lt;V&gt;</code></td>
<td>An abstract class that defines a task</td>
</tr>
<tr>
<td><code>ForkJoinPool</code></td>
<td>Manages the execution of <code>ForkJoinTasks</code></td>
</tr>
<tr>
<td><code>RecursiveAction</code></td>
<td>A subclass of <code>ForkJoinTask&lt;V&gt;</code> for tasks that do not return values</td>
</tr>
<tr>
<td><code>RecursiveTask&lt;V&gt;</code></td>
<td>A subclass of <code>ForkJoinTask&lt;V&gt;</code> for tasks that return values</td>
</tr>
</tbody>
</table>

Here is how they relate. A `ForkJoinPool` manages the execution of `ForkJoinTasks`. `ForkJoinTask` is an abstract class that is extended by the abstract classes `RecursiveAction` and `RecursiveTask`. Typically, your code will extend these classes to create a task. Before looking at the process in detail, an overview of the key aspects of each class will be helpful.

**NOTE** The class `CountedCompleter` (added by JDK 8) also extends `ForkJoinTask`. However, a discussion of `CountedCompleter` is beyond the scope of this book.

`ForkJoinTask<V>`

`ForkJoinTask<V>` is an abstract class that defines a task that can be managed by a `ForkJoinPool`. The type parameter `V` specifies the result type of the task. `ForkJoinTask` differs from `Thread` in that `ForkJoinTask` represents lightweight abstraction of a task, rather than a thread of execution. `ForkJoinTasks` are executed by threads managed by a thread pool of type `ForkJoinPool`. This mechanism allows a large number of tasks to be managed by a small number of actual threads. Thus, `ForkJoinTasks` are very efficient when compared to threads.

`ForkJoinTask` defines many methods. At the core are `fork()` and `join()`, shown here:

```java
final ForkJoinTask<V> fork()
final V join()
```

The `fork()` method submits the invoking task for asynchronous execution of the invoking task. This means that the thread that calls `fork()` continues to run. The `fork()` method returns `this` after the task is scheduled for execution. Prior to JDK 8, `fork()` could be executed only from within the computational portion of
another **ForkJoinTask**, which is running within a **ForkJoinPool**. (You will see how to create the computational portion of a task shortly.) However, with the advent of JDK 8, if **fork()** is not called while executing within a **ForkJoinPool**, then a common pool is automatically used. The **join()** method waits until the task on which it is called terminates. The result of the task is returned. Thus, through the use of **fork()** and **join()**, you can start one or more new tasks and then wait for them to finish.

Another important **ForkJoinTask** method is **invoke()**. It combines the fork and join operations into a single call because it begins a task and then waits for it to end. It is shown here:

```java
final V invoke()
```

The result of the invoking task is returned.

You can invoke more than one task at a time by using **invokeAll()**. Two of its forms are shown here:

```java
static void invokeAll(ForkJoinTask<? extends V> taskA, ForkJoinTask<? extends V> taskB)
static void invokeAll(ForkJoinTask<? extends V> ... taskList)
```

In the first case, **taskA** and **taskB** are executed. In the second case, all specified tasks are executed. In both cases, the calling thread waits until all of the specified tasks have terminated. Prior to JDK 8, the **invokeAll()** method could be executed only from within the computational portion of another **ForkJoinTask**, which is running within a **ForkJoinPool**. JDK 8’s inclusion of the common pool relaxed this requirement.

**RecursiveAction**

A subclass of **ForkJoinTask** is **RecursiveAction**. This class encapsulates a task that does not return a result. Typically, your code will extend **RecursiveAction** to create a task that has a **void** return type. **RecursiveAction** specifies four methods, but only one is usually of interest: the abstract method called **compute()**. When you extend **RecursiveAction** to create a concrete class, you will put the code that defines the task inside **compute()**. The **compute()** method represents the **computational** portion of the task.

The **compute()** method is defined by **RecursiveAction** like this:

```java
protected abstract void compute()
```

Notice that **compute()** is **protected** and **abstract**. This means that it must be implemented by a subclass (unless that subclass is also abstract).

In general, **RecursiveAction** is used to implement a recursive, divide-and-conquer strategy for tasks that don’t return results. (See “The Divide-and-Conquer Strategy” later in this chapter.)

**RecursiveTask<V>**
Another subclass of `ForkJoinTask` is `RecursiveTask<V>`. This class encapsulates a task that returns a result. The result type is specified by `V`. Typically, your code will extend `RecursiveTask<V>` to create a task that returns a value. Like `RecursiveAction`, it too specifies four methods, but often only the abstract `compute()` method is used, which represents the computational portion of the task. When you extend `RecursiveTask<V>` to create a concrete class, put the code that represents the task inside `compute()`. This code must also return the result of the task.

The `compute()` method is defined by `RecursiveTask<V>` like this:

```java
protected abstract V compute()
```

Notice that `compute()` is `protected` and `abstract`. This means that it must be implemented by a subclass. When implemented, it must return the result of the task.

In general, `RecursiveTask` is used to implement a recursive, divide-and-conquer strategy for tasks that return results. (See “The Divide-and-Conquer Strategy” later in this chapter.)

### ForkJoinPool

The execution of `ForkJoinTasks` takes place within a `ForkJoinPool`, which also manages the execution of the tasks. Therefore, in order to execute a `ForkJoinTask`, you must first have a `ForkJoinPool`. Beginning with JDK 8, there are two ways to acquire a `ForkJoinPool`. First, you can explicitly create one by using a `ForkJoinPool` constructor. Second, you can use what is referred to as the `common pool`. The common pool (which was added by JDK 8) is a static `ForkJoinPool` that is automatically available for your use. Each method is introduced here, beginning with manually constructing a pool.

`ForkJoinPool` defines several constructors. Here are two commonly used ones:

```java
ForkJoinPool()
ForkJoinPool(int pLevel)
```

The first creates a default pool that supports a level of parallelism equal to the number of processors available in the system. The second lets you specify the level of parallelism. Its value must be greater than zero and not more than the limits of the implementation. The level of parallelism determines the number of threads that can execute concurrently. As a result, the level of parallelism effectively determines the number of tasks that can be executed simultaneously. (Of course, the number of tasks that can execute simultaneously cannot exceed the number of processors.)

It is important to understand that the level of parallelism `does not`, however, limit the number of tasks that can be managed by the pool. A `ForkJoinPool` can manage many more tasks than its level of parallelism. Also, the level of parallelism is only a target. It is not a guarantee.

After you have created an instance of `ForkJoinPool`, you can start a task in a number of different ways. The first task started is often thought of as the main task. Frequently, the
main task begins subtasks that are also managed by the pool. One common way to begin a main task is to call `invoke()` on the `ForkJoinPool`. It is shown here:

```java
<T> T invoke(ForkJoinTask<T> task)
```

This method begins the task specified by `task`, and it returns the result of the task. This means that the calling code waits until `invoke()` returns.

To start a task without waiting for its completion, you can use `execute()`. Here is one of its forms:

```java
void execute(ForkJoinTask<? super T> task)
```

In this case, `task` is started, but the calling code does not wait for its completion. Rather, the calling code continues execution asynchronously.

Beginning with JDK 8, it is not necessary to explicitly construct a `ForkJoinPool` because a common pool is available for your use. In general, if you are not using a pool that you explicitly created, then the common pool will automatically be used. Although it won’t always be necessary, you can obtain a reference to the common pool by calling `commonPool()`, which is defined by `ForkJoinPool`. It is shown here:

```java
static ForkJoinPool commonPool()
```

A reference to the common pool is returned. The common pool provides a default level of parallelism. It can be set by use of a system property. (See the API documentation for details.) Typically, the default common pool is a good choice for many applications. Of course, you can always construct your own pool.

There are two basic ways to start a task using the common pool. First, you can obtain a reference to the pool by calling `commonPool()` and then use that reference to call `invoke()` or `execute()`, as just described. Second, you can call `ForkJoinTask` methods such as `fork()` or `invoke()` on the task from outside its computational portion. In this case, the common pool will automatically be used. In other words, `fork()` and `invoke()` will start a task using the common pool if the task is not already running within a `ForkJoinPool`.

`ForkJoinPool` manages the execution of its threads using an approach called work-stealing. Each worker thread maintains a queue of tasks. If one worker thread’s queue is empty, it will take a task from another worker thread. This adds to overall efficiency and helps maintain a balanced load. (Because of demands on CPU time by other processes in the system, even two worker threads with identical tasks in their respective queues may not complete at the same time.)

One other point: `ForkJoinPool` uses daemon threads. A daemon thread is automatically terminated when all user threads have terminated. Thus, there is no need to explicitly shut down a `ForkJoinPool`. However, with the exception of the common pool, it is possible to do so by calling `shutdown()`. The `shutdown()` method has no effect on the common pool.
The Divide-and-Conquer Strategy

As a general rule, users of the Fork/Join Framework will employ a divide-and-conquer strategy that is based on recursion. This is why the two subclasses of ForkJoinTask are called RecursiveAction and RecursiveTask. It is anticipated that you will extend one of these classes when creating your own fork/join task.

The divide-and-conquer strategy is based on recursively dividing a task into smaller subtasks until the size of a subtask is small enough to be handled sequentially. For example, a task that applies a transform to each element in an array of \( N \) integers can be broken down into two subtasks in which each transforms half the elements in the array. That is, one subtask transforms the elements 0 to \( N/2 \), and the other transforms the elements \( N/2 \) to \( N \).

In turn, each subtask can be reduced to another set of subtasks, each transforming half of the remaining elements. This process of dividing the array will continue until a threshold is reached in which a sequential solution is faster than creating another division.

The advantage of the divide-and-conquer strategy is that the processing can occur in parallel. Therefore, instead of cycling through an entire array using a single thread, pieces of the array can be processed simultaneously. Of course, the divide-and-conquer approach works in many cases in which an array (or collection) is not present, but the most common uses involve some type of array, collection, or grouping of data.

One of the keys to best employing the divide-and-conquer strategy is correctly selecting the threshold at which sequential processing (rather than further division) is used. Typically, an optimal threshold is obtained through profiling the execution characteristics. However, very significant speed-ups will still occur even when a less-than-optimal threshold is used. It is, however, best to avoid overly large or overly small thresholds. At the time of this writing, the Java API documentation for ForkJoinTask\(<T>\) states that, as a rule-of-thumb, a task should perform somewhere between 100 and 10,000 computational steps.

It is also important to understand that the optimal threshold value is also affected by how much time the computation takes. If each computational step is fairly long, then smaller thresholds might be better. Conversely, if each computational step is quite short, then larger thresholds could yield better results. For applications that are to be run on a known system, with a known number of processors, you can use the number of processors to make informed decisions about the threshold value. However, for applications that will be running on a variety of systems, the capabilities of which are not known in advance, you can make no assumptions about the execution environment.

One other point: Although multiple processors may be available on a system, other tasks (and the operating system, itself) will be competing with your application for CPU time. Thus, it is important not to assume that your program will have unrestricted access to all CPUs. Furthermore, different runs of the same program may display different run time characteristics because of varying task loads.

A Simple First Fork/Join Example

At this point, a simple example that demonstrates the Fork/Join Framework and the divide-
and-conquer strategy will be helpful. Following is a program that transforms the elements in an array of `double` into their square roots. It does so via a subclass of `RecursiveAction`. Notice that it creates its own `ForkJoinPool`.

```java
// A simple example of the basic divide-and-conquer strategy.
// In this case, RecursiveAction is used.
import java.util.concurrent.*;
import java.util.*;

// A ForkJoinTask (via RecursiveAction) that transforms
// the elements in an array of doubles into their square roots.
```
class SqrtTransform extends RecursiveAction {
    // The threshold value is arbitrarily set at 1,000 in this example.
    // In real-world code, its optimal value can be determined by
    // profiling and experimentation.
    final int seqThreshold = 1000;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;

    SqrtTransform(double[] vals, int s, int e) {
        data = vals;
        start = s;
        end = e;
    }

    // This is the method in which parallel computation will occur.
    protected void compute() {

        // If number of elements is below the sequential threshold,
        // then process sequentially.
        if ((end - start) < seqThreshold) {
            // Transform each element into its square root.
            for (int i = start; i < end; i++) {
                data[i] = Math.sqrt(data[i]);
            }
        }
        else {
            // Otherwise, continue to break the data into smaller pieces.
            int middle = (start + end) / 2;

            // Invoke new tasks, using the subdivided data.
            invokeAll(new SqrtTransform(data, start, middle),
                    new SqrtTransform(data, middle, end));
        }
    }
}

// Demonstrate parallel execution.
class ForkJoinDemo {
    public static void main(String args[]) {
        // Create a task pool.
        ForkJoinPool fjp = new ForkJoinPool();

        double[] nums = new double[100000];

        // Give nums some values.
        for (int i = 0; i < nums.length; i++)
            nums[i] = (double) i;
    }
}
The output from the program is shown here:

```
A portion of the original sequence:
0.0 1.0 2.0 3.0 4.0 5.0 6.0 7.0 9.0 9.0

A portion of the transformed sequence (to four decimal places):
0.0000 1.0000 1.4142 1.7321 2.0000 2.2361 2.4495 2.6458 2.8284 3.0000
```

As you can see, the values of the array elements have been transformed into their square roots.

Let's look closely at how this program works. First, notice that `SqrtTransform` is a class that extends `RecursiveAction`. As explained, `RecursiveAction` extends `ForkJoinTask` for tasks that do not return results. Next, notice the `final` variable `seqThreshold`. This is the value that determines when sequential processing will take place. This value is set (somewhat arbitrarily) to 1,000. Next, notice that a reference to the array to be processed is stored in `data` and that the fields `start` and `end` are used to indicate the boundaries of the elements to be accessed.

The main action of the program takes place in `compute()`. It begins by checking if the number of elements to be processed is below the sequential processing threshold. If it is, then those elements are processed (by computing their square root in this example). If the sequential processing threshold has not been reached, then two new tasks are started by calling `invokeAll()`. In this case, each subtask processes half the elements. As explained earlier, `invokeAll()` waits until both tasks return. After all of the recursive calls unwind, each element in the array will have been modified, with much of the action taking place in parallel (if multiple processors are available).

As mentioned, beginning with JDK 8, it is not necessary to explicitly construct a `ForkJoinPool` because a common pool is available for your use. Furthermore, using the common pool is a simple matter. For example, you can obtain a reference to the common
pool by calling the static `commonPool()` method defined by `ForkJoinPool`. Therefore, the preceding program could be rewritten to use the common pool by replacing the call to the `ForkJoinPool` constructor with a call to `commonPool()`, as shown here:

```java
ForkJoinPool fjp = ForkJoinPool.commonPool();
```

Alternatively, there is no need to explicitly obtain a reference to the common pool because calling the `ForkJoinTask` methods `invoke()` or `fork()` on a task that is not already part of a pool will cause it to execute within the common pool automatically. For example, in the preceding program, you can eliminate the `fjp` variable entirely and start the task using this line:

```java
task.invoke();
```

As this discussion shows, the common pool is one of the enhancements JDK 8 made to the Fork/Join Framework that improves its ease-of-use. Furthermore, in many cases, the common pool is the preferable approach, assuming that JDK 7 compatibility is not required.

---

**Understanding the Impact of the Level of Parallelism**

Before moving on, it is important to understand the impact that the level of parallelism has on the performance of a fork/join task and how the parallelism and the threshold interact. The program shown in this section lets you experiment with different degrees of parallelism and threshold values. Assuming that you are using a multicore computer, you can interactively observe the effect of these values.

In the preceding example, the default level of parallelism was used. However, you can specify the level of parallelism that you want. One way is to specify it when you create a `ForkJoinPool` using this constructor:

```java
ForkJoinPool(int pLevel)
```

Here, `pLevel` specifies the level of parallelism, which must be greater than zero and less than the implementation defined limit.

The following program creates a fork/join task that transforms an array of `doubles`. The transformation is arbitrary, but it is designed to consume several CPU cycles. This was done to ensure that the effects of changing the threshold or the level of parallelism would be more clearly displayed. To use the program, specify the threshold value and the level of parallelism on the command line. The program then runs the tasks. It also displays the amount of time it takes the tasks to run. To do this, it uses `System.nanoTime()`, which returns the value of the JVM’s high-resolution timer.
// A simple program that lets you experiment with the effects of
// changing the threshold and parallelism of a ForkJoinTask.
import java.util.concurrent.*;

// A ForkJoinTask (via RecursiveAction) that performs a
// transform on the elements of an array of doubles.
class Transform extends RecursiveAction {
    // Sequential threshold, which is set by the constructor.
    int seqThreshold;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;
Transform(double[] vals, int s, int e, int t) {
    data = vals;
    start = s;
    end = e;
    seqThreshold = t;
}

// This is the method in which parallel computation will occur.
protected void compute() {

    // If number of elements is below the sequential threshold,
    // then process sequentially.
    if((end - start) < seqThreshold) {
        // The following code assigns an element at an even index the
        // square root of its original value. An element at an odd
        // index is assigned its cube root. This code is designed
        // to simply consume CPU time so that the effects of concurrent
        // execution are more readily observable.
        for(int i = start; i < end; i++) {
            if((data[i] % 2) == 0)
                data[i] = Math.sqrt(data[i]);
            else
                data[i] = Math.cbrt(data[i]);
        }
    }
    else {
        // Otherwise, continue to break the data into smaller pieces.

        // Find the midpoint.
        int middle = (start + end) / 2;

        // Invoke new tasks, using the subdivided data.
        invokeAll(new Transform(data, start, middle, seqThreshold),
                   new Transform(data, middle, end, seqThreshold));
    }
}

// Demonstrate parallel execution.

class FJExperiment {

    public static void main(String args[]) {
        int pLevel;
        int threshold;

        if(args.length != 2) {
            System.out.println("Usage: FJExperiment parallelism threshold ");
            return;
        }

        pLevel = Integer.parseInt(args[0]);
        threshold = Integer.parseInt(args[1]);

        // These variables are used to time the task.
        long beginT, endT;
To use the program, specify the level of parallelism followed by the threshold limit. You should try experimenting with different values for each, observing the results. Remember, to be effective, you must run the code on a computer with at least two processors. Also, understand that two different runs may (almost certainly will) produce different results because of the effect of other processes in the system consuming CPU time.

To give you an idea of the difference that parallelism makes, try this experiment. First, execute the program like this:

```java
java PJExperiment 1 1000
```

This requests 1 level of parallelism (essentially sequential execution) with a threshold of 1,000. Here is a sample run produced on a dual-core computer:

```
Level of parallelism: 1
Sequential threshold: 1000
Elapsed time: 259677487 ns
```

Now, specify 2 levels of parallelism like this:

```java
java PJExperiment 2 1000
```

Here is sample output from this run produced by the same dual-core computer:
As is evident, adding parallelism substantially decreases execution time, thus increasing the speed of the program. You should experiment with varying the threshold and parallelism on your own computer. The results may surprise you.

Here are two other methods that you might find useful when experimenting with the execution characteristics of a fork/join program. First, you can obtain the level of parallelism by calling `getParallelism()`, which is defined by `ForkJoinPool`. It is shown here:

```java
int getParallelism()
```

It returns the parallelism level currently in effect. Recall that for pools that you create, by default, this value will equal the number of available processors. (To obtain the parallelism level for the common pool, you can also use `getCommonPoolParallelism()`, which was added by JDK 8.) Second, you can obtain the number of processors available in the system by calling `availableProcessors()`, which is defined by the `Runtime` class. It is shown here:

```java
int availableProcessors()
```

The value returned may change from one call to the next because of other system demands.

### An Example that Uses RecursiveTask<T>

The two preceding examples are based on `RecursiveAction`, which means that they concurrently execute tasks that do not return results. To create a task that returns a result, use `RecursiveTask`. In general, solutions are designed in the same manner as just shown. The key difference is that the `compute()` method returns a result. Thus, you must aggregate the results, so that when the first invocation finishes, it returns the overall result. Another difference is that you will typically start a subtask by calling `fork()` and `join()` explicitly (rather than implicitly by calling `invokeAll()`, for example).

The following program demonstrates `RecursiveTask`. It creates a task called `Sum` that returns the summation of the values in an array of `double`. In this example, the array consists of 5,000 elements. However, every other value is negative. Thus, the first values in the array are 0, –1, 2, –3, 4, and so on. (So that this example will work with both JDK 7 and JDK 8, it creates its own pool. You might try changing it to use the common pool as an exercise.)
// A simple example that uses RecursiveTask.<V>.
import java.util.concurrent.*;

// A RecursiveTask that computes the summation of an array of doubles.
class Sum extends RecursiveTask<Double> {

    // The sequential threshold value.
    final int seqThreshold = 500;

    // Array to be accessed.
    double[] data;

    // Determines what part of data to process.
    int start, end;

    Sum(double[] vals, int s, int e) {
        data = vals;
    }
}
Here's the output from the program:

```
Summation -2500.0
```

There are a couple of interesting items in this program. First, notice that the two subtasks are executed by calling `fork()`, as shown here:
In this case, `fork()` is used because it starts a task but does not wait for it to finish. (Thus, it asynchronously runs the task.) The result of each task is obtained by calling `join()`, as shown here:

```java
sum = subTaskA.join() + subTaskB.join();
```

This statement waits until each task ends. It then adds the results of each and assigns the total to `sum`. Thus, the summation of each subtask is added to the running total. Finally, `compute()` ends by returning `sum`, which will be the final total when the first invocation returns.

There are other ways to approach the handling of the asynchronous execution of the subtasks. For example, the following sequence uses `fork()` to start `subTaskA` and uses `invoke()` to start and wait for `subTaskB`:

```java
subTaskA.fork();
sum = subTaskB.invoke() + subTaskA.join();
```

Another alternative is to have `subTaskB` call `compute()` directly, as shown here:

```java
subTaskA.fork();
sum = subTaskB.compute() + subTaskA.join();
```

**Executing a Task Asynchronously**

The preceding programs have called `invoke()` on a `ForkJoinPool` to initiate a task. This approach is commonly used when the calling thread must wait until the task has completed (which is often the case) because `invoke()` does not return until the task has terminated. However, you can start a task asynchronously. In this approach, the calling thread continues to execute. Thus, both the calling thread and the task execute simultaneously. To start a task asynchronously, use `execute()`, which is also defined by `ForkJoinPool`. It has the two forms shown here:

```java
void execute(ForkJoinTask<?> task)
void execute(Runnable task)
```

In both forms, `task` specifies the task to run. Notice that the second form lets you specify a `Runnable` rather than a `ForkJoinTask` task. Thus, it forms a bridge between Java’s traditional approach to multithreading and the new Fork/Join Framework. It is important to remember that the threads used by a `ForkJoinPool` are daemon. Thus, they will end when the main thread ends. As a result, you may need to keep the main thread alive until the tasks have finished.
Cancelling a Task
A task can be cancelled by calling `cancel()`, which is defined by `ForkJoinTask`. It has this general form:

```java
boolean cancel(boolean interruptOK)
```

It returns `true` if the task on which it was called is cancelled. It returns `false` if the task has ended or can't be cancelled. At this time, the `interruptOK` parameter is not used by the default implementation. In general, `cancel()` is intended to be called from code outside the task because a task can easily cancel itself by returning.

You can determine if a task has been cancelled by calling `isCancelled()`, as shown here:

```java
final boolean isCancelled()
```

It returns `true` if the invoking task has been cancelled prior to completion and `false` otherwise.

Determining a Task's Completion Status
In addition to `isCancelled()`, which was just described, `ForkJoinTask` includes two other methods that you can use to determine a task's completion status. The first is `isCompletedNormally()`, which is shown here:

```java
final boolean isCompletedNormally()
```

It returns `true` if the invoking task completed normally, that is, if it did not throw an exception and it was not cancelled via a call to `cancel()`. It returns `false` otherwise.

The second is `isCompletedAbnormally()`, which is shown here:

```java
final boolean isCompletedAbnormally()
```

It returns `true` if the invoking task completed because it was cancelled or because it threw an exception. It returns `false` otherwise.

Restarting a Task
Normally, you cannot rerun a task. In other words, once a task completes, it cannot be restarted. However, you can reinitialize the state of the task (after it has completed) so it can be run again. This is done by calling `reinitialize()`, as shown here:

```java
void reinitialize()
```

This method resets the state of the invoking task. However, any modification made to any persistent data that is operated upon by the task will not be undone. For example, if the task modifies an array, then those modifications are not undone by calling `reinitialize()`.

Things to Explore
The preceding discussion presented the fundamentals of the Fork/Join Framework and described several commonly used methods. However, Fork/Join is a rich framework that includes additional capabilities that give you extended control over concurrency. Although it is far beyond the scope of this book to examine all of the issues and nuances surrounding parallel programming and the Fork/Join Framework, a sampling of the other features are mentioned here.

**A Sampling of Other ForkJoinTask Features**

In some cases, you will want to ensure that methods such as `invokeAll()` and `fork()` are called only from within a `ForkJoinTask`. (This may be especially important when using JDK 7, which does not support the common pool.) This is usually a simple matter, but occasionally, you may have code that can be executed from either inside or outside a task. You can determine if your code is executing inside a task by calling `inForkJoinPool()`. You can convert a `Runnable` or `Callable` object into a `ForkJoinTask` by using the `adapt()` method defined by `ForkJoinTask`. It has three forms, one for converting a `Callable`, one for a `Runnable` that does not return a result, and one for a `Runnable` that does return a result. In the case of a `Callable`, the `call()` method is run. In the case of `Runnable`, the `run()` method is run.

You can obtain an approximate count of the number of tasks that are in the queue of the invoking thread by calling `getQueuedTaskCount()`. You can obtain an approximate count of how many tasks the invoking thread has in its queue that are in excess of the number of other threads in the pool that might “steal” them, by calling `getSurplusQueuedTaskCount()`. Remember, in the Fork/Join Framework, work-stealing is one way in which a high level of efficiency is obtained. Although this process is automatic, in some cases, the information may prove helpful in optimizing throughput.

`ForkJoinTask` defines the following variants of `join()` and `invoke()` that begin with the prefix `quietly`. They are shown here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>final void quietlyJoin()</code></td>
<td>Joins a task, but does not return a result or throw an exception.</td>
</tr>
<tr>
<td><code>final void quietlyInvoke()</code></td>
<td>Invokes a task, but does not return a result or throw an exception.</td>
</tr>
</tbody>
</table>

In essence, these methods are similar to their non-quiet counterparts except they don’t return values or throw exceptions.

You can attempt to “un-invoke” (in other words, unschedule) a task by calling `tryUnfork()`. JDK 8 adds several methods, such as `getForkJoinTaskTag()` and `setForkJoinTaskTag()`, that support tags. Tags are short integer values that are linked with a task. They may be useful in specialized applications.
**ForkJoinTask** implements **Serializable**. Thus, it can be serialized. However, serialization is not used during execution.

**A Sampling of Other ForkJoinPool Features**

One method that is quite useful when tuning fork/join applications is **ForkJoinPool**’s override of **toString()**. It displays a “user-friendly” synopsis of the state of the pool. To see it in action, use this sequence to start and then wait for the task in the **FJExperiment** class of the task experimenter program shown earlier:

```java
// Asynchronously start the main ForkJoinTask. 
fjp.execute(task);

// Display the state of the pool while waiting. 
while(!task.isDone()) {
    System.out.println(fjp);
}
```

When you run the program, you will see a series of messages on the screen that describe the state of the pool. Here is an example of one. Of course, your output may vary, based on the number of processors, threshold values, task load, and so on.

```
java.util.concurrent.ForkJoinPool@141d683[Running, parallelism = 2, size = 2, active = 0, running = 2, steals = 0, tasks = 0, submissions = 1]
```

You can determine if a pool is currently idle by calling **isQuiescent()**. It returns **true** if the pool has no active threads and **false** otherwise.

You can obtain the number of worker threads currently in the pool by calling **getPoolSize()**. You can obtain an approximate count of the active threads in the pool by calling **getActiveThreadCount()**.

To shut down a pool, call **shutdown()**. Currently active tasks will still be executed, but no new tasks can be started. To stop a pool immediately, call **shutdownNow()**. In this case, an attempt is made to cancel currently active tasks. (It is important to point out, however, that neither of these methods affects the common pool.) You can determine if a pool is shut down by calling **isShutdown()**. It returns **true** if the pool has been shut down and **false** otherwise. To determine if the pool has been shut down and all tasks have been completed, call **isTerminated()**.

**Some Fork/Join Tips**

Here are a few tips to help you avoid some of the more troublesome pitfalls associated with using the Fork/Join Framework. First, avoid using a sequential threshold that is too low. In general, erring on the high side is better than erring on the low side. If the threshold is too low, more time can be consumed generating and switching tasks than in processing the tasks. Second, usually it is best to use the default level of parallelism. If you specify a
smaller number, it may significantly reduce the benefits of using the Fork/Join Framework. In general, a ForkJoinTask should not use synchronized methods or synchronized blocks of code. Also, you will not normally want to have the compute() method use other types of synchronization, such as a semaphore. (The new Phaser can, however, be used when appropriate because it is compatible with the fork/join mechanism.) Remember, the main idea behind a ForkJoinTask is the divide-and-conquer strategy. Such an approach does not normally lend itself to situations in which outside synchronization is needed. Also, avoid situations in which substantial blocking will occur through I/O. Therefore, in general, a ForkJoinTask will not perform I/O. Simply put, to best utilize the Fork/Join Framework, a task should perform a computation that can run without outside blocking or synchronization.

One last point: Except under unusual circumstances, do not make assumptions about the execution environment that your code will run in. This means you should not assume that some specific number of processors will be available, or that the execution characteristics of your program won't be affected by other processes running at the same time.

The Concurrency Utilities Versus Java’s Traditional Approach

Given the power and flexibility found in the concurrency utilities, it is natural to ask the following question: Do they replace Java’s traditional approach to multithreading and synchronization? The answer is a resounding no! The original support for multithreading and the built-in synchronization features are still the mechanism that should be employed for many, many Java programs, applets, and servlets. For example, synchronized, wait(), and notify() offer elegant solutions to a wide range of problems. However, when extra control is needed, the concurrency utilities are available to handle the chore. Furthermore, the Fork/Join Framework offers a powerful way to integrate parallel programming techniques into your more sophisticated applications.
Of the many new features added by JDK 8, the two that are, arguably, the most important are lambda expressions and the stream API. Lambda expressions were described in Chapter 15. The stream API is described here. As you will see, the stream API is designed with lambda expressions in mind. Moreover, the stream API provides some of the most significant demonstrations of the power that lambdas bring to Java.

Although its design compatibility with lambda expressions is impressive, the key aspect of the stream API is its ability to perform very sophisticated operations that search, filter, map, or otherwise manipulate data. For example, using the stream API, you can construct sequences of actions that resemble, in concept, the type of database queries for which you might use SQL. Furthermore, in many cases, such actions can be performed in parallel, thus providing a high level of efficiency, especially when large data sets are involved. Put simply, the stream API provides a powerful means of handling data in an efficient, yet easy to use way.

Before continuing, an important point needs to be made: The stream API uses some of Java’s most advanced features. To fully understand and utilize it requires a solid understanding of generics and lambda expressions. The basic concepts of parallel execution and a working knowledge of the Collections Framework are also needed. (See Chapters 14, 15, 18, and 28.)

**Stream Basics**

Let’s begin by defining the term *stream* as it applies to the stream API: a stream is a conduit for data. Thus, a stream represents a sequence of objects. A stream operates on a data source, such as an array or a collection. A stream, itself, never provides storage for the data. It simply moves data, possibly filtering, sorting, or otherwise operating on that data in the process. As a general rule, however, a stream operation by itself does not modify the data source. For example, sorting a stream does not change the order of the source. Rather, sorting a stream results in the creation of a new stream that produces the sorted result.
NOTE It is necessary to state that the term stream as used here differs from the use of stream when the I/O classes were described earlier in this book. Although an I/O stream can act conceptually much like one of the streams defined by java.util.stream, they are not the same. Thus, throughout this chapter, when the term stream is used, it refers to objects based on one of the stream types described here.

Stream Interfaces
The stream API defines several stream interfaces, which are packaged in java.util.stream. At the foundation is BaseStream, which defines the basic functionality available in all streams. BaseStream is a generic interface declared like this:

```
interface BaseStream<T, S extends BaseStream<T, S>>
```

Here, T specifies the type of the elements in the stream, and S specifies the type of stream that extends BaseStream. BaseStream extends the AutoCloseable interface; thus, a stream can be managed in a try-with-resources statement. In general, however, only those streams whose data source requires closing (such as those connected to a file) will need to be closed. In most cases, such as those in which the data source is a collection, there is no need to close the stream. The methods declared by BaseStream are shown in Table 29-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void close()</td>
<td>Closes the invoking stream, calling any registered close handlers. (As explained in the text, few streams need to be closed.)</td>
</tr>
<tr>
<td>boolean isParallel( )</td>
<td>Returns true if the invoking stream is parallel. Returns false if the stream is sequential.</td>
</tr>
<tr>
<td>Iterator&lt;T&gt; iterator()</td>
<td>Obtains an iterator to the stream and returns a reference to it. (Terminal operation.)</td>
</tr>
<tr>
<td>S onClose(Runnable handler)</td>
<td>Returns a new stream with the close handler specified by handler. This handler will be called when the stream is closed. (Intermediate operation.)</td>
</tr>
<tr>
<td>S parallel( )</td>
<td>Returns a parallel stream based on the invoking stream. If the invoking stream is already parallel, then that stream is returned. (Intermediate operation.)</td>
</tr>
<tr>
<td>S sequential( )</td>
<td>Returns a sequential stream based on the invoking stream. If the invoking stream is already sequential, then that stream is returned. (Intermediate operation.)</td>
</tr>
<tr>
<td>Spliterator&lt;T&gt; spliterator()</td>
<td>Obtains a spliterator to the stream and returns a reference to it. (Terminal operation.)</td>
</tr>
<tr>
<td>S unordered( )</td>
<td>Returns an unordered stream based on the invoking stream. If the invoking stream is already unordered, then that stream is returned. (Intermediate operation.)</td>
</tr>
</tbody>
</table>

Table 29-1 The Methods Declared by BaseStream
From **BaseStream** are derived several types of stream interfaces. The most general of these is **Stream**. It is declared as shown here:

```java
interface Stream<T>
```

Here, `T` specifies the type of the elements in the stream. Because it is generic, **Stream** is used for all reference types. In addition to the methods that it inherits from **BaseStream**, the **Stream** interface adds several of its own, a sampling of which is shown in Table 29-2.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>R A&gt; R collect(Comparator&lt;? super T&gt; a, R&gt; collectionFun)</code></td>
<td>Collects elements into a container, which is changeable, and returns the container. This is called a reducible operation. Here, <code>R</code> specifies the type of the resulting container and <code>T</code> specifies the element type of the invoking stream. <code>A</code> specifies the internal accumulated type. The <code>collectionFun</code> specifies how the collection process works. (Terminal operation.)</td>
</tr>
<tr>
<td><code>long count( )</code></td>
<td>Counts the number of elements in the stream and returns the result. (Terminal operation.)</td>
</tr>
<tr>
<td><code>Stream&lt;T&gt; filter(Predicate&lt;? super T&gt; pred)</code></td>
<td>Produces a stream that contains those elements from the invoking stream that satisfy the predicate specified by <code>pred</code>. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>void forEach(Consumer&lt;? super T&gt; action)</code></td>
<td>For each element in the invoking stream, the code specified by <code>action</code> is executed. (Terminal operation.)</td>
</tr>
<tr>
<td><code>&lt;R&gt; Stream&lt;T&gt; map(Function&lt;? super T, ? extends R&gt; mapFun)</code></td>
<td>Applies <code>mapFun</code> to the elements from the invoking stream, yielding a new stream that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>DoubleStream mapToDouble( ToDoubleFunction&lt;? super T&gt; mapFun)</code></td>
<td>Applies <code>mapFun</code> to the elements from the invoking stream, yielding a new <code>DoubleStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>IntStream mapToInt( ToIntFunction&lt;? super T&gt; mapFun)</code></td>
<td>Applies <code>mapFun</code> to the elements from the invoking stream, yielding a new <code>IntStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>LongStream mapToLong( ToLongFunction&lt;? super T&gt; mapFun)</code></td>
<td>Applies <code>mapFun</code> to the elements from the invoking stream, yielding a new <code>LongStream</code> that contains those elements. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>Optional&lt;T&gt; max( Comparator&lt;? super T&gt; comp)</code></td>
<td>Using the ordering specified by <code>comp</code>, finds and returns the maximum element in the invoking stream. (Terminal operation.)</td>
</tr>
<tr>
<td><code>Optional&lt;T&gt; min( Comparator&lt;? super T&gt; comp)</code></td>
<td>Using the ordering specified by <code>comp</code>, finds and returns the minimum element in the invoking stream. (Terminal operation.)</td>
</tr>
<tr>
<td><code>T reduce(IdentityBi, BinaryOperator&lt;? super T&gt; accumulator)</code></td>
<td>Returns a result based on the elements in the invoking stream. This is called a reduction operation. (Terminal operation.)</td>
</tr>
<tr>
<td><code>Stream&lt;T&gt; sorted( )</code></td>
<td>Produces a new stream that contains the elements of the invoking stream sorted in natural order. (Intermediate operation.)</td>
</tr>
<tr>
<td><code>Object[] toArray( )</code></td>
<td>Creates an array from the elements in the invoking stream. (Terminal operation.)</td>
</tr>
</tbody>
</table>
In both tables, notice that many of the methods are notated as being either terminal or intermediate. The difference between the two is very important. A terminal operation consumes the stream. It is used to produce a result, such as finding the minimum value in the stream, or to execute some action, as is the case with the forEach() method. Once a stream has been consumed, it cannot be reused. Intermediate operations produce another stream. Thus, intermediate operations can be used to create a pipeline that performs a sequence of actions. One other point: intermediate operations do not take place immediately. Instead, the specified action is performed when a terminal operation is executed on the new stream created by an intermediate operation. This mechanism is referred to as lazy behavior, and the intermediate operations are referred to as lazy. The use of lazy behavior enables the stream API to perform more efficiently.

Another key aspect of streams is that some intermediate operations are stateless and some are stateful. In a stateless operation, each element is processed independently of the others. In a stateful operation, the processing of an element may depend on aspects of the other elements. For example, sorting is a stateful operation because an element’s order depends on the values of the other elements. Thus, the sorted() method is stateful. However, filtering elements based on a stateless predicate is stateless because each element is handled individually. Thus, filter() can (and should be) stateless. The difference between stateless and stateful operations is especially important when parallel processing of a stream is desired because a stateful operation may require more than one pass to complete.

Because Stream operates on object references, it can’t operate directly on primitive types. To handle primitive type streams, the stream API defines the following interfaces:

- DoubleStream
- IntStream
- LongStream

These streams all extend BaseStream and have capabilities similar to Stream except that they operate on primitive types rather than reference types. They also provide some convenience methods, such as boxed(), that facilitate their use.

Because streams of objects are the most common, Stream is the primary focus of this chapter, but the primitive type streams can be used in much the same way.

**How to Obtain a Stream**

You can obtain a stream in a number of ways. Perhaps the most common is when a stream is obtained for a collection. Beginning with JDK 8, the Collection interface has been expanded to include two methods that obtain a stream from a collection. The first is stream(), shown here:

    default Stream<E> stream()
Its default implementation returns a sequential stream. The second method is `parallelStream()`, shown next:

```java
default Stream<E> parallelStream()
```

Its default implementation returns a parallel stream, if possible. (If a parallel stream can not be obtained, a sequential stream may be returned instead.) Parallel streams support parallel execution of stream operations. Because `Collection` is implemented by every collection, these methods can be used to obtain a stream from any collection class, such as `ArrayList` or `HashSet`.

A stream can also be obtained from an array by use of the static `stream()` method, which was added to the `Arrays` class by JDK 8. One of its forms is shown here:

```java
static <T> Stream<T> stream(T[] array)
```

This method returns a sequential stream to the elements in `array`. For example, given an array called `addresses` of type `Address`, the following obtains a stream to it:

```java
Stream<Address> addrStream = Arrays.stream(addresses);
```

Several overloads of the `stream()` method are also defined, such as those that handle arrays of the primitive types. They return a stream of type `IntStream`, `DoubleStream`, or `LongStream`.

Streams can be obtained in a variety of other ways. For example, many stream operations return a new stream, and a stream to an I/O source can be obtained by calling `lines()` on a `BufferedReader`. However a stream is obtained, it can be used in the same way as any other stream.

### A Simple Stream Example

Before going any further, let’s work through an example that uses streams. The following program creates an `ArrayList` called `myList` that holds a collection of integers (which are automatically boxed into the `Integer` reference type). Next, it obtains a stream that uses `myList` as a source. It then demonstrates various stream operations.

```java
// Demonstrate several stream operations.

import java.util.*;
import java.util.stream.*;

class StreamDemo {
    public static void main(String[] args) {
```
// Create a list of Integer values.
ArrayList<Integer> myList = new ArrayList<>();
myList.add(7);
myList.add(18);
myList.add(10);
myList.add(24);
myList.add(17);
myList.add(5);

System.out.println("Original list: " + myList);

// Obtain a Stream to the array list.
Stream<Integer> myStream = myList.stream();

// Obtain the minimum and maximum value by use of min(),
// max(), isPresent(), and get().
Optional<Integer> minVal = myStream.min(Integer::compare);
if (minVal.isPresent()) System.out.println("Minimum value: " + minVal.get());

// Must obtain a new stream because previous call to min()
// is a terminal operation that consumed the stream.
myStream = myList.stream();
Optional<Integer> maxVal = myStream.max(Integer::compare);
if (maxVal.isPresent()) System.out.println("Maximum value: " + maxVal.get());

// Sort the stream by use of sorted().
Stream<Integer> sortedStream = myList.stream().sorted();

// Display the sorted stream by use of forEach().
System.out.println("Sorted stream: ");
sortedStream.forEach(n -> System.out.print(n + " "));
System.out.println();

// Display only the odd values by use of filter().
Stream<Integer> oddVals =
    myList.stream().sorted().filter(n -> (n % 2) == 1);
System.out.println("Odd values: ");
oddVals.forEach(n -> System.out.print(n + " "));
System.out.println();

// Display only the odd values that are greater than 5. Notice that // two filter operations are pipelined.
oddVals = myList.stream().filter(n -> (n % 2) == 1)
    .filter(n -> n > 5);
System.out.println("Odd values greater than 5: ");
oddVals.forEach(n -> System.out.print(n + " "));
System.out.println();
}
Let's look closely at each stream operation. After creating an `ArrayList`, the program obtains a stream for the list by calling `stream()`, as shown here:

```java
Stream<Integer> myStream = myList.stream();
```

As explained, the `Collection` interface now defines the `stream()` method, which obtains a stream from the invoking collection. Because `Collection` is implemented by every collection class, `stream()` can be used to obtain stream for any type of collection, including the `ArrayList` used here. In this case, a reference to the stream is assigned to `myStream`. Next, the program obtains the minimum value in the stream (which is, of course, also the minimum value in the data source) and displays it, as shown here:

```java
Optional<Integer> minVal = myStream.min(Comparator::compare);
if(minVal.isPresent()) System.out.println("Minimum value: "+minVal.get());
```

Recall from Table 29-2 that `min()` is declared like this:

```java
Optional<T> min(Comparator<? super T> comp)
```

First, notice that the type of `min()`'s parameter is a `Comparator`. This comparator is used to compare two elements in the stream. In the example, `min()` is passed a method reference to `Integer`'s `compare()` method, which is used to implement a `Comparator` capable of comparing two `Integers`. Next, notice that the return type of `min()` is `Optional`. The `Optional` class is described in Chapter 19, but briefly, here is how it works. `Optional` is a generic class packaged in `java.util` and declared like this:

```java
class Optional<T>
```

Here, `T` specifies the element type. An `Optional` instance can either contain a value of type `T` or be empty. You can use `isPresent()` to determine if a value is present. Assuming that a value is available, it can be obtained by calling `get()`. In this example, the object returned will hold the minimum value of the stream as an `Integer` object.

One other point about the preceding line: `min()` is a terminal operation that consumes the stream. Thus, `myStream` cannot be used again after `min()` executes.

The next lines obtain and display the maximum value in the stream:
First, `myStream` is once again assigned the stream returned by `myList.stream()`. As just explained, this is necessary because the previous call to `min()` consumed the previous stream. Thus, a new one is needed. Next, the `max()` method is called to obtain the maximum value. Like `min()`, `max()` returns an `Optional` object. Its value is obtained by calling `get()`.

The program then obtains a sorted stream through the use of this line:

```java
Stream<Integer> sortedStream = myList.stream().sorted();
```

Here, the `sorted()` method is called on the stream returned by `myList.stream()`. Because `sorted()` is an intermediate operation, its result is a new stream, and this is the stream assigned to `sortedStream`. The contents of the sorted stream are displayed by use of `forEach()`:

```java
sortedStream.forEach((n) -> System.out.print(n + " "));
```

Here, the `forEach()` method executes an operation on each element in the stream. In this case, it simply calls `System.out.print()` for each element in `sortedStream`. This is accomplished by use of a lambda expression. The `forEach()` method has this general form:

```java
void forEach(Consumer<? super T> action)
```

`Consumer` is a generic functional interface declared in `java.util.function`. Its abstract method is `accept()`, shown here:

```java
void accept(T objRef)
```

The lambda expression in the call to `forEach()` provides the implementation of `accept()`. The `forEach()` method is a terminal operation. Thus, after it completes, the stream has been consumed.

Next, a sorted stream is filtered by `filter()` so that it contains only odd values:

```java
Stream<Integer> oddVals = myList.stream().sorted().filter(n -> (n % 2) == 1);
```

The `filter()` method filters a stream based on a predicate. It returns a new stream that contains only those elements that satisfy the predicate. It is shown here:

```java
Stream<T> filter(Predicate<? super T> pred)
```

`Predicate` is a generic functional interface defined in `java.util.function`. Its abstract method is `test()`, which is shown here:
boolean test(T objRef)

It returns \texttt{true} if the object referred to by \texttt{objRef} satisfies the predicate, and \texttt{false} otherwise. The lambda expression passed to \texttt{filter()} implements this method. Because \texttt{filter()} is an intermediate operation, it returns a new stream that contains filtered values, which, in this case, are the odd numbers. These elements are then displayed via \texttt{forEach()} as before.

Because \texttt{filter()}, or any other intermediate operation, returns a new stream, it is possible to filter a filtered stream a second time. This is demonstrated by the following line, which produces a stream that contains only those odd values greater than 5:

```java
oddVals = myList.stream().filter(n -> (n % 2) == 1).
         filter(n -> n > 5);
```

Notice that lambda expressions are passed to both filters.

\textbf{Reduction Operations}

Consider the \texttt{min()} and \texttt{max()} methods in the preceding example program. Both are terminal operations that return a result based on the elements in the stream. In the language of the stream API, they represent \textit{reduction operations} because each reduces a stream to a single value—in this case, the minimum and maximum. The stream API refers to these as \textit{special case} reductions because they perform a specific function. In addition to \texttt{min()} and \texttt{max()}, other special case reductions are also available, such as \texttt{count()}, which counts the number of elements in a stream. However, the stream API generalizes this concept by providing the \texttt{reduce()} method. By using \texttt{reduce()}, you can return a value from a stream based on any arbitrary criteria. By definition, all reduction operations are terminal operations.

\texttt{Stream} defines three versions of \texttt{reduce()}. The two we will use first are shown here:

- \texttt{Optional<T> reduce(BinaryOperator<T> accumulator)}
- \texttt{T reduce(T identityVal, BinaryOperator<T> accumulator)}

The first form returns an object of type \texttt{Optional}, which contains the result. The second form returns an object of type \texttt{T} (which is the element type of the stream). In both forms, \texttt{accumulator} is a function that operates on two values and produces a result. In the second form, \texttt{identityVal} is a value such that an accumulator operation involving \texttt{identityVal} and any element of the stream yields that element, unchanged. For example, if the operation is addition, then the identity value will be 0 because 0 + x is x. For multiplication, the value will be 1, because 1 * x is x.

\texttt{BinaryOperator} is a functional interface declared in \texttt{java.util.function} that extends the \texttt{BiFunction} functional interface. \texttt{BiFunction} defines this abstract method:

- \texttt{R apply(T val, U val2)}
Here, R specifies the result type, T is the type of the first operand, and U is the type of second operand. Thus, apply() applies a function to its two operands (val and val2) and returns the result. When BinaryOperator extends BiFunction, it specifies the same type for all the type parameters. Thus, as it relates to BinaryOperator, apply() looks like this:

```java
T apply(T val, T val2)
```

Furthermore, as it relates to reduce(), val will contain the previous result and val2 will contain the next element. In its first invocation, val will contain either the identity value or the first element, depending on which version of reduce() is used.

It is important to understand that the accumulator operation must satisfy three constraints. It must be

- Stateless
- Non-interfering
- Associative

As explained earlier, stateless means that the operation does not rely on any state information. Thus, each element is processed independently. Non-interfering means that the data source is not modified by the operation. Finally, the operation must be associative. Here, the term associative is used in its normal, arithmetic sense, which means that, given an associative operator used in a sequence of operations, it does not matter which pair of operands are processed first. For example,

```java
(10 * 2) * 7
```

yields the same result as

```java
10 * (2 * 7)
```

Associativity is of particular importance to the use of reduction operations on parallel streams, discussed in the next section.

The following program demonstrates the versions of reduce() just described:
As the output here shows, both uses of `reduce()` produce the same result:

```
Product as Optional: 2570400
Product as int: 2570400
```

In the program, the first version of `reduce()` uses the lambda expression to produce a product of two values. In this case, because the stream contains `Integer` values, the `Integer` objects are automatically unboxed for the multiplication and reboxed to return the result. The two values represent the current value of the running result and the next element in the stream. The final result is returned in an object of type `Optional`. The value is obtained by calling `get()` on the returned object.

In the second version, the identity value is explicitly specified, which for multiplication is 1. Notice that the result is returned as an object of the element type, which is `Integer` in this case.

Although simple reduction operations such as multiplication are useful for examples, reductions are not limited in this regard. For example, assuming the preceding program, the following obtains the product of only the even values:

```
int evenProduct = myList.stream().reduce(1, (a, b) -> {
    if (b % 2 == 0) return a * b; else return a;
});
```
Pay special attention to the lambda expression. If \( b \) is even, then \( a \times b \) is returned. Otherwise, \( a \) is returned. This works because \( a \) holds the current result and \( b \) holds the next element, as explained earlier.

**Using Parallel Streams**

Before exploring any more of the stream API, it will be helpful to discuss parallel streams. As has been pointed out previously in this book, the parallel execution of code via multicore processors can result in a substantial increase in performance. Because of this, parallel programming has become an important part of the modern programmer’s job. However, parallel programming can be complex and error-prone. One of the benefits that the stream library offers is the ability to easily—and reliably—parallel process certain operations.

Parallel processing of a stream is quite simple to request: just use a parallel stream. As mentioned earlier, one way to obtain a parallel stream is to use the `parallelStream()` method defined by `Collection`. Another way to obtain a parallel stream is to call the `parallel()` method on a sequential stream. The `parallel()` method is defined by `BaseStream`, as shown here:

```java
S parallel()
```

It returns a parallel stream based on the sequential stream that invokes it. (If it is called on a stream that is already parallel, then the invoking stream is returned.) Understand, of course, that even with a parallel stream, parallelism will be achieved only if the environment supports it.

Once a parallel stream has been obtained, operations on the stream can occur in parallel, assuming that parallelism is supported by the environment. For example, the first `reduce()` operation in the preceding program can be parallelized by substituting `parallelStream()` for the call to `stream()`:

```java
Optional<Integer> productObj = myList.parallelStream().reduce((a,b) -> a*b);
```

The results will be the same, but the multiplications can occur in different threads. As a general rule, any operation applied to a parallel stream must be stateless. It should also be non-interfering and associative. This ensures that the results obtained by executing operations on a parallel stream are the same as those obtained from executing the same operations on a sequential stream.

When using parallel streams, you might find the following version of `reduce()` especially helpful. It gives you a way to specify how partial results are combined:

```java
<T> U reduce(T identityVal, BiFunction<? super T, U> accumulator, BinaryOperator<U> combiner)
```

In this version, `combiner` defines the function that combines two values that have been produced by the `accumulator` function. Assuming the preceding program, the following
statement computes the product of the elements in `myList` by use of a parallel stream:

```java
int parallelProduct = myList.parallelStream().reduce(1, (a,b) -> a*b,
                                                 (a,b) -> a*b);
```

As you can see, in this example, both the accumulator and combiner perform the same function. However, there are cases in which the actions of the accumulator must differ from those of the combiner. For example, consider the following program. Here, `myList` contains a list of `double` values. It then uses the combiner version of `reduce()` to compute the product of the square roots of each element in the list.

```java
import java.util.*;
import java.util.stream.*;

class StreamDemo3 {
    public static void main(String[] args) {
        // This is now a list of double values.
        ArrayList<Double> myList = new ArrayList<>();
        myList.add(7.0);
        myList.add(18.0);
        myList.add(10.0);
        myList.add(24.0);
        myList.add(17.0);
        myList.add(5.0);
        double productOfSqrRoots = myList.parallelStream().reduce(1.0,
                                                                   (a,b) -> a * Math.sqrt(b),
                                                                   (a,b) -> a * b);
        System.out.println("Product of square roots: " + productOfSqrRoots);
    }
}
```

Notice that the accumulator function multiplies the square roots of two elements, but the combiner multiplies the partial results. Thus, the two functions differ. Moreover, for this computation to work correctly, they must differ. For example, if you tried to obtain the product of the square roots of the elements by using the following statement, an error would result:

```java
// This won't work.
double productOfSqrRoots2 = myList.parallelStream().reduce(1.0,
                                                                (a,b) -> a * Math.sqrt(b));
```

In this version of `reduce()`, the accumulator and the combiner function are one and the
same. This results in an error because when two partial results are combined, their square
roots are multiplied together rather than the partial results, themselves.
As a point of interest, if the stream in the preceding call to reduce( ) had been changed to
a sequential stream, then the operation would yield the correct answer because there would
have been no need to combine two partial results. The problem occurs when a parallel
stream is used.
You can switch a parallel stream to sequential by calling the sequential( ) method, which
is specified by BaseStream. It is shown here:

S sequential( )

In general, a stream can be switched between parallel and sequential on an as-
needed basis.
There is one other aspect of a stream to keep in mind when using parallel execution: the
order of the elements. Streams can be either ordered or unordered. In general, if the data
source is ordered, then the stream will also be ordered. However, when using a parallel
stream, a performance boost can sometimes be obtained by allowing a stream to be
unordered. When a parallel stream is unordered, each partition of the stream can be
operated on independently, without having to coordinate with the others. In cases in which
the order of the operations does not matter, it is possible to specify unordered behavior by
calling the unordered( ) method, shown here:

S unordered( )

One other point: the forEach( ) method may not preserve the ordering of a
parallel stream. If you want to perform an operation on each element in a parallel
stream while preserving the order, consider using forEachOrdered( ). It is used
just like forEach( ).

Mapping
Often it is useful to map the elements of one stream to another. For example, a stream that
contains a database of name, telephone, and e-mail address information might map only the
name and e-mail address portions to another stream. As another example, you might want
to apply some transformation to the elements in a stream. To do this, you could map the
transformed elements to a new stream. Because mapping operations are quite common, the
stream API provides built-in support for them. The most general mapping method is map( ). It is shown here:

<R> Stream<R> map(Function<? super T, ? extends R> mapFunc)

Here, R specifies the type of elements of the new stream; T is the type of elements
of the invoking stream; and mapFunc is an instance of Function, which does the
mapping. The map function must be stateless and non-interfering. Since a new
stream is returned, map( ) is an intermediate method.
Function is a functional interface declared in java.util.function. It is declared as shown
Function\(<T, R>\)

As it relates to \texttt{map()}\, T is the element type and \(R\) is the result of the mapping.

\textbf{Function} has the abstract method shown here:

\(\texttt{R apply(T val)}\)

Here, \(\texttt{val}\) is a reference to the object being mapped. The mapped result is returned.

The following is a simple example of \texttt{map()}\. It provides a variation on the previous example program. As before, the program computes the product of the square roots of the values in an \texttt{ArrayList}\. In this version, however, the square roots of the elements are first mapped to a new stream. Then, \texttt{reduce()}\ is employed to compute the product.

```java
// Map one stream to another.
import java.util.*;
import java.util.stream.*;

class StreamDemo4 {
    public static void main(String[] args) {
        // A list of double values.
        ArrayList<Double> myList = new ArrayList<Double>();
        myList.add(7.0);
        myList.add(18.0);
        myList.add(10.0);
        myList.add(24.0);
        myList.add(17.0);
        myList.add(5.0);

        // Map the square root of the elements in myList to a new stream.
        Stream<Double> sqrtRootStrm = myList.stream().map((a) -> Math.sqrt(a));

        // Find the product of the square roots.
        double productOfSqrRoots = sqrtRootStrm.reduce(1.0, (a,b) -> a*b);
        System.out.println("Product of square roots is " + productOfSqrRoots);
    }
}
```

The output is the same as before. The difference between this version and the previous is simply that the transformation (i.e., the computation of the square roots) occurs during mapping, rather than during the reduction. Because of this, it is possible to use the two-parameter form of \texttt{reduce()}\ to compute the product because it is no longer necessary to provide a separate combiner function.

Here is an example that uses \texttt{map()}\ to create a new stream that contains only selected fields from the original stream. In this case, the original stream contains objects of type \texttt{NamePhoneEmail}, which contains names, phone numbers, and e-mail addresses. The program then maps only the names and phone numbers to a new stream of \texttt{NamePhone}. 
objects. The e-mail addresses are discarded.

```java
// Use map() to create a new stream that contains only
// selected aspects of the original stream.
import java.util.*;
import java.util.stream.*;

class NamePhoneEmail {
    String name;
    String phonenum;
    String email;

    NamePhoneEmail(String n, String p, String e) {
        name = n;
        phonenum = p;
        email = e;
    }
}

class NamePhone {
    String name;
    String phonenum;

    NamePhone(String n, String p) {
        name = n;
        phonenum = p;
    }
}

class StreamDemo5 {

    public static void main(String[] args) {

        // A list of names, phone numbers, and e-mail addresses.
        ArrayList<NamePhoneEmail> myList = new ArrayList<>();
        myList.add(new NamePhoneEmail("Larry", "555-5555", "LarrySelder.com"));
        myList.add(new NamePhoneEmail("James", "555-4444", "JamesSelder.com"));
        myList.add(new NamePhoneEmail("Mary", "555-3333", "MarySelder.com"));

        System.out.println("Original values in myList: ");
        myList.stream().forEach( (a) -> {
            System.out.println(a.name + " " + a.phonenum + " " + a.email);
        });
        System.out.println();

        // Map just the names and phone numbers to a new stream.
        Stream<NamePhone> nameAndPhone = myList.stream().map( 
            (a) -> new NamePhone(a.name, a.phonenum) 
        );

        System.out.println("List of names and phone numbers: ");
        nameAndPhone.forEach( (a) -> {
            System.out.println(a.name + " " + a.phonenum);
        });
    }
}
```

The output, shown here, verifies the mapping:
Because you can pipeline more than one intermediate operation together, you can easily create very powerful actions. For example, the following statement uses `filter()` and then `map()` to produce a new stream that contains only the name and phone number of the elements with the name "James":

```java
Stream<NamePhone> nameAndPhone = myList.stream()
    .filter(a -> a.name.equals("James"))
    .map((a) -> new NamePhone(a.name, a.phonenum));
```

This type of filter operation is very common when creating database-style queries. As you gain experience with the stream API, you will find that such chains of operations can be used to create very sophisticated queries, merges, and selections on a data stream.

In addition to the version just described, three other versions of `map()` are provided. They return a primitive stream, as shown here:

```java
IntStream mapToInt(ToIntFunction<? super T> mapFunc)
LongStream mapToLong(ToLongFunction<? super T> mapFunc)
DoubleStream mapToDouble(ToDoubleFunction<? super T> mapFunc)
```

Each `mapFunc` must implement the abstract method defined by the specified interface, returning a value of the indicated type. For example, `ToDoubleFunction` specifies the `applyAsDouble(T val)` method, which must return the value of its parameter as a `double`.

Here is an example that uses a primitive stream. It first creates an `ArrayList` of `Double` values. It then uses `stream()` followed by `mapToInt()` to create an `IntStream` that contains the ceiling of each value.
The stream produced by `mapToInt( )` contains the ceiling values of the original elements in `myList`.

Before leaving the topic of mapping, it is necessary to point out that the stream API also provides methods that support flat maps. These are `flatMap( )`, `flatMapToInt( )`, `flatMapToLong( )`, and `flatMapToDouble( )`. The flat map methods are designed to handle situations in which each element in the original stream is mapped to more than one element in the resulting stream.

**Collecting**

As the preceding examples have shown, it is possible (indeed, common) to obtain a stream from a collection. Sometimes it is desirable to obtain the opposite: to obtain a collection from a stream. To perform such an action, the stream API provides the `collect( )` method.
It has two forms. The one we will use first is shown here:

```java
<R, A> R collect(Collector<? super T, A, R> collectorFunc)
```

Here, `R` specifies the type of the result, and `T` specifies the element type of the invoking stream. The internal accumulated type is specified by `A`. The `collectorFunc` specifies how the collection process works. The `collect()` method is a terminal operation.

The **Collector** interface is declared in `java.util.stream`, as shown here:

```java
interface Collector<T, A, R>
```

`T`, `A`, and `R` have the same meanings as just described. **Collector** specifies several methods, but for the purposes of this chapter, we won’t need to implement them. Instead, we will use two of the predefined collectors that are provided by the **Collectors** class, which is packaged in `java.util.stream`.

The **Collectors** class defines a number of static collector methods that you can use as-is. The two we will use are **toList()** and **toSet()**, shown here:

```java
static <T> Collector<T, ?, List<T>> toList()
static <T> Collector<T, ?, Set<T>> toSet()
```

The **toList()** method returns a collector that can be used to collect elements into a **List**. The **toSet()** method returns a collector that can be used to collect elements into a **Set**. For example, to collect elements into a **List**, you can call `collect()` like this:

```java
collect(Collectors.toList())
```

The following program puts the preceding discussion into action. It reworks the example in the previous section so that it collects the names and phone numbers into a **List** and a **Set**.
// Use collect() to create a List and a Set from a stream.

import java.util.*;
import java.util.stream.*;

class NamePhoneEmail {
    String name;
    String phoneNum;
    String email;

    NamePhoneEmail(String n, String p, String e) {
        name = n;
        phoneNum = p;
        email = e;
    }
}

class NamePhone {
    String name;
    String phoneNum;

    NamePhone(String n, String p) {
        name = n;
        phoneNum = p;
    }
}

class StreamDemo {

    public static void main(String[] args) {

        // A list of names, phone numbers, and e-mail addresses.
        ArrayList<NamePhoneEmail> myList = new ArrayList<>() {
            myList.add(new NamePhoneEmail("Larry", "555-5555",
                "Larry@HerbSchildt.com"));
            myList.add(new NamePhoneEmail("James", "555-4444",
                "James@HerbSchildt.com"));
            myList.add(new NamePhoneEmail("Mary", "555-3333",
                "Mary@HerbSchildt.com"));

        // Map just the names and phone numbers to a new stream.
        Stream<NamePhone> nameAndPhone = myList.stream().map(
            (a) -> new NamePhone(a.name, a.phoneNum)
        );

        // Use collect to create a List of the names and phone numbers.
        List<NamePhone> npList = nameAndPhone.collect(Collectors.toList());
    }
}
The output is shown here:

Names and phone numbers in a List:
Larry: 555-5555
James: 555-4444
Mary: 555-3333

Names and phone numbers in a Set:
James: 555-4444
Larry: 555-5555
Mary: 555-3333

In the program, the following line collects the name and phone numbers into a List by using toList():

List<NamePhone> npList = nameAndPhone.collect(Collectors.toList());

After this line executes, the collection referred to by npList can be used like any other List collection. For example, it can be cycled through by using a for-each for loop, as shown in the next line:

for(NamePhone e : npList)
    System.out.println(e.name + ": " + e.phonenumber);

The creation of a Set via collect(Collectors.toSet()) works in the same way. The ability to move data from a collection to a stream, and then back to a collection again is a very powerful attribute of the stream API. It gives you the ability to operate on a collection through a stream, but then repackage it as a collection. Furthermore, the stream operations can, if appropriate, occur in parallel.

The version of collect() used by the previous example is quite convenient, and often the one you want, but there is a second version that gives you more control over the collection
Here, target specifies how the object that holds the result is created. For example, to use a LinkedList as the result collection, you would specify its constructor. The accumulator function adds an element to the result and combiner combines two partial results. Thus, these functions work similarly to the way they do in reduce(). For both, they must be stateless and non-interfering. They must also be associative.

Note that the target parameter is of type Supplier. It is a functional interface declared in java.util.function. It specifies only the get() method, which has no parameters and, in this case, returns an object of type R. Thus, as it relates to collect(), get() returns a reference to a mutable storage object, such as a collection.

Note also that the types of accumulator and combiner are BiConsumer. This is a functional interface defined in java.util.function. It specifies the abstract method accept() that is shown here:

```java
void accept(T obj, U obj2)
```

This method performs some type of operation on obj and obj2. As it relates to accumulator, obj specifies the target collection, and obj2 specifies the element to add to that collection. As it relates to combiner, obj and obj2 specify two collections that will be combined.

Using the version of collect() just described, you could use a LinkedList as the target in the preceding program, as shown here:

```java
List<NamePhone> npList = nameAndPhone.collect{
    () -> new LinkedList<>(),
    (list, element) -> list.add(element),
    (listA, listB) -> listA.addAll(listB)};
```

Notice that the first argument to collect() is a lambda expression that returns a new LinkedList. The second argument uses the standard collection method add() to add an element to the list. The third element uses addAll() to combine two linked lists. As a point of interest, you can use any method defined by LinkedList to add an element to the list. For example, you could use addFirst() to add elements to the start of the list, as shown here:

```java
(list, element) -> list.addFirst(element)
```

As you may have guessed, it is not always necessary to specify a lambda expression for the arguments to collect(). Often, method and/or constructor references will suffice. For example, again assuming the preceding program, this statement creates a HashSet that
contains all of the elements in the `nameAndPhone` stream:

```java
HashSet<NamePhone> npSet = nameAndPhone.collect(HashSet::new,
        HashSet::add,
        HashSet::addAll);
```

Notice that the first argument specifies the `HashSet` constructor reference. The second and third specify method references to `HashSet`'s `add()` and `addAll()` methods.

One last point: In the language of the stream API, the `collect()` method performs what is called a mutable reduction. This is because the result of the reduction is a mutable (i.e., changeable) storage object, such as a collection.

### Iterators and Streams

Although a stream is not a data storage object, you can still use an iterator to cycle through its elements in much the same way as you would use an iterator to cycle through the elements of a collection. The stream API supports two types of iterators. The first is the traditional `Iterator`. The second is `Spliterator`, which was added by JDK 8. It provides significant advantages in certain situations when used with parallel streams.

#### Use an Iterator with a Stream

As just mentioned, you can use an iterator with a stream in just the same way that you do with a collection. Iterators are discussed in Chapter 18, but a brief review will be useful here. Iterators are objects that implement the `Iterator` interface declared in `java.util`. Its two key methods are `hasNext()` and `next()`. If there is another element to iterate, `hasNext()` returns `true`, and `false` otherwise. The `next()` method returns the next element in the iteration.

---

**NOTE** JDK 8 adds additional iterator types that handle the primitive streams: `PrimitiveIterator`, `PrimitiveIterator.OfDouble`, `PrimitiveIterator.OfLong`, and `PrimitiveIterator.OfInt`. These iterators all extend the `Iterator` interface and work in the same general way as those based directly on `Iterator`.

To obtain an iterator to a stream, call `iterator()` on the stream. The version used by `Stream` is shown here.

```java
Iterator<T> iterator()
```

Here, `T` specifies the element type. (The primitive streams return iterators of the appropriate primitive type.)
The following program shows how to iterate through the elements of a stream. In this case, the strings in an `ArrayList` are iterated, but the process is the same for any type of stream.

```java
// Use an iterator with a stream.

import java.util.*;
import java.util.stream.*;

class StreamDemo8 {
    public static void main(String[] args) {
        // Create a list of Strings.
        ArrayList<String> myList = new ArrayList<>();
        myList.add("Alpha");
        myList.add("Beta");
        myList.add("Gamma");
        myList.add("Delta");
        myList.add("Phi");
        myList.add("Omega");

        // Obtain a Stream to the array list.
        Stream<String> myStream = myList.stream();
        // Obtain an iterator to the stream.
        Iterator<String> itr = myStream.iterator();

        // Iterate the elements in the stream.
        while(itr.hasNext())
            System.out.println(itr.next());
    }
}
```

The output is shown here:

Alpha  
Beta   
Gamma  
Delta  
Phi    
Omega

**Use Spliterator**

Spliterator offers an alternative to Iterator, especially when parallel processing is involved. In general, Spliterator is more sophisticated than Iterator, and a discussion of Spliterator is found in Chapter 18. However, it will be useful to review its key features here. Spliterator defines several methods, but we only need to use three. The first is
tryAdvance( ). It performs an action on the next element and then advances the iterator. It is shown here:

    boolean tryAdvance(Consumer<? super T> action)

Here, action specifies the action that is executed on the next element in the iteration. tryAdvance( ) returns true if there is a next element. It returns false if no elements remain. As discussed earlier in this chapter, Consumer declares one method called accept( ) that receives an element of type T as an argument and returns void.

Because tryAdvance( ) returns false when there are no more elements to process, it makes the iteration loop construct very simple, for example:

    while(splitItr.tryAdvance( // perform action here );

As long as tryAdvance( ) returns true, the action is applied to the next element. When tryAdvance( ) returns false, the iteration is complete. Notice how tryAdvance( ) consolidates the purposes of hasNext( ) and next( ) provided by Iterator into a single method. This improves the efficiency of the iteration process.

The following version of the preceding program substitutes a Spliterator for the Iterator:
In some cases, you might want to perform some action on each element collectively, rather than one at a time. To handle this type of situation, Spliterator provides the `forEachRemaining()` method, shown here:

```java
default void forEachRemaining(Consumer<? super T> action)
```

This method applies `action` to each unprocessed element and then returns. For example, assuming the preceding program, the following displays the strings remaining in the stream:

```java
splitItr.forEachRemaining((n) -> System.out.println(n));
```

Notice how this method eliminates the need to provide a loop to cycle through the elements one at a time. This is another advantage of Spliterator.

One other Spliterator method of particular interest is `trySplit()`. It splits the elements being iterated in two, returning a new Spliterator to one of the partitions. The other partition remains accessible by the original Spliterator. It is shown here:

```java
Spliterator<T> trySplit()
```
If it is not possible to split the invoking `Spliterator`, `null` is returned. Otherwise, a reference to the partition is returned. For example, here is another version of the preceding program that demonstrates `trySplit()`:

```java
// Demonstrate trySplit().
import java.util.*;
import java.util.stream.*;

class StreamDemo10 {
    public static void main(String[] args) {
        // Create a list of strings.
        ArrayList<String> myList = new ArrayList<>();
        myList.add("Alpha");
        myList.add("Beta");
        myList.add("Gamma");
        myList.add("Delta");
        myList.add("Phi");
        myList.add("Omega");

        // Obtain a Stream to the array list.
        Stream<String> myStream = myList.stream();

        // Obtain a Spliterator.
        Spliterator<String> splitItr = myStream.splitter();

        // Now, split the first iterator.
        Spliterator<String> splitItr2 = splitItr.trySplit();

        // If splitItr could be split, use splitItr2 first.
        if (splitItr2 != null) {
            System.out.println("Output from splitItr2: ");
            splitItr2.forEachRemaining(n -> System.out.println(n));
        }

        // Now, use the splitItr.
        System.out.println("\nOutput from splitItr: ");
        splitItr.forEachRemaining(n -> System.out.println(n));
    }
}
```

The output is shown here:
Although splitting the Spliterator in this simple illustration is of no practical value, splitting can be of great value when parallel processing over large data sets. However, in many cases, it is better to use one of the other Stream methods in conjunction with a parallel stream, rather than manually handling these details with Spliterator. Spliterator is primarily for the cases in which none of the predefined methods seems appropriate.

**More to Explore in the Stream API**

This chapter has discussed several key aspects of the stream API and introduced the techniques required to use them, but the stream API has much more to offer. To begin, here are a few of the other methods provided by Stream that you will find helpful:

- To determine if one or more elements in a stream satisfy a specified predicate, use allMatch( ), anyMatch( ), or noneMatch( ).
- To obtain the number of elements in the stream, call count( ).
- To obtain a stream that contains only unique elements, use distinct( ).
- To create a stream that contains a specified set of elements, use of( ).

One last point: the stream API is a powerful addition to Java. It is likely that it will be enhanced over time to include even more functionality. Therefore, a periodic perusal of its API documentation is advised.
When Java was originally released, it included a set of eight packages, called the core API. Each subsequent release added to the API. Today, the Java API contains a very large number of packages. Many of the packages support areas of specialization that are beyond the scope of this book. However, several packages warrant an examination here. Four are `java.util.regex`, `java.lang.reflect`, `java.rmi`, and `java.text`. They support regular expression processing, reflection, Remote Method Invocation (RMI), and text formatting, respectively. The chapter ends by introducing the new date and time API in `java.time` and its subpackages.

The regular expression package lets you perform sophisticated pattern matching operations. This chapter provides an in-depth introduction to this package along with extensive examples. Reflection is the ability of software to analyze itself. It is an essential part of the Java Beans technology that is covered in Chapter 37. Remote Method Invocation (RMI) allows you to build Java applications that are distributed among several machines. This chapter provides a simple client/server example that uses RMI. The text formatting capabilities of `java.text` have many uses. The one examined here formats date and time strings. The new date and time API supplies an up-to-date approach to handling date and time.

**The Core Java API Packages**

At the time of this writing, Table 30-1 lists all of the core API packages defined by Java (those in the `java` namespace) and summarizes their functions.
<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.awt.dnd</td>
<td>Supports drag-and-drop operations.</td>
</tr>
<tr>
<td>java.awt.event</td>
<td>Handles events.</td>
</tr>
<tr>
<td>java.awt.font</td>
<td>Represents various types of fonts.</td>
</tr>
<tr>
<td>java.awt.geom</td>
<td>Allows you to work with geometric shapes.</td>
</tr>
<tr>
<td>java.awt.imageresizer</td>
<td>Allows input of Japanese, Chinese, and Korean characters to text editing components.</td>
</tr>
<tr>
<td>java.awt.im.spi</td>
<td>Supports alternative input devices.</td>
</tr>
<tr>
<td>java.awt.image</td>
<td>Processes images.</td>
</tr>
<tr>
<td>java.awt.image.renderable</td>
<td>Supports rendering-independent images.</td>
</tr>
<tr>
<td>java.awt.print</td>
<td>Supports general print capabilities.</td>
</tr>
<tr>
<td>java.beans</td>
<td>Allows you to build software components.</td>
</tr>
<tr>
<td>java.beans.beancontext</td>
<td>Provides an execution environment for Beans.</td>
</tr>
<tr>
<td>java.nio</td>
<td>Inputs and outputs data.</td>
</tr>
<tr>
<td>java.lang</td>
<td>Provides core functionality.</td>
</tr>
<tr>
<td>java.lang.annotation</td>
<td>Supports annotations (metadata).</td>
</tr>
<tr>
<td>java.lang.instrument</td>
<td>Supports program instrumentation.</td>
</tr>
<tr>
<td>java.lang.invoke</td>
<td>Supports dynamic languages.</td>
</tr>
<tr>
<td>java.lang.management</td>
<td>Supports management of the execution environment.</td>
</tr>
<tr>
<td>java.lang.ref</td>
<td>Enables some interaction with the garbage collector.</td>
</tr>
<tr>
<td>java.lang.reflect</td>
<td>Analyses code at run time.</td>
</tr>
<tr>
<td>java.math</td>
<td>Handles large integers and decimal numbers.</td>
</tr>
<tr>
<td>java.net</td>
<td>Supports networking.</td>
</tr>
<tr>
<td>java.nio</td>
<td>Top-level package for the NIO classes. Encapsulates buffers.</td>
</tr>
<tr>
<td>java.nio.channels</td>
<td>Encapsulates channels, which are used by the NIO system.</td>
</tr>
<tr>
<td>java.nio.channels.spi</td>
<td>Supports service providers for channels.</td>
</tr>
<tr>
<td>java.nio.charset</td>
<td>Encapsulates character sets.</td>
</tr>
<tr>
<td>java.nio.charset.spi</td>
<td>Supports service providers for character sets.</td>
</tr>
<tr>
<td>java.nio.file</td>
<td>Provides NIO support for files.</td>
</tr>
<tr>
<td>java.nio.file.attribute</td>
<td>Supports NIO file attributes.</td>
</tr>
<tr>
<td>java.nio.file.spi</td>
<td>Supports NIO service providers for files.</td>
</tr>
<tr>
<td>java.rmi</td>
<td>Provides remote method invocation.</td>
</tr>
<tr>
<td>java.rmi.activation</td>
<td>Activates persistent objects.</td>
</tr>
<tr>
<td>java.rmi.dgc</td>
<td>Manages distributed garbage collection.</td>
</tr>
<tr>
<td>java.rmi.registry</td>
<td>Maps names to remote object references.</td>
</tr>
<tr>
<td>java.rmi.server</td>
<td>Supports remote method invocation.</td>
</tr>
<tr>
<td>java.security</td>
<td>Handles certificates, keys, digests, signatures, and other security functions.</td>
</tr>
</tbody>
</table>
Table 30-1  The Core Java API Packages

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.security.cert</td>
<td>Parses and manages certificates.</td>
</tr>
<tr>
<td>java.security.interfaces</td>
<td>Defines interfaces for DSA (Digital Signature Algorithm) keys.</td>
</tr>
<tr>
<td>java.security.spec</td>
<td>Specifies keys and algorithm parameters.</td>
</tr>
<tr>
<td>java.sql</td>
<td>Communicates with a SQL (Structured Query Language) database.</td>
</tr>
<tr>
<td>java.text</td>
<td>Formats, searches, and manipulates text.</td>
</tr>
<tr>
<td>java.text.api</td>
<td>Supports service providers for text formatting classes in java.text.</td>
</tr>
<tr>
<td>java.time</td>
<td>Primary support for the new date and time API. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.time.chrono</td>
<td>Supports alternative, non-Gregorian calendars. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.time.format</td>
<td>Supports date and time formatting. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.time.temporal</td>
<td>Supports extended date and time functionality. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.time.zone</td>
<td>Supports time zones. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.util</td>
<td>Contains common utilities.</td>
</tr>
<tr>
<td>java.util.concurrent</td>
<td>Supports the concurrent utilities.</td>
</tr>
<tr>
<td>java.util.concurrent.atomic</td>
<td>Supports atomic (that is, indivisible) operations on variables without the use of locks.</td>
</tr>
<tr>
<td>java.util.concurrent.locks</td>
<td>Supports synchronization locks.</td>
</tr>
<tr>
<td>java.util.function</td>
<td>Provides several functional interfaces. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.util.jar</td>
<td>Creates and reads JAR files.</td>
</tr>
<tr>
<td>java.util.logging</td>
<td>Supports logging of information related to a program's execution.</td>
</tr>
<tr>
<td>java.util.prefs</td>
<td>Encapsulates information relating to user preference.</td>
</tr>
<tr>
<td>java.util.regex</td>
<td>Supports regular expression processing.</td>
</tr>
<tr>
<td>java.util.spi</td>
<td>Supports service providers for the utility classes in java.util.</td>
</tr>
<tr>
<td>java.util.stream</td>
<td>Supports the new stream API. (Added by JDK 8.)</td>
</tr>
<tr>
<td>java.util.zip</td>
<td>Reads and writes compressed and uncompressed ZIP files.</td>
</tr>
</tbody>
</table>

Regular Expression Processing

The java.util.regex package supports regular expression processing. As the term is used here, a *regular expression* is a string of characters that describes a character sequence. This general description, called a *pattern*, can then be used to find matches in other character sequences. Regular expressions can specify wildcard characters, sets of characters, and various quantifiers. Thus, you can specify a regular expression that represents a general form that can match several different specific character sequences.

There are two classes that support regular expression processing: **Pattern** and **Matcher**. These classes work together. Use **Pattern** to define a regular expression. Match the pattern against another sequence using **Matcher**.

### Pattern

The **Pattern** class defines no constructors. Instead, a pattern is created by calling the **compile()** factory method. One of its forms is shown here:

```
static Pattern compile(String pattern)
```

Here, `pattern` is the regular expression that you want to use. The **compile()** method transforms the string in `pattern` into a pattern that can be used for pattern matching by the **Matcher** class. It returns a **Pattern** object that contains the pattern.
Once you have created a \texttt{Pattern} object, you will use it to create a \texttt{Matcher}. This is done by calling the \texttt{matcher()} factory method defined by \texttt{Pattern}. It is shown here:

\\begin{verbatim}
Matcher matcher(CharSequence \texttt{str})
\\end{verbatim}

Here \texttt{str} is the character sequence that the pattern will be matched against. This is called the \textit{input sequence}. \texttt{CharSequence} is an interface that defines a read-only set of characters. It is implemented by the \texttt{String} class, among others. Thus, you can pass a string to \texttt{matcher()}.

\texttt{Matcher} class has no constructors. Instead, you create a \texttt{Matcher} by calling the \texttt{matcher()} factory method defined by \texttt{Pattern}, as just explained. Once you have created a \texttt{Matcher}, you will use its methods to perform various pattern matching operations. The simplest pattern matching method is \texttt{matches()}, which simply determines whether the character sequence matches the pattern. It is shown here:

\\begin{verbatim}
boolean matches()
\\end{verbatim}

It returns \texttt{true} if the sequence and the pattern match, and \texttt{false} otherwise. Understand that the entire sequence must match the pattern, not just a subsequence of it.

To determine if a subsequence of the input sequence matches the pattern, use \texttt{find()}. One version is shown here:

\\begin{verbatim}
boolean find()
\\end{verbatim}

It returns \texttt{true} if there is a matching subsequence and \texttt{false} otherwise. This method can be called repeatedly, allowing it to find all matching subsequences. Each call to \texttt{find()} begins where the previous one left off.

You can obtain a string containing the last matching sequence by calling \texttt{group()}. One of its forms is shown here:

\\begin{verbatim}
String group()
\\end{verbatim}

The matching string is returned. If no match exists, then an \texttt{IllegalStateException} is thrown.

You can obtain the index within the input sequence of the current match by calling \texttt{start()}. The index one past the end of the current match is obtained by calling \texttt{end()}. The forms used in this chapter are shown here:

\\begin{verbatim}
int start()
int end()
\\end{verbatim}

Both throw \texttt{IllegalStateException} if no match exists.

You can replace all occurrences of a matching sequence with another sequence by calling \texttt{replaceAll()}, shown here:
String replaceAll(String newStr)

Here, newStr specifies the new character sequence that will replace the ones that match the pattern. The updated input sequence is returned as a string.

**Regular Expression Syntax**

Before demonstrating Pattern and Matcher, it is necessary to explain how to construct a regular expression. Although no rule is complicated by itself, there are a large number of them, and a complete discussion is beyond the scope of this chapter. However, a few of the more commonly used constructs are described here.

In general, a regular expression is comprised of normal characters, character classes (sets of characters), wildcard characters, and quantifiers. A normal character is matched as-is. Thus, if a pattern consists of "xy", then the only input sequence that will match it is "xy".

Characters such as newline and tab are specified using the standard escape sequences, which begin with a \. For example, a newline is specified by \n. In the language of regular expressions, a normal character is also called a literal.

A character class is a set of characters. A character class is specified by putting the characters in the class between brackets. For example, the class [wxyz] matches w, x, y, or z.

To specify an inverted set, precede the characters with a ^. For example, [^wxyz] matches any character except w, x, y, or z. You can specify a range of characters using a hyphen. For example, to specify a character class that will match the digits 1 through 9, use [1-9].

The wildcard character is the . (dot) and it matches any character. Thus, a pattern that consists of "." will match these (and other) input sequences: "A", "a", "x", and so on.

A quantifier determines how many times an expression is matched. The quantifiers are shown here:

<table>
<thead>
<tr>
<th>Quantifier</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>+</td>
<td>Match one or more.</td>
</tr>
<tr>
<td>*</td>
<td>Match zero or more.</td>
</tr>
<tr>
<td>?</td>
<td>Match zero or one.</td>
</tr>
</tbody>
</table>

For example, the pattern "x+" will match "x", "xx", and "xxx", among others.

One other point: In general, if you specify an invalid expression, a PatternSyntaxException will be thrown.

**Demonstrating Pattern Matching**

The best way to understand how regular expression pattern matching operates is to work through some examples. The first, shown here, looks for a match with a literal pattern:
The output from the program is shown here:

```
Testing Java against Java.
Matches

Testing Java against Java 8.
No Match
```

Let's look closely at this program. The program begins by creating the pattern that contains the sequence "Java". Next, a Matcher is created for that pattern that has the input sequence "Java". Then, the matches( ) method is called to determine if the input sequence matches the pattern. Because the sequence and the pattern are the same, matches( ) returns true. Next, a new Matcher is created with the input sequence "Java 8" and matches( ) is called again. In this case, the pattern and the input sequence differ, and no match is found. Remember, the matches( ) function returns true only when the input sequence precisely matches the pattern. It will not return true just because a subsequence matches.

You can use find( ) to determine if the input sequence contains a subsequence that matches
the pattern. Consider the following program:

```java
// Use find() to find a subsequence.
import java.util.regex.*;

class RegExp2 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("Java");
        Matcher mat = pat.matcher("Java 8");

        System.out.println("Looking for Java in Java 8.");
        if(mat.find()) System.out.println("subsequence found");
        else System.out.println("No Match");
    }
}
```

The output is shown here:

```
Looking for Java in Java 8.
subsequence found
```

In this case, `find()` finds the subsequence "Java".
The `find()` method can be used to search the input sequence for repeated occurrences of the pattern because each call to `find()` picks up where the previous one left off. For example, the following program finds two occurrences of the pattern "test":

```java
// Use find() to find multiple subsequences.
import java.util.regex.*;

class RegExp3 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("test");
        Matcher mat = pat.matcher("test 1 2 3 test");

        while(mat.find()) {
            System.out.println("test found at index "+
                             mat.start());
        }
    }
}
```

The output is shown here:

```
test found at index 0
test found at index 11
```

As the output shows, two matches were found. The program uses the `start()` method to obtain the index of each match.
Using Wildcards and Quantifiers

Although the preceding programs show the general technique for using Pattern and Matcher, they don’t show their power. The real benefit of regular expression processing is not seen until wildcards and quantifiers are used. To begin, consider the following example that uses the + quantifier to match any arbitrarily long sequence of Ws:

```java
// Use a quantifier.
import java.util.regex.*;

class RegExpExpr4 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("W+");
        Matcher mat = pat.matcher("W WW WWW");
        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}
```

The output from the program is shown here:

```
Match: W
Match: WW
Match: WWW
```

As the output shows, the regular expression pattern "W+" matches any arbitrarily long sequence of Ws.

The next program uses a wildcard to create a pattern that will match any sequence that begins with e and ends with d. To do this, it uses the dot wildcard character along with the + quantifier.

```java
// Use wildcard and quantifier.
import java.util.regex.*;

class RegExpExpr5 {
    public static void main(String args[]) {
        Pattern pat = Pattern.compile("e.+d");
        Matcher mat = pat.matcher("extend cup end table");

        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}
```

You might be surprised by the output produced by the program, which is shown here:
Only one match is found, and it is the longest sequence that begins with \textit{e} and ends with \textit{d}. You might have expected two matches: "extend" and "end". The reason that the longer sequence is found is that, by default, \texttt{find()} matches the longest sequence that fits the pattern. This is called \textit{greedy behavior}. You can specify \textit{reluctant behavior} by adding the \texttt{?} quantifier to the pattern, as shown in this version of the program. It causes the shortest matching pattern to be obtained.

```java
// Use the ? quantifier.
import java.util.regex.*;

class RegExp6 {
    public static void main(String args[]) {
        // Use reluctant matching behavior.
        Pattern pat = Pattern.compile("e.+?d");
        Matcher mat = pat.matcher("extend cup end table");

        while(mat.find())
            System.out.println("Match: " + mat.group());
    }
}
```

The output from the program is shown here:

```
Match: extend
Match: end
```

As the output shows, the pattern "e.+?d" will match the shortest sequence that begins with \textit{e} and ends with \textit{d}. Thus, two matches are found.

\textbf{Working with Classes of Characters}
Sometimes you will want to match any sequence that contains one or more characters, in any order, that are part of a set of characters. For example, to match whole words, you want to match any sequence of the letters of the alphabet. One of the easiest ways to do this is to use a character class, which defines a set of characters. Recall that a character class is created by putting the characters you want to match between brackets. For example, to match the lowercase characters a through z, use \texttt{[a-z]}. The following program demonstrates this technique:
Using `replaceAll()` method supplied by `Matcher` lets you perform powerful search and replace operations that use regular expressions. For example, the following program replaces all occurrences of sequences that begin with "Jon" with "Eric":

```java
import java.util.regex.*;

class RegExpr8 {
    public static void main(String args[]) {
        // Use `replaceAll()`.
        String str = "Jon Jonathan Frank Ken Todd";

        Pattern pat = Pattern.compile("Jon.*? ");
        Matcher mat = pat.matcher(str);
        System.out.println("Original sequence: " + str);
        str = mat.replaceAll("Eric ");
        System.out.println("Modified sequence: " + str);
    }
}
```

The output is shown here:

```
Original sequence: Jon Jonathan Frank Ken Todd
Modified sequence: Eric Eric Frank Eric Todd
```
Because the regular expression "Jon.*?" matches any string that begins with Jon followed by zero or more characters, ending in a space, it can be used to match and replace both Jon and Jonathan with the name Eric. Such a substitution is not easily accomplished without pattern matching capabilities.

**Using split()**
You can reduce an input sequence into its individual tokens by using the **split()** method defined by **Pattern**. One form of the **split()** method is shown here:

```java
String[] split(CharSequence str)
```

It processes the input sequence passed in `str`, reducing it into tokens based on the delimiters specified by the pattern.

For example, the following program finds tokens that are separated by spaces, commas, periods, and exclamation points:

```java
// Use split().
import java.util.regex.*;

class RegExpEx9 {
    public static void main(String args[]) {
        // Match lowercase words.
        Pattern pat = Pattern.compile("[ ,!]");

        String strs[] = pat.split("one two, alpha 12! done.");
        for(int i=0; i < strs.length; i++)
            System.out.println("Next token: " + strs[i]);
    }
}
```

The output is shown here:

```
Next token: one
Next token: two
Next token: alpha
Next token: 12
Next token: done
```

As the output shows, the input sequence is reduced to its individual tokens. Notice that the delimiters are not included.
Two Pattern-Matching Options
Although the pattern-matching techniques described in the foregoing offer the greatest flexibility and power, there are two alternatives which you might find useful in some circumstances. If you only need to perform a one-time pattern match, you can use the matches( ) method defined by Pattern. It is shown here:

```java
static boolean matches(String pattern, CharSequence str)
```

It returns true if pattern matches str and false otherwise. This method automatically compiles pattern and then looks for a match. If you will be using the same pattern repeatedly, then using matches( ) is less efficient than compiling the pattern and using the pattern-matching methods defined by Matcher, as described previously.

You can also perform a pattern match by using the matches( ) method implemented by String. It is shown here:

```java
boolean matches(String pattern)
```

If the invoking string matches the regular expression in pattern, then matches( ) returns true. Otherwise, it returns false.

Exploring Regular Expressions
The overview of regular expressions presented in this section only hints at their power. Since text parsing, manipulation, and tokenization are a large part of programming, you will likely find Java’s regular expression subsystem a powerful tool that you can use to your advantage. It is, therefore, wise to explore the capabilities of regular expressions. Experiment with several different types of patterns and input sequences. Once you understand how regular expression pattern matching works, you will find it useful in many of your programming endeavors.

Reflection
Reflection is the ability of software to analyze itself. This is provided by the java.lang.reflect package and elements in Class. Reflection is an important capability, especially when using components called Java Beans. It allows you to analyze a software component and describe its capabilities dynamically, at run time rather than at compile time. For example, by using reflection, you can determine what methods, constructors, and fields a class supports. Reflection was introduced in Chapter 12. It is examined further here. The package java.lang.reflect includes several interfaces. Of special interest is Member, which defines methods that allow you to get information about a field, constructor, or method of a class. There are also ten classes in this package. These are listed in Table 30-2.
The following application illustrates a simple use of the Java reflection capabilities. It prints the constructors, fields, and methods of the class `java.awt.Dimension`. The program begins by using the `forName()` method of `Class` to get a class object for `java.awt.Dimension`. Once this is obtained, `getConstructors()`, `getFields()`, and `getMethods()` are used to analyze this class object. They return arrays of `Constructor`, `Field`, and `Method` objects that provide the information about the object. The `Constructor`, `Field`, and `Method` classes define several methods that can be used to obtain information about an object. You will want to explore these on your own. However, each supports the `toString()` method. Therefore, using `Constructor`, `Field`, and `Method` objects as arguments to the `println()` method is straightforward, as shown in the program.

<table>
<thead>
<tr>
<th>Class</th>
<th>Primary Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>AccessibleObject</td>
<td>Allows you to bypass the default access control checks.</td>
</tr>
<tr>
<td>Array</td>
<td>Allows you to dynamically create and manipulate arrays.</td>
</tr>
<tr>
<td>Constructor</td>
<td>Provides information about a constructor.</td>
</tr>
<tr>
<td>Executable</td>
<td>An abstract superclass extended by <code>Method</code> and <code>Constructor</code>. (Added by JDK 8.)</td>
</tr>
<tr>
<td>Field</td>
<td>Provides information about a field.</td>
</tr>
<tr>
<td>Method</td>
<td>Provides information about a method.</td>
</tr>
<tr>
<td>Modifier</td>
<td>Provides information about class and member access modifiers.</td>
</tr>
<tr>
<td>Parameter</td>
<td>Provides information about parameters. (Added by JDK 8.)</td>
</tr>
<tr>
<td>Proxy</td>
<td>Supports dynamic proxy classes.</td>
</tr>
<tr>
<td>ReflectPermission</td>
<td>Allows reflection of private or protected members of a class.</td>
</tr>
</tbody>
</table>

Table 30-2 Classes Defined in `java.lang.reflect`
Here is the output from this program. (The precise order may differ slightly from that shown.)
The next example uses Java's reflection capabilities to obtain the public methods of a class. The program begins by instantiating class `A`. The `getClass()` method is applied to this object reference, and it returns the `Class` object for class `A`. The `getDeclaredMethods()` method returns an array of `Method` objects that describe only the methods declared by this class. Methods inherited from superclasses such as `Object` are not included.

Each element of the `methods` array is then processed. The `getModifiers()` method returns an `int` containing flags that describe which modifiers apply for this element. The `Modifier` class provides a set of `isX` methods, shown in Table 30-3, that can be used to examine this value. For example, the static method `isPublic()` returns `true` if its argument includes the `public` modifier. Otherwise, it returns `false`. In the following program, if the method supports public access, its name is obtained by the `getName()` method and is then printed.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static boolean isAbstract(int $val$)</td>
<td>Returns true if $val$ has the abstract flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isFinal(int $val$)</td>
<td>Returns true if $val$ has the final flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isInterface(int $val$)</td>
<td>Returns true if $val$ has the interface flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isNative(int $val$)</td>
<td>Returns true if $val$ has the native flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isPrivate(int $val$)</td>
<td>Returns true if $val$ has the private flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isProtected(int $val$)</td>
<td>Returns true if $val$ has the protected flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isPublic(int $val$)</td>
<td>Returns true if $val$ has the public flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isStatic(int $val$)</td>
<td>Returns true if $val$ has the static flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isStrict(int $val$)</td>
<td>Returns true if $val$ has the strict flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isSynchronized(int $val$)</td>
<td>Returns true if $val$ has the synchronized flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isTransient(int $val$)</td>
<td>Returns true if $val$ has the transient flag set and false otherwise.</td>
</tr>
<tr>
<td>static boolean isVolatile(int $val$)</td>
<td>Returns true if $val$ has the volatile flag set and false otherwise.</td>
</tr>
</tbody>
</table>

Table 30-3 The "is" Methods Defined by Modifier That Determine Modifiers
Here is the output from this program:

```
Public Methods:
a1
a2
```

**Modifier** also includes a set of static methods that return the type of modifiers that can be applied to a specific type of program element. These methods are:

- static int classModifiers()
- static int constructorModifiers()
- static int fieldModifiers()
static int interfaceModifiers( )
static int methodModifiers( )
static int parameterModifiers( ) (Added by JDK 8.)

For example, methodModifiers() returns the modifiers that can be applied to a
method. Each method returns flags, packed into an int, that indicate which
modifiers are legal. The modifier values are defined by constants in Modifier,
which include PROTECTED, PUBLIC, PRIVATE, STATIC, FINAL, and so on.

**Remote Method Invocation (RMI)**
Remote Method Invocation (RMI) allows a Java object that executes on one machine to
invoke a method of a Java object that executes on another machine. This is an important
feature, because it allows you to build distributed applications. While a complete discussion
of RMI is outside the scope of this book, the following simplified example describes the basic
principles involved.

**A Simple Client/Server Application Using RMI**
This section provides step-by-step directions for building a simple client/server application
by using RMI. The server receives a request from a client, processes it, and returns a result.
In this example, the request specifies two numbers. The server adds these together and
returns the sum.

**Step One: Enter and Compile the Source Code**
This application uses four source files. The first file, AddServerIntf.java, defines the
remote interface that is provided by the server. It contains one method that accepts two
double arguments and returns their sum. All remote interfaces must extend the Remote
interface, which is part of java.rmi. Remote defines no members. Its purpose is simply to
indicate that an interface uses remote methods. All remote methods can throw a
RemoteException.

```java
import java.rmi.*;

public interface AddServerIntf extends Remote {
    double add(double d1, double d2) throws RemoteException,
}
```

The second source file, AddServerImpl.java, implements the remote interface. The
implementation of the add() method is straightforward. Remote objects typically extend
UnicastRemoteObject, which provides functionality that is needed to make objects
available from remote machines.
The third source file, `AddServer.java`, contains the main program for the server machine. Its primary function is to update the RMI registry on that machine. This is done by using the `rebind()` method of the `Naming` class (found in `java.rmi`). That method associates a name with an object reference. The first argument to the `rebind()` method is a string that names the server as "AddServer". Its second argument is a reference to an instance of `AddServerImpl`

```java
import java.rmi.*;
import java.rmi.server.*;

public class AddServerImpl extends UnicastRemoteObject
    implements AddServerIntf {

    public AddServerImpl() throws RemoteException {
    }
    public double add(double d1, double d2) throws RemoteException {
        return d1 + d2;
    }
}
```

The fourth source file, `AddClient.java`, implements the client side of this distributed application. `AddClient.java` requires three command-line arguments. The first is the IP address or name of the server machine. The second and third arguments are the two numbers that are to be summed.

The application begins by forming a string that follows the URL syntax. This URL uses the `rmi` protocol. The string includes the IP address or name of the server and the string "AddServer". The program then invokes the `lookup()` method of the `Naming` class. This method accepts one argument, the `rmi` URL, and returns a reference to an object of type `AddServerIntf`. All remote method invocations can then be directed to this object.

The program continues by displaying its arguments and then invokes the remote `add()` method. The sum is returned from this method and is then printed.
import java.rmi.*;

public class AddClient {
    public static void main(String args[]) {
        try {
            String addServerURL = "rmi://" + args[0] + "/AddServer";
            AddServerIntf addServerIntf =
                (AddServerIntf) Naming.lookup(addServerURL);
            System.out.println("The first number is: " + args[1]);
            double d1 = Double.valueOf(args[1]).doubleValue();
            System.out.println("The second number is: " + args[2]);
            double d2 = Double.valueOf(args[2]).doubleValue();
            System.out.println("The sum is: " + addServerIntf.add(d1, d2));
        } catch (Exception e) {
            System.out.println("Exception: " + e);
        }
    }
}

After you enter all the code, use javac to compile the four source files that you created.

**Step Two: Manually Generate a Stub if Required**

In the context of RMI, a stub is a Java object that resides on the client machine. Its function is to present the same interfaces as the remote server. Remote method calls initiated by the client are actually directed to the stub. The stub works with the other parts of the RMI system to formulate a request that is sent to the remote machine.

A remote method may accept arguments that are simple types or objects. In the latter case, the object may have references to other objects. All of this information must be sent to the remote machine. That is, an object passed as an argument to a remote method call must be serialized and sent to the remote machine. Recall from Chapter 20 that the serialization facilities also recursively process all referenced objects.

If a response must be returned to the client, the process works in reverse. Note that the serialization and deserialization facilities are also used if objects are returned to a client.

Prior to Java 5, stubs needed to be built manually by using rmic. This step is not required for modern versions of Java. However, if you are working in a legacy environment, then you can use the rmic compiler, as shown here, to build a stub:

    rmic AddServerImpl

    This command generates the file AddServerImpl_Stub.class. When using rmic, be sure that CLASSPATH is set to include the current directory.

**Step Three: Install Files on the Client and Server Machines**

Copy AddClient.class, AddServerImpl_Stub.class (if needed), and AddServerIntf.class to a directory on the client machine. Copy AddServerIntf.class, AddServerImpl.class, AddServerImpl_Stub.class (if needed), and AddServer.class
Step Four: Start the RMI Registry on the Server Machine
The JDK provides a program called `rmiregistry`, which executes on the server machine. It maps names to object references. First, check that the `CLASSPATH` environment variable includes the directory in which your files are located. Then, start the RMI Registry from the command line, as shown here:

```
start rmiregistry
```

When this command returns, you should see that a new window has been created. You need to leave this window open until you are done experimenting with the RMI example.

Step Five: Start the Server
The server code is started from the command line, as shown here:

```
java AddServer
```

Recall that the `AddServer` code instantiates `AddServerImpl` and registers that object with the name "AddServer".

Step Six: Start the Client
The `AddClient` software requires three arguments: the name or IP address of the server machine and the two numbers that are to be summed together. You may invoke it from the command line by using one of the two formats shown here:

```
java AddClient server1 8 9
java AddClient 11.12.13.14 8 9
```

In the first line, the name of the server is provided. The second line uses its IP address (11.12.13.14).

You can try this example without actually having a remote server. To do so, simply install all of the programs on the same machine, start `rmiregistry`, start `AddServer`, and then execute `AddClient` using this command line:

```
java AddClient 127.0.0.1 8 9
```
Here, the address 127.0.0.1 is the “loop back” address for the local machine. Using this address allows you to exercise the entire RMI mechanism without actually having to install the server on a remote computer. (If you are using a firewall, then this approach may not work.)

In either case, sample output from this program is shown here:

    The first number is: 8
    The second number is: 5
    The sum is: 17.0

---

**NOTE** When working with RMI in the real world, it may be necessary for the server to install a security manager.

---

**Formatting Date and Time with java.text**

The package *java.text* allows you to format, parse, search, and manipulate text. This section examines two of its most commonly used classes: those that format date and time information. However, it is important to state at the outset that the new date and time API described later in this chapter offers a modern approach to handling date and time that also supports formatting. Of course, legacy code will continue to use the classes shown here for some time.

**DateFormat Class**

*DateFormat* is an abstract class that provides the ability to format and parse dates and times. The *getDateInstance()* method returns an instance of *DateFormat* that can format date information. It is available in these forms:

    static final DateFormat getDateInstance( )
    static final DateFormat getDateInstance(int style)
    static final DateFormat getDateInstance(int style, Locale locale)

The argument *style* is one of the following values: *DEFAULT*, *SHORT*, *MEDIUM*, *LONG*, or *FULL*. These are *int* constants defined by *DateFormat*. They cause different details about the date to be presented. The argument *locale* is one of the static references defined by *Locale* (refer to Chapter 19 for details). If the *style* and/or *locale* is not specified, defaults are used.

One of the most commonly used methods in this class is *format()* . It has several overloaded forms, one of which is shown here:

    final String format(Date d)
The argument is a `Date` object that is to be displayed. The method returns a string containing the formatted information.

The following listing illustrates how to format date information. It begins by creating a `Date` object. This captures the current date and time information. Then it outputs the date information by using different styles and locales.

```java
// Demonstrate date formats.
import java.text.*;
import java.util.*;

class DateDemo {
    public static void main(String[] args) {
        Date date = new Date();
        DateDemo df;
        df = DateDemo.getDateInstance(DateDemo.SHORT, Locale.JAPAN);
        System.out.println("Japan: " + df.format(date));
        df = DateDemo.getDateInstance(DateDemo.MEDIUM, Locale.KORSA);
        System.out.println("Korea: " + df.format(date));
        df = DateDemo.getDateInstance(DateDemo.LONG, Locale.UK);
        System.out.println("United Kingdom: " + df.format(date));
        df = DateDemo.getDateInstance(DateDemo.FULL, Locale.US);
        System.out.println("United States: " + df.format(date));
    }
}
```

Sample output from this program is shown here:

```
Japan: 14/01/01
Korea: 2014. 1. 1
United Kingdom: 01 January 2014
United States: Wednesday, January 1, 2014
```

The `getTimeInstance()` method returns an instance of `DateFormat` that can format time information. It is available in these versions:

- static final `format` method as `getTimeInstance()`
- static final `format` method as `getTimeInstance(int style)`
- static final `format` method as `getTimeInstance(int style, Locale locale)`

The argument `style` is one of the following values: `DEFAULT`, `SHORT`, `MEDIUM`, `LONG`, or `FULL`. These are `int` constants defined by `DateFormat`. They cause different details about the time to be presented. The argument `locale` is one of the static references defined by `Locale`. If the `style` and/or `locale` is not specified, defaults are used.

The following listing illustrates how to format time information. It begins by creating a
**Date** object. This captures the current date and time information. Then it outputs the time information by using different styles and locales.

```java
// Demonstrate time formats.
import java.text.*;
import java.util.*;
public class TimeFormatDemo {
    public static void main(String args[]) {
        Date date = new Date();
        DateFormat df;
        df = DateFormat.getTimeInstance(DateFormat.SHORT, Locale.JAPAN);
        System.out.println("Japan: "+ df.format(date));

        df = DateFormat.getTimeInstance(DateFormat.LONG, Locale.UK);
        System.out.println("United Kingdom:"+ df.format(date));

        df = DateFormat.getTimeInstance(DateFormat.FULL, Locale.CANADA);
        System.out.println("Canada:"+ df.format(date));
    }
}
```

Sample output from this program is shown here:

```
Japan: 13:06
United Kingdom: 13:06:53 CST
Canada: 1:06:53 o’clock PM CST
```

The **DateFormat** class also has a `getDateTimeInstance()` method that can format both date and time information. You may wish to experiment with it on your own.

**SimpleDateFormat Class**

**SimpleDateFormat** is a concrete subclass of **DateFormat**. It allows you to define your own formatting patterns that are used to display date and time information.

One of its constructors is shown here:

```java
SimpleDateFormat(String formatString)
```

The argument `formatString` describes how date and time information is displayed. An example of its use is given here:

```java
SimpleDateFormat sdf = SimpleDateFormat("dd MMM yyyy hh:mm:ss zzz");
```

The symbols used in the formatting string determine the information that is displayed. Table 30-4 lists these symbols and gives a description of each.
In most cases, the number of times a symbol is repeated determines how that data is presented. Text information is displayed in an abbreviated form if the pattern letter is repeated less than four times. Otherwise, the unabbreviated form is used. For example, a zzzzz pattern can display Pacific Daylight Time, and a zzz pattern can display PDT.

For numbers, the number of times a pattern letter is repeated determines how many digits are presented. For example, hh:mm:ss can present 01:51:15, but h:m:s displays the same time value as 1:51:15.

Finally, M or MM causes the month to be displayed as one or two digits. However, three or more repetitions of M cause the month to be displayed as a text string.

The following program shows how this class is used:
The Time and Date API Added by JDK 8

In Chapter 19, Java's long-standing approach to handling date and time through the use of classes such as `Calendar` and `GregorianCalendar` was discussed. At the time of this writing, this traditional approach is still in widespread use and is something that all Java programmers need to be familiar with. However, with the release of JDK 8, Java now includes another approach to handling time and date. This new approach is defined in the following packages:

<table>
<thead>
<tr>
<th>Package</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.time</td>
<td>Provides top-level classes that support time and date.</td>
</tr>
<tr>
<td>java.time.chrono</td>
<td>Supports alternative, non-Gregorian calendars.</td>
</tr>
<tr>
<td>java.time.format</td>
<td>Supports time and date formatting.</td>
</tr>
<tr>
<td>java.time.temporal</td>
<td>Supports extended date and time functionality.</td>
</tr>
<tr>
<td>java.time.zone</td>
<td>Supports time zones.</td>
</tr>
</tbody>
</table>

These new packages define a large number of classes, interfaces, and enumerations that provide extensive, finely grained support for time and date operations. Because of the number of elements that comprise the new time and date API, it can seem fairly
intimidating at first. However, it is well organized and logically structured. Its size reflects the detail of control and flexibility that it provides. Although it is far beyond the scope of this book to examine each element in this extensive API, we will look at several of its main classes. As you will see, these classes are sufficient for many uses.

Time and Date Fundamentals

In java.time are defined several top-level classes that give you easy access to the time and date. Three of these are LocalDate, LocalTime, and LocalDateTime. As their names suggest, they encapsulate the local date, time, and date and time. Using these classes, it is easy to obtain the current date and time, format the date and time, and compare dates and times, among other operations.

LocalDate encapsulates a date that uses the default Gregorian calendar as specified by ISO 8601. LocalTime encapsulates a time, as specified by ISO 8601. LocalDateTime encapsulates both date and time. These classes contain a large number of methods that give you access to the date and time components, allow you to compare dates and times, add or subtract date or time components, and so on. Because a common naming convention for methods is employed, once you know how to use one of these classes, the others are easy to master.

(LocalDate, LocalTime, and LocalDateTime do not define public constructors. Rather, to obtain an instance, you will use a factory method. One very convenient method is now(), which is defined for all three classes. It returns the current date and/or time of the system. Each class defines several versions, but we will use its simplest form. Here is the version we will use as defined by LocalDate:

    static LocalDate now() 

The version for LocalTime is shown here:

    static LocalTime now() 

The version for LocalDateTime is shown here:

    static LocalDateTime now() 

As you can see, in each case, an appropriate object is returned. The object returned by now() can be displayed in its default, human-readable form by use of a println() statement, for example. However, it is also possible to take full control over the formatting of date and time.

The following program uses LocalDate and LocalTime to obtain the current date and time and then displays them. Notice how now() is called to retrieve the current date and time.
// A simple example of LocalDate and LocalTime.
import java.time.*;

class DateTimeDemo {
    public static void main(String args[]) {
        LocalDate curDate = LocalDate.now();
        System.out.println(curDate);

        LocalTime curTime = LocalTime.now();
        System.out.println(curTime);
    }
}

Sample output is shown here:

2014-01-01
14:03:41.436

The output reflects the default format that is given to the date and time. (The next section shows how to specify a different format.)

Because the preceding program displays both the current date and the current time, it could have been more easily written using the LocalDate class. In this approach, only a single instance needs to be created and only a single call to now() is required, as shown here:

    LocalDateTime curDateTime = LocalDateTime.now();
    System.out.println(curDateTime);

Using this approach, the default output includes both date and time. Here is a sample:

2014-01-01T14:04:56.795

One other point: from a LocalDateTime instance, it is possible to obtain a reference to the date or time component by using the toLocalDate() and toLocalTime() methods, shown here:

    LocalDate toLocalDate()
    LocalTime toLocalTime()

Each returns a reference to the indicated element.

Formatting Date and Time
Although the default formats shown in the preceding examples will be adequate for some uses, often you will want to specify a different format. Fortunately, this is easy to do because LocalDate, LocalTime, and LocalDateTime all provide the format() method, shown

}
here:

```java
String format(DateTimeFormatter fntr)
```

Here, `fntr` specifies the instance of `DateTimeFormatter` that will provide the format.

`DateTimeFormatter` is packaged in `java.time.format`. To obtain a `DateTimeFormatter` instance, you will typically use one of its factory methods. Three are shown here:

```java
static DateTimeFormatter ofLocalizedDate(FormatStyle fmtDate)
static DateTimeFormatter ofLocalizedTime(FormatStyle fmtTime)
static DateTimeFormatter ofLocalizedDateTime(FormatStyle fmtDate, FormatStyle fmtTime)
```

Of course, the type of `DateTimeFormatter` that you create will be based on the type of object it will be operating on. For example, if you want to format the date in a `LocalDate` instance, then use `ofLocalizedDate()`. The specific format is specified by the `FormatStyle` parameter.

`FormatStyle` is an enumeration that is packaged in `java.time.format`. It defines the following constants:

- `FULL`
- `LONG`
- `MEDIUM`
- `SHORT`

These specify the level of detail that will be displayed. (Thus, this form of `DateTimeFormatter` works similarly to `java.text.SimpleDateFormat`, described earlier in this chapter.)

Here is an example that uses `DateTimeFormatter` to display the current date and time:
In some situations, you may want a format different from the ones you can specify by use of `FormatStyle`. One way to accomplish this is to use a predefined formatter, such as `ISO_DATE` or `ISO_TIME`, provided by `DateTimeFormatter`. Another way is to create a custom format by specifying a pattern. To do this, you can use the `ofPattern()` factory method of `DateTimeFormatter`. One version is shown here:

```java
static DateTimeFormatter ofPattern(String fmtPattern)
```

Here, `fmtPattern` specifies a string that contains the date and time pattern that you want. It returns a `DateTimeFormatter` that will format according to that pattern. The default locale is used.

In general, a pattern consists of format specifiers, called *pattern letters*. A pattern letter will be replaced by the date or time component that it specifies. The full list of pattern letters is shown in the API documentation for `ofPattern()`. Here is a sampling. Note that the pattern letters are case-sensitive.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>AM/PM indicator</td>
</tr>
<tr>
<td>d</td>
<td>Day in month</td>
</tr>
<tr>
<td>E</td>
<td>Day in week</td>
</tr>
<tr>
<td>h</td>
<td>Hour, 12-hour clock</td>
</tr>
<tr>
<td>H</td>
<td>Hour, 24-hour clock</td>
</tr>
<tr>
<td>M</td>
<td>Month</td>
</tr>
</tbody>
</table>
In general, the precise output that you see will be determined by how many times a pattern letter is repeated. (Thus, `DateTimeFormatter` works a bit like `java.text.SimpleDateFormat`, described earlier in this chapter.) For example, assuming that the month is April, the patterns:

- `M MM MMM MMMM`

produce the following formatted output:

```
4 04 Apr April
```

Frankly, experimentation is the best way to understand what each pattern letter does and how various repetitions affect the output.

When you want to output a pattern letter as text, enclose the text between single quotation marks. In general, it is a good idea to enclose all non-pattern characters within single quotation marks to avoid problems if the set of pattern letters changes in subsequent versions of Java.

The following program demonstrates the use of a date and time pattern:

```java
// Create a custom date and time format.
import java.time.*;
import java.time.format.*;

class DateTimeDemo3 {
    public static void main(String args[]) {
        LocalDate curDateTime = LocalDateTime.now();
        System.out.println(curDateTime.format(
            DateTimeFormatter.ofPattern("MM/dd/yyyy h:mm a")));
    }
}
```

Sample output is shown here:

```
January 1, 2014 2:22 PM
```

One other point about creating custom date and time output: `LocalDate`, `LocalTime`, and `LocalDateTime` define methods that let you obtain various date and time components. For example, `getHour()` returns the hour as an `int`; `getMonth()` returns the month in the form of a `Month` enumeration value; and `getYear()` returns the year as an `int`. Using
these, and other methods, you can manually construct output. You can also use these values for other purposes, such as when creating specialized timers.

**Parsing Date and Time Strings**

`LocalDate`, `LocalTime`, and `LocalDateTime` provide the ability to parse date and/or time strings. To do this, call `parse()` on an instance of one of those classes. It has two forms. The first uses the default formatter that parses the date and/or time formatted in the standard ISO fashion, such as 03:31 for time and 2014-08-02 for date. The form of this version of `parse()` for `LocalDateTime` is shown here. (Its form for the other classes is similar except for the type of object returned.)

```java
static LocalDateTime parse(CharSequence dateTimeStr)
```

Here, `dateTimeStr` is a string that contains the date and time in the proper format. If the format is invalid, an error will result.

If you want to parse a date and/or time string that is in a format other than ISO format, you can use a second form of `parse()` that lets you specify your own formatter. The version specified by `LocalDateTime` is shown next. (The other classes provide a similar form except for the return type.)

```java
static LocalDateTime parse(CharSequence dateTimeStr, DateTimeFormatter dateTimeFmtr)
```

Here, `dateTimeFmtr` specifies the formatter that you want to use.

Here is a simple example that parses a date and time string by use of a custom formatter:

```java
import java.time.*;
import java.time.format.*;

class DateTimeDemo {
    public static void main(String args[]) {
        // Obtain a LocalDateTime object by parsing a date and time string.
        LocalDateTime curDateTime = LocalDateTime.parse("June 21, 2014 12:01 AM", DateTimeFormatter.ofPattern("MM/dd/yyyy hh:mm a"));

        // Now, display the parsed date and time.
        System.out.println(curDateTime.format(DateTimeFormatter.ofPattern("MM/dd/yyyy hh:mm a")));
    }
}
```

Sample output is shown here:

```
June 21, 2014 12:01 AM
```

**Other Things to Explore in java.time**

Although you will want to explore all of the date and time packages, a good place to start is
with `java.time`. It contains a great deal of functionality that you may find useful. Begin by examining the methods defined by `LocalDate`, `LocalTime`, and `LocalDateTime`. Each has methods that let you add or subtract dates and/or times, adjust dates and/or times by a given component, compare dates and/or times, and create instances based on date and/or time components, among others. Other classes in `java.time` that you may find of particular interest include `Instant`, `Duration`, and `Period`. `Instant` encapsulates an instant in time. `Duration` encapsulates a length of time. `Period` encapsulates a length of date.
In Part II, you saw how to build very simple user interfaces with the AWT classes. Although the AWT is still a crucial part of Java, its component set is no longer widely used to create graphical user interfaces. Today, most programmers use Swing or JavaFX for this purpose. JavaFX is discussed in Part IV. Here, Swing is introduced. Swing is a framework that provides more powerful and flexible GUI components than does the AWT. As a result, it is the GUI that has been widely used by Java programmers for more than a decade.

Coverage of Swing is divided between three chapters. This chapter introduces Swing. It begins by describing Swing’s core concepts. It then shows the general form of a Swing program, including both applications and applets. It concludes by explaining how painting is accomplished in Swing. The next chapter presents several commonly used Swing components. The third chapter introduces Swing-based menus. It is important to understand that the number of classes and interfaces in the Swing packages is quite large, and they can’t all be covered in this book. (In fact, full coverage of Swing requires an entire book of its own.) However, these three chapters will give you a basic understanding of this important topic.


The Origins of Swing
Swing did not exist in the early days of Java. Rather, it was a response to deficiencies present in Java’s original GUI subsystem: the Abstract Window Toolkit. The AWT defines a basic set of controls, windows, and dialog boxes that support a usable, but limited graphical interface. One reason for the limited nature of the AWT is that it translates its various visual components into their corresponding, platform-specific equivalents, or peers. This means that the look and feel of a component is defined by the platform, not by Java. Because the
AWT components use native code resources, they are referred to as *heavyweight*. The use of native peers led to several problems. First, because of variations between operating systems, a component might look, or even act, differently on different platforms. This potential variability threatened the overarching philosophy of Java: write once, run anywhere. Second, the look and feel of each component was fixed (because it is defined by the platform) and could not be (easily) changed. Third, the use of heavyweight components caused some frustrating restrictions. For example, a heavyweight component was always opaque.

Not long after Java’s original release, it became apparent that the limitations and restrictions present in the AWT were sufficiently serious that a better approach was needed. The solution was Swing. Introduced in 1997, Swing was included as part of the Java Foundation Classes (JFC). Swing was initially available for use with Java 1.1 as a separate library. However, beginning with Java 1.2, Swing (and the rest of the JFC) was fully integrated into Java.

**Swing Is Built on the AWT**

Before moving on, it is necessary to make one important point: although Swing eliminates a number of the limitations inherent in the AWT, Swing *does not* replace it. Instead, Swing is built on the foundation of the AWT. This is why the AWT is still a crucial part of Java. Swing also uses the same event handling mechanism as the AWT. Therefore, a basic understanding of the AWT and of event handling is required to use Swing. (The AWT is covered in Chapters 25 and 26. Event handling is described in Chapter 24.)

**Two Key Swing Features**

As just explained, Swing was created to address the limitations present in the AWT. It does this through two key features: lightweight components and a pluggable look and feel. Together they provide an elegant, yet easy-to-use solution to the problems of the AWT. More than anything else, it is these two features that define the essence of Swing. Each is examined here.

**Swing Components Are Lightweight**

With very few exceptions, Swing components are *lightweight*. This means that they are written entirely in Java and do not map directly to platform-specific peers. Thus, lightweight components are more efficient and more flexible. Furthermore, because lightweight components do not translate into native peers, the look and feel of each component is determined by Swing, not by the underlying operating system. As a result, each component will work in a consistent manner across all platforms.

**Swing Supports a Pluggable Look and Feel**

Swing supports a *pluggable look and feel* (PLAF). Because each Swing component is rendered by Java code rather than by native peers, the look and feel of a component is under the control of Swing. This fact means that it is possible to separate the look and feel
of a component from the logic of the component, and this is what Swing does. Separating
out the look and feel provides a significant advantage: it becomes possible to change the
way that a component is rendered without affecting any of its other aspects. In other words,
it is possible to “plug in” a new look and feel for any given component without creating any
side effects in the code that uses that component. Moreover, it becomes possible to define
entire sets of look-and-feels that represent different GUI styles. To use a specific style, its
look and feel is simply “plugged in.” Once this is done, all components are automatically
rendered using that style.
Pluggable look-and-feels offer several important advantages. It is possible to define a look
and feel that is consistent across all platforms. Conversely, it is possible to create a look and
feel that acts like a specific platform. For example, if you know that an application will be
running only in a Windows environment, it is possible to specify the Windows look and feel.
It is also possible to design a custom look and feel. Finally, the look and feel can be changed
dynamically at run time.
Java 8 provides look-and-feels, such as metal and Nimbus, that are available to all Swing
users. The metal look and feel is also called the Java look and feel. It is platform-
independent and available in all Java execution environments. It is also the default look and
feel. Windows environments also have access to the Windows look and feel. This book uses
the default Java look and feel (metal) because it is platform independent.

The MVC Connection
In general, a visual component is a composite of three distinct aspects:

- The way that the component looks when rendered on the screen
- The way that the component reacts to the user
- The state information associated with the component

No matter what architecture is used to implement a component, it must implicitly
contain these three parts. Over the years, one component architecture has proven
itself to be exceptionally effective: Model-View-Controller, or MVC for short.
The MVC architecture is successful because each piece of the design corresponds to an
aspect of a component. In MVC terminology, the model corresponds to the state information
associated with the component. For example, in the case of a check box, the model contains
a field that indicates if the box is checked or unchecked. The view determines how the
component is displayed on the screen, including any aspects of the view that are affected by
the current state of the model. The controller determines how the component reacts to the
user. For example, when the user clicks a check box, the controller reacts by changing the
model to reflect the user’s choice (checked or unchecked). This then results in the view
being updated. By separating a component into a model, a view, and a controller, the
specific implementation of each can be changed without affecting the other two. For
instance, different view implementations can render the same component in different ways
without affecting the model or the controller.
Although the MVC architecture and the principles behind it are conceptually sound, the high level of separation between the view and the controller is not beneficial for Swing components. Instead, Swing uses a modified version of MVC that combines the view and the controller into a single logical entity called the UI delegate. For this reason, Swing’s approach is called either the Model-Delegate architecture or the Separable Model architecture. Therefore, although Swing’s component architecture is based on MVC, it does not use a classical implementation of it.

Swing’s pluggable look and feel is made possible by its Model-Delegate architecture. Because the view (look) and controller (feel) are separate from the model, the look and feel can be changed without affecting how the component is used within a program. Conversely, it is possible to customize the model without affecting the way that the component appears on the screen or responds to user input.

To support the Model-Delegate architecture, most Swing components contain two objects. The first represents the model. The second represents the UI delegate. Models are defined by interfaces. For example, the model for a button is defined by the ButtonModel interface. UI delegates are classes that inherit ComponentUI. For example, the UI delegate for a button is ButtonUI. Normally, your programs will not interact directly with the UI delegate.

**Components and Containers**
A Swing GUI consists of two key items: components and containers. However, this distinction is mostly conceptual because all containers are also components. The difference between the two is found in their intended purpose: As the term is commonly used, a component is an independent visual control, such as a push button or slider. A container holds a group of components. Thus, a container is a special type of component that is designed to hold other components. Furthermore, in order for a component to be displayed, it must be held within a container. Thus, all Swing GUIs will have at least one container. Because containers are components, a container can also hold other containers. This enables Swing to define what is called a containment hierarchy, at the top of which must be a top-level container.

Let's look a bit more closely at components and containers.

**Components**
In general, Swing components are derived from the JComponent class. (The only exceptions to this are the four top-level containers, described in the next section.) JComponent provides the functionality that is common to all components. For example, JComponent supports the pluggable look and feel. JComponent inherits the AWT classes Container and Component. Thus, a Swing component is built on and compatible with an AWT component.

All of Swing’s components are represented by classes defined within the package
Swing defines two types of containers. The first are top-level containers: JFrame, JApplet, JWindow, and JDialog. These containers do not inherit JComponent. They do, however, inherit the AWT classes Component and Container. Unlike Swing’s other components, which are lightweight, the top-level containers are heavyweight. This makes the top-level containers a special case in the Swing component library.

As the name implies, a top-level container must be at the top of a containment hierarchy. A top-level container is not contained within any other container. Furthermore, every containment hierarchy must begin with a top-level container. The one most commonly used for applications is JFrame. The one used for applets is JApplet.

The second type of containers supported by Swing are lightweight containers. Lightweight containers do inherit JComponent. An example of a lightweight container is JPanel, which is a general-purpose container. Lightweight containers are often used to organize and manage groups of related components because a lightweight container can be contained within another container. Thus, you can use lightweight containers such as JPanel to create subgroups of related controls that are contained within an outer container.

The Top-Level Container Panes

Each top-level container defines a set of panes. At the top of the hierarchy is an instance of JRootPane. JRootPane is a lightweight container whose purpose is to manage the other panes. It also helps manage the optional menu bar. The panes that comprise the root pane are called the glass pane, the content pane, and the layered pane.
The glass pane is the top-level pane. It sits above and completely covers all other panes. By default, it is a transparent instance of `JPanel`. The glass pane enables you to manage mouse events that affect the entire container (rather than an individual control) or to paint over any other component, for example. In most cases, you won’t need to use the glass pane directly, but it is there if you need it.

The layered pane is an instance of `JLayeredPane`. The layered pane allows components to be given a depth value. This value determines which component overlays another. (Thus, the layered pane lets you specify a Z-order for a component, although this is not something that you will usually need to do.) The layered pane holds the content pane and the (optional) menu bar.

Although the glass pane and the layered panes are integral to the operation of a top-level container and serve important purposes, much of what they provide occurs behind the scene. The pane with which your application will interact the most is the content pane, because this is the pane to which you will add visual components. In other words, when you add a component, such as a button, to a top-level container, you will add it to the content pane. By default, the content pane is an opaque instance of `JPanel`.

### The Swing Packages

Swing is a very large subsystem and makes use of many packages. At the time of this writing, these are the packages defined by Swing.

<table>
<thead>
<tr>
<th>javax.swing</th>
<th>javax.swing.plaf.basic</th>
<th>javax.swing.text</th>
</tr>
</thead>
<tbody>
<tr>
<td>javax.swing.border</td>
<td>javax.swing.plaf.metal</td>
<td>javax.swing.text.html</td>
</tr>
<tr>
<td>javax.swing.colorchooser</td>
<td>javax.swing.plaf.multi</td>
<td>javax.swing.text.html.parser</td>
</tr>
<tr>
<td>javax.swing.event</td>
<td>javax.swing.plaf.nimbus</td>
<td>javax.swing.text.rtf</td>
</tr>
<tr>
<td>javax.swing.filechooser</td>
<td>javax.swing.plaf.synth</td>
<td>javax.swing.tree</td>
</tr>
<tr>
<td>javax.swing.table</td>
<td>javax.swing.undo</td>
<td></td>
</tr>
</tbody>
</table>

The main package is `javax.swing`. This package must be imported into any program that uses Swing. It contains the classes that implement the basic Swing components, such as push buttons, labels, and check boxes.

### A Simple Swing Application

Swing programs differ from both the console-based programs and the AWT-based programs shown earlier in this book. For example, they use a different set of components and a different container hierarchy than does the AWT. Swing programs also have special requirements that relate to threading. The best way to understand the structure of a Swing program is to work through an example. There are two types of Java programs in which Swing is typically used. The first is a desktop application. The second is the applet. This section shows how to create a Swing application. The creation of a Swing applet is described later in this chapter.

Although quite short, the following program shows one way to write a Swing application. In
the process, it demonstrates several key features of Swing. It uses two Swing components: 
**JFrame** and **JLabel**. **JFrame** is the top-level container that is commonly used for Swing applications. **JLabel** is the Swing component that creates a label, which is a component that displays information. The label is Swing's simplest component because it is passive. That is, a label does not respond to user input. It just displays output. The program uses a **JFrame** container to hold an instance of a **JLabel**. The label displays a short text message.

```java
// A simple Swing application.
import javax.swing.*;

class SwingDemo {
    SwingDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("A Simple Swing Application");
        // Give the frame an initial size.
        jfrm.setSize(275, 100);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a text-based label.
        JLabel jlab = new JLabel(" Swing means powerful GUIs. ");

        // Add the label to the content pane.
        jfrm.add(jlab);

        // Display the frame.
        jfrm.setVisible(true);
    }

    public static void main(String args[]) {
        // Create the frame on the event dispatching thread.
        SwingUtilities.invokeLater(new Runnable() {
            public void run() {
                new SwingDemo();
            }
        });
    }
}
```

Swing programs are compiled and run in the same way as other Java applications. Thus, to compile this program, you can use this command line:

```
javac SwingDemo.java
```

To run the program, use this command line:
When the program is run, it will produce a window similar to that shown in Figure 31-1. Because the **SwingDemo** program illustrates several core Swing concepts, we will examine it carefully, line by line. The program begins by importing `javax.swing`. As mentioned, this package contains the components and models defined by Swing. For example, `javax.swing` defines classes that implement labels, buttons, text controls, and menus. It will be included in all programs that use Swing.

![A Simple Swing Application](image)

Figure 31-1 The window produced by the **SwingDemo** program

Next, the program declares the **SwingDemo** class and a constructor for that class. The constructor is where most of the action of the program occurs. It begins by creating a **JFrame**, using this line of code:

```
JFrame jfrm = new JFrame("A Simple Swing Application");
```

This creates a container called `jfrm` that defines a rectangular window complete with a title bar; close, minimize, maximize, and restore buttons; and a system menu. Thus, it creates a standard, top-level window. The title of the window is passed to the constructor.

Next, the window is sized using this statement:

```
jfrm.setSize(275, 100);
```

The `setSize( )` method (which is inherited by **JFrame** from the AWT class **Component**) sets the dimensions of the window, which are specified in pixels. Its general form is shown here:

```
void setSize(int width, int height)
```

In this example, the width of the window is set to 275 and the height is set to 100.

By default, when a top-level window is closed (such as when the user clicks the close box), the window is removed from the screen, but the application is not terminated. While this default behavior is useful in some situations, it is not what is needed for most applications. Instead, you will usually want the entire application to terminate when its top-level window is closed. There are a couple of ways to achieve this. The easiest way is to call **setDefaultCloseOperation( )**, as the program does:
After this call executes, closing the window causes the entire application to terminate. The general form of `setDefaultCloseOperation()` is shown here:

```java
void setDefaultCloseOperation(int what)
```

The value passed in `what` determines what happens when the window is closed. There are several other options in addition to `JFrame.EXIT_ON_CLOSE`. They are shown here:

- `DISPOSE_ON_CLOSE`
- `HIDE_ON_CLOSE`
- `DO NOTHING ON CLOSE`

Their names reflect their actions. These constants are declared in `WindowConstants`, which is an interface declared in `javax.swing` that is implemented by `JFrame`.

The next line of code creates a Swing `JLabel` component:

```java
JLabel jlab = new JLabel(" Swing means powerful GUIs.");
```

`JLabel` is the simplest and easiest-to-use component because it does not accept user input. It simply displays information, which can consist of text, an icon, or a combination of the two. The label created by the program contains only text, which is passed to its constructor. The next line of code adds the label to the content pane of the frame:

```java
jfrm.add(jlab);
```

As explained earlier, all top-level containers have a content pane in which components are stored. Thus, to add a component to a frame, you must add it to the frame's content pane. This is accomplished by calling `add()` on the `JFrame` reference (jfrm in this case). The general form of `add()` is shown here:

```java
Component add(Component comp)
```

The `add()` method is inherited by `JFrame` from the AWT class `Container`. By default, the content pane associated with a `JFrame` uses border layout. The version of `add()` just shown adds the label to the center location. Other versions of `add()` enable you to specify one of the border regions. When a component is added to the center, its size is adjusted automatically to fit the size of the center.

Before continuing, an important historical point needs to be made. Prior to JDK 5, when adding a component to the content pane, you could not invoke the `add()` method directly on a `JFrame` instance. Instead, you needed to call `add()` on the content pane of the `JFrame` object. The content pane can be obtained by calling `getContentPane()` on a
**JFrame** instance. The `getContentPane()` method is shown here:

```java
Container getContentPane()
```

It returns a `Container` reference to the content pane. The `add()` method was then called on that reference to add a component to a content pane. Thus, in the past, you had to use the following statement to add `jlab` to `jfrm`:

```java
jfrm.getContentPane().add(jlab); // old-style
```

Here, `getContentPane()` first obtains a reference to content pane, and then `add()` adds the component to the container linked to this pane. This same procedure was also required to invoke `remove()` to remove a component and `setLayout()` to set the layout manager for the content pane. You will see explicit calls to `getContentPane()` frequently throughout pre-5.0 code. Today, the use of `getContentPane()` is no longer necessary. You can simply call `add()`, `remove()`, and `setLayout()` directly on `JFrame` because these methods have been changed so that they operate on the content pane automatically.

The last statement in the `SwingDemo` constructor causes the window to become visible:

```java
jfrm.setVisible(true);
```

The `setVisible()` method is inherited from the AWT `Component` class. If its argument is `true`, the window will be displayed. Otherwise, it will be hidden. By default, a `JFrame` is invisible, so `setVisible(true)` must be called to show it.

Inside `main()`, a `SwingDemo` object is created, which causes the window and the label to be displayed. Notice that the `SwingDemo` constructor is invoked using these lines of code:

```java
SwingUtilities.invokeLater(new Runnable() {
    public void run() {
        new SwingDemo();
    }
});
```

This sequence causes a `SwingDemo` object to be created on the *event dispatching thread* rather than on the main thread of the application. Here's why. In general, Swing programs are event-driven. For example, when a user interacts with a component, an event is generated. An event is passed to the application by calling an event handler defined by the application. However, the handler is executed on the event dispatching thread provided by Swing and not on the main thread of the application. Thus, although event handlers are defined by your program, they are called on a thread that was not created by your program. To avoid problems (including the potential for deadlock), all Swing GUI components must be created and updated from the event dispatching thread, not the main thread of the application. However, `main()` is executed on the main thread. Thus, `main()` cannot
directly instantiate a **SwingDemo** object. Instead, it must create a **Runnable** object that executes on the event dispatching thread and have this object create the GUI. To enable the GUI code to be created on the event dispatching thread, you must use one of two methods that are defined by the **SwingUtilities** class. These methods are `invokeLater()` and `invokeAndWait()`. They are shown here:

```java
static void invokeLater(Runnable obj)
static void invokeAndWait(Runnable obj)
    throws InterruptedException, InvocationTargetException
```

Here, `obj` is a **Runnable** object that will have its `run()` method called by the event dispatching thread. The difference between the two methods is that `invokeLater()` returns immediately, but `invokeAndWait()` waits until `obj.run()` returns. You can use one of these methods to call a method that constructs the GUI for your Swing application, or whenever you need to modify the state of the GUI from code not executed by the event dispatching thread. You will normally want to use `invokeLater()`, as the preceding program does. However, when constructing the initial GUI for an applet, you will need to use `invokeAndWait()`.

**Event Handling**

The preceding example showed the basic form of a Swing program, but it left out one important part: event handling. Because **JLabel** does not take input from the user, it does not generate events, so no event handling was needed. However, the other Swing components do respond to user input and the events generated by those interactions need to be handled. Events can also be generated in ways not directly related to user input. For example, an event is generated when a timer goes off. Whatever the case, event handling is a large part of any Swing-based application.

The event handling mechanism used by Swing is the same as that used by the AWT. This approach is called the *delegation event model*, and it is described in Chapter 24. In many cases, Swing uses the same events as does the AWT, and these events are packaged in `java.awt.event`. Events specific to Swing are stored in `javax.swing.event`. Although events are handled in Swing in the same way as they are with the AWT, it is still useful to work through a simple example. The following program handles the event generated by a Swing push button. Sample output is shown in Figure 31-2.

![An Event Example](image)

**Figure 31-2**  Output from the **EventDemo** program
// Handle an event in a Swing program.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class EventDemo {
    JLabel jlab;

    EventDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("An Event Example");
        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());
        // Give the frame an initial size.
        jfrm.setSize(220, 90);
        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Make two buttons.
        JButton jbtnAlpha = new JButton("Alpha");
        JButton jbtnBeta = new JButton("Beta");

        // Add action listener for Alpha.
        jbtnAlpha.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                jlab.setText("Alpha was pressed.");
            }
        });

        // Add action listener for Beta.
        jbtnBeta.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                jlab.setText("Beta was pressed.");
            }
        });

        // Add the buttons to the content pane.
        jfrm.add(jbtnAlpha);
        jfrm.add(jbtnBeta);

        // Create a text-based label.
        jlab = new JLabel("Press a button.");

        // Add the label to the content pane.
        jfrm.add(jlab);

        // Display the frame.
        jfrm.setVisible(true);
    }
}
public static void main(String args[]) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(new Runnable() {
        public void run() {
            new EventDemo();
        }
    });
}

First, notice that the program now imports both the java.awt and java.awt.event packages. The java.awt package is needed because it contains the FlowLayout class, which supports the standard flow layout manager used to lay out components in a frame. (See Chapter 26 for coverage of layout managers.) The java.awt.event package is needed because it defines the ActionListener interface and the ActionEvent class.

The EventDemo constructor begins by creating a JFrame called jfrm. It then sets the layout manager for the content pane of jfrm to FlowLayout. Recall that, by default, the content pane uses BorderLayout as its layout manager. However, for this example, FlowLayout is more convenient. Notice that FlowLayout is assigned using this statement:

        jfrm.setLayout(new FlowLayout());

As explained, in the past you had to explicitly call getContentPane() to set the layout manager for the content pane. This requirement was removed as of JDK 5.

After setting the size and default close operation, EventDemo( ) creates two push buttons, as shown here:

        JButton btnAlpha = new JButton("Alpha");
        JButton btnBeta = new JButton("Beta");

The first button will contain the text "Alpha" and the second will contain the text "Beta". Swing push buttons are instances of JButton. JButton supplies several constructors. The one used here is

        JButton(String msg)

The msg parameter specifies the string that will be displayed inside the button.

When a push button is pressed, it generates an ActionEvent. Thus, JButton provides the addActionListener( ) method, which is used to add an action listener. (JButton also provides removeActionListener( ) to remove a listener, but this method is not used by the program.) As explained in Chapter 24, the ActionListener interface defines only one method: actionPerformed( ). It is shown again here for your convenience:

        void actionPerformed(ActionEvent ae)
This method is called when a button is pressed. In other words, it is the event handler that is called when a button press event has occurred.

Next, event listeners for the button’s action events are added by the code shown here:

```java
// Add action listener for Alpha.
btnAlpha.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent ae) {
        jlab.setText("Alpha was pressed.");
    }
});

// Add action listener for Beta.
btnBeta.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent ae) {
        jlab.setText("Beta was pressed.");
    }
});
```

Here, anonymous inner classes are used to provide the event handlers for the two buttons. Each time a button is pressed, the string displayed in `jlab` is changed to reflect which button was pressed.

Beginning with JDK 8, lambda expressions can also be used to implement event handlers. For example, the event handler for the Alpha button could be written like this:

```java
btnAlpha.addActionListener((ae) -> jlab.setText("Alpha was pressed."));
```

As you can see, this code is shorter. For the benefit of readers using versions of Java prior to JDK 8, subsequent examples will not use lambda expressions, but you should consider using them for new code that you create.

Next, the buttons are added to the content pane of `jfrm`:

```java
jfrm.add(btnAlpha);
jfrm.add(btnBeta);
```

Finally, `jlab` is added to the content pane and window is made visible. When you run the program, each time you press a button, a message is displayed in the label that indicates which button was pressed.

One last point: Remember that all event handlers, such as `actionPerformed()`, are called on the event dispatching thread. Therefore, an event handler must return quickly in order to avoid slowing down the application. If your application needs to do something time consuming as the result of an event, it must use a separate thread.

Create a Swing Applet
The second type of program that commonly uses Swing is the applet. Swing-based applets are similar to AWT-based applets, but with an important difference: A Swing applet extends JApplet rather than Applet. JApplet is derived from Applet. Thus, JApplet includes all of the functionality found in Applet and adds support for Swing. JApplet is a top-level Swing container, which means that it is not derived from JComponent. Because JApplet is a top-level container, it includes the various panes described earlier. This means that all components are added to JApplet’s content pane in the same way that components are added to JFrame’s content pane.

Swing applets use the same four life-cycle methods as described in Chapter 23: init( ), start( ), stop( ), and destroy( ). Of course, you need override only those methods that are needed by your applet. Painting is accomplished differently in Swing than it is in the AWT, and a Swing applet will not normally override the paint( ) method. (Painting in Swing is described later in this chapter.)

One other point: All interaction with components in a Swing applet must take place on the event dispatching thread, as described in the previous section. This threading issue applies to all Swing programs.

Here is an example of a Swing applet. It provides the same functionality as the previous application, but does so in applet form. Figure 31-3 shows the program when executed by appletviewer.

![Figure 31-3](image-url) Output from the example Swing applet
// A simple Swing-based applet

import javax.swing.*;
import java.awt.*;
import java.awt.event.*;

/*
 * This HTML can be used to launch the applet:

<applet code="MySwingApplet" width=220 height=90>
</applet>
*/

public class MySwingApplet extends JApplet {

    JButton jbtnAlpha;
    JButton jbtnBeta;
    JLabel jlab;

    // Initialize the applet.
    public void init() {
        try {
            SwingUtilities.invokeLater(new Runnable () {
                public void run() {
                    makeGUI(); // initialize the GUI
                }
            });
        } catch(Exception exc) {
            System.out.println("Can’t create because of "+ exc);
        }
    }
}
There are two important things to notice about this applet. First, **MySwingApplet** extends **JApplet**. As explained, all Swing-based applets extend **JApplet** rather than **Applet**.

Second, the **init()** method initializes the Swing components on the event dispatching thread by setting up a call to **makeGUI()**. Notice that this is accomplished through the use of **invokeAndWait()** rather than **invokeLater()**. Applets must use **invokeAndWait()** because the **init()** method must not return until the entire initialization process has been completed. In essence, the **start()** method cannot be called until after initialization, which means that the GUI must be fully constructed.
Inside `makeGUI()`, the two buttons and label are created, and the action listeners are added to the buttons. Although this example is quite simple, this same general approach must be used when building any Swing GUI that will be used by an applet.

**Painting in Swing**

Although the Swing component set is quite powerful, you are not limited to using it because Swing also lets you write directly into the display area of a frame, panel, or one of Swing’s other components, such as `JLabel`. Although many (perhaps most) uses of Swing will *not* involve drawing directly to the surface of a component, it is available for those applications that need this capability. To write output directly to the surface of a component, you will use one or more drawing methods defined by the AWT, such as `drawLine()` or `drawRect()`. Thus, most of the techniques and methods described in Chapter 25 also apply to Swing. However, there are also some very important differences, and the process is discussed in detail in this section.

**Painting Fundamentals**

Swing’s approach to painting is built on the original AWT-based mechanism, but Swing’s implementation offers more finely grained control. Before examining the specifics of Swing-based painting, it is useful to review the AWT-based mechanism that underlies it.

The AWT class `Component` defines a method called `paint()` that is used to draw output directly to the surface of a component. For the most part, `paint()` is not called by your program. (In fact, only in the most unusual cases should it ever be called by your program.) Rather, `paint()` is called by the run-time system whenever a component must be rendered. This situation can occur for several reasons. For example, the window in which the component is displayed can be overwritten by another window and then uncovered. Or, the window might be minimized and then restored. The `paint()` method is also called when a program begins running. When writing AWT-based code, an application will override `paint()` when it needs to write output directly to the surface of the component.

Because `JComponent` inherits `Component`, all Swing’s lightweight components inherit the `paint()` method. However, you *will not* override it to paint directly to the surface of a component. The reason is that Swing uses a bit more sophisticated approach to painting that involves three distinct methods: `paintComponent()`, `paintBorder()`, and `paintChildren()`. These methods paint the indicated portion of a component and divide the painting process into its three distinct, logical actions. In a lightweight component, the original AWT method `paint()` simply executes calls to these methods, in the order just shown.

To paint to the surface of a Swing component, you will create a subclass of the component and then override its `paintComponent()` method. This is the method that paints the interior of the component. You will not normally override the other two painting methods. When overriding `paintComponent()`, the first thing you must do is call
super.paintComponent( ), so that the superclass portion of the painting process takes place. (The only time this is not required is when you are taking complete, manual control over how a component is displayed.) After that, write the output that you want to display. The paintComponent( ) method is shown here:

```java
protected void paintComponent(Graphics g)
```

The parameter g is the graphics context to which output is written. To cause a component to be painted under program control, call repaint( ). It works in Swing just as it does for the AWT. The repaint( ) method is defined by Component. Calling it causes the system to call paint( ) as soon as it is possible to do so. Because painting is a time-consuming operation, this mechanism allows the run-time system to defer painting momentarily until some higher-priority task has completed, for example. Of course, in Swing the call to paint( ) results in a call to paintComponent( ). Therefore, to output to the surface of a component, your program will store the output until paintComponent( ) is called. Inside the overridden paintComponent( ), you will draw the stored output.

Compute the Paintable Area
When drawing to the surface of a component, you must be careful to restrict your output to the area that is inside the border. Although Swing automatically clips any output that will exceed the boundaries of a component, it is still possible to paint into the border, which will then get overwritten when the border is drawn. To avoid this, you must compute the paintable area of the component. This is the area defined by the current size of the component minus the space used by the border. Therefore, before you paint to a component, you must obtain the width of the border and then adjust your drawing accordingly.

To obtain the border width, call getInsets( ), shown here:

```java
Insets getInsets()
```

This method is defined by Container and overridden by JComponent. It returns an Insets object that contains the dimensions of the border. The inset values can be obtained by using these fields:

```java
int top;
int bottom;
int left;
int right;
```

These values are then used to compute the drawing area given the width and the height of the component. You can obtain the width and height of the component by calling getWidth( ) and getHeight( ) on the component. They are shown here:
int getWidth()
int getHeight()

By subtracting the value of the insets, you can compute the usable width and height of the component.

**A Paint Example**

Here is a program that puts into action the preceding discussion. It creates a class called PaintPanel that extends JPanel. The program then uses an object of that class to display lines whose endpoints have been generated randomly. Sample output is shown in Figure 31-4.

![Paint Demo](image)

**Figure 31-4** Sample output from the PaintPanel program
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import java.util.*;

// This class extends JPanel. It overrides
// the paintComponent() method so that random
// lines are plotted in the panel.
class PaintPanel extends JPanel {
    Insets ins; // holds the panel's insets
    Random rand; // used to generate random numbers

    // Construct a panel.
    PaintPanel() {

        // Put a border around the panel.
        setBorder(  
            BorderFactory.createLineBorder(Color.RED, 5));

        rand = new Random();
    }

    // Override the paintComponent() method.
    protected void paintComponent(Graphics g) {
        // Always call the superclass method first.
        super.paintComponent(g);
        int x, y, x2, y2;

        // Get the height and width of the component.
        int height = getHeight();
        int width = getWidth();

        // Get the insets.
        ins = getInsets();

        // Draw ten lines whose endpoints are randomly generated.
        for(int i=0; i < 10; i++) {

            // Draw a line.
            g.drawLine(x, y, x2, y2);

            // Generate the endpoints.
            x = rand.nextInt(width - ins.left);  
            y = rand.nextInt(height - ins.top);
            x2 = rand.nextInt(width - ins.left);  
            y2 = rand.nextInt(height - ins.top);
        }
    }
}
Let’s examine this program closely. The PaintPanel class extends JPanel. JPanel is one of Swing’s lightweight containers, which means that it is a component that can be added to the content pane of a JFrame. To handle painting, PaintPanel overrides the paintComponent() method. This enables PaintPanel to write directly to the surface of the component when painting takes place. The size of the panel is not specified because the program uses the default border layout and the panel is added to the center. This results in
the panel being sized to fill the center. If you change the size of the window, the size of the panel will be adjusted accordingly.

Notice that the constructor also specifies a 5-pixel wide, red border. This is accomplished by setting the border by using the `setBorder()` method, shown here:

```java
void setBorder(Border border)
```

*Border* is the Swing interface that encapsulates a border. You can obtain a border by calling one of the factory methods defined by the *BorderFactory* class. The one used in the program is `createLineBorder()`, which creates a simple line border. It is shown here:

```java
static Border createLineBorder(Color clr, int width)
```

Here, *clr* specifies the color of the border and *width* specifies its width in pixels.

Inside the override of `paintComponent()`, notice that it first calls `super.paintComponent()`. As explained, this is necessary to ensure that the component is properly drawn. Next, the width and height of the panel are obtained along with the insets. These values are used to ensure the lines lie within the drawing area of the panel. The drawing area is the overall width and height of a component less the border width. The computations are designed to work with differently sized *PaintPanels* and borders. To prove this, try changing the size of the window. The lines will still all lie within the borders of the panel.

The *PaintDemo* class creates a *PaintPanel* and then adds the panel to the content pane. When the application is first displayed, the overridden `paintComponent()` method is called, and the lines are drawn. Each time you resize or hide and restore the window, a new set of lines are drawn. In all cases, the lines fall within the paintable area.
The previous chapter described several of the core concepts relating to Swing and showed the general form of both a Swing application and a Swing applet. This chapter continues the discussion of Swing by presenting an overview of several Swing components, such as buttons, check boxes, trees, and tables. The Swing components provide rich functionality and allow a high level of customization. Because of space limitations, it is not possible to describe all of their features and attributes. Rather, the purpose of this overview is to give you a feel for the capabilities of the Swing component set.

The Swing component classes described in this chapter are shown here:

These components are all lightweight, which means that they are all derived from `JComponent`.

Also discussed is the `ButtonGroup` class, which encapsulates a mutually exclusive set of Swing buttons, and `ImageIcon`, which encapsulates a graphics image. Both are defined by Swing and packaged in `javax.swing`.

One other point: The Swing components are demonstrated in applets because the code for an applet is more compact than it is for a desktop application. However, the same techniques apply to both applets and applications.

**JLabel and ImageIcon**

`JLabel` is Swing’s easiest-to-use component. It creates a label and was introduced in the preceding chapter. Here, we will look at `JLabel` a bit more closely. `JLabel` can be used to display text and/or an icon. It is a passive component in that it does not respond to user input. `JLabel` defines several constructors. Here are three of them:

```
JLabel(Icon icon)
JLabel(String str)
```
JLabel(String str, Icon icon, int align)

Here, str and icon are the text and icon used for the label. The align argument
specifies the horizontal alignment of the text and/or icon within the dimensions of
the label. It must be one of the following values: LEFT, RIGHT, CENTER,
LEADING, or TRAILING. These constants are defined in the SwingConstants
interface, along with several others used by the Swing classes.

Notice that icons are specified by objects of type Icon, which is an interface defined by
Swing. The easiest way to obtain an icon is to use the ImageIcon class. ImageIcon
implements Icon and encapsulates an image. Thus, an object of type ImageIcon can be
passed as an argument to the Icon parameter of JLabel's constructor. There are several
ways to provide the image, including reading it from a file or downloading it from a URL.

Here is the ImageIcon constructor used by the example in this section:

    ImageIcon(String filename)

It obtains the image in the file named filename.
The icon and text associated with the label can be obtained by the following methods:

    Icon getIcon( )
    String getText( )

The icon and text associated with a label can be set by these methods:

    void setIcon(Icon icon)
    void setText(String str)

Here, icon and str are the icon and text, respectively. Therefore, using setText( )
it is possible to change the text inside a label during program execution.

The following applet illustrates how to create and display a label containing both an icon
and a string. It begins by creating an ImageIcon object for the file hourglass.png, which
depicts an hourglass. This is used as the second argument to the JLabel constructor. The
first and last arguments for the JLabel constructor are the label text and the alignment.
Finally, the label is added to the content pane.
// Demonstrate JLabel and ImageIcon.
import java.awt.*;
import javax.swing.*;
/**
 *<applet code="JLabelDemo" width=250 height=200>
 */

public class JLabelDemo extends JApplet {

    public void init() {
        try {
            SwingUtilities.invokeLater(
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                },
            );
        } catch (Exception exc) {
            System.out.println("Can't create because of " + exc);
        }
    }

    private void makeGUI() {

      // Create an icon.
      ImageIcon ii = new ImageIcon("hourglass.png");
      // Create a label.
      JLabel jl = new JLabel("Hourglass", ii, JLabel.CENTER);
      // Add the label to the content pane.
      add(jl);
    }
}

Output from the label example is shown here:
**JTextField**

*JTextField* is the simplest Swing text component. It is also probably its most widely used text component. *JTextField* allows you to edit one line of text. It is derived from *JTextComponent*, which provides the basic functionality common to Swing text components. *JTextField* uses the *Document* interface for its model. Three of *JTextField*’s constructors are shown here:

- JTextField(int *cols*)
- JTextField(String *str*, int *cols*)
- JTextField(String *str*)

Here, *str* is the string to be initially presented, and *cols* is the number of columns in the text field. If no string is specified, the text field is initially empty. If the number of columns is not specified, the text field is sized to fit the specified string.

*JTextField* generates events in response to user interaction. For example, an *ActionEvent* is fired when the user presses ENTER. A *CaretEvent* is fired each time the caret (i.e., the cursor) changes position. (*CaretEvent* is packaged in *javax.swing.event.*)

Other events are also possible. In many cases, your program will not need to handle these events. Instead, you will simply obtain the string currently in the text field when it is needed. To obtain the text currently in the text field, call *getText()*.

The following example illustrates *JTextField*. It creates a *JTextField* and adds it to the content pane. When the user presses ENTER, an action event is generated. This is handled by displaying the text in the status window.
// Demonstrate JTextField.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

/*
<applet code="JTextFieldDemo" width=300 height=50>
</applet>
*/

public class JTextFieldDemo extends JApplet {
    JTextField jtf;

    public void init() {
        try {
            SwingUtilities.invokeLater(
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                }
            );
        } catch (Exception exc) {
            System.out.println("Can't create because of "+ exc);
        }
    }

    private void makeGUI() {
        // Change to flow layout.
        setLayout(new FlowLayout());

        // Add text field to content pane.
        jtf = new JTextField(15);
        add(jtf);
        jtf.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                // Show text when user presses ENTER.
                showStatus(jtf.getText());
            }
        });
    }
}

Output from the text field example is shown here:
The Swing Buttons

Swing defines four types of buttons: JButton, JToggleButton, JCheckBox, and JRadioButton. All are subclasses of the AbstractButton class, which extends JComponent. Thus, all buttons share a set of common traits.

AbstractButton contains many methods that allow you to control the behavior of buttons. For example, you can define different icons that are displayed for the button when it is disabled, pressed, or selected. Another icon can be used as a rollover icon, which is displayed when the mouse is positioned over a button. The following methods set these icons:

- void setDisabledIcon(Icon di)
- void setPressedIcon(Icon pi)
- void setSelectedIcon(Icon si)
- void setRolloverIcon(Icon ri)

Here, di, pi, si, and ri are the icons to be used for the indicated purpose.

The text associated with a button can be read and written via the following methods:

- String getText( )
- void setText(String str)

Here, str is the text to be associated with the button.

The model used by all buttons is defined by the ButtonModel interface. A button generates an action event when it is pressed. Other events are possible. Each of the concrete button classes is examined next.

JButton

The JButton class provides the functionality of a push button. You have already seen a simple form of it in the preceding chapter. JButton allows an icon, a string, or both to be associated with the push button. Three of its constructors are shown here:

- JButton(Icon icon)
- JButton(String str)
- JButton(String str, Icon icon)

Here, str and icon are the string and icon used for the button.

When the button is pressed, an ActionEvent is generated. Using the ActionEvent object passed to the actionPerformed() method of the registered ActionListener, you can
obtain the action command string associated with the button. By default, this is the string displayed inside the button. However, you can set the action command by calling 
setActionCommand( ) on the button. You can obtain the action command by calling 
getActionCommand( ) on the event object. It is declared like this:

    String getActionCommand( )

    The action command identifies the button. Thus, when using two or more buttons 
    within the same application, the action command gives you an easy way to 
    determine which button was pressed.

In the preceding chapter, you saw an example of a text-based button. The following demonstrates an icon-based button. It displays four push buttons and a label. Each button displays an icon that represents a timepiece. When a button is pressed, the name of that timepiece is displayed in the label.
// Demonstrate an icon-based JButton.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/*
<applet code="JButtonDemo" width=250 height=750>
</applet>
*/

class JButtonDemo extends JApplet
implements ActionListener {
    JLabel jlab;

    public void init() {
        try {
            SwingUtilities.invokeLater(  
                new Runnable() {
                    public void run() {
                        makeGUI();  
                    }
                }  
            );
        } catch (Exception exc) {
            System.out.println("Can't create because of "+ exc);
        }
    }

    private void makeGUI() {
        // Change to flow layout.
        setLayout(new FlowLayout());

        // Add buttons to content pane.
        ImageIcon hourglass = new ImageIcon("hourglass.png");
        JButton jb = new JButton(hourglass);
        jb.setActionCommand("Hourglass");
        jb.addActionListener(this);
        add(jb);

        ImageIcon analog = new ImageIcon("analog.png");
        jb = new JButton(analog);
        jb.setActionCommand("Analog Clock");
        jb.addActionListener(this);
        add(jb);

        ImageIcon digital = new ImageIcon("digital.png");
        jb = new JButton(digital);
        jb.setActionCommand("Digital Clock");
        jb.addActionListener(this);
        add(jb);
    }
}
Output from the button example is shown here:

JToggleButton
A useful variation on the push button is called a toggle button. A toggle button looks just like a push button, but it acts differently because it has two states: pushed and released. That is, when you press a toggle button, it stays pressed rather than popping back up as a regular push button does. When you press the toggle button a second time, it releases (pops up). Therefore, each time a toggle button is pushed, it toggles between its two states. Toggle buttons are objects of the JToggleButton class. JToggleButton implements AbstractButton. In addition to creating standard toggle buttons, JToggleButton is a superclass for two other Swing components that also represent two-state controls. These are JCheckBox and JRadioButton, which are described later in this chapter. Thus,
**JToggleButton** defines the basic functionality of all two-state components.

**JToggleButton** defines several constructors. The one used by the example in this section is shown here:

```
JToggleButton(String str)
```

This creates a toggle button that contains the text passed in `str`. By default, the button is in the off position. Other constructors enable you to create toggle buttons that contain images, or images and text.

**JToggleButton** uses a model defined by a nested class called **JToggleButton.ToggleButtonModel**. Normally, you won’t need to interact directly with the model to use a standard toggle button.

Like **JButton**, **JToggleButton** generates an action event each time it is pressed. Unlike **JButton**, however, **JToggleButton** also generates an item event. This event is used by those components that support the concept of selection. When a **JToggleButton** is pressed in, it is selected. When it is popped out, it is deselected.

To handle item events, you must implement the **ItemListener** interface. Recall from Chapter 24, that each time an item event is generated, it is passed to the **itemStateChanged( )** method defined by **ItemListener**. Inside **itemStateChanged( )**, the **getItem( )** method can be called on the **ItemEvent** object to obtain a reference to the **JToggleButton** instance that generated the event. It is shown here:

```
Object getItem( )
```

A reference to the button is returned. You will need to cast this reference to **JToggleButton**.

The easiest way to determine a toggle button’s state is by calling the **isSelected( )** method (inherited from **AbstractButton**) on the button that generated the event. It is shown here:

```
boolean isSelected( )
```

It returns **true** if the button is selected and **false** otherwise.

Here is an example that uses a toggle button. Notice how the item listener works. It simply calls **isSelected( )** to determine the button’s state.
/ Demonstrate JToggleButton.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/*
  <applet code="JToggleButtonDemo" width=200 height=80>
  </applet>
*/

public class JToggleButtonDemo extends JApplet {

  JLabel jlab;
  JToggleButton jbtn;

  public void init() {
    try {
      SwingUtilities.invokeLater{
        new Runnable() {
          public void run() {
            makeGUI();
          }
        }
      };
    }
  }
}
The output from the toggle button example is shown here:

![Applet Viewer: JToggleButtonDemo](image)

**Check Boxes**

The `JCheckBox` class provides the functionality of a check box. Its immediate superclass is `JToggleButton`, which provides support for two-state buttons, as just described. `JCheckBox` defines several constructors. The one used here is

```java
// Change to flow layout.
setLayout(new FlowLayout());

// Create a label.
jlab = new JLabel("Button is off.");

// Make a toggle button.
jbtn = new JToggleButton("On/Off");

// Add an item listener for the toggle button.
jbtn.addItemListener(new ItemListener() { 
    public void itemStateChanged(ItemEvent ie) {
        if(jbtn.isSelected())
            jlab.setText("Button is on.");
        else
            jlab.setText("Button is off.");
    }
});

// Add the toggle button and label to the content pane.
add(jbtn);
add(jlab);
```
JCheckBox(String str)

It creates a check box that has the text specified by str as a label. Other
constructors let you specify the initial selection state of the button and specify an
icon.
When the user selects or deselects a check box, an ItemEvent is generated. You can obtain
a reference to the JCheckBox that generated the event by calling getItem() on the
ItemEvent passed to the itemStateChanged() method defined by ItemListener. The
easiest way to determine the selected state of a check box is to call isSelected() on the
JCheckBox instance.
The following example illustrates check boxes. It displays four check boxes and a label.
When the user clicks a check box, an ItemEvent is generated. Inside the
itemStateChanged() method, getItem() is called to obtain a reference to the
JCheckBox object that generated the event. Next, a call to isSelected() determines if the
box was selected or cleared. The getText() method gets the text for that check box and
uses it to set the text inside the label.
// Demonstrate JCheckBox.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/*
 <applet code="JCheckBoxDemo" width=270 height=50>
 </applet>
 */

public class JCheckBoxDemo extends JApplet
  implements ItemListener {

  JLabel jlab;

  public void init() {
    try {
      SwingUtilities.invokeLater(
        new Runnable() {
          public void run() {
            makeGUI();
          }
        }
      );
    } catch (Exception exc) {
      System.out.println("Can't create because of "+exc);
    }
  }

  private void makeGUI() {

    // Change to flow layout.
s.setLayout(new FlowLayout());

    // Add check boxes to the content pane.
    JCheckBox cb = new JCheckBox("C");
    cb.addItemListener(this);
    add(cb);

    cb = new JCheckBox("C++");
    cb.addItemListener(this);
    add(cb);

  }

}
Radio buttons are a group of mutually exclusive buttons, in which only one button can be selected at any one time. They are supported by the `JRadioButton` class, which extends `JToggleButton`. `JRadioButton` provides several constructors. The one used in the example is shown here:

```java
JRadioButton(String str)
```

Here, `str` is the label for the button. Other constructors let you specify the initial selection state of the button and specify an icon.

In order for their mutually exclusive nature to be activated, radio buttons must be configured into a group. Only one of the buttons in the group can be selected at any time. For example, if a user presses a radio button that is in a group, any previously selected button in that group is automatically deselected. A button group is created by the
**ButtonGroup** class. Its default constructor is invoked for this purpose. Elements are then added to the button group via the following method:

```java
void add(AbstractButton ab)
```

Here, `ab` is a reference to the button to be added to the group.

A `JRadioButton` generates action events, item events, and change events each time the button selection changes. Most often, it is the action event that is handled, which means that you will normally implement the `ActionListener` interface. Recall that the only method defined by `ActionListener` is `actionPerformed()`. Inside this method, you can use a number of different ways to determine which button was selected. First, you can check its action command by calling `getActionCommand()`. By default, the action command is the same as the button label, but you can set the action command to something else by calling `setActionCommand()` on the radio button. Second, you can call `getSource()` on the `ActionEvent` object and check that reference against the buttons. Third, you can check each radio button to find out which one is currently selected by calling `isSelected()` on each button. Finally, each button could use its own action event handler implemented as either an anonymous inner class or a lambda expression. Remember, each time an action event occurs, it means that the button being selected has changed and that one and only one button will be selected.

The following example illustrates how to use radio buttons. Three radio buttons are created. The buttons are then added to a button group. As explained, this is necessary to cause their mutually exclusive behavior. Pressing a radio button generates an action event, which is handled by `actionPerformed()`. Within that handler, the `getActionCommand()` method gets the text that is associated with the radio button and uses it to set the text within a label.
// Demonstrate JRadioButton
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/
<applet code="JRadioButtonDemo" width=300 height=50>
</applet>
*/

public class JRadioButtonDemo extends JApplet
implements ActionListener {
    JLabel jlab;

    public void init() {
        try {
            SwingUtilities.invokeLater()
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                }
            },
        } catch (Exception exc) {
            System.out.println("Can't create because of " + exc);
        }
    }

    private void makeGUI() {
        // Change to flow layout.
        setLayout(new FlowLayout());

        // Create radio buttons and add them to content pane.
        JRadioButton b1 = new JRadioButton("A");
        b1.addActionListener(this);
        add(b1);
JTabbedPane encapsulates a tabbed pane. It manages a set of components by linking them with tabs. Selecting a tab causes the component associated with that tab to come to the forefront. Tabbed panes are very common in the modern GUI, and you have no doubt used them many times. Given the complex nature of a tabbed pane, they are surprisingly easy to create and use.

JTabbedPane defines three constructors. We will use its default constructor, which creates an empty control with the tabs positioned across the top of the pane. The other two constructors let you specify the location of the tabs, which can be along any of the four sides. JTabbedPane uses the SingleSelectionModel model. Tabs are added by calling addTab(). Here is one of its forms:

```java
JRadioButton b2 = new JRadioButton("B");
b2.addActionListener(this);
add(b2);

JRadioButton b3 = new JRadioButton("C");
b3.addActionListener(this);
add(b3);

// Define a button group.
ButtonGroup bg = new ButtonGroup();
bg.add(b1);
bg.add(b2);
bg.add(b3);

// Create a label and add it to the content pane.
jlab = new JLabel("Select One");
add(jlab);
}

// Handle button selection.
public void actionPerformed(ActionEvent ae) {
    jlab.setText("You selected "+ ae.getActionCommand());
    }
```
void addTab(String name, Component comp)

Here, name is the name for the tab, and comp is the component that should be added to the tab. Often, the component added to a tab is a JPanel that contains a group of related components. This technique allows a tab to hold a set of components.

The general procedure to use a tabbed pane is outlined here:

1. Create an instance of JTabbedPane.
2. Add each tab by calling addTab().
3. Add the tabbed pane to the content pane.

The following example illustrates a tabbed pane. The first tab is titled "Cities" and contains four buttons. Each button displays the name of a city. The second tab is titled "Colors" and contains three check boxes. Each check box displays the name of a color. The third tab is titled "Flavors" and contains one combo box. This enables the user to select one of three flavors.
// Demonstrate JTabbedPane.
import javax.swing.*;
*/

public class JTabbedPaneDemo extends JApplet {

    public void init() {
        try {
            SwingUtilities.invokeLater(new Runnable() {
                public void run() {
                    makeGUI();
                }
            });
        } catch (Exception exc) {
            System.out.println("Can't create because of "+ exc);
        }
    }

    private void makeGUI() {
        JTabbedPane jtp = new JTabbedPane();
        jtp.addTab("Cities", new CitiesPanel());
        jtp.addTab("Colors", new ColorsPanel());
        jtp.addTab("Flavors", new FlavorsPanel());
        add(jtp);
    }

    // Make the panels that will be added to the tabbed pane.
    class CitiesPanel extends JPanel {
        CitiesPanel() {
            JButton b1 = new JButton("New York");
            add(b1);
            JButton b2 = new JButton("London");
            add(b2);
        }
    }

    class ColorsPanel extends JPanel {
        ColorsPanel() {
            JButton b1 = new JButton("Red");
            add(b1);
            JButton b2 = new JButton("Blue");
            add(b2);
        }
    }

    class FlavorsPanel extends JPanel {
        FlavorsPanel() {
            JButton b1 = new JButton("Vanilla");
            add(b1);
            JButton b2 = new JButton("Strawberry");
            add(b2);
        }
    }
}
class ColorsPanel extends JPanel {
    public ColorsPanel() {
        JCheckBox cb1 = new JCheckBox("Red");
        add(cb1);
        JCheckBox cb2 = new JCheckBox("Green");
        add(cb2);
        JCheckBox cb3 = new JCheckBox("Blue");
        add(cb3);
    }
}

class FlavorsPanel extends JPanel {
    public FlavorsPanel() {
        JComboBox<String> jcb = new JComboBox<String>();
        jcb.addItem("Vanilla");
        jcb.addItem("Chocolate");
        jcb.addItem("Strawberry");
        add(jcb);
    }
}

Output from the tabbed pane example is shown in the following three illustrations:

![Tabbed Pane Example Output](image)
**JScrollPane** is a lightweight container that automatically handles the scrolling of another component. The component being scrolled can be either an individual component, such as a table, or a group of components contained within another lightweight container, such as a **JPanel**. In either case, if the object being scrolled is larger than the viewable area, horizontal and/or vertical scroll bars are automatically provided, and the component can be scrolled through the pane. Because **JScrollPane** automates scrolling, it usually eliminates the need to manage individual scroll bars.

The viewable area of a scroll pane is called the *viewport*. It is a window in which the component being scrolled is displayed. Thus, the viewport displays the visible portion of the component being scrolled. The scroll bars scroll the component through the viewport. In its default behavior, a **JScrollPane** will dynamically add or remove a scroll bar as needed. For example, if the component is taller than the viewport, a vertical scroll bar is added. If the component will completely fit within the viewport, the scroll bars are removed.

**JScrollPane** defines several constructors. The one used in this chapter is shown here:

```java
JScrollPane(Component comp)
```

The component to be scrolled is specified by *comp*. Scroll bars are automatically displayed when the content of the pane exceeds the dimensions of the viewport.

Here are the steps to follow to use a scroll pane:

1. Create the component to be scrolled.
2. Create an instance of **JScrollPane**, passing to it the object to scroll.
3. Add the scroll pane to the content pane.

The following example illustrates a scroll pane. First, a **JPanel** object is created, and 400 buttons are added to it, arranged into 20 columns. This panel is then added to a scroll pane, and the scroll pane is added to the content pane. Because the panel is larger than the viewport, vertical and horizontal scroll bars appear automatically. You can use the scroll bars to scroll the buttons into view.
// Demonstrate JScrollPane.
import java.awt.*;
import javax.swing.*;

/*
<applet code=“JScrollPaneDemo” width=300 height=250>
</applet>
*/

public class JScrollPaneDemo extends JApplet {
    public void init() {
        try {
            SwingUtilities.invokeLater(
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                }
            );
        } catch (Exception exc) {
            System.out.println("Can’t create because of “ + exc);
        }
    }

    private void makeGUI() {
        // Add 400 buttons to a panel.
        JPanel jp = new JPanel();
        jp.setLayout(new GridLayout(20, 20));
        int b = 0;

        for(int i = 0; i < 20; i++) {
            for(int j = 0; j < 20; j++) {
                jp.add(new JButton("Button “ + b++));
            }
        }

        // Create the scroll pane.
        JScrollPane jsp = new JScrollPane(jp);

        // Add the scroll pane to the content pane.
        // Because the default border layout is used,
        // the scroll pane will be added to the center.
        add(jsp, BorderLayout.CENTER);
    }
}

Output from the scroll pane example is shown here:
**JList**

In Swing, the basic list class is called **JList**. It supports the selection of one or more items from a list. Although the list often consists of strings, it is possible to create a list of just about any object that can be displayed. **JList** is so widely used in Java that it is highly unlikely that you have not seen one before.

In the past, the items in a **JList** were represented as **Object** references. However, beginning with JDK 7, **JList** was made generic and is now declared like this:

```java
class JList<E>
```

Here, **E** represents the type of the items in the list. **JList** provides several constructors. The one used here is

```java
JList<E[ ] items)
```

This creates a **JList** that contains the items in the array specified by **items**. **JList** is based on two models. The first is **ListModel**. This interface defines how access to the list data is achieved. The second model is the **ListSelectionModel** interface, which defines methods that determine what list item or items are selected.

Although a **JList** will work properly by itself, most of the time you will wrap a **JList** inside a **JScrollPane**. This way, long lists will automatically be scrollable, which simplifies GUI design. It also makes it easy to change the number of entries in a list without having to change the size of the **JList** component.

A **JList** generates a **ListSelectionEvent** when the user makes or changes a selection. This event is also generated when the user deselects an item. It is handled by implementing **ListSelectionListener**. This listener specifies only one method, called **valueChanged()**, which is shown here:

```java
void valueChanged(ListSelectionEvent le)
```
Here, le is a reference to the event. Although ListSelectionEvent does provide some methods of its own, normally you will interrogate the JList object itself to determine what has occurred. Both ListSelectionEvent and ListSelectionListener are packaged in javax.swing.event.

By default, a JList allows the user to select multiple ranges of items within the list, but you can change this behavior by calling setSelectionMode( ), which is defined by JList. It is shown here:

```java
void setSelectionMode(int mode)
```

Here, mode specifies the selection mode. It must be one of these values defined by ListSelectionModel:

- SINGLE_SELECTION
- SINGLE_INTERVAL_SELECTION
- MULTIPLE_INTERVAL_SELECTION

The default, multiple-interval selection, lets the user select multiple ranges of items within a list. With single-interval selection, the user can select one range of items. With single selection, the user can select only a single item. Of course, a single item can be selected in the other two modes, too. It’s just that they also allow a range to be selected.

You can obtain the index of the first item selected, which will also be the index of the only selected item when using single-selection mode, by calling getSelectedIndex( ), shown here:

```java
int getSelectedIndex( )
```

Indexing begins at zero. So, if the first item is selected, this method will return 0. If no item is selected, –1 is returned.

Instead of obtaining the index of a selection, you can obtain the value associated with the selection by calling getSelectedValue( ):

```java
E getSelectedValue( )
```

It returns a reference to the first selected value. If no value has been selected, it returns null.

The following applet demonstrates a simple JList, which holds a list of cities. Each time a city is selected in the list, a ListSelectionEvent is generated, which is handled by the valueChanged( ) method defined by ListSelectionListener. It responds by obtaining the index of the selected item and displaying the name of the selected city in a label.
/ Demonstrate JList.
import javax.swing.*;
import javax.swing.event.*;
import java.awt.*;
import java.awt.event.*;

/*
  <applet code="JListDemo" width=200 height=120>
</applet>
*/

public class JListDemo extends JApplet {
  JList<String> jlst;
  JLabel jlab;
  JScrollPane jsrnlp;

  // Create an array of cities.
  String Cities[] = { "New York", "Chicago", "Houston",
                     "Denver", "Los Angeles", "Seattle",
                     "London", "Paris", "New Delhi",
                     "Hong Kong", "Tokyo", "Sydney" };

  public void init() {
    try {
      SwingUtilities.invokeAndWait(new Runnable() {
        public void run() {
          makeGUI();
        }
      });
    } catch (Exception exc) {
      System.out.println("Can't create because of " + exc);
    }
  }
}
private void makeGUI() {
    // Change to flow layout.
    setLayout(new FlowLayout());

    // Create a JList.
    jList = new JList<String>(Cities);

    // Set the list selection mode to single selection.
    jList.setSelectionMode(ListSelectionModel.SINGLE_SELECTION);

    // Add the list to a scroll pane.
    jScroll - new JScrollPane(jList);

    // Set the preferred size of the scroll pane.
    jScroll.setPreferredSize(new Dimension(120, 90));

    // Make a label that displays the selection.
    jLab - new JLabel("Choose a City");

    // Add selection listener for the list.
    jList.addListSelectionListener(new ListSelectionListener() {
        public void valueChanged(ListSelectionEvent le) {
            // Get the index of the changed item.
            int idx = jList.getSelectedIndex();

            // Display selection, if item was selected.
            if(idx != -1)
                jLab.setText("Current selection: " + Cities[idx]);
            else // Otherwise, reprompt.
                jLab.setText("Choose a City");
        }
    });

    // Add the list and label to the content pane.
    add(jScroll);
    add(jLab);
}
Swing provides a combo box (a combination of a text field and a drop-down list) through the `JComboBox` class. A combo box normally displays one entry, but it will also display a drop-down list that allows a user to select a different entry. You can also create a combo box that lets the user enter a selection into the text field.

In the past, the items in a `JComboBox` were represented as `Object` references. However, beginning with JDK 7, `JComboBox` was made generic and is now declared like this:

```java
class JComboBox<E>
```

Here, `E` represents the type of the items in the combo box.

The `JComboBox` constructor used by the example is shown here:

```java
JComboBox(E[] items)
```

Here, `items` is an array that initializes the combo box. Other constructors are available.

`JComboBox` uses the `ComboBoxModel`. Mutable combo boxes (those whose entries can be changed) use the `MutableComboBoxModel`.

In addition to passing an array of items to be displayed in the drop-down list, items can be dynamically added to the list of choices via the `addItem()` method, shown here:

```java
void addItem(E obj)
```

Here, `obj` is the object to be added to the combo box. This method must be used only with mutable combo boxes.

`JComboBox` generates an action event when the user selects an item from the list.

`JComboBox` also generates an item event when the state of selection changes, which occurs when an item is selected or deselected. Thus, changing a selection means that two item events will occur: one for the deselected item and another for the selected item. Often, it is sufficient to simply listen for action events, but both event types are available for your use.

One way to obtain the item selected in the list is to call `getSelectedItem()` on the combo box. It is shown here:

```java
Object getSelectedItem()
```
You will need to cast the returned value into the type of object stored in the list. The following example demonstrates the combo box. The combo box contains entries for "Hourglass", "Analog", "Digital", and "Stopwatch". When a timepiece is selected, an icon-based label is updated to display it. You can see how little code is required to use this powerful component.

```java
// Demonstrate JComboBox.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
/*
 <applet code="JComboBoxDemo" width=300 height=200>
 </applet>
*/
```
public class JComboBoxDemo extends JApplet {
    JLabel jLab;
    ImageIcon hourglass, analog, digital, stopwatch;
    JComboBox<String> jcb;

    String timepieces[] = { "Hourglass", "Analog", "Digital", "Stopwatch" };

    public void init() {
        try {
            SwingUtilities.invokeLater()
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                };
            } catch (Exception exc) {
                System.out.println("Can't create because of "+exc);
            }
        } };

    private void makeGUI() {
        // Change to flow layout.
        setLayout(new FlowLayout());

        // Instantiate a combo box and add it to the content pane.
        jcb = new JComboBox<String>(timepieces);
        add(jcb);

        // Handle selections.
        jcb.addActionListener(new ActionListener() {
            public void actionPerformed(ActionEvent ae) {
                String s = (String) jcb.getSelectedItem();
                jLab.setIcon(new ImageIcon(s + ".png"));
            }
        });

        // Create a label and add it to the content pane.
        jLab = new JLabel(new ImageIcon("hourglass.png"));
        add(jLab);
    }
}

Output from the combo box example is shown here:
Trees

A tree is a component that presents a hierarchical view of data. The user has the ability to expand or collapse individual subtrees in this display. Trees are implemented in Swing by the `JTree` class. A sampling of its constructors is shown here:

```java
JTree(Object obj[])
JTree(Vector<?> v)
JTree(TreeNode tn)
```

In the first form, the tree is constructed from the elements in the array `obj`. The second form constructs the tree from the elements of vector `v`. In the third form, the tree whose root node is specified by `tn` specifies the tree.

Although `JTree` is packaged in `javax.swing`, its support classes and interfaces are packaged in `javax.swing.tree`. This is because the number of classes and interfaces needed to support `JTree` is quite large.

`JTree` relies on two models: `TreeModel` and `TreeSelectionModel`. A `JTree` generates a variety of events, but three relate specifically to trees: `TreeExpansionEvent`, `TreeSelectionEvent`, and `TreeModelEvent`. `TreeExpansionEvent` events occur when a node is expanded or collapsed. A `TreeSelectionEvent` is generated when the user selects or deselects a node within the tree. A `TreeModelEvent` is fired when the data or structure of the tree changes. The listeners for these events are `TreeExpansionListener`, `TreeSelectionListener`, and `TreeModelListener`, respectively. The tree event classes and listener interfaces are packaged in `javax.swing.event`.

The event handled by the sample program shown in this section is `TreeSelectionEvent`. To listen for this event, implement `TreeSelectionListener`. It defines only one method, called `valueChanged()`, which receives the `TreeSelectionEvent` object. You can obtain
the path to the selected object by calling `getPath()`

```java
TreePath getPath()
```

It returns a `TreePath` object that describes the path to the changed node. The `TreePath` class encapsulates information about a path to a particular node in a tree. It provides several constructors and methods. In this book, only the `toString()` method is used. It returns a string that describes the path.

The `TreeNode` interface declares methods that obtain information about a tree node. For example, it is possible to obtain a reference to the parent node or an enumeration of the child nodes. The `MutableTreeNode` interface extends `TreeNode`. It declares methods that can insert and remove child nodes or change the parent node.

The `DefaultMutableTreeNode` class implements the `MutableTreeNode` interface. It represents a node in a tree. One of its constructors is shown here:

```java
DefaultMutableTreeNode(Object obj)
```

Here, `obj` is the object to be enclosed in this tree node. The new tree node doesn't have a parent or children.

To create a hierarchy of tree nodes, the `add()` method of `DefaultMutableTreeNode` can be used. Its signature is shown here:

```java
void add(MutableTreeNode child)
```

Here, `child` is a mutable tree node that is to be added as a child to the current node.

`JTree` does not provide any scrolling capabilities of its own. Instead, a `JTree` is typically placed within a `JScrollPane`. This way, a large tree can be scrolled through a smaller viewport.

Here are the steps to follow to use a tree:

1. Create an instance of `JTree`.
2. Create a `JScrollPane` and specify the tree as the object to be scrolled.
3. Add the tree to the scroll pane.
4. Add the scroll pane to the content pane.

The following example illustrates how to create a tree and handle selections. The program creates a `DefaultMutableTreeNode` instance labeled "Options". This is the top node of the tree hierarchy. Additional tree nodes are then created, and the `add()` method is called to connect these nodes to the tree. A reference to the top node in the tree is provided as the argument to the `JTree` constructor. The tree is then provided as the argument to the `JScrollPane` constructor. This scroll pane is then added to the content pane. Next, a label is created and added to the content pane. The tree selection is displayed in this label. To receive selection events from the tree, a `TreeSelectionListener` is registered for the tree. Inside the...
valueChanged() method, the path to the current selection is obtained and displayed.

```java
// Demonstrate JTree.
import java.awt.*;
import javax.swing.event.*;
import javax.swing.*;
import javax.swing.tree.*;
/*
   <applet code="JTreeDemo" width=400 height=200>
   </applet>
*/
public class JTreeDemo extends JApplet {
    JTree tree;
    JLabel jlab;

    public void init() {
        try {
            SwingUtilities.invokeLater(
                new Runnable() {
                    public void run() {
                        makeGUI();
                    }
                }
            );
            } catch (Exception exc) {
                System.out.println("Can't create because of " + exc);
            }
        }

        private void makeGUI() {

            // Create top node of tree.
            DefaultMutableTreeNode top = new DefaultMutableTreeNode("Options");

            // Create subtree of "A".
            DefaultMutableTreeNode a = new DefaultMutableTreeNode("A");
            top.add(a);
            DefaultMutableTreeNode a1 = new DefaultMutableTreeNode("A1");
            a.add(a1);
            DefaultMutableTreeNode a2 = new DefaultMutableTreeNode("A2");
            a.add(a2);

            // Create subtree of "B"
            DefaultMutableTreeNode b = new DefaultMutableTreeNode("B");
            top.add(b);
            DefaultMutableTreeNode b1 = new DefaultMutableTreeNode("B1");
            b.add(b1);
            DefaultMutableTreeNode b2 = new DefaultMutableTreeNode("B2");
            b.add(b2);
            DefaultMutableTreeNode b3 = new DefaultMutableTreeNode("B3");
            b.add(b3);

            // Create the tree.
            tree = new JTree(top);

            // Add the tree to a scroll pane.
            JScrollPane jsp = new JScrollPane(tree);

            // Add the scroll pane to the content pane.
            add(jsp);

            // Add the label to the content pane.
            jlab = new JLabel();
            add(jlab, BorderLayout.SOUTH);

            // Handle tree selection events.
            tree.addTreeSelectionListener(new TreeSelectionListener() {
                public void valueChanged(TreeSelectionEvent tse) {
                    jlab.setText("Selection is " + tse.getPath());
                }
            });
        }
    }
Output from the tree example is shown here:

![Tree Diagram]

The string presented in the text field describes the path from the top tree node to the selected node.

**JTable**

**JTable** is a component that displays rows and columns of data. You can drag the cursor on column boundaries to resize columns. You can also drag a column to a new position. Depending on its configuration, it is also possible to select a row, column, or cell within the table, and to change the data within a cell. **JTable** is a sophisticated component that offers many more options and features than can be discussed here. (It is perhaps Swing’s most complicated component.) However, in its default configuration, **JTable** still offers substantial functionality that is easy to use—especially if you simply want to use the table to present data in a tabular format. The brief overview presented here will give you a general understanding of this powerful component.

Like **JTree**, **JTable** has many classes and interfaces associated with it. These are packaged in `javax.swing.table`.

At its core, **JTable** is conceptually simple. It is a component that consists of one or more columns of information. At the top of each column is a heading. In addition to describing the data in a column, the heading also provides the mechanism by which the user can change the size of a column or change the location of a column within the table. **JTable** does not provide any scrolling capabilities of its own. Instead, you will normally wrap a **JTable** inside a ** JScrollPane**.

**JTable** supplies several constructors. The one used here is

```java
JTable(Object data[], Object colHeads[])
```

Here, `data` is a two-dimensional array of the information to be presented, and `colHeads` is a one-dimensional array with the column headings.

**JTable** relies on three models. The first is the table model, which is defined by the
TableModel interface. This model defines those things related to displaying data in a two-
dimensional format. The second is the table column model, which is represented by
TableModel. JTable is defined in terms of columns, and it is
TableModel that specifies the characteristics of a column. These two models are
packaged in javax.swing.table. The third model determines how items are selected, and it
is specified by the ListSelectionModel, which was described when JList was discussed.
A JTable can generate several different events. The two most fundamental to a table’s
operation are ListSelectionEvent and TableModelEvent. A ListSelectionEvent is
generated when the user selects something in the table. By default, JTable allows you to
select one or more complete rows, but you can change this behavior to allow one or more
columns, or one or more individual cells to be selected. A TableModelEvent is fired when
that table’s data changes in some way. Handling these events requires a bit more work than
it does to handle the events generated by the previously described components and is
beyond the scope of this book. However, if you simply want to use JTable to display data
(as the following example does), then you don’t need to handle any events.
Here are the steps required to set up a simple JTable that can be used to display data:

1. Create an instance of JTable.
2. Create a JScrollPane object, specifying the table as the object to scroll.
3. Add the table to the scroll pane.
4. Add the scroll pane to the content pane.

The following example illustrates how to create and use a simple table. A one-
dimensional array of strings called colHeads is created for the column headings.
A two-dimensional array of strings called data is created for the table cells. You
can see that each element in the array is an array of three strings. These arrays are
passed to the JTable constructor. The table is added to a scroll pane, and then the
scroll pane is added to the content pane. The table displays the data in the data
array. The default table configuration also allows the contents of a cell to be edited.
Changes affect the underlying array, which is data in this case.
```java
// Demonstrate JTable.
import java.awt.*;
import javax.swing.*;
/**
 * <applet code="JTableDemo" width=400 height=200>
 */
</applet>

public class JTableDemo extends JApplet {
  public void init() {
    try {
      SwingUtilities.invokeLater(
        new Runnable() {
          public void run() {
            makeGUI();
          }
        });
    } catch (Exception exc) {
      System.out.println("Can't create because of ", exc);
    }
  }

  private void makeGUI() {
    // Initialize column headings.
    String[] colHeads = { "Name", "Extension", "ID#" };
    // Initialize data.
    Object[][] data = {
      {"Gail", 4567, 665"},
      {"Ken", 7568, 555"},
      {"Viviane", 5434, 497"},
      {"Melanie", 7345, 922"},
      {"Aune", 1237, 333"},
      {"John", 5656, 314"},
      {"Marr", 5678, 621"},
      {"Claire", 6741, 444"},
      {"Irvin", 9023, 519"},
      {"Elin", 1134, 512"},
      {"Jennifer", 5689, 112"},
      {"Ed", 9030, 133"},
      {"Helen", 6751, 145"}
    };
    // Create the table.
    JTable table = new JTable(data, colHeads);
    // Add the table to a scroll pane.
    JScrollPane jsp = new JScrollPane(table);
    // Add the scroll pane to the content pane.
    add(jsp);
  }
}

Output from this example is shown here:
<table>
<thead>
<tr>
<th>Name</th>
<th>Extension</th>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>Call</td>
<td>1587</td>
<td>015</td>
</tr>
<tr>
<td>Pete</td>
<td>7886</td>
<td>955</td>
</tr>
<tr>
<td>Maggie</td>
<td>5634</td>
<td>567</td>
</tr>
<tr>
<td>Melanie</td>
<td>7345</td>
<td>977</td>
</tr>
<tr>
<td>Anne</td>
<td>1237</td>
<td>313</td>
</tr>
<tr>
<td>John</td>
<td>5555</td>
<td>314</td>
</tr>
<tr>
<td>Brad</td>
<td>9872</td>
<td>217</td>
</tr>
<tr>
<td>Clare</td>
<td>6711</td>
<td>414</td>
</tr>
<tr>
<td>Emma</td>
<td>9023</td>
<td>519</td>
</tr>
</tbody>
</table>

Applet started.
This chapter introduces another fundamental aspect of the Swing GUI environment: the menu. Menus form an integral part of many applications because they present the program’s functionality to the user. Because of their importance, Swing provides extensive support for menus. They are an area in which Swing’s power is readily apparent. The Swing menu system supports several key elements, including

- The menu bar, which is the main menu for an application.
- The standard menu, which can contain either items to be selected or other menus (submenus).
- The popup menu, which is usually activated by right-clicking the mouse.
- The toolbar, which provides rapid access to program functionality, often paralleling menu items.
- The action, which enables two or more different components to be managed by a single object. Actions are commonly used with menus and toolbars.

Swing menus also support accelerator keys, which enable menu items to be selected without having to activate the menu, and mnemonics, which allow a menu item to be selected by the keyboard once the menu options are displayed.

**Menu Basics**

The Swing menu system is supported by a group of related classes. The ones used in this chapter are shown in Table 33-1, and they represent the core of the menu system. Although they may seem a bit confusing at first, Swing menus are quite easy to use. Swing allows a high degree of customization, if desired; however, you will normally use the menu classes as-is because they support all of the most needed options. For example, you can easily add images and keyboard shortcuts to a menu.
Here is a brief overview of how the classes fit together. To create the top-level menu for an application, you first create a `JMenuBar` object. This class is, loosely speaking, a container for menus. To the `JMenuBar` instance, you will add instances of `JMenu`. Each `JMenu` object defines a menu. That is, each `JMenu` object contains one or more selectable items. The items displayed by a `JMenu` are objects of `JMenuItem`. Thus, a `JMenuItem` defines a selection that can be chosen by the user.

As an alternative or adjunct to menus that descend from the menu bar, you can also create stand-alone, popup menus. To create a popup menu, first create an object of type `JPopupMenu`. Then, add `JMenuItem`s to it. A popup menu is normally activated by clicking the right mouse button when the mouse is over a component for which a popup menu has been defined.

In addition to “standard” menu items, you can also include check boxes and radio buttons in a menu. A check box menu item is created by `JCheckBoxMenuItem`. A radio button menu item is created by `JRadioButtonMenuItem`. Both of these classes extend `JMenuItem`. They can be used in standard menus and popup menus.

`JToolBar` creates a stand-alone component that is related to the menu. It is often used to provide fast access to functionality contained within the menus of the application. For example, a toolbar might provide fast access to the formatting commands supported by a word processor.

`JSeparator` is a convenience class that creates a separator line in a menu.

One key point to understand about Swing menus is that each menu item extends `AbstractButton`. Recall that `AbstractButton` is also the superclass of all of Swing’s button components, such as `JButton`. Thus, all menu items are, essentially, buttons. Obviously, they won’t actually look like buttons when used in a menu, but they will, in many ways, act like buttons. For example, selecting a menu item generates an action event in the same way that pressing a button does.

Another key point is that `JMenuItem` is a superclass of `JMenu`. This allows the creation of submenus, which are, essentially, menus within menus. To create a submenu, you first create and populate a `JMenu` object and then add it to another `JMenu` object. You will see this process in action in the following section.
As mentioned in passing previously, when a menu item is selected, an action event is generated. The action command string associated with that action event will, by default, be the name of the selection. Thus, you can determine which item was selected by examining the action command. Of course, you can also use separate anonymous inner classes or lambda expressions to handle each menu item’s action events. In this case, the menu selection is already known, and there is no need to examine the action command string to determine which item was selected.

Menus can also generate other types of events. For example, each time that a menu is activated, selected, or canceled, a `MenuEvent` is generated that can be listened for via a `MenuListener`. Other menu-related events include `MenuKeyEvent`, `MenuDragMouseEvent`, and `PopupMenuEvent`. In many cases, however, you need only watch for action events, and in this chapter, we will use only action events.

### An Overview of `JMenuBar`, `JMenu`, and ` JMenuItem`

Before you can create a menu, you need to know something about the three core menu classes: `JMenuBar`, `JMenu`, and ` JMenuItem`. These form the minimum set of classes needed to construct a main menu for an application. `JMenu` and ` JMenuItem` are also used by popup menus. Thus, these classes form the foundation of the menu system.

#### `JMenuBar`

As mentioned, `JMenuBar` is essentially a container for menus. Like all components, it inherits `JComponent` (which inherits `Container` and `Component`). It has only one constructor, which is the default constructor. Therefore, initially the menu bar will be empty, and you will need to populate it with menus prior to use. Each application has one and only one menu bar.

`JMenuBar` defines several methods, but often you will only need to use one: `add()`. The `add()` method adds a ` JMenu` to the menu bar. It is shown here:

```java
JMenu add(JMenu menu)
```

Here, `menu` is a `JMenu` instance that is added to the menu bar. A reference to the menu is returned. Menus are positioned in the bar from left to right, in the order in which they are added. If you want to add a menu at a specific location, then use this version of `add()`, which is inherited from `Container`:

```java
Component add(Component menu, int idx)
```

Here, `menu` is added at the index specified by `idx`. Indexing begins at 0, with 0 being the left-most menu.

In some cases, you might want to remove a menu that is no longer needed. You can do this by calling `remove()`, which is inherited from `Container`. It has these two forms:

```java
void remove(Component menu)
void remove(int idx)
```
Here, *menu* is a reference to the menu to remove, and *idx* is the index of the menu to remove. Indexing begins at zero.

Another method that is sometimes useful is `getMenuCount()` , shown here:

```java
int getMenuCount()
```

It returns the number of elements contained within the menu bar.

`JMenuBar` defines some other methods that you might find helpful in specialized applications. For example, you can obtain an array of references to the menus in the bar by calling `getSubElements()` . You can determine if a menu is selected by calling `isSelected()` .

Once a menu bar has been created and populated, it is added to a `JFrame` by calling `setJMenuBar()` on the `JFrame` instance. (Menu bars are not added to the content pane.) The `setJMenuBar()` method is shown here:

```java
void setJMenuBar(JMenuBar mb)
```

Here, `mb` is a reference to the menu bar. The menu bar will be displayed in a position determined by the look and feel. Usually, this is at the top of the window.

**JMenu**

`JMenu` encapsulates a menu, which is populated with `JMenuItems`. As mentioned, it is derived from `JMenuItem`. This means that one `JMenu` can be a selection in another `JMenu`. This enables one menu to be a submenu of another. `JMenu` defines a number of constructors. For example, here is the one used in the examples in this chapter:

```java
JMenu(String name)
```

This constructor creates a menu that has the title specified by `name`. Of course, you don't have to give a menu a name. To create an unnamed menu, you can use the default constructor:

```java
JMenu()
```

Other constructors are also supported. In each case, the menu is empty until menu items are added to it.

`JMenu` defines many methods. Here is a brief description of some commonly used ones. To add an item to the menu, use the `add()` method, which has a number of forms, including the two shown here:

```java
JMenuItem add(JMenuItem item)
```

```java
JMenuItem add(Component item, int idx)
```

Here, `item` is the menu item to add. The first form adds the item to the end of the menu. The second form adds the item at the index specified by `idx`. As expected, indexing starts at zero. Both forms return a reference to the item added. As a point of interest, you can also use `insert()` to add menu items to a menu.
You can add a separator (an object of type `JSeparator`) to a menu by calling `addSeparator()`, shown here:

```java
void addSeparator()
```

The separator is added onto the end of the menu. You can insert a separator into a menu by calling `insertSeparator(int idx)`, shown next:

```java
void insertSeparator(int idx)
```

Here, `idx` specifies the zero-based index at which the separator will be added.

You can remove an item from a menu by calling `remove()`. Two of its forms are shown here:

```java
void remove(JMenuItem menu)
void remove(int idx)
```

In this case, `menu` is a reference to the item to remove and `idx` is the index of the item to remove.

You can obtain the number of items in the menu by calling `getMenuComponentCount()`, shown here:

```java
int getMenuComponentCount()
```

You can get an array of the items in the menu by calling `getMenuComponents()`, shown next:

```java
Component[] getMenuComponents()
```

An array containing the components is returned.

`JMenuItem`

`JMenuItem` encapsulates an element in a menu. This element can be a selection linked to some program action, such as Save or Close, or it can cause a submenu to be displayed. As mentioned, `JMenuItem` is derived from `AbstractButton`, and every item in a menu can be thought of as a special kind of button. Therefore, when a menu item is selected, an action event is generated. (This is similar to the way a `JButton` fires an action event when it is pressed.) `JMenuItem` defines many constructors. The ones used in this chapter are shown here:

```java
JMenuItem(String name)
JMenuItem(Icon image)
JMenuItem(String name, Icon image)
JMenuItem(String name, int mnem)
JMenuItem(Action action)
```

The first constructor creates a menu item with the name specified by `name`. The
second creates a menu item that displays the image specified by `image`. The third creates a menu item with the name specified by `name` and the image specified by `image`. The fourth creates a menu item with the name specified by `name` and uses the keyboard mnemonic specified by `mnem`. This mnemonic enables you to select an item from the menu by pressing the specified key. The last constructor creates a menu item using the information specified in `action`. A default constructor is also supported.

Because menu items inherit `AbstractButton`, you have access to the functionality provided by `AbstractButton`. One such method that is often useful with menus is `setEnabled()`, which you can use to enable or disable a menu item. It is shown here:

```java
void setEnabled(boolean enable)
```

If `enable` is `true`, the menu item is enabled. If `enable` is `false`, the item is disabled and cannot be selected.

### Create a Main Menu

Traditionally, the most commonly used menu is the main menu. This is the menu defined by the menu bar, and it is the menu that defines all (or nearly all) of the functionality of an application. Fortunately, Swing makes creating and managing the main menu easy. This section shows you how to construct a basic main menu. Subsequent sections will show you how to add options to it.

Constructing the main menu requires several steps. First, create the `JMenuBar` object that will hold the menus. Next, construct each menu that will be in the menu bar. In general, a menu is constructed by first creating a `JMenu` object and then adding `JMenuItem`s to it. After the menus have been created, add them to the menu bar. The menu bar, itself, must then be added to the frame by calling `setJMenuBar()`. Finally, for each menu item, you must add an action listener that handles the action event fired when the menu item is selected.

A good way to understand the process of creating and managing menus is to work through an example. Here is a program that creates a simple menu bar that contains three menus. The first is a standard File menu that contains Open, Close, Save, and Exit selections. The second menu is called Options, and it contains two submenus called Colors and Priority. The third menu is called Help, and it has one item: About. When a menu item is selected, the name of the selection is displayed in a label in the content pane. Sample output is shown in Figure 33-1.
// Demonstrate a simple main menu.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class MenuDemo implements ActionListener {

    JLabel jlab;

    MenuDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Menu Demo");
        jfrm.setSize(200, 100);
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
        jfrm.add(jlab = new JLabel("Hello World"));
        jfrm.setVisible(true);
    }
}

// Specify FlowLayout for the layout manager.
frm.setLayout(new FlowLayout());

// Give the frame an initial size.
frm.setSize(220, 200);

// Terminate the program when the user closes the application.
frm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

// Create a label that will display the menu selection.
jl = new JLabel();

// Create the menu bar.
JMenuBar jm = new JMenuBar();

// Create the File menu.
JMenu jmFile = new JMenu("File");
JMenuItem jmOpen = new JMenuItem("Open");
JMenuItem jmClose = new JMenuItem("Close");
JMenuItem jmSave = new JMenuItem("Save");
JMenuItem jmExit = new JMenuItem("Exit");
jmFile.add(jmOpen);
jmFile.add(jmClose);
jmFile.add(jmSave);
jmFile.add(jmExit);
jm.add(jmFile);

// Create the Options menu.
JMenu jmOptions = new JMenu("Options");

// Create the Colors submenu.
JMenu jmColors = new JMenu("Colors");
JMenuItem jmRed = new JMenuItem("Red");
JMenuItem jmGreen = new JMenuItem("Green");
JMenuItem jmBlue = new JMenuItem("Blue");
jmColors.add(jmRed);
jmColors.add(jmGreen);
jmColors.add(jmBlue);
jmOptions.add(jmColors);

// Create the Priority submenu.
JMenu jmPriority = new JMenu("Priority");
JMenuItem jmHigh = new JMenuItem("High");
JMenuItem jmLow = new JMenuItem("Low");
jmPriority.add(jmHigh);
jmPriority.add(jmLow);
jmOptions.add(jmPriority);

// Create the Reset menu item.
JMenuItem jmReset = new JMenuItem("Reset");
jmOptions.addSeparator();
jmOptions.add(jmReset);
// Finally, add the entire options menu to
// the menu bar
jmb.add(jmOptions);

// Create the Help menu.
JMenu jmHelp = new JMenu("Help");
JMenuItem jmAbout = new JMenuItem("About");
jmHelp.add(jmAbout);
jmb.add(jmHelp);

// Add action listeners for the menu items.
jmiOpen.addActionListener(this);
jmiClose.addActionListener(this);
jmiSave.addActionListener(this);
jmiRed.addActionListener(this);
jmiBlue.addActionListener(this);
jmiHigh.addActionListener(this);
jmiLow.addActionListener(this);
jmiReset.addActionListener(this);
jmiAbout.addActionListener(this);

// Add the label to the content pane.
jfm.add(jlab);

// Add the menu bar to the frame.
jfm.setJMenuBar(jmb);

// Display the frame.
jfm.setVisible(true);

public void actionPerformed(ActionEvent ae) {
    // Get the action command from the menu selection.
    String comStr = ae.getActionCommand();

    // If user chooses Exit, then exit the program.
    if (comStr.equals("Exit")) System.exit(0);

    // Otherwise, display the selection.
    jlab.setText(comStr + " Selected");
}

public static void main(String args[]) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(new Runnable() {
        public void run() {
            new MenuDemo();
        }
    });
}
Let's examine, in detail, how the menus in this program are created, beginning with the `MenuDemo` constructor. It starts by creating a `JFrame` and setting its layout manager, size, and default close operation. (These operations are described in Chapter 31.) A `JLabel` is then constructed. It will be used to display a menu selection. Next, the menu bar is constructed and a reference to it is assigned to `jmb` by this statement:

```java
// Create the menu bar.
JMenuBar jmb = new JMenuBar();
```

Then, the File menu `jmFile` and its menu entries are created by this sequence:

```java
// Create the File menu.
JMenu jmFile = new JMenu("File");
JMenuItem jmiOpen = new JMenuItem("Open");
JMenuItem jmiClose = new JMenuItem("Close");
JMenuItem jmiSave = new JMenuItem("Save");
JMenuItem jmiExit = new JMenuItem("Exit");
```

The names Open, Close, Save, and Exit will be shown as selections in the menu. Next, the menu entries are added to the file menu by this sequence:

```java
jmFile.add(jmiOpen);
jmFile.add(jmiClose);
jmFile.add(jmiSave);
jmFile.addSeparator();
jmFile.add(jmiExit);
```

Finally, the File menu is added to the menu bar with this line:

```java
jmb.add(jmFile);
```

Once the preceding code sequence completes, the menu bar will contain one entry: File. The File menu will contain four selections in this order: Open, Close, Save, and Exit. However,
notice that a separator has been added before Exit. This visually separates Exit from the preceding three selections.

The Options menu is constructed using the same basic process as the File menu. However, the Options menu consists of two submenus, Colors and Priority, and a Reset entry. The submenus are first constructed individually and then added to the Options menu. The Reset item is added last. Then, the Options menu is added to the menu bar. The Help menu is constructed using the same process.

Notice that MenuDemo implements the ActionListener interface and action events generated by a menu selection are handled by the actionPerformed() method defined by MenuDemo. Therefore, the program adds this as the action listener for the menu items. Notice that no listeners are added to the Colors or Priority items because they are not actually selections. They simply activate submenus.

Finally, the menu bar is added to the frame by the following line:

```java
jfrm.setJMenuBar(jmb);
```

As mentioned, menu bars are not added to the content pane. They are added directly to the JFrame.

The actionPerformed() method handles the action events generated by the menu. It obtains the action command string associated with the selection by calling getActionCommand() on the event. It stores a reference to this string in comStr. Then, it tests the action command against "Exit", as shown here:

```java
if(comStr.equals("Exit")) System.exit(0);
```

If the action command is "Exit", then the program terminates by calling System.exit(). This method causes the immediate termination of a program and passes its argument as a status code to the calling process, which is usually the operating system or the browser. By convention, a status code of zero means normal termination. Anything else indicates that the program terminated abnormally. For all other menu selections, the choice is displayed.

At this point, you might want to experiment a bit with the MenuDemo program. Try adding another menu or adding additional items to an existing menu. It is important that you understand the basic menu concepts before moving on because this program will evolve throughout the course of this chapter.

**Add Mnemonics and Accelerators to Menu Items**

The menu created in the preceding example is functional, but it is possible to make it better. In real applications, a menu usually includes support for keyboard shortcuts because they give an experienced user the ability to select menu items rapidly. Keyboard shortcuts come in two forms: mnemonics and accelerators. As it applies to menus, a mnemonic defines a key that lets you select an item from an active menu by typing the key. Thus, a mnemonic
allows you to use the keyboard to select an item from a menu that is already being displayed. An accelerator is a key that lets you select a menu item without having to first activate the menu.

A mnemonic can be specified for both JMenuItem and JMenu objects. There are two ways to set the mnemonic for JMenuItem. First, it can be specified when an object is constructed using this constructor:

```
JMenuItem(String name, int mnem)
```

In this case, the name is passed in `name` and the mnemonic is passed in `mnem`.

Second, you can set the mnemonic by calling `setMnemonic( )`. To specify a mnemonic for JMenu, you must call `setMnemonic( )`. This method is inherited by both classes from AbstractButton and is shown next:

```
void setMnemonic(int mnem)
```

Here, `mnem` specifies the mnemonic. It should be one of the constants defined in `java.awt.event.KeyEvent`, such as `KeyEvent.VK_F` or `KeyEvent.VK_Z`. (There is another version of `setMnemonic( )` that takes a `char` argument, but it is considered obsolete.) Mnemonics are not case sensitive, so in the case of `VK_A`, typing either `a` or `A` will work.

By default, the first matching letter in the menu item will be underscored. In cases in which you want to underscore a letter other than the first match, specify the index of the letter as an argument to `setDisplayMnemonicIndex( )`, which is inherited by both JMenu and JMenuItem from AbstractButton. It is shown here:

```
void setDisplayedMnemonicIndex(int idx)
```

The index of the letter to underscore is specified by `idx`.

An accelerator can be associated with a JMenuItem object. It is specified by calling `setAccelerator( )`, shown next:

```
void setAccelerator(KeyStroke ks)
```

Here, `ks` is the key combination that is pressed to select the menu item.

`KeyStroke` is a class that contains several factory methods that construct various types of keystroke accelerators. The following are three examples:

```
static KeyStroke getKeyStroke(char ch)
static KeyStroke getKeyStroke(Character ch, int modifier)
static KeyStroke getKeyStroke(int ch, int modifier)
```

Here, `ch` specifies the accelerator character. In the first version, the character is specified as a `char` value. In the second, it is specified as an object of type `Character`. In the third, it is a value of type `KeyEvent`, previously described. The value of `modifier` must be one or more of the following constants, defined in the
The `java.awt.event.InputEvent` class:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>InputEvent.ALT_DOWN_MASK</code></td>
<td><code>InputEvent.ALT_GRAPH_DOWN_MASK</code></td>
</tr>
<tr>
<td><code>InputEvent.CTRL_DOWN_MASK</code></td>
<td><code>InputEvent.META_DOWN_MASK</code></td>
</tr>
<tr>
<td><code>InputEvent.SHIFT_DOWN_MASK</code></td>
<td></td>
</tr>
</tbody>
</table>

Therefore, if you pass `VK_A` for the key character and `InputEvent.CTRL_DOWN_MASK` for the modifier, the accelerator key combination is `CTRL-A`.

The following sequence adds both mnemonics and accelerators to the File menu created by the `MenuDemo` program in the previous section. After making this change, you can select the File menu by typing `ALT-F`. Then, you can use the mnemonics `O`, `C`, `S`, or `E` to select an option. Alternatively, you can directly select a File menu option by pressing `CTRL-O`, `CTRL-C`, `CTRL-S`, or `CTRL-E`. Figure 33-2 shows how this menu looks when activated.

    // Create the File menu with mnemonics and accelerators.
    JMenu jmFile = new JMenu("File");
    jmFile.setMnemonic(KeyEvent.VK_F);
    JMenuItem jmiOpen = new JMenuItem("Open",
                                       KeyEvent.VK_O);
    jmiOpen.setAccelerator(
                           KeyStroke.getKeyStroke(KeyEvent.VK_O,
                                                   InputEvent.CTRL_DOWN_MASK));
    JMenuItem jmiClose = new JMenuItem("Close",
                                         KeyEvent.VK_C);
    jmiClose.setAccelerator(
                           KeyStroke.getKeyStroke(KeyEvent.VK_C,
                                                   InputEvent.CTRL_DOWN_MASK));
    JMenuItem jmiSave = new JMenuItem("Save",
                                         KeyEvent.VK_S);
    jmiSave.setAccelerator(
                           KeyStroke.getKeyStroke(KeyEvent.VK_S,
                                                   InputEvent.CTRL_DOWN_MASK));
    JMenuItem jmiExit = new JMenuItem("Exit",
                                         KeyEvent.VK_E);
    jmiExit.setAccelerator(
                           KeyStroke.getKeyStroke(KeyEvent.VK_E,
                                                   InputEvent.CTRL_DOWN_MASK));
Add Images and Tooltips to Menu Items
You can add images to menu items or use images instead of text. The easiest way to add an image is to specify it when the menu item is being constructed using one of these constructors:

```
JMenuItem(Icon image)
JMenuItem(String name, Icon image)
```

The first creates a menu item that displays the image specified by `image`. The second creates a menu item with the name specified by `name` and the image specified by `image`. For example, here the About menu item is associated with an image when it is created.

```
ImageIcon icon = new ImageIcon("AboutIcon.gif");
JMenuItem jmiAbout = new JMenuItem("About", icon);
```

After this addition, the icon specified by `icon` will be displayed next to the text "About" when the Help menu is displayed. This is shown in Figure 33-3. You can also add an icon to a menu item after the item has been created by calling `setIcon()`, which is inherited from `AbstractButton`. You can specify the horizontal alignment of the image relative to the text by calling `setHorizontalTextPosition()`. 
You can specify a disabled icon, which is shown when the menu item is disabled, by calling `setDisabledIcon()` . Normally, when a menu item is disabled, the default icon is shown in gray. If a disabled icon is specified, then that icon is displayed when the menu item is disabled.

A *tooltip* is a small message that describes an item. It is automatically displayed if the mouse remains over the item for a moment. You can add a tooltip to a menu item by calling `setToolTipText()` on the item, specifying the text you want displayed. It is shown here:

```java
void setToolTipText(String msg)
```

In this case, `msg` is the string that will be displayed when the tooltip is activated.

For example, this creates a tooltip for the About item:

```java
jmiAbout.setToolTipText("Info about the MenuDemo program.");
```

As a point of interest, `setToolTipText()` is inherited by `JMenuItem` from `JComponent`. This means you can add a tooltip to other types of components, such as a push button. You might want to try this on your own.

### Use JRadioButtonMenuItem and JCheckBoxMenuItem

Although the type of menu items used by the preceding examples are, as a general rule, the most commonly used, Swing defines two others: check boxes and radio buttons. These items can streamline a GUI by allowing a menu to provide functionality that would otherwise require additional, stand-alone components. Also, sometimes, including check boxes or radio buttons in a menu simply seems the most natural place for a specific set of features.

Whatever your reason, Swing makes it easy to use check boxes and radio buttons in menus, and both are examined here.

To add a check box to a menu, create a `JCheckBoxMenuItem`. It defines several constructors. This is the one used in this chapter:

```java
JCheckBoxMenuItem(String name)
```
Here, *name* specifies the name of the item. The initial state of the check box is unchecked. If you want to specify the initial state, you can use this constructor:

```java
JCheckBoxMenuItem(String name, boolean state)
```

In this case, if *state* is *true*, the box is initially checked. Otherwise, it is cleared. *JCheckBoxMenuItem* also provides constructors that let you specify an icon. Here is one example:

```java
JCheckBoxMenuItem(String name, Icon icon)
```

In this case, *name* specifies the name of the item and the image associated with the item is passed in *icon*. The item is initially unchecked. Other constructors are also supported.

Check boxes in menus work like stand-alone check boxes. For example, they generate action events and item events when their state changes. Check boxes are especially useful in menus when you have options that can be selected and you want to display their selected/deselected status.

A radio button can be added to a menu by creating an object of type *JRadioButtonMenuItem*. *JRadioButtonMenuItem* inherits *JMenuItem*. It provides a rich assortment of constructors. The ones used in this chapter are shown here:

```java
JRadioButtonMenuItem(String name)
JRadioButtonMenuItem(String name, boolean state)
```

The first constructor creates an unselected radio button menu item that is associated with the name passed in *name*. The second lets you specify the initial state of the button. If *state* is *true*, the button is initially selected. Otherwise, it is deselected. Other constructors let you specify an icon. Here is one example:

```java
JRadioButtonMenuItem(String name, Icon icon, boolean state)
```

This creates a radio button menu item that is associated with the name passed in *name* and the image passed in *icon*. If *state* is *true*, the button is initially selected. Otherwise, it is deselected. Several other constructors are supported.

A *JRadioButtonMenuItem* works like a stand-alone radio button, generating item and action events. Like stand-alone radio buttons, menu-based radio buttons must be put into a button group in order for them to exhibit mutually exclusive selection behavior. Because both *JCheckBoxMenuItem* and *JRadioButtonMenuItem* inherit *JMenuItem*, each has all of the functionality provided by *JMenuItem*. Aside from having the extra capabilities of check boxes and radio buttons, they act like and are used like other menu items.

To try check box and radio button menu items, first remove the code that creates the Options menu in the *MenuDemo* example program. Then substitute the following code sequence, which uses check boxes for the Colors submenu and radio buttons for the Priority
submenu. After making the substitution, the Options menu will look like those shown in Figure 33-4.

```java
// Create the Options menu.
JMenu jmOptions = new JMenu("Options");

// Create the Colors submenu.
JMenu jmColors = new JMenu("Colors");
```

Figure 33-4  The effects of check box (a) and radio button (b) menu items
Create a Popup Menu

A popular alternative or addition to the menu bar is the popup menu. Typically, a popup menu is activated by clicking the right mouse button when over a component. Popup menus are supported in Swing by the `JPopupMenu` class. `JPopupMenu` has two constructors. In this chapter, only the default constructor is used:

```java
JPopupMenu();
```
It creates a default popup menu. The other constructor lets you specify a title for the menu. Whether this title is displayed is subject to the look and feel.

In general, popup menus are constructed like regular menus. First, create a `JPopupMenu` object, and then add menu items to it. Menu item selections are also handled in the same way: by listening for action events. The main difference between a popup menu and regular menu is the activation process.

Activating a popup menu requires three steps.

1. You must register a listener for mouse events.
2. Inside the mouse event handler, you must watch for the popup trigger.
3. When a popup trigger is received, you must show the popup menu by calling `show()`.

Let’s examine each of these steps closely.

A popup menu is normally activated by clicking the right mouse button when the mouse pointer is over a component for which a popup menu is defined. Thus, the popup trigger is usually caused by right-clicking the mouse on a popup menu–enabled component. To listen for the popup trigger, implement the `MouseListener` interface and then register the listener by calling the `addMouseListener()` method. As described in Chapter 24, `MouseListener` defines the methods shown here:

```java
void mouseClicked(MouseEvent me)
void mouseEntered(MouseEvent me)
void mouseExited(MouseEvent me)
void mousePressed(MouseEvent me)
void mouseReleased(MouseEvent me)
```

Of these, two are very important relative to the popup menu: `mousePressed()` and `mouseReleased()`. Depending on the installed look and feel, either of these two events can trigger a popup menu. For this reason, it is often easier to use a `MouseAdapter` to implement the `MouseListener` interface and simply override `mousePressed()` and `mouseReleased()`.

`MouseEvent` class defines several methods, but only four are commonly needed when activating a popup menu. They are shown here:

```java
int getX( )
int getY( )
boolean isPopupTrigger( )
Component getComponent( )
```
The current X,Y location of the mouse relative to the source of the event is found by calling `getX()` and `getY()`. These are used to specify the upper-left corner of the popup menu when it is displayed. The `isPopupTrigger()` method returns `true` if the mouse event represents a popup trigger and `false` otherwise. You will use this method to determine when to pop up the menu. To obtain a reference to the component that generated the mouse event, call `getComponent()`.

To actually display the popup menu, call the `show()` method defined by `JPopupMenu`, shown next:

```java
void show(Component invoker, int upperX, int upperY)
```

Here, `invoker` is the component relative to which the menu will be displayed. The values of `upperX` and `upperY` define the X,Y location of the upper-left corner of the menu, relative to `invoker`. A common way to obtain the invoker is to call `getComponent()` on the event object passed to the mouse event handler.

The preceding theory can be put into practice by adding a popup Edit menu to the `MenuDemo` program shown at the start of this chapter. This menu will have three items called Cut, Copy, and Paste. Begin by adding the following instance variable to `MenuDemo`:

```java
JPopupMenu jpu;
```

The `jpu` variable will hold a reference to the popup menu.

Next, add the following code sequence to the `MenuDemo` constructor:
This sequence begins by constructing an instance of `JPopupMenu` and storing it in `jpu`. Then, it creates the three menu items, Cut, Copy, and Paste, in the usual way, and adds them to `jpu`. This finishes the construction of the popup Edit menu. Popup menus are not added to the menu bar or any other object.

Next, a `MouseListener` is added by creating an anonymous inner class. This class is based on the `MouseAdapter` class, which means that the listener need only override those methods that are relevant to the popup menu: `mousePressed()` and `mouseReleased()`. The adapter provides default implementations of the other `MouseListener` methods.

Notice that the mouse listener is added to `jfrm`. This means that a right-button click inside any part of the content pane will trigger the popup menu.

The `mousePressed()` and `mouseReleased()` methods call `isPopupTrigger()` to determine if the mouse event is a popup trigger event. If it is, the popup menu is displayed by calling `show()`. The invoker is obtained by calling `getComponent()` on the mouse event. In this case, the invoker will be the content pane. The X,Y coordinates of the upper-left corner are obtained by calling `getX()` and `getY()`. This makes the menu pop up with its upper-left corner directly under the mouse pointer.

Finally, you also need to add these action listeners to the program. They handle the action events fired when the user selects an item from the popup menu.
After you have made these additions, the popup menu can be activated by clicking the right mouse button anywhere inside the content pane of the application. Figure 33-5 shows the result.

One other point about the preceding example. Because the invoker of the popup menu is always \texttt{jfrm}, in this case, you could pass it explicitly rather than calling \texttt{getComponent()} . To do so, you must make \texttt{jfrm} into an instance variable of the \texttt{MenuDemo} class (rather than a local variable) so that it is accessible to the inner class. Then you can use this call to \texttt{show()} to display the popup menu:

\begin{verbatim}
    jpu.show(jfrm, me.getX(), me.getY());
\end{verbatim}

Although this works in this example, the advantage of using \texttt{getComponent()} is that the popup menu will automatically pop up relative to the invoking component. Thus, the same code could be used to display any popup menu relative to its invoking object.

Figure 33-5  A popup Edit menu

\section*{Create a Toolbar}

A toolbar is a component that can serve as both an alternative and as an adjunct to a menu. A toolbar contains a list of buttons (or other components) that give the user immediate access to various program options. For example, a toolbar might contain buttons that select various font options, such as bold, italics, highlight, or underline. These options can be selected without needing to drop through a menu. Typically, toolbar buttons show icons rather than text, although either or both are allowed. Furthermore, tooltips are often associated with icon-based toolbar buttons. Toolbars can be positioned on any side of a window by dragging the toolbar, or they can be dragged out of the window entirely, in which case they become free floating.

In Swing, toolbars are instances of the \texttt{JToolBar} class. Its constructors enable you to create
a toolbar with or without a title. You can also specify the layout of the toolbar, which will be either horizontal or vertical. The JToolBar constructors are shown here:

- JToolBar()
- JToolBar(String title)
- JToolBar(int how)
- JToolBar(String title, int how)

The first constructor creates a horizontal toolbar with no title. The second creates a horizontal toolbar with the title specified by title. The title will show only when the toolbar is dragged out of its window. The third creates a toolbar that is oriented as specified by how. The value of how must be either JToolBar.VERTICAL or JToolBar.HORIZONTAL. The fourth constructor creates a toolbar that has the title specified by title and is oriented as specified by how.

A toolbar is typically used with a window that uses a border layout. There are two reasons for this. First, it allows the toolbar to be initially positioned along one of the four border positions. Frequently, the top position is used. Second, it allows the toolbar to be dragged to any side of the window.

In addition to dragging the toolbar to different locations within a window, you can also drag it out of the window. Doing so creates an undocked toolbar. If you specify a title when you create the toolbar, then that title will be shown when the toolbar is undocked.

You add buttons (or other components) to a toolbar in much the same way that you add them to a menu bar. Simply call add(). The components are shown in the toolbar in the order in which they are added.

Once you have created a toolbar, you do not add it to the menu bar (if one exists). Instead, you add it to the window container. As mentioned, typically you will add a toolbar to the top (that is, north) position of a border layout, using a horizontal orientation. The component that will be affected is added to the center of the border layout. Using this approach causes the program to begin running with the toolbar in the expected location. However, you can drag the toolbar to any of the other positions. Of course, you can also drag the toolbar out of the window.

To illustrate the toolbar, we will add one to the MenuDemo program. The toolbar will present three debugging options: set a breakpoint, clear a breakpoint, and resume program execution. Three steps are needed to add the toolbar.

First, remove this line from the program.

```java
jfrm.setLayout(new FlowLayout());
```

By removing this line, the JFrame automatically uses a border layout.

Second, because BorderLayout is being used, change the line that adds the label jlab to the frame, as shown next:
jfrm.add(jlab, BorderLayout.CENTER);

This line explicitly adds \texttt{jlab} to the center of the border layout. (Explicitly specifying the center position is technically not necessary because, by default, components are added to the center when a border layout is used. However, explicitly specifying the center makes it clear to anyone reading the code that a border layout is being used and that \texttt{jlab} goes in the center.)

Next, add the following code, which creates the Debug toolbar.

// Create a Debug toolbar.
JToolBar jtb = new JToolBar("Debug");

// Load the images.
ImageIcon set = new ImageIcon("setBP.gif");
ImageIcon clear = new ImageIcon("clearBP.gif");
ImageIcon resume = new ImageIcon("resume.gif");

// Create the toolbar buttons.
JButton jbtnSet = new JButton(set);
jbtnSet.setActionCommand("Set Breakpoint");
jbtnSet.setToolTipText("Set Breakpoint");

JButton jbtnClear = new JButton(clear);
jbtnClear.setActionCommand("Clear Breakpoint");
jbtnClear.setToolTipText("Clear Breakpoint");

JButton jbtnResume = new JButton(resume);
jbtnResume.setActionCommand("Resume");
jbtnResume.setToolTipText("Resume");

// Add the buttons to the toolbar.
jtb.add(jbtnSet);
jtb.add(jbtnClear);
jtb.add(jbtnResume);

// Add the toolbar to the north position of
// the content pane.
jfrm.add(jtb, BorderLayout.NORTH);

Let's look at this code closely. First, a \texttt{JToolBar} is created and given the title "Debug". Then, a set of \texttt{ImageIcon} objects are created that hold the images for the toolbar buttons. Next, three toolbar buttons are created. Notice that each has an image, but no text. Also, each is explicitly given an action command and a tooltip. The action commands are set because the buttons are not given names when they are constructed. Tooltips are especially useful when applied to icon-based toolbar components because sometimes it's hard to
design images that are intuitive to all users. The buttons are then added to the toolbar, and the toolbar is added to the north side of the border layout of the frame.

Finally, add the action listeners for the toolbar, as shown here:

```java
// Add the toolbar action listeners.
btnSet.addActionListener(this);
btnClear.addActionListener(this);
btnResume.addActionListener(this);
```

Each time the user presses a toolbar button, an action event is fired, and it is handled in the same way as the other menu-related events. Figure 33-6 shows the toolbar in action.

**Use Actions**

Often, a toolbar and a menu item contain items in common. For example, the same functions provided by the Debug toolbar in the preceding example might also be offered through a menu selection. In such a case, selecting an option (such as setting a breakpoint) causes the same action to occur, independently of whether the menu or the toolbar was used. Also, both the toolbar button and the menu item would (most likely) use the same icon. Furthermore, when a toolbar button is disabled, the corresponding menu item would also need to be disabled. Such a situation would normally lead to a fair amount of duplicated, interdependent code, which is less than optimal. Fortunately, Swing provides a solution: the action.

An action is an instance of the `Action` interface. `Action` extends the `ActionListener` interface and provides a means of combining state information with the `actionPerformed()` event handler. This combination allows one action to manage two or more components. For example, an action lets you centralize the control and handling of a toolbar button and a menu item. Instead of having to duplicate code, your program need only create an action that automatically handles both components.

Because `Action` extends `ActionListener`, an action must provide an implementation of the `actionPerformed()` method. This handler will process the action events generated by the objects linked to the action.
In addition to the inherited `actionPerformed()` method, `Action` defines several methods of its own. One of particular interest is `putValue()`. It sets the value of the various properties associated with an action and is shown here:

```java
void putValue(String key, Object val)
```

It assigns `val` to the property specified by `key` that represents the desired property. Although not used by the example that follows, it is helpful to note that `Action` also supplies the `getValue()` method that obtains a specified property. It is shown here:

```java
Object getValue(String key)
```

It returns a reference to the property specified by `key`.

The key values used by `putValue()` and `getValue()` include those shown here:

<table>
<thead>
<tr>
<th>Key Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>static final String ACCELERATOR_KEY</td>
<td>Represents the accelerator property. Accelerators are specified as <code>KeyStroke</code> objects.</td>
</tr>
<tr>
<td>static final String ACTION_COMMAND_KEY</td>
<td>Represents the action command property. An action command is specified as a string.</td>
</tr>
<tr>
<td>static final String DISPLAYED_MNEMONIC_INDEX_KEY</td>
<td>Represents the index of the character displayed as the mnemonic. This is an <code>Integer</code> value.</td>
</tr>
<tr>
<td>static final String</td>
<td>Represents the large icon associated with the action. The icon is specified as an object of type</td>
</tr>
<tr>
<td>LARGE_ICON_KEY</td>
<td>Icon.</td>
</tr>
<tr>
<td>----------------</td>
<td>-------</td>
</tr>
<tr>
<td>static final String LONG_DESCRIPTION</td>
<td>Represents a long description of the action. This description is specified as a string.</td>
</tr>
<tr>
<td>static final String MNEMONIC_KEY</td>
<td>Represents the mnemonic property. A mnemonic is specified as a <code>KeyEvent</code> constant.</td>
</tr>
<tr>
<td>static final String NAME</td>
<td>Represents the name of the action (which also becomes the name of the button or menu item to which the action is linked). The name is specified as a string.</td>
</tr>
<tr>
<td>static final String SELECTED_KEY</td>
<td>Represents the selection status. If set, the item is selected. The state is represented by a <code>Boolean</code> value.</td>
</tr>
<tr>
<td>static final String SHORT_DESCRIPTION</td>
<td>Represents the tooltip text associated with the action. The tooltip text is specified as a string.</td>
</tr>
<tr>
<td>static final String SMALL_ICON</td>
<td>Represents the icon associated with the action. The icon is specified as an object of type <code>Icon</code>.</td>
</tr>
</tbody>
</table>

For example, to set the mnemonic to the letter X, use this call to `putValue()`:

```java
actionOb.putValue(MNEMONIC_KEY, new Integer(KeyEvent.VK_X));
```

One `Action` property that is not accessible through `putValue()` and `getValue()` is the enabled/disabled status. For this, you use the `setEnabled()` and `isEnabled()` methods. They are shown here:

```java
void setEnabled(boolean enabled)
boolean isEnabled()
```

For `setEnabled()`, if `enabled` is `true`, the action is enabled. Otherwise, it is...
disabled. If the action is enabled, **isEnabled()** returns **true**. Otherwise, it returns **false**.

Although you can implement all of the **Action** interface yourself, you won’t usually need to. Instead, Swing provides a partial implementation called **AbstractAction** that you can extend. By extending **AbstractAction**, you need implement only one method: **actionPerformed()**. The other **Action** methods are provided for you. **AbstractAction** provides three constructors. The one used in this chapter is shown here:

```
AbstractAction(String name, Icon image)
```

It constructs an **AbstractAction** that has the name specified by **name** and the icon specified by **image**.

Once you have created an action, it can be added to a **JToolBar** and used to construct a **JMenuItem**. To add an action to a **JToolBar**, use this version of **add()**:

```
void add(Action actObj)
```

Here, **actObj** is the action that is being added to the toolbar. The properties defined by **actObj** are used to create a toolbar button. To create a menu item from an action, use this **JMenuItem** constructor:

```
JMenuItem(Action actObj)
```

Here, **actObj** is the action used to construct a menu item according to its properties.

---

**NOTE** In addition to **JToolBar** and **JMenuItem**, actions are also supported by several other Swing components, such as **JPopupMenu**, **JButton**, **JRadioButton**, and **JCheckBox**. **JRadioButtonMenuItem** and **JCheckBoxMenuItem** also support actions.

To illustrate the benefit of actions, we will use them to manage the Debug toolbar created in the previous section. We will also add a Debug submenu under the Options main menu. The Debug submenu will contain the same selections as the Debug toolbar: Set Breakpoint, Clear Breakpoint, and Resume. The same actions that support these items in the toolbar will also support these items in the menu. Therefore, instead of having to create duplicate code to handle both the toolbar and menu, both are handled by the actions.

Begin by creating an inner class called **DebugAction** that extends **AbstractAction**, as shown here:
DebugAction extends AbstractAction. It creates an action class that will be used to define the properties associated with the Debug menu and toolbar. Its constructor has five parameters that let you specify the following items:

- Name
- Icon
- Mnemonic
- Accelerator
- Tooltip

The first two are passed to AbstractAction’s constructor via super. The other three properties are set through calls to putValue().

The actionPerformed() method of DebugAction handles events for the action. This means that when an instance of DebugAction is used to create a toolbar button and a menu item, events generated by either of those components are handled by the actionPerformed() method in DebugAction. Notice that this handler displays the
selection in jlab. In addition, if the Set Breakpoint option is selected, then the Clear Breakpoint option is enabled and the Set Breakpoint option is disabled. If the Clear Breakpoint option is selected, then the Set Breakpoint option is enabled and the Clear Breakpoint option is disabled. This illustrates how an action can be used to enable or disable a component. When an action is disabled, it is disabled for all uses of that action. In this case, if Set Breakpoint is disabled, then it is disabled both in the toolbar and in the menu.

Next, add these **DebugAction** instance variables to **MenuDemo**:

```java
DebugAction setAct;
DebugAction clearAct;
DebugAction resumeAct;
```

Next, create three **ImageIcon**s that represent the Debug options, as shown here:

```java
// Load the images for the actions.
ImageIcon setIcon = new ImageIcon("setBP.gif");
ImageIcon clearIcon = new ImageIcon("clearBP.gif");
ImageIcon resumeIcon = new ImageIcon("resume.gif");
```

Now, create the actions that manage the Debug options, as shown here:

```java
// Create actions.
setAct =
    new DebugAction("Set Breakpoint",
        setIcon,
        KeyEvent.VK_S,
        KeyEvent.VK_B,
        "Set a break point.");

clearAct =
    new DebugAction("Clear Breakpoint",
        clearIcon,
        KeyEvent.VK_C,
        KeyEvent.VK_L,
        "Clear a break point.");

resumeAct =
    new DebugAction("Resume",
        resumeIcon,
        KeyEvent.VK_R,
        KeyEvent.VK_R,
        "Resume execution after breakpoint.");

// Initially disable the Clear Breakpoint option.
clearAct.setEnabled(false);
```
Notice that the accelerator for Set Breakpoint is B and the accelerator for Clear Breakpoint is L. The reason these keys are used rather than S and C is that these keys are already allocated by the File menu for Save and Close. However, they can still be used as mnemonics because each mnemonic is localized to its own menu. Also notice that the action that represents Clear Breakpoint is initially disabled. It will be enabled only after a breakpoint has been set.

Next, use the actions to create buttons for the toolbar and then add those buttons to the toolbar, as shown here:

```java
// Create the toolbar buttons by using the actions.
JButton jbntSet = new JButton(setAct);
JButton jbntClear = new JButton(clearAct);
JButton jbntResume = new JButton(resumeAct);

// Create a Debug toolbar.
JToolBar jtb = new JToolBar("Breakpoints");

// Add the buttons to the toolbar.
jtb.add(jbntSet);
jtb.add(jbntClear);
jtb.add(jbntResume);

// Add the toolbar to the north position of
// the content pane.
jfrm.add(jtb, BorderLayout.NORTH);
```

Finally, create the Debug menu, as shown next:

```java
// Now, create a Debug menu that goes under the Options
// menu bar item. Use the actions to create the items.
JMenu jmDebug = new JMenu("Debug");
JMenuItem jmiSetBP = new JMenuItem(setAct);
JMenuItem jmiClearBP = new JMenuItem(clearAct);
JMenuItem jmiResume = new JMenuItem(resumeAct);
jmDebug.add(jmiSetBP);
jmDebug.add(jmiClearBP);
jmDebug.add(jmiResume);
jmOptions.add(jmDebug);
```

After making these changes and additions, the actions that you created will be used to manage both the Debug menu and the toolbar. Thus, changing a property in the action (such as disabling it) will affect all uses of that action. The program will now look as shown in Figure 33-7.
Put the Entire MenuDemo Program Together
Throughout the course of this discussion, many changes and additions have been made to the MenuDemo program shown at the start of the chapter. Before concluding, it will be helpful to assemble all the pieces. Doing so not only eliminates any ambiguity about the way the pieces fit together, but it also gives you a complete menu demonstration program that you can experiment with.

The following version of MenuDemo includes all of the additions and enhancements described in this chapter. For clarity, the program has been reorganized, with separate methods being used to construct the various menus and toolbar. Notice that several of the menu-related variables, such as jmb, jmFile, and jtb, have been made into instance variables.
// The complete MenuDemo program.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class MenuDemo implements ActionListener {

    JLabel jlab;
    JMenuBar jmb;
    JToolBar jtb;
    JPopupMenu jpu;

    DebugAction setAct;
    DebugAction clearAct;
    DebugAction resumeAct;

    MenuDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Complete Menu Demo");

        // Use default border layout.

        // Give the frame an initial size.
        jfrm.setSize(360, 280);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a label that will display the menu selection.
        jlab = new JLabel();

        // Create the menu bar.
        jmb = new JMenuBar();

        // Make the File menu.
        makeFileMenu();
    }
}
// Construct the Debug actions.
makeActions();

// Make the toolbar.
makeToolBar();

// Make the Options menu.
makeOptionsMenu();

// Make the Help menu.
makeHelpMenu();

// Make the edit popup menu.
makeEditFPMenu();

// Add a listener for the popup trigger.
jrp.addMouseListener(new MouseAdapter() {  
    public void mousePressed(MouseEvent me) {  
        if (me.isPopupTrigger())  
            jpu.show(me.getComponent(), me.getX(), me.getY());
    }
    public void mouseReleased(MouseEvent me) {  
        if (me.isPopupTrigger())  
            jpu.show(me.getComponent(), me.getX(), me.getY());
    }
});

// Add the label to the center of the content pane.
jrp.add(jlab, SwingConstants.CENTER);

// Add the toolbar to the north position of
// the content pane.
jrp.add(jtb, BorderLayout.NORTH);

// Add the menu bar to the frame.
jrpmJMenuBar(jmb);

// Display the frame.
jrpm.setVisible(true);

// Handle menu item action events.
// This does NOT handle events generated
// by the Debug options.
public void actionPerformed(ActionEvent ae) {  
    // Get the action command from the menu selection.
    String comStr = ae.getActionCommand();

    // If user chooses Exit, then exit the program.
    if (comStr.equals("Exit")) System.exit(0);

    // Otherwise, display the selection.
    jlab.setText(comStr + " Selected");
}
// An action class for the Debug menu.
// and toolbar.
class DebugAction extends AbstractAction {
    public DebugAction(String name, Icon image, int mnemonic,
                        int accel, String tip) {
        super(name, image);
        putValue(ACCELERATOR_KEY,
                 KeyStroke.getKeyStroke(accel,
                             InputEvent.CTRL_DOWN_MASK));
        putValue(MNEMONIC_KEY, new Integer(mnemonic));
        putValue(SHORT_DESCRIPTION, tip);
    }
}

// Handle events for both the toolbar and the Debug menu.
public void actionPerformed(ActionEvent ae) {
    String comStr = ae.getActionCommand();
    jlab.setText(comStr + " Selected");

    // Toggle the enabled status of the Set and Clear Breakpoint options.
    if(comStr.equals("Set Breakpoint")) {
        setAct.setEnabled(false);
        clearAct.setEnabled(true);
    } else if(comStr.equals("Clear Breakpoint")) {
        setAct.setEnabled(true);
        clearAct.setEnabled(false);
    }
}

// Create the File menu with mnemonics and accelerators.
void makeFileMenu() {
    JMenuItem jmFile = new JMenuItem("File");
    jmFile.setMnemonic(KeyEvent.VK_F);

    JMenuItem jmOpen = new JMenuItem("Open",
                                    KeyEvent.VK_O);
    jmOpen.setAccelerator(KeyStroke.getKeyStroke(KeyEvent.VK_O,
                            InputEvent.CTRL_DOWN_MASK));

    JMenuItem jmTemp = new JMenuItem("Temp",
                                    KeyEvent.VK_T);

    JMenuItem jmSave = new JMenuItem("Save",
                                     KeyEvent.VK_S);
    jmSave.setAccelerator(KeyStroke.getKeyStroke(KeyEvent.VK_S,
                             InputEvent.CTRL_DOWN_MASK));
JMenuItem jmiExit = new JMenuItem("Exit",
                           KeyEvent.VK_E);

jmiExit.setAccelerator(
    KeyStroke.getKeyStroke(KeyEvent.VK_E,
                           InputEvent.CTRL_DOWN_MASK));

jFile.add(jmiOpen);
jFile.add(jmiClose);
jFile.add(jmiSave);
jFile.addSeparator();
jFile.add(jmiExit);
jm.add(jFile);

// Add the action listeners for the File menu.
jmiOpen.addActionListener(this);
jmiClose.addActionListener(this);
jmiSave.addActionListener(this);
jmiExit.addActionListener(this);

// Create the Options menu.
void makeOptionsMenu() {
    JMenu jmOptions = new JMenu("Options");

    // Create the Colors submenu.
    JMenu jmColors = new JMenu("Colors");

    // Use check boxes for colors. This allows
    // the user to select more than one color.
    JCheckBoxMenuItem jmiRed = new JCheckBoxMenuItem("Red");
    JCheckBoxMenuItem jmiGreen = new JCheckBoxMenuItem("Green");
    JCheckBoxMenuItem jmiBlue = new JCheckBoxMenuItem("Blue");

    // Add the items to the Colors menu.
    jmColors.add(jmiRed);
    jmColors.add(jmiGreen);
    jmColors.add(jmiBlue);
    jmOptions.add(jmColors);

    // Create the Priority submenu.
    JMenu jmPriority = new JMenu("Priority");

    // Use radio buttons for the priority setting.
    // This lets the menu show which priority is used
    // but also ensures that one and only one priority
    // can be selected at any one time. Notice that
    // the High radio button is initially selected.
    JRadioButtonMenuItem jmiHigh = new JRadioButtonMenuItem("High", true);
    JRadioButtonMenuItem jmiLow =
        new JRadioButtonMenuItem("Low");

    // Add the items to the Priority menu.
    jmPriority.add(jmiHigh);
// Create a button group for the radio button
// menu items.
ButtonGroup bg = new ButtonGroup();
bg.add(jmiLow);
bg.add(jmiHigh);
bg.add(jmiHigh);
bg.add(jmiLow);

// Now, create a Debug submenu that goes under
// the Options menu bar item. Use actions to
// create the items.
JMenu jmDebug = new JMenu("Debug");
JMenuItem jmiSetBP = new JMenuItem(setAct);
JMenuItem jmiClearBP = new JMenuItem(clearAct);
JMenuItem jmiResume = new JMenuItem(resumeAct);

// Add the items to the Debug menu.
jmDebug.add(jmiSetBP);
jmDebug.add(jmiClearBP);
jmDebug.add(jmiResume);
jmOptions.add(jmDebug);

// Create the Reset menu item.
JMenuItem jmiReset = new JMenuItem("Reset");
jmOptions.addSeparator();
jmOptions.add(jmiReset);

// Finally, add the entire options menu to
// the menu bar
jmb.add(jmOptions);

// Add the action listeners for the Options menu,
// except for those supported by the Debug menu.
imRed.addActionListener(this);
imGreen.addActionListener(this);
imBlue.addActionListener(this);
imHigh.addActionListener(this);
imLow.addActionListener(this);
imReset.addActionListener(this);

// Create the Help menu.
void makeHelpMenu() {
    JMenu jmHelp = new JMenu("Help");

    // Add an icon to the About menu item.
    ImageIcon icon = new ImageIcon("AboutIcon.gif");

    JMenuItem jmiAbout = new JMenuItem("About", icon);
imAbout.setToolTipTextText("Info about the MenuDemo program.");
jmHelp.add(jmiAbout);
jm.add(jmHelp);
}
// Add action listener for About
jmlAbout.addActionListener(this);

// Construct the actions needed by the Debug menu
// and toolbar.
void makeActions()
{
    // Load the images for the actions.
    ImageIcon setIcon = new ImageIcon("setBP.gif");
    ImageIcon clearIcon = new ImageIcon("clearBP.gif");
    ImageIcon resumeIcon = new ImageIcon("resume.gif");

    // Create actions.
    setAct =
        new DebugAction("Set Breakpoint",
                        setIcon,
                        KeyEvent.VK_S,
                        KeyEvent.VK_S,
                        "Set a break point.");

    clearAct =
        new DebugAction("Clear Breakpoint",
                        clearIcon,
                        KeyEvent.VK_C,
                        KeyEvent.VK_C,
                        "Clear a break point.");

    resumeAct =
        new DebugAction("Resume",
                        resumeIcon,
                        KeyEvent.VK_R,
                        KeyEvent.VK_R,
                        "Resume execution after breakpoint.");

    // Initially disable the Clear Breakpoint option.
    clearAct.setEnabled(false);
}

// Create the Debug toolbar.
void makeToolBar()
{
    // Create the toolbar buttons by using the actions.
    JButton jbtnSet = new JButton(setAct);
    JButton jbtnClear = new JButton(clearAct);
    JButton jbtnResume = new JButton(resumeAct);

    // Create the Debug toolbar.
    jtb = new JToolBar("Breakpoints");

    // Add the buttons to the toolbar.
    jtb.add(jbtnSet);
    jtb.add(jbtnClear);
    jtb.add(jbtnResume);
}
Continuing Your Exploration of Swing

Swing defines a very large GUI toolkit. It has many more features that you will want to explore on your own. For example, it supplies dialog classes, such as `JOptionPane` and `JDialog`, that you can use to streamline the construction of dialog windows. It also provides additional controls beyond those introduced in Chapter 31. Two you will want to explore are `JSpinner` (which creates a spin control) and `JFormattedTextField` (which supports formatted text). You will also want to experiment with defining your own models for the various components. Frankly, the best way to become familiar with Swing’s capabilities is to experiment with it.
<table>
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<th>PART</th>
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Like all successful languages, Java continues to evolve and improve. This also applies to its libraries. One of the most important examples of this evolutionary process is found in its GUI frameworks. As explained earlier in the book, the original GUI framework was the AWT. Because of its several limitations, it was soon followed by Swing, which offered a far superior approach to creating GUIs. Swing was so successful that it has remained the primary Java GUI framework for over a decade. (And a decade is a long time in the fast-moving world of programming!) However, Swing was designed when the enterprise application dominated software development. Today, consumer applications, and especially mobile apps, have risen in importance, and such applications often demand a GUI that has “visual sparkle.” Furthermore, no matter the type of application, the trend is toward more exciting visual effects. To better handle these types of GUIs, a new approach was needed, and this lead to the creation of JavaFX. JavaFX is Java’s next-generation client platform and GUI framework.

JavaFX provides a powerful, streamlined, flexible framework that simplifies the creation of modern, visually exciting GUIs. As such, it is a very large system, and, as was the case with Swing discussed in Part III, it is not possible to describe it fully in this book. Instead, the purpose of this and the next two chapters is to introduce several of its key features and techniques. Once you understand the fundamentals, you will find it easy to explore other aspects of JavaFX on your own.

One question that naturally arises relating to JavaFX is this: Is JavaFX designed as a replacement for Swing? The answer is a qualified Yes. However, given the large amount of Swing legacy code and the legions of programmers who know how to program for Swing, Swing will be in use for a very long time. This is especially true for enterprise applications. Nevertheless, JavaFX has clearly been positioned as the platform of the future. It is expected that, over the next few years, JavaFX will supplant Swing for new projects. JavaFX is something that no Java programmer can afford to ignore.

Before continuing, it is important to mention that the development of JavaFX occurred in two main phases. The original JavaFX was based on a scripting language called JavaFX Script. However, JavaFX Script has been discontinued. Beginning with the release of
JavaFX 2.0, JavaFX has been programmed in Java itself and provides a comprehensive API. JavaFX also supports FXML, which can be (but is not required to be) used to specify the user interface. JavaFX has been bundled with Java since JDK 7, update 4. The latest version of JavaFX is JavaFX 8, which is bundled with JDK 8. (The version number is 8 to align with the JDK version. Thus, the numbers 3 through 7 were skipped.) Because, at the time of this writing, JavaFX 8 represents the latest version of JavaFX, it is the version of JavaFX discussed here. Furthermore, when the term JavaFX is used in this and the following chapters, it refers to JavaFX 8.

---

**NOTE** This and the following two chapters assume that you have a basic understanding of event handling as introduced in Chapter 24, and Swing fundamentals, as described by the preceding three chapters.

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**JavaFX Basic Concepts**

In general, the JavaFX framework has all of the good features of Swing. For example, JavaFX is lightweight. It can also support an MVC architecture. Much of what you already know about creating GUIs using Swing is conceptually applicable to JavaFX. That said, there are significant differences between the two.

From a programmer’s point of view, the first differences you notice between JavaFX and Swing are the organization of the framework and the relationship of the main components. Simply put, JavaFX offers a more streamlined, easier-to-use, updated approach. JavaFX also greatly simplifies the rendering of objects because it handles repainting automatically. It is no longer necessary for your program to handle this task manually. The preceding is not intended to imply that Swing is poorly designed. It is not. It is just that the art and science of programming has moved forward, and JavaFX has received the benefits of that evolution. Simply put, JavaFX facilitates a more visually dynamic approach to GUIs.

**The JavaFX Packages**

The JavaFX elements are contained in packages that begin with the `javafx` prefix. At the time of this writing, there are more than 30 JavaFX packages in its API library. Here are four examples: `javafx.application`, `javafx.stage`, `javafx.scene`, and `javafx.scene.layout`. Although we will only use a few of these packages in this chapter, you will want to spend some time browsing their capabilities. JavaFX offers a wide array of functionality.

**The Stage and Scene Classes**

The central metaphor implemented by JavaFX is the `stage`. As in the case of an actual stage play, a stage contains a `scene`. Thus, loosely speaking, a stage defines a space and a scene
defines what goes in that space. Or, put another way, a stage is a container for scenes and a scene is a container for the items that comprise the scene. As a result, all JavaFX applications have at least one stage and one scene. These elements are encapsulated in the JavaFX API by the Stage and Scene classes. To create a JavaFX application, you will, at minimum, add at least one Scene object to a Stage. Let’s look a bit more closely at these two classes.

**Stage** is a top-level container. All JavaFX applications automatically have access to one Stage, called the primary stage. The primary stage is supplied by the run-time system when a JavaFX application is started. Although you can create other stages, for many applications, the primary stage will be the only one required.

As mentioned, **Scene** is a container for the items that comprise the scene. These can consist of controls, such as push buttons and check boxes, text, and graphics. To create a scene, you will add those elements to an instance of Scene.

### Nodes and Scene Graphs

The individual elements of a scene are called nodes. For example, a push button control is a node. However, nodes can also consist of groups of nodes. Furthermore, a node can have a child node. In this case, a node with a child is called a parent node or branch node. Nodes without children are terminal nodes and are called leaves. The collection of all nodes in a scene creates what is referred to as a scene graph, which comprises a tree.

There is one special type of node in the scene graph, called the root node. This is the top-level node and is the only node in the scene graph that does not have a parent. Thus, with the exception of the root node, all other nodes have parents, and all nodes either directly or indirectly descend from the root node.

The base class for all nodes is Node. There are several other classes that are, either directly or indirectly, subclasses of Node. These include Parent, Group, Region, and Control, to name a few.

### Layouts

JavaFX provides several layout panes that manage the process of placing elements in a scene. For example, the FlowPane class provides a flow layout and the GridPane class supports a row/column grid-based layout. Several other layouts, such as BorderPane (which is similar to the AWT's BorderLayout), are available. The layout panes are packaged in javafx.scene.layout.

### The Application Class and the Life-cycle Methods

A JavaFX application must be a subclass of the Application class, which is packaged in javafx.application. Thus, your application class will extend Application. The Application class defines three life-cycle methods that your application can override. These are called init(), start(), and stop(), and are shown here, in the order in which they are called:
void init( )

abstract void start(Stage primaryStage)

void stop( )

The init( ) method is called when the application begins execution. It is used to perform various initializations. As will be explained, however, it cannot be used to create a stage or build a scene. If no initializations are required, this method need not be overridden because an empty, default version is provided.

The start( ) method is called after init( ). This is where your application begins and it can be used to construct and set the scene. Notice that it is passed a reference to a Stage object. This is the stage provided by the run-time system and is the primary stage. (You can also create other stages, but you won’t need to for simple applications.) Notice that this method is abstract. Thus, it must be overridden by your application.

When your application is terminated, the stop( ) method is called. It is here that you can handle any cleanup or shutdown chores. In cases in which no such actions are needed, an empty, default version is provided.

Launching a JavaFX Application
To start a free-standing JavaFX application, you must call the launch( ) method defined by Application. It has two forms. Here is the one used in this chapter:

public static void launch(String ... args)

Here, args is a possibly empty list of strings that typically specify command-line arguments. When called, launch( ) causes the application to be constructed, followed by calls to init( ) and start( ). The launch( ) method will not return until after the application has terminated. This version of launch( ) starts the subclass of Application from which launch( ) is called. The second form of launch( ) lets you specify a class other than the enclosing class to start.

Before moving on, it is necessary to make an important point: JavaFX applications that have been packaged by using the javafxpackager tool (or its equivalent in an IDE) do not need to include a call to launch( ). However, its inclusion often simplifies the test/debug cycle, and it lets the program be used without the creation of a JAR file. Thus, it is included in all of the JavaFX programs in this book.

A JavaFX Application Skeleton
All JavaFX applications share the same basic skeleton. Therefore, before looking at any more JavaFX features, it will be useful to see what that skeleton looks like. In addition to showing the general form of a JavaFX application, the skeleton also illustrates how to launch the application and demonstrates when the life-cycle methods are called. A message noting when each life-cycle method is called is displayed on the console. The complete skeleton is shown here:
// A JavaFX application skeleton.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;

public class JavaFXSkel extends Application {

    public static void main(String[] args) {

        System.out.println("Launching JavaFX application.");

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the init() method.
    public void init() {
System.out.println("Inside the init() method.");

// Override the start() method.
public void start(Stage myStage) {

    System.out.println("Inside the start() method.");

    // Give the stage a title.
    myStage.setTitle("JavaFX Skeleton.");

    // Create a root node. In this case, a flow layout pane
    // is used, but several alternatives exist.
    FlowPane rootNode = new FlowPane();

    // Create a scene.
    Scene myScene = new Scene(rootNode, 300, 200);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Show the stage and its scene.
    myStage.show();

}

// Override the stop() method.
public void stop() {
    System.out.println("Inside the stop() method.");
}

Although the skeleton is quite short, it can be compiled and run. It produces the window shown here:
It also produces the following output on the console:

```
Launching JavaFX application.
Inside the init() method.
Inside the start() method.
```

When you close the window, this message is displayed on the console:

```
Inside the stop() method.
```

Of course, in a real program, the life-cycle methods would not normally output anything to `System.out`. They do so here simply to illustrate when each method is called. Furthermore, as explained earlier, you will need to override the `init()` and `stop()` methods only if your application must perform special startup or shutdown actions. Otherwise, you can use the default implementations of these methods provided by the `Application` class.

Let’s examine this program in detail. It begins by importing four packages. The first is `javafx.application`, which contains the `Application` class. The `Scene` class is packaged in `javafx.scene`, and `Stage` is packaged in `javafx.stage`. The `javafx.scene.layout` package provides several layout panes. The one used by the program is `FlowPane`.

Next, the application class `JavaFXSkel` is created. Notice that it extends `Application`. As explained, `Application` is the class from which all JavaFX applications are derived. `JavaFXSkel` contains two methods. The first is `main()`. It is used to launch the application via a call to `launch()`. Notice that the `args` parameter to `main()` is passed to the `launch()` method. Although this is a common approach, you can pass a different set of parameters to `launch()`, or none at all. One other point: As explained earlier, `launch()` is required by a free-standing application, but not in other cases. When it is not needed, `main()` is also not needed. However, for reasons already explained, both `main()` and `launch()` are included in the JavaFX programs in this book.

When the application begins, the `init()` method is called first by the JavaFX run-time system. For the sake of illustration, it simply displays a message on `System.out`, but it would normally be used to initialize some aspect of the application. Of course, if no initialization is required, it is not necessary to override `init()` because an empty, default implementation is provided. It is important to emphasize that `init()` cannot be used to create the stage or scene portions of a GUI. Rather, these items should be constructed and displayed by the `start()` method.

After `init()` finishes, the `start()` method executes. It is here that the initial scene is created and set to the primary stage. Let’s look at this method line-by-line. First, notice that `start()` has a parameter of type `Stage`. When `start()` is called, this parameter will receive a reference to the primary stage of the application. It is to this stage that you will set a scene for the application.

After displaying a message on the console that `start()` has begun execution, it sets the title of the stage using this call to `setTitle()`:
Although this step is not necessarily required, it is customary for stand-alone applications. This title becomes the name of the main application window.

Next, a root node for a scene is created. The root node is the only node in a scene graph that does not have a parent. In this case, a FlowPane is used for the root node, but there are several other classes that can be used for the root.

    FlowPane rootNode = new FlowPane();

As mentioned, a FlowPane is a layout manager that uses a flow layout. This is a layout in which elements are positioned line-by-line, with lines wrapping as needed. (Thus, it works much like the FlowLayout class used by the AWT and Swing.) In this case, a horizontal flow is used, but it is possible to specify a vertical flow. Although not needed by this skeletal application, it is also possible to specify other layout properties, such as a vertical and horizontal gap between elements, and an alignment. You will see an example of this later in this chapter.

The following line uses the root node to construct a Scene:

    Scene myScene = new Scene(rootNode, 300, 200);

Scene provides several versions of its constructor. The one used here creates a scene that has the specified root with the specified width and height. It is shown here:

    Scene(Parent rootnode, double width, double height)

Notice that the type of rootnode is Parent. It is a subclass of Node and encapsulates nodes that can have children. Also notice that the width and the height are double values. This lets you pass fractional values, if needed. In the skeleton, the root is rootNode, the width is 300 and the height is 200.

The next line in the program sets myScene as the scene for myStage:

    myStage.setScene(myScene);

Here, setScene( ) is a method defined by Stage that sets the scene to that specified by its argument.

In cases in which you don’t make further use of the scene, you can combine the previous two steps, as shown here:

    myStage.setScene(new Scene(rootNode, 300, 200));

Because of its compactness, this form will be used by most of the subsequent examples.
The last line in `start()` displays the stage and its scene:

```java
mystage.show();
```

In essence, `show()` shows the window that was created by the stage and screen. When you close the application, its window is removed from the screen and the `stop()` method is called by the JavaFX run-time system. In this case, `stop()` simply displays a message on the console, illustrating when it is called. However, `stop()` would not normally display anything. Furthermore, if your application does not need to handle any shutdown actions, there is no reason to override `stop()` because an empty, default implementation is provided.

**Compiling and Running a JavaFX Program**

One important advantage of JavaFX is that the same program can be run in a variety of different execution environments. For example, you can run a JavaFX program as a stand-alone desktop application, inside a web browser, or as a Web Start application. However, different ancillary files may be needed in some cases, for example, an HTML file or a Java Network Launch Protocol (JNLP) file.

In general, a JavaFX program is compiled like any other Java program. However, because of the need for additional support for various execution environments, the easiest way to compile a JavaFX application is to use an Integrated Development Environment (IDE) that fully supports JavaFX programming, such as NetBeans. Just follow the instructions for the IDE you are using.

Alternatively, if you want to compile and test a JavaFX application using the command-line tools, you can easily do so. Just compile and run the application in the normal way, using `javac` and `java`. Be aware that using the command-line compiler neither creates any HTML or JNLP files that would be needed if you want to run the application in a way other than as a stand-alone application, nor does it create a JAR file for the program. To create these files, you need to use a tool such as `javafxpackager`.

**The Application Thread**

In the preceding discussion, it was mentioned that you cannot use the `init()` method to construct a stage or scene. You also cannot create these items inside the application’s constructor. The reason is that a stage or scene must be constructed on the **application thread**. However, the application’s constructor and the `init()` method are called on the main thread, also called the **launcher thread**. Thus, they can’t be used to construct a stage or scene. Instead, you must use the `start()` method, as the skeleton demonstrates, to create the initial GUI because `start()` is called on the application thread.

Furthermore, any changes to the GUI currently displayed must be made from the application thread. Fortunately, in JavaFX, events are sent to your program on the application thread. Therefore, event handlers can be used to interact with the GUI. The
A Simple JavaFX Control: Label

The primary ingredient in most user interfaces is the control because a control enables the user to interact with the application. As you would expect, JavaFX supplies a rich assortment of controls. The simplest control is the label because it just displays a message, which, in this example, is text. Although quite easy to use, the label is a good way to introduce the techniques needed to begin building a scene graph.

The JavaFX label is an instance of the `Label` class, which is packaged in `javafx.scene.control`. `Label` inherits `Labeled` and `Control`, among other classes. The `Labeled` class defines several features that are common to all labeled elements (that is, those that can contain text), and `Control` defines features related to all controls. `Label` defines three constructors. The one we will use here is

```java
Label(String str)
```

Here, `str` is the string that is displayed.

Once you have created a label (or any other control), it must be added to the scene’s content, which means adding it to the scene graph. To do this, you will first call `getChildren()` on the root node of the scene graph. It returns a list of the child nodes in the form of an `ObservableList<Node>`. `ObservableList` is packaged in `javafx.collections`, and it inherits `java.util.List`, which means that it supports all of the features available to a list as defined by the Collections Framework. Using the returned list of child nodes, you can add the label to the list by calling `add()`, passing in a reference to the label.

The following program puts the preceding discussion into action by creating a simple JavaFX application that displays a label:
// Demonstrate a JavaFX label.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;

public class JavaFXLabelDemo extends Application {

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch()
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a JavaFX label.");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        Label myLabel = new Label("This is a JavaFX label");

        // Add the label to the scene graph.
        rootNode.getChildren().add(myLabel);

        // Show the stage and its scene.
        myStage.show();
    }
}

This program produces the following window:
In the program, pay special attention to this line:

```java
rootNode.getChildren().add(myLabel);
```

It adds the label to the list of children for which `rootNode` is the parent. Although this line could be separated into its individual pieces if necessary, you will often see it as shown here. Before moving on, it is useful to point out that `ObservableList` provides a method called `addAll()` that can be used to add two or more children to the scene graph in a single call. (You will see an example of this shortly.) To remove a control from the scene graph, call `remove()` on the `ObservableList`. For example,

```java
rootNode.getChildren().remove(myLabel);
```

removes `myLabel` from the scene.

**Using Buttons and Events**

Although the program in the preceding section presents a simple example of using a JavaFX control and constructing a scene graph, it does not show how to handle events. As you know, most GUI controls generate events that are handled by your program. For example, buttons, check boxes, and lists all generate events when they are used. In many ways, event handling in JavaFX is similar to event handling in Swing or the AWT, but it’s more streamlined. Therefore, if you already are proficient at handling events for these other two GUIs, you will have no trouble using the event handling system provided by JavaFX.

One commonly used control is the button. This makes button events one of the most frequently handled. Therefore, a button is a good way to demonstrate the fundamentals of event handling in JavaFX. For this reason, the fundamentals of event handling and the button are introduced together.

**Event Basics**

The base class for JavaFX events is the `Event` class, which is packaged in `javafx.event`. `Event` inherits `java.util.EventObject`, which means that JavaFX events share the same
basic functionality as other Java events. Several subclasses of Event are defined. The one that we will use here is ActionEvent. It handles action events generated by a button.
In general, JavaFX uses what is, in essence, the delegation event model approach to event handling. To handle an event, you must first register the handler that acts as a listener for the event. When the event occurs, the listener is called. It must then respond to the event and return. In this regard, JavaFX events are managed much like Swing events, for example.
Events are handled by implementing the EventHandler interface, which is also in javafx.event. It is a generic interface with the following form:

```java
interface EventHandler<T extends Event>
```
Here, T specifies the type of event that the handler will handle. It defines one method, called handle(), which receives the event object as a parameter. It is shown here:

```java
void handle(T eventObj)
```
Here, eventObj is the event that was generated. Typically, event handlers are implemented through anonymous inner classes or lambda expressions, but you can use stand-alone classes for this purpose if it is more appropriate to your application (for example, if one event handler will handle events from more than one source).

Although not required by the examples in this chapter, it is sometimes useful to know the source of an event. This is especially true if you are using one handler to handle events from different sources. You can obtain the source of the event by calling getSource(), which is inherited from java.util.EventObject. It is shown here:

```java
Object getSource()
```
Other methods in Event let you obtain the event type, determine if the event has been consumed, consume an event, fire an event, and obtain the target of the event. When an event is consumed, it stops the event from being passed to a parent handler.

One last point: In JavaFX, events are processed via an event dispatch chain. When an event is generated, it is passed to the root node of the chain. The event is then passed down the chain to the target of the event. After the target node processes the event, the event is passed back up the chain, thus allowing parent nodes a chance to process the event, if necessary. This is called event bubbling. It is possible for a node in the chain to consume an event, which prevents it from being further processed.

NOTE Although not used in this introduction to JavaFX, an application can also implement an event filter, which can be used to manage events.
A filter is added to a node by calling `addEventFilter()` which is defined by Node. A filter can consume an event, thus preventing further processing.

**Introducing the Button Control**

In JavaFX, the push button control is provided by the Button class, which is in javafx.scene.control. Button inherits a fairly long list of base classes that include ButtonBase, Labeled, Region, Control, Parent, and Node. If you examine the API documentation for Button, you will see that much of its functionality comes from its base classes. Furthermore, it supports a wide array of options. However, here we will use its default form. Buttons can contain text, graphics, or both. In this chapter, we will use text-based buttons. An example of a graphics-based button is shown in the next chapter.

Button defines three constructors. The one we will use is shown here:

```
Button(String str)
```

In this case, `str` is the message that is displayed in the button.

When a button is pressed, an `ActionEvent` is generated. `ActionEvent` is packaged in javafx.event. You can register a listener for this event by using `setOnAction()`, which has this general form:

```
final void setOnAction(EventHandler<ActionEvent> handler)
```

Here, `handler` is the handler being registered. As mentioned, often you will use an anonymous inner class or lambda expression for the handler. The `setOnAction()` method sets the property `onAction`, which stores a reference to the handler. As with all other Java event handling, your handler must respond to the event as fast as possible and then return. If your handler consumes too much time, it will noticeably slow down the application. For lengthy operations, you must use a separate thread of execution.

**Demonstrating Event Handling and the Button**

The following program demonstrates event handling. It uses two buttons and a label. Each time a button is pressed, the label is set to display which button was pressed.
// Demonstrate JavaFX events and buttons:

import javafx.application.;
import javafx.scene.;
import javafx.stage.;
import javafx.scene.layout.;
import javafx.scene.control.;
import javafx.event.;
import javafx.geometry.;

public class JavaFXEventDemo extends Application {

    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {
        // Give the stage a title.
        myStage.setTitle("Demonstrate JavaFX Buttons and Events.");
    }
}
Sample output from this program is shown here:
Let's examine a few key portions of this program. First, notice how buttons are created by these two lines:

```java
Button btnAlpha = new Button("Alpha");
Button btnBeta = new Button("Beta");
```

This creates two text-based buttons. The first displays the string Alpha; the second displays Beta.

Next, an action event handler is set for each of these buttons. The sequence for the Alpha button is shown here:

```java
// Handle the action events for the Alpha button.
btnAlpha.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        response.setText("Alpha was pressed.");
    }
});
```

As explained, buttons respond to events of type `ActionEvent`. To register a handler for these events, the `setOnAction()` method is called on the button. It uses an anonymous inner class to implement the `EventHandler` interface. (Recall that `EventHandler` defines only the `handle()` method.) Inside `handle()`, the text in the `response` label is set to reflect the fact that the Alpha button was pressed. Notice that this is done by calling the `setText()` method on the label. Events are handled by the Beta button in the same way. Note that `response` is declared as a field within `FXEventDemo`, rather than as a local variable. This is because it is accessed within the button event handlers, which are anonymous inner classes.

After the event handlers have been set, the `response` label and the buttons `btnAlpha` and `btnBeta` are added to the scene graph by using a call to `addAll()`:

```java
rootNode.getChildren().addAll(btnAlpha, btnBeta, response);
```

The `addAll()` method adds a list of nodes to the invoking parent node. Of course, these nodes could have been added by three separate calls to `add()`, but the `addAll()` method is more convenient to use in this situation.

There are two other things of interest in this program that relate to the way the controls are displayed in the window. First, when the root node is created, this statement is used:

```java
FlowPane rootNode = new FlowPane(10, 10);
```

Here, the `FlowPane` constructor is passed two values. These specify the horizontal and vertical gap that will be left around elements in the scene. If these gaps are not specified,
then two elements (such as two buttons) would be positioned in such a way that no space is between them. Thus, the controls would run together, creating a very unappealing user interface. Specifying gaps prevents this.

The second point of interest is the following line, which sets the alignment of the elements in the FlowPane:

```java
rootNode.setAlignment(Pos.CENTER);
```

Here, the alignment of the elements is centered. This is done by calling `setAlignment()` on the FlowPane. The value `Pos.CENTER` specifies that both a vertical and horizontal center will be used. Other alignments are possible. `Pos` is an enumeration that specifies alignment constants. It is packaged in `javafx.geometry`.

Before moving on, one more point needs to be made. The preceding program used anonymous inner classes to handle button events. However, because the EventHandler interface defines only one abstract method, `handle()`, a lambda expression could have passed to `setOnAction()`, instead. In this case, the parameter type of `setOnAction()` would supply the target context for the lambda expression. For example, here is the handler for the Alpha button, rewritten to use a lambda:

```java
btnAlpha.setOnAction((ae) ->
    response.setText("Alpha was pressed.");
```

Notice that the lambda expression is more compact than the anonymous inner class. Because lambda expressions are a new feature just recently added to Java, but the anonymous inner class is a widely used construct, readily understood by nearly all Java programmers, the event handlers in subsequent examples will use anonymous inner classes. This will also allow the examples to be compiled by readers using JDK 7 (which does not support lambdas). However, on your own, you might want to experiment with converting them to lambda expressions. It is a good way to gain experience using lambdas in your own code.

**Drawing Directly on a Canvas**

As mentioned early on, JavaFX handles rendering tasks for you automatically, rather than you handling them manually. This is one of the most important ways that JavaFX improves on Swing. As you may know, in Swing or the AWT, you must call the `repaint()` method to cause a window to be repainted. Furthermore, your application needs to store the window contents, redrawing them when painting is requested. JavaFX eliminates this tedious mechanism because it keeps track of what you display in a scene and redisplays that scene as needed. This is called *retained mode*. With this approach, there is no need to call a method like `repaint()`. Rendering is automatic.

One place that JavaFX’s approach to rendering is especially helpful is when displaying
graphics objects, such as lines, circles, and rectangles. JavaFX’s graphics methods are found in the `GraphicsContext` class, which is part of `java.scene.canvas`. These methods can be used to draw directly on the surface of a canvas, which is encapsulated by the `Canvas` class in `java.scene.canvas`. When you draw something, such as a line, on a canvas, JavaFX automatically renders it whenever it needs to be redisplayed.

Before you can draw on a canvas, you must perform two steps. First, you must create a `Canvas` instance. Second, you must obtain a `GraphicsContext` object that refers to that canvas. You can then use the `GraphicsContext` to draw output on the canvas.

The `Canvas` class is derived from `Node`; thus it can be used as a node in a scene graph. `Canvas` defines two constructors. One is the default constructor, and the other is the one shown here:

```java
Canvas(double width, double height)
```

Here, `width` and `height` specify the dimensions of the canvas.

To obtain a `GraphicsContext` that refers to a canvas, call `getGraphicsContext2D()`.

Here is its general form:

```java
GraphicsContext getGraphicsContext2D()
```

The graphics context for the canvas is returned.

`GraphicsContext` defines a large number of methods that draw shapes, text, and images, and support effects and transforms. If sophisticated graphics programming is in your future, you will definitely want to study its capabilities closely. For our purposes, we will use only a few of its methods, but they will give you a sense of its power. They are described here.

You can draw a line using `strokeLine()`, shown here:

```java
void strokeLine(double startX, double startY, double endX, double endY)
```

It draws a line from `startX,startY` to `endX,endY`, using the current stroke, which can be a solid color or some more complex style.

To draw a rectangle, use either `strokeRect()` or `fillRect()`, shown here:

```java
void strokeRect(double topX, double topY, double width, double height)
void fillRect(double topX, double topY, double width, double height)
```

The upper-left corner of the rectangle is at `topX,topY`. The `width` and `height` parameters specify its width and height. The `strokeRect()` method draws the outline of a rectangle using the current stroke, and `fillRect()` fills the rectangle with the current fill. The current fill can be as simple as a solid color or something more complex.

To draw an ellipse, use either `strokeOval()` or `fillOval()`, shown next:

```java
void strokeOval(double topX, double topY, double width, double height)
void fillOval(double topX, double topY, double width, double height)
```
The upper-left corner of the rectangle that bounds the ellipse is at $topX, topY$. The width and height parameters specify its width and height. The `strokeOval()` method draws the outline of an ellipse using the current stroke, and `fillOval()` fills the oval with the current fill. To draw a circle, pass the same value for width and height.

You can draw text on a canvas by using the `strokeText()` and `fillText()` methods. We will use this version of `fillText()`:

```java
void fillText(String str, double topX, double topY)
```

It displays `str` starting at the location specified by $topX, topY$, filling the text with the current fill.

You can set the font and font size of the text being displayed by using `setFont()`. You can obtain the font used by the canvas by calling `getFont()`. By default, the system font is used. You can create a new font by constructing a `Font` object. `Font` is packaged in `javafx.scene.text`. For example, you can create a default font of a specified size by using this constructor:

```java
Font(double fontSize)
```

Here, `fontSize` specifies the size of the font.

You can specify the fill and stroke using these two methods defined by `Canvas`:

```java
void setFill(Paint newFill)
void setStroke(Paint newStroke)
```

Notice that the parameter of both methods is of type `Paint`. This is an abstract class packaged in `javafx.scene.paint`. Its subclasses define fills and strokes. The one we will use is `Color`, which simply describes a solid color. `Color` defines several static fields that specify a wide array of colors, such as `Color.BLUE`, `Color.RED`, `Color.GREEN`, and so on.

The following program uses the aforementioned methods to demonstrate drawing on a canvas. It first displays a few graphic objects on the canvas. Then, each time the Change Color button is pressed, the color of three of the objects changes color. If you run the program, you will see that the shapes whose color is not changed are unaffected by the change in color of the other objects. Furthermore, if you try covering and then uncovering the window, you will see that the canvas is automatically repainted, without any other actions on the part of your program. Sample output is shown here:
// Demonstrate drawing.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.shape.*;
import javafx.scene.canvas.*;
import javafx.scene.paint.*;
import javafx.scene.text.*;

public class DirectDrawDemo extends Application {
    GraphicsContext gc;
Color[] colors = { Color.RED, Color.BLUE, Color.GREEN, Color.BLACK };  
int colorIdx = 0;

public static void main(String[] args) {
    // Start the JavaFX application by calling launch().
    launch(args);
}

// Override the start() method.
public void start(Stage myStage) {
    // Give the stage a title.
    myStage.setTitle("Draw Directly to a Canvas.");

    // Use a FlowPane for the root node.
    FlowPane rootNode = new FlowPane();

    // Center the nodes in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 450, 450);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Create a canvas.
    Canvas myCanvas = new Canvas(400, 400);

    // Get the graphics context for the canvas.
    gc = myCanvas.getGraphicsContext2D();

    // Create a push button.
    Button btnChangeColor = new Button("Change Color");

    // Handle the action events for the Change Color button.
    btnChangeColor.setOnAction(new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            // Set the stroke and fill color.
            gc.setStroke(colors[colorIdx]);
            gc.setFill(colors[colorIdx]);

            // Redraw the line, text, and filled rectangle in the
            // new color. This leaves the color of the other nodes
            // unchanged.
            gc.strokeLine(0, 0, 200, 200);
            gc.fillText("This is drawn on the canvas.", 60, 50);
            gc.fillRect(100, 320, 300, 40);  
        }
    });
It is important to emphasize that GraphicsContext supports many more operations than those demonstrated by the preceding program. For example, you can apply various transforms, rotations, and effects. Despite its power, its various features are easy to master and use. One other point: A canvas is transparent. Therefore, if you stack canvases, the contents of both will show. This may be useful in some situations.

NOTE javafx.scene.shape contains several classes that can also be used to draw various types of graphical shapes, such as circles, arcs, and lines. These are represented by nodes and can, therefore, be directly part of the scene graph. You will want to explore these on your own.
The previous chapter described several of the core concepts relating to the JavaFX GUI framework. In the process, it introduced two controls: the label and the button. This chapter continues the discussion of JavaFX controls. It begins by describing how to include images in a label and button. It then presents an overview of several more JavaFX controls, including check boxes, lists, and trees. Keep in mind that JavaFX is a rich and powerful framework. The purpose of this chapter is to introduce a representative sampling of the JavaFX controls and to describe several common techniques. Once you understand the basics, you will be able to easily learn the other controls.

The JavaFX control classes discussed in this chapter are shown here:

These and the other JavaFX controls are packaged in `javafx.scene.control`. Also discussed are the `Image` and `ImageView` classes, which provide support for images in controls; `Tooltip`, which is used to add tooltips to a control; as well as various effects and transforms.

### Using Image and ImageView

Several of JavaFX’s controls let you include an image. For example, in addition to text, you can specify an image in a label or a button. Furthermore, you can embed stand-alone images in a scene directly. At the foundation for JavaFX’s support for images are two classes: `Image` and `ImageView`. `Image` encapsulates the image, itself, and `ImageView` manages the display of an image. Both classes are packaged in `javafx.scene.image`.

The `Image` class loads an image from either an `InputStream`, a URL, or a path to the image file. `Image` defines several constructors; this is the one we will use:

```java
Image(String url)
```

Here, `url` specifies a URL or a path to a file that supplies the image. The argument
is assumed to refer to a path if it does not constitute a properly formed URL.
Otherwise, the image is loaded from the URL. The examples that follow will load images from files on the local file system. Other constructors let you specify various options, such as the image’s width and height. One other point: Image is not derived from Node. Thus, it cannot, itself, be part of a scene graph.

Once you have an Image, you will use ImageView to display it. ImageView is derived from Node, which means that it can be part of a scene graph. ImageView defines three constructors. The first one we will use is shown here:

```
ImageView(Image image)
```

This constructor creates an ImageView that uses image for its image.

Putting the preceding discussion into action, here is a program that loads an image of an hourglass and displays it via ImageView. The hourglass image is contained in a file called hourglass.png, which is assumed to be in the local directory.
// Load and display an image.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class ImageDemo extends Application {

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Display an Image");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Use center alignment.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);
In the program, pay close attention to the following sequence that loads the image and then creates an `ImageView` that uses that image:

```java
// Create an image.
Image hourglass = new Image("HourGlass.png");

// Create an image view that uses the image.
ImageView hourglassIV = new ImageView(hourglass);
```

As explained, an image by itself cannot be added to the scene graph. It must first be embedded in an `ImageView`. In cases in which you won't make further use of the image, you can specify a URL or filename when creating an `ImageView`. In this case, there is no need to explicitly create an `Image`. Instead, an `Image` instance containing the specified image is constructed.
automatically and embedded in the `ImageView`. Here is the `ImageView` constructor that does this:

```java
ImageView(String url)
```

Here, `url` specifies the URL or the path to a file that contains the image.

**Adding an Image to a Label**

As explained in the previous chapter, the `Label` class encapsulates a label. It can display a text message, a graphic, or both. So far, we have used it to display only text, but it is easy to add an image. To do so, use this form of `Label`'s constructor:

```java
Label(String str, Node image)
```

Here, `str` specifies the text message and `image` specifies the image. Notice that the image is of type `Node`. This allows great flexibility in the type of image added to the label, but for our purposes, the image type will be `ImageView`.

Here is a program that demonstrates a label that includes a graphic. It creates a label that displays the string "Hourglass" and shows the image of an hourglass that is loaded from the `hourglass.png` file.
// Demonstrate an image in a label.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class LabelImageDemo extends Application {

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Use an Image in a Label");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane();

        // Use center alignment.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create an ImageView that contains the specified image.
        ImageView hourglassIV = new ImageView("hourglass.png");

        // Create a label that contains both an image and text.
        Label hourglassLabel = new Label("Hourglass", hourglassIV);

        // Add the label to the scene graph.
        rootNode.getChildren().add(hourglassLabel);

        // Show the stage and its scene.
        myStage.show();
    }
}
Here is the window produced by the program:

As you can see, both the image and the text are displayed. Notice that the text is to the right of the image. This is the default. You can change the relative positions of the image and text by calling `setContentDisplay( )` on the label. It is shown here:

```
final void setContentDisplay(ContentDisplay position)
```

The value passed to `position` determines how the text and image is displayed. It must be one of these values, which are defined by the `ContentDisplay` enumeration:

<table>
<thead>
<tr>
<th>Bottom</th>
<th>Right</th>
</tr>
</thead>
<tbody>
<tr>
<td>CENTER</td>
<td>TEXT_ONLY</td>
</tr>
<tr>
<td>GRAPHIC_ONLY</td>
<td>TOP</td>
</tr>
<tr>
<td>LEFT</td>
<td></td>
</tr>
</tbody>
</table>

With the exception of `TEXT_ONLY` and `GRAPHIC_ONLY`, the values specify the location of the image. For example, if you add this line to the preceding program:

```
hourglassLabel.setContentDisplay(ContentDisplay.TOP);
```

the image of the hourglass will be above the text, as shown here:
The other two values let you display either just the text or just the image. This might be useful if your application wants to use an image at some times, and not at others, for example. (If you want only an image, you can simply display it without using a label, as described in the previous section.)

You can also add an image to a label after it has been constructed by using the `setGraphic()` method. It is shown here:

```java
final void setGraphic(Node image)
```

Here, `image` specifies the image to add.

### Using an Image with a Button

**Button** is JavaFX’s class for push buttons. The preceding chapter introduced the **Button** class. There, you saw an example of a button that contained text. Although such buttons are common, you are not limited to this approach because you can include an image. You can also use only the image if you choose. The procedure for adding an image to a button is similar to that used to add an image to a label. First obtain an **ImageView** of the image. Then add it to the button. One way to add the image is to use this constructor:

```java
Button(String str, Node image)
```

Here, `str` specifies the text that is displayed within the button and `image` specifies the image. You can specify the position of the image relative to the text by using `setContentDisplay()` in the same way as just described for **Label**.

Here is an example that displays two buttons that contain images. The first shows an hourglass. The second shows an analog clock. When a button is pressed, the selected timepiece is reported. Notice that the text is displayed beneath the image.

```java
// Use an image with a button.
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
```
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.image.*;

public class ButtonImageDemo extends Application {

    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Use Images with Buttons");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the components in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 250, 450);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        response = new Label("Push a Button");

        // Create two image-based buttons.
        Button btnHourglass = new Button("Hourglass",
                new ImageView("hourglass.png"));
        Button btnAnalogClock = new Button("Analog Clock",
                new ImageView("analog.png"));

        // Position the text under the image.
        btnHourglass.setContentDisplay(ContentDisplay.TOP);
        btnAnalogClock.setContentDisplay(ContentDisplay.TOP);

        // Handle the action events for the hourglass button.
        btnHourglass.setOnAction(new EventHandler<ActionEvent>() {
            public void handle(ActionEvent ae) {
                response.setText("Hourglass Pressed");
            }
        });
    }
}
The output produced by this program is shown here:

If you want a button that contains only the image, pass a null string for the text when constructing the button and then call `setContentDisplay()`, passing in the parameter `ContentDisplay.GRAPHIC_ONLY`. For example, if you make these modifications to the previous program, the output will look like this:
ToggleButton

A useful variation on the push button is called the *toggle button*. A toggle button looks just like a push button, but it acts differently because it has two states: pushed and released.

That is, when you press a toggle button, it stays pressed rather than popping back up as a regular push button does. When you press the toggle button a second time, it releases (pops up). Therefore, each time a toggle button is pushed, it toggles between these two states. In JavaFX, a toggle button is encapsulated in the `ToggleButton` class. Like `Button`, `ToggleButton` is also derived from `ButtonBase`. It implements the `Toggle` interface, which defines functionality common to all types of two-state buttons.

`ToggleButton` defines three constructors. This is the one we will use:

```
ToggleButton(String str)
```

Here, `str` is the text displayed in the button. Another constructor allows you to include an image. Like other buttons, a `ToggleButton` generates an action event when it is pressed.

Because `ToggleButton` defines a two-state control, it is commonly used to let the user select an option. When the button is pressed, the option is selected. When the button is released, the option is deselected. For this reason, a program usually needs to determine the toggle button’s state. To do this, use the `isSelected()` method, shown here:
final boolean isSelected( )

It returns true if the button is pressed and false otherwise.

Here is a short program that demonstrates ToggleButton:

```java
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class ToggleButtonDemo extends Application {

    ToggleButton tbOnOff;
    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a Toggle Button");

        // Use a FlowPane for the root node. In this case, // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 220, 120);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        response = new Label("Push the Button.");

        // Create the toggle button.
        tbOnOff = new ToggleButton("On/Off");
    }

    @Override
    public void setup() {
    }

    @Override
    public void start(Stage primaryStage) {
        // The controller setup
    }
}
```
Sample output produced by the program is shown here, with the button pressed:

In the program, notice how the pressed/released state of the toggle button is determined by the following lines of code inside the button's action event handler.

```java
if (tbOnOff.isSelected()) response.setText("Button is on.");
else response.setText("Button is off.");
```

When the button is pressed, `isSelected()` returns `true`. When the button is released, `isSelected()` returns `false`.

One other point: It is possible to use two or more toggle buttons in a group. In this case, only one button can be in its pressed state at any one time. The process of creating and using a group of toggle buttons is similar to that required to use radio buttons. It is described in the following section.

**RadioButton**

Another type of button provided by JavaFX is the `radio button`. Radio buttons are a group of mutually exclusive buttons, in which only one button can be selected at any one time. They are supported by the `RadioButton` class, which extends both `ButtonBase` and `ToggleButton`. It also implements the `Toggle` interface. Thus, a radio button is a specialized form of a toggle button. You have almost certainly seen radio buttons in action because they are the primary control employed when the user must select only one option.
among several alternatives.

To create a radio button, we will use the following constructor:

```java
RadioButton(String str)
```

Here, `str` is the label for the button. Like other buttons, when a `RadioButton` is used, an action event is generated.

For their mutually exclusive nature to be activated, radio buttons must be configured into a group. Only one of the buttons in the group can be selected at any time. For example, if a user presses a radio button that is in a group, any previously selected button in that group is automatically deselected. A button group is created by the `ToggleGroup` class, which is packaged in `javafx.scene.control`. `ToggleGroup` provides only a default constructor. Radio buttons are added to the toggle group by calling the `setToggleGroup( )` method, defined by `ToggleButton`, on the button. It is shown here:

```java
final void setToggleGroup(ToggleGroup tg)
```

Here, `tg` is a reference to the toggle button group to which the button is added. After all radio buttons have been added to the same group, their mutually exclusive behavior will be enabled.

In general, when radio buttons are used in a group, one of the buttons is selected when the group is first displayed in the GUI. Here are two ways to do this.

First, you can call `setSelected( )` on the button that you want to select. It is defined by `ToggleButton` (which is a superclass of `RadioButton`). It is shown here:

```java
final void setSelected(boolean state)
```

If `state` is `true`, the button is selected. Otherwise, it is deselected. Although the button is selected, no action event is generated.

A second way to initially select a radio button is to call `fire( )` on the button. It is shown here:

```java
void fire()
```

This method results in an action event being generated for the button if the button was previously not selected.

There are a number of different ways to use radio buttons. Perhaps the simplest is to simply respond to the action event that is generated when one is selected. The following program shows an example of this approach. It uses radio buttons to allow the user to select a type of transportation.
// A simple demonstration of Radio Buttons.
//
// This program responds to the action events generated
// by a radio button selection. It also shows how to
// fire the button under program control.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class RadioButtonDemo extends Application {

    Label response;

    public static void main(String[] args) {

// Start the JavaFX application by calling launch().
public void launch(String[] args) {
}

// Override the start() method.
public void start(Stage myStage) {
    // Give the stage a title.
    myStage.setTitle("Demonstrate Radio Buttons");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10.
    FlowPane rootNode = new FlowPane(10, 10);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 320, 220);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Create a label that will report the selection.
    response = new Label();

    // Create the radio buttons.
    RadioButton rbTrain = new RadioButton("Train");
    RadioButton rbCar = new RadioButton("Car");
    RadioButton rbPlane = new RadioButton("Airplane");

    // Create a toggle group.
    ToggleGroup tg = new ToggleGroup();

    // Add each button to a toggle group.
    rbTrain.setToggleGroup(tg);
    rbCar.setToggleGroup(tg);
    rbPlane.setToggleGroup(tg);

    // Handle action events for the radio buttons.
    rbTrain.setOnAction(new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            response.setText("Transport selected is train.");
        }
    });

    rbCar.setOnAction(new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            response.setText("Transport selected is car.");
        }
    });

    rbPlane.setOnAction(new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            response.setText("Transport selected is airplane.");
        }
    });
Sample output is shown here:

```
RadioButton rbTrain = new RadioButton("Train");
RadioButton rbCar = new RadioButton("Car");
RadioButton rbPlane = new RadioButton("Airplane");

Next, a ToggleGroup is constructed:

    ToggleGroup tg = new ToggleGroup();

Finally, each radio button is added to the toggle group:

    rbTrain.setToggleGroup(tg);
    rbCar.setToggleGroup(tg);
    rbPlane.setToggleGroup(tg);
```

As explained, radio buttons must be part of a toggle group in order for their mutually exclusive behavior to be activated.

After the event handlers for each radio button have been defined, the rbTrain button is selected by calling fire() on it. This causes that button to be selected and an action event to
Handling Change Events in a Toggle Group

Although there is nothing wrong, per se, with managing radio buttons by handling action events, as just shown, sometimes it is more appropriate (and easier) to listen to the entire toggle group for changes. When a change takes place, the event handler can easily determine which radio button has been selected and take action accordingly. To use this approach, you must register a ChangeListener on the toggle group. When a change event occurs, you can then determine which button was selected. To try this approach, remove the action event handlers and the call to `fire()` from the preceding program and substitute the following:

```java
// Use a change listener to respond to a change of selection within
// the group of radio buttons.
        tg.selectedToggleProperty().addListener(new ChangeListener<Toggle>() {
            public void changed(ObservableValue<? extends Toggle> changed,
                                 Toggle oldVal, Toggle newVal) {
                // Cast new to RadioButton.
                RadioButton rb = (RadioButton) newVal;
                // Display the selection.
                response.setText("Transport selected is " + rb.getText());
            }
        });

        // Select the first button. This will cause a change event
        // on the toggle group.
        rbTrain.setSelected(true);
```

You will also need to add this `import` statement:

```java
import javafx.beans.value.*;
```

It supports the `ChangeListener` interface.

The output from this program is the same as before; each time a selection is made, the `response` label is updated. However, in this case, only one event handler is needed for the enter group, rather than three (one for each button). Let's now look at this code more closely.

First, a change event listener is registered for the toggle group. To listen for change events, you must implement the `ChangeListener` interface. This is done by calling `addListener()` on the object returned by `selectedToggleProperty()`. The `ChangeListener` interface defines only one method, called `changed()`. It is shown here:

```java
void changed(ObservableValue<? extends T> changed, T oldVal, T newVal)
```

In this case, `changed` is the instance of `ObservableValue<T>`, which encapsulates an object that can be watched for changes. The `oldVal` and `newVal` parameters pass the previous value and the new value, respectively. Thus, in this
case, newVal holds a reference to the radio button that has just been selected. In this example, the setSelected() method, rather than fire(), is called to set the initial selection. Because setting the initial selection causes a change to the toggle group, it results in a change event being generated when the program first begins. You can also use fire(), but setSelected() was used to demonstrate that any change to the toggle group generates a change event.

An Alternative Way to Handle Radio Buttons
Although handling events generated by radio buttons is often useful, sometimes it is more appropriate to ignore those events and simply obtain the currently selected button when that information is needed. This approach is demonstrated by the following program. It adds a button called Confirm Transport Selection. When this button is pressed, the currently selected radio button is obtained and then the selected transport is displayed in a label. When you try the program, notice that changing the selected radio button does not cause the confirmed transport to change until you press the Confirm Transport Selection button.
/ This radio button example demonstrates how the
// currently selected button in a group can be obtained
// under program control, when it is needed, rather
// than responding to action or change events.
//
// In this example, no events related to the radio
// buttons are handled. Instead, the current selection
// is simply obtained when the Confirm Transport Selection push
// button is pressed.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class RadioButtonDemo2 extends Application {

    Label response;
    ToggleGroup tg;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Radio Buttons");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 200, 140);

        // Set the scene on the stage.
        myStage.setScene(myScene);
    }
}
// Create two labels.
Label choose = new Label("Select a Transport Type");
response = new Label("No transport confirmed");

// Create push button used to confirm the selection.
Button btnConfirm = new Button("Confirm Transport Selection");

// Create the radio buttons.
RadioButton rbTrain = new RadioButton("Train");
RadioButton rbCar = new RadioButton("Car");
RadioButton rbPlane = new RadioButton("Airplane");

// Create a toggle group.
tg = new ToggleGroup();

// Add each button to a toggle group.
rbTrain.setToggleGroup(tg);
rbCar.setToggleGroup(tg);
rbPlane.setToggleGroup(tg);

// Initially select one of the radio buttons.
rbTrain.setSelected(true);

// Handle action events for the confirm button.
btnConfirm.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        // Get the radio button that is currently selected.
        RadioButton rb = (RadioButton) tg.getSelectedToggle();

        // Display the selection.
        response.setText(rb.getText() + " is confirmed.");
    }
});

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(180);

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(choose, rbTrain, rbCar, rbPlane,
    separator, btnConfirm, response);

// Show the stage and its scene.
myStage.show();
Most of the program is easy to understand, but two key points are of special interest. First, inside the action event handler for the `btnConfirm` button, notice that the selected radio button is obtained by the following line:

```java
RadioButton rb = (RadioButton) tg.getSelectedToggle();
```

Here, the `getSelectedToggle()` method (defined by `ToggleGroup`) obtains the current selection for the toggle group (which, in this case, is a group of radio buttons). It is shown here:

```java
final Toggle getSelectedToggle()
```

It returns a reference to the `Toggle` that is selected. In this case, the return value is cast to `RadioButton` because this is the type of button in the group.

The second thing to notice is the use of a visual separator, which is created by this sequence:

```java
Separator separator = new Separator();
separator.setPrefWidth(180);
```

The `Separator` class creates a line, which can be either vertical or horizontal. By default, it creates a horizontal line. (A second constructor lets you choose a vertical separator.) `Separator` helps visually organize the layout of controls. It is packaged in `javafx.scene.control`. Next, the width of the separator line is set by calling `setPrefWidth()`, passing in the width.

**CheckBox**

The `CheckBox` class encapsulates the functionality of a check box. Its immediate superclass is `ButtonBase`. Although you are no doubt familiar with check boxes because they are widely used controls, the JavaFX check box is a bit more sophisticated than you may at first think. This is because `CheckBox` supports three states. The first two are checked or unchecked, as you would expect, and this is the default behavior. The third state is `indeterminate` (also called `undefined`). It is typically used to indicate that the state of the check box has not been set or that it is not relevant to a specific situation. If you need the indeterminate state, you will need to explicitly enable it.
**CheckBox** defines two constructors. The first is the default constructor. The second lets you specify a string that identifies the box. It is shown here:

```java
CheckBox(String str)
```

It creates a check box that has the text specified by `str` as a label. As with other buttons, a **CheckBox** generates an action event when it is selected.

Here is a program that demonstrates check boxes. It displays check boxes that let the user select various deployment options, which are Web, Desktop, and Mobile. Each time a check box state changes, an action event is generated and handled by displaying the new state (selected or cleared) and by displaying a list of all selected boxes.

```java
// Demonstrate Check Boxes.
import javafx.application.*;
import javafx.scene.*;
```
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class CheckboxDemo extends Application {

    CheckBox cbWeb;
    CheckBox cbDesktop;
    CheckBox cbMobile;

    Label response;
    Label allTargets;

    String targets = "";

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Checkboxes");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 230, 140);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        Label heading = new Label("Select Deployment Options");

        // Create a label that will report the state of the
        // selected check box.
        response = new Label("No Deployment Selected");

        // Create a label that will report all targets selected.
        allTargets = new Label("Target List: <none>");

        // Create the check boxes.
        cbWeb = new CheckBox("Web");
chDesktop = new CheckBox("Desktop");
chMobile = new CheckBox("Mobile");

// Handle action events for the check boxes.
chWeb.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(chWeb.isSelected())
            response.setText("Web deployment selected.");
        else
            response.setText("Web deployment cleared.");

        showAll();
    }
});

chDesktop.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(chDesktop.isSelected())
            response.setText("Desktop deployment selected.");
        else
            response.setText("Desktop deployment cleared.");

        showAll();
    }
});

chMobile.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(chMobile.isSelected())
            response.setText("Mobile deployment selected.");
        else
            response.setText("Mobile deployment cleared.");

        showAll();
    }
});

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(200);

// Add controls to the scene graph.
rootNode.getChildren().addAll(heading, separator, chWeb, chDesktop, chMobile, response, allTargets);

// Show the stage and its scene.
myStage.show();

// Update and show the targets list.
void showAll() {
    targets = "";
    if(chWeb.isSelected()) targets += "Web ";
    if(chDesktop.isSelected()) targets += "Desktop ";
    if(chMobile.isSelected()) targets += "Mobile"
    if(targets.equals("")) targets = "<none>";

    allTargets.setText("Target List: " + targets);
}
The operation of this program is straightforward. Each time a check box is changed, an action command is generated. To determine if the box is checked or unchecked, the `isSelected()` method is called.

As mentioned, by default, `CheckBox` implements two states: checked and unchecked. If you want to add the indeterminate state, it must be explicitly enabled. To do this, call `setAllowIndeterminate()`, shown here:

```java
final void setAllowIndeterminate(boolean enable)
```

In this case, if `enable` is `true`, the indeterminate state is enabled. Otherwise, it is disabled. When the indeterminate state is enabled, the user can select between checked, unchecked, and indeterminate.

You can determine if a check box is in the indeterminate state by calling `isIndeterminate()`, shown here:

```java
final boolean isIndeterminate()
```

It returns `true` if the checkbox state is indeterminate and `false` otherwise.

You can see the effect of a three-state check box by modifying the preceding program. First, enable the indeterminate state on the check boxes by calling `setAllowIndeterminate()` on each check box, as shown here:

```java
cbWeb.setAllowIndeterminate(true);
```

```
```

Next, handle the indeterminate state inside the action event handlers. For example, here is the modified handler for `cbWeb`:
cbWeb.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if (cbWeb.isIndeterminate())
            response.setText("Web deployment indeterminate.");
        else if (cbWeb.isSelected())
            response.setText("Web deployment selected.");
        else
            response.setText("Web deployment cleared.");

        showAll();
    }
});

Now, all three states are tested. Update the other two handlers in the same way. After making these changes, the indeterminate state can be selected, as this sample output shows:

Here, the Web check box is indeterminate.

**ListView**

Another commonly used control is the list view, which in JavaFX is encapsulated by `ListView`. List views are controls that display a list of entries from which you can select one or more. Because of their ability to make efficient use of limited screen space, list views are popular alternatives to other types of selection controls.

`ListView` is a generic class that is declared like this:

```
class ListView<T>
```

Here, `T` specifies the type of entries stored in the list view. Often, these are entries of type `String`, but other types are also allowed.

`ListView` defines two constructors. The first is the default constructor, which creates an empty `ListView`. The second lets you specify the list of entries in the list. It is shown here:

```
ListView(ObservableList<T> list)
```

Here, `list` specifies a list of the items that will be displayed. It is an object of type `ObservableList`, which defines a list of observable objects. It inherits `java.util.List`. Thus, it supports the standard collection methods.
**ObservableList** is packaged in **javafx.collections**.

Probably the easiest way to create an **ObservableList** for use in a **ListView** is to use the factory method **observableArrayList()**, which is a static method defined by the **FXCollections** class (which is also packaged in **javafx.collections**). The version we will use is shown here:

```java
static <E> ObservableList<E> observableArrayList(E ... elements)
```

In this case, **E** specifies the type of elements, which are passed via **elements**.

By default, a **ListView** allows only one item in the list to be selected at any one time. However, you can allow multiple selections by changing the selection mode. For now, we will use the default, single-selection model.

Although **ListView** provides a default size, sometimes you will want to set the preferred height and/or width to best match your needs. One way to do this is to call the **setPrefHeight()** and **setPrefWidth()** methods, shown here:

```java
final void setPrefHeight(double height)
final void setPrefWidth(double width)
```

Alternatively, you can use a single call to set both dimensions at the same time by use of **setPrefSize()**, shown here:

```java
void setPrefSize(double width, double height)
```

There are two basic ways in which you can use a **ListView**. First, you can ignore events generated by the list and simply obtain the selection in the list when your program needs it. Second, you can monitor the list for changes by registering a change listener. This lets you respond each time the user changes a selection in the list. This is the approach used here.

To listen for change events, you must first obtain the selection model used by the **ListView**. This is done by calling **getSelectionModel()** on the list. It is shown here:

```java
final MultipleSelectionModel<T> getSelectionModel()
```

It returns a reference to the model. **MultipleSelectionModel** is a class that defines the model used for multiple selections, and it inherits **SelectionModel**. However, multiple selections are allowed in a **ListView** only if multiple-selection mode is turned on.

Using the model returned by **getSelectionModel()**, you will obtain a reference to the selected item property that defines what takes place when an element in the list is selected. This is done by calling **selectedItemProperty()**, shown next:

```java
final ReadOnlyObjectProperty<T> selectedItemProperty()
```

You will add the change listener to this property.

The following example puts the preceding discussion into action. It creates a list view that displays various types of transportation, allowing the user to select one. When one is
chosen, the selection is displayed.

// Demonstrate a list view.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.beans.value.*;
import javafx.collections.*;

class ListViewDemo extends Application {
    Label response;
}
public static void main(String[] args) {

    // Start the JavaFX application by calling launch().
    launch(args);
}

// Override the start() method.
public void start(Stage myStage) {

    // Give the stage a title.
    myStage.setTitle("ListView Demo");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10.
    FlowPane rootNode = new FlowPane(10, 10);
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 200, 120);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Create a label.
    response = new Label("Select Transport Type");

    // Create an ObservableList of entries for the list view.
    ObservableList<String> transportTypes =
        FXCollections.observableArrayList("Train", "Car", "Airplane");

    // Create the list view.
    ListView<String> lvTransport = new ListView<String>(transportTypes);

    // Set the preferred height and width.
    lvTransport.setPrefSize(80, 80);

    // Get the list view selection model.
    MultipleSelectionModel<String> lvSelModel =
        lvTransport.getSelectionModel();

    // Use a change listener to respond to a change of selection within
    // a list view.
    lvSelModel.selectedItemProperty().addListener(
        new ChangeListener<String>() {
            public void changed(ObservableValue<? extends String> changed,
                                String oldVal, String newVal) {

                // Display the selection.
                response.setText("Transport selected is " + newVal);
            }
        });

    // Add the label and list view to the scene graph.
    rootNode.getChildren().addAll(lvTransport, response);

    // Show the stage and its scene.
    myStage.show();
}
In the program, pay special attention to how the **ListView** is constructed. First, an **ObservableList** is created by this line:

```java
ObservableList<String> transportTypes =
    FXCollections.observableArrayList( "Train", "Car", "Airplane" );
```

It uses the `observableArrayList()` method to create a list of strings. Then, the **ObservableList** is used to initialize a **ListView**, as shown here:

```java
ListView<String> lvTransport = new ListView<String>(transportTypes);
```

The program then sets the preferred width and height of the control.

Now, notice how the selection model is obtained for `lvTransport`:

```java
MultipleSelectionModel<String> lvSelModel =
    lvTransport.getSelectionModel();
```

As explained, **ListView** uses **MultipleSelectionModel**, even when only a single selection is allowed. The `selectedItemProperty()` method is then called on the model and a change listener is registered to the returned item.

**ListView Scrollbars**

One very useful feature of **ListView** is that when the number of items in the list exceeds the number that can be displayed within its dimensions, scrollbars are automatically added. For example, if you change the declaration of `transportTypes` so that it includes "Bicycle" and "Walking", as shown here:

```java
ObservableList<String> transportTypes =
    FXCollections.observableArrayList( "Train", "Car", "Airplane",
                                      "Bicycle", "Walking" );
```

the `lvTransport` control now looks like the one shown here:
Enabling Multiple Selections
If you want to allow more than one item to be selected, you must explicitly request it. To do so, you must set the selection mode to `SelectionMode.MULTIPLE` by calling `setSelectionMode( )` on the `ListView` model. It is shown here:

```java
final void setSelectionMode(SelectionMode mode)
```

In this case, `mode` must be either `SelectionMode.MULTIPLE` or `SelectionMode.SINGLE`.

When multiple-selection mode is enabled, you can obtain the list of the selections two ways: as a list of selected indices or as a list of selected items. We will use a list of selected items, but the procedure is similar when using a list of the indices of the selected items. (Note, indexing of items in a `ListView` begins at zero.)

To get a list of the selected items, call `getSelectedItems( )` on the selection model. It is shown here:

```java
ObservableList<T> getSelectedItems( )
```

It returns an `ObservableList` of the items. Because `ObservableList` extends `java.util.List`, you can access the items in the list just as you would any other `List` collection.

To experiment with multiple selections, you can modify the preceding program as follows. First, make `lvTransport` final so it can be accessed within the change event handler. Next, add this line:

```java
lvTransport.getSelectionModel().setSelectionMode(SelectionMode.MULTIPLE);
```

It enables multiple-selection mode for `lvTransport`. Finally, replace the change event handler with the one shown here:
After making these changes, the program will display all selected forms of transports, as the following output shows:

```
ComboBox
A control related to the list view is the combo box, which is implemented in JavaFX by the ComboBox class. A combo box displays one selection, but it will also display a drop-down list that allows the user to select a different item. You can also allow the user to edit a selection. ComboBox inherits ComboBoxBase, which provides much of its functionality. Unlike the ListView, which can allow multiple selections, ComboBox is designed for single-selection.

ComboBox is a generic class that is declared like this:

```java
class ComboBox<T>
```

Here, T specifies the type of entries. Often, these are entries of type String, but other types are also allowed.

ComboBox defines two constructors. The first is the default constructor, which creates an empty ComboBox. The second lets you specify the list of entries. It is shown here:

```java
ComboBox(ObservableList<T> list)
```
In this case, `list` specifies a list of the items that will be displayed. It is an object of type `ObservableList`, which defines a list of observable objects. As explained in the previous section, `ObservableList` inherits `java.util.List`. As also previously explained, an easy way to create an `ObservableList` is to use the factory method `observableArrayList()`, which is a static method defined by the `FXCollections` class.

A `ComboBox` generates an action event when its selection changes. It will also generate a change event. Alternatively, it is also possible to ignore events and simply obtain the current selection when needed.

You can obtain the current selection by calling `getValue()`, shown here:

```java
final T getValue()
```

If the value of a combo box has not yet been set (by the user or under program control), then `getValue()` will return `null`. To set the value of a `ComboBox` under program control, call `setValue()`:

```java
final void setValue(T newVal)
```

Here, `newVal` becomes the new value.

The following program demonstrates a combo box by reworking the previous list view example. It handles the action event generated by the combo box.
// Demonstrate a combo box.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.geometry.*;
import javafx.collections.*;
import javafx.event.*;

public class ComboBoxDemo extends Application {

    ComboBox<String> cbTransport;
    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("ComboBox Demo");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 280, 120);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label.
        response = new Label();
As mentioned, `ComboBox` can be configured to allow the user to edit a selection. Assuming that it contains only entries of type `String`, it is easy to enable editing capabilities. Simply call `setEditable()` shown here:

```java
final void setEditable(boolean enable)
```

If `enable` is `true`, editing is enabled. Otherwise, it is disabled. To see the effects of editing, add this line to the preceding program:

```java
chTransport.setEditable(true);
```
After making this addition, you will be able to edit the selection. 

**ComboBox** supports many additional features and functionality beyond those mentioned here. You might find it interesting to explore further. Also, an alternative to a combo box in some cases is the **ChoiceBox** control. You will find it easy to use because it has similarities to both **ListView** and **ComboBox**.

**TextField**

Although the controls discussed earlier are quite useful and are frequently found in a user interface, they all implement a means of selecting a predetermined option or action. However, sometimes you will want the user to enter a string of his or her own choosing. To accommodate this type of input, JavaFX includes several text-based controls. The one we will look at is **TextField**. It allows one line of text to be entered. Thus, it is useful for obtaining names, ID strings, addresses, and the like. Like all text controls, **TextField** inherits **TextInputControl**, which defines much of its functionality.

**TextField** defines two constructors. The first is the default constructor, which creates an empty text field that has the default size. The second lets you specify the initial contents of the field. Here, we will use the default constructor.

Although the default size is sometimes adequate, often you will want to specify its size. This is done by calling `setPrefColumnCount()`, shown here:

```java
final void setPrefColumnCount(int columns)
```

The `columns` value is used by **TextField** to determine its size.

You can set the text in a text field by calling `setText()`. You can obtain the current text by calling `getText()`. In addition to these fundamental operations, **TextField** supports several other capabilities that you might want to explore, such as cut, paste, and append. You can also select a portion of the text under program control.

One especially useful **TextField** option is the ability to set a prompting message inside the text field when the user attempts to use a blank field. To do this, call `setPromptText()`, shown here:

```java
final void setPromptText(String str)
```

In this case, `str` is the string displayed in the text field when no text has been entered. It is displayed using low-intensity (such as a gray tone).

When the user presses enter while inside a **TextField**, an action event is generated. Although handling this event is often helpful, in some cases, your program will simply obtain the text when it is needed, rather than handling action events. Both approaches are demonstrated by the following program. It creates a text field that requests a search string. When the user presses enter while the text field has input focus, or presses the Get Search String button, the string is obtained and displayed. Notice that a prompting message is also included.
// Demonstrate a text field.
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class TextFieldDemo extends Application {
    TextField tf;
    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a TextField");

        // Use a FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 230, 140);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label that will report the contents of the
        // text field.
        response = new Label("Search String: ");

        // Create a button that gets the text.
        Button btnGetText = new Button("Get Search String");

        // Create a text field.
        tf = new TextField();

        // Set the prompt.
        tf.setPromptText("Enter Search String");
Sample output is shown here:

Other text controls that you will want to examine include **TextArea**, which supports multiline text, and **PasswordField**, which can be used to input passwords. You might also find **HTMLEditor** helpful.

**ScrollPane**
Sometimes, the contents of a control will exceed the amount of screen space that you want to give to it. Here are two examples: A large image may not fit within reasonable boundaries, or you might want to display text that is longer than will fit within a small
window. Whatever the reason, JavaFX makes it easy to provide scrolling capabilities to any node in a scene graph. This is accomplished by wrapping the node in a ScrollPane. When a ScrollPane is used, scrollbars are automatically implemented that scroll the contents of the wrapped node. No further action is required on your part. Because of the versatility of ScrollPane, you will seldom need to use individual scrollbar controls.

ScrollPane defines two constructors. The first is the default constructor. The second lets you specify a node that you want to scroll. It is shown here:

```
ScrollPane(Node content)
```

In this case, content specifies the information to be scrolled. When using the default constructor, you will add the node to be scrolled by calling `setContent()`.

It is shown here:

```
final void setContent(Node content)
```

After you have set the content, add the scroll pane to the scene graph. When displayed, the content can be scrolled.

---

NOTE You can also use `setContent()` to change the content being scrolled by the scroll pane. Thus, what is being scrolled can be changed during the execution of your program.

Although a default size is provided, as a general rule, you will want to set the dimensions of the viewport. The viewport is the viewable area of a scroll pane. It is the area in which the content being scrolled is displayed. Thus, the viewport displays the visible portion of the content. The scrollbars scroll the content through the viewport. Thus, by moving a scrollbar, you change what part of the content is visible.

You can set the viewport dimensions by using these two methods:

```
final void setPrefViewportHeight(double height)
final void setPrefViewportWidth(double width)
```

In its default behavior, a ScrollPane will dynamically add or remove a scrollbar as needed. For example, if the component is taller than the viewport, a vertical scrollbar is added. If the component will completely fit within the viewport, the scrollbars are removed.

One nice feature of ScrollPane is its ability to pan the contents by dragging the mouse. By default, this feature is off. To turn it on, use `setPannable()`, shown here:

```
final void setPannable(boolean enable)
```
If `enable` is **true**, then panning is allowed. Otherwise, it is disabled. You can set the position of the scrollbars under program control using `setHvalue()` and `setVvalue()`, shown here:

```java
final void setHvalue(double newHval)
final void setVvalue(double newVval)
```

The new horizontal position is specified by `newHval`, and the new vertical position is specified by `newVval`. By default, scrollbar positions start at zero.

**ScrollPane** supports various other options. For example, it is possible to set the minimum and maximum scrollbar positions. You can also specify when and if the scrollbars are shown by setting a scrollbar policy. The current position of the scrollbars can be obtained by calling `getHvalue()` and `getVvalue()`.

The following program demonstrates **ScrollPane** by using one to scroll the contents of a multiline label. Notice that it also enables panning.
// Demonstrate a scroll pane.
// This program scrolls the contents of a multiline
// label, but any node can be scrolled.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;

public class ScrollPaneDemo extends Application {

    ScrollPane scrlPane;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate a ScrollPane");

        // Use a FlowPane for the root node.
        FlowPane rootNode = new FlowPane(10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 200, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label that will be scrolled.
        Label scrlLabel = new Label("A ScrollPane streamlines the process of\n" +
One of JavaFX's most powerful controls is the **TreeView**. It presents a hierarchical view of
data in a tree-like format. In this context, the term *hierarchical* means some items are subordinate to others. For example, a tree is commonly used to display the contents of a file system. In this case, the individual files are subordinate to the directory that contains them.

In a **TreeView**, branches can be expanded or collapsed on demand by the user. This allows hierarchical data to be presented in a compact, yet expandable form. Although **TreeView** supports many customization options, you will often find that the default tree style and capabilities are suitable. Therefore, even though trees support a sophisticated structure, they are still quite easy to work with.

**TreeView** implements a conceptually simple, tree-based data structure. A tree begins with a single *root node* that indicates the start of the tree. Under the root are one or more *child nodes*. There are two types of child nodes: *leaf nodes* (also called *terminal nodes*), which have no children, and *branch nodes*, which form the root nodes of *subtrees*. A subtree is simply a tree that is part of a larger tree. The sequence of nodes that leads from the root to a specific node is called a *path*.

One very useful feature of **TreeView** is that it automatically provides scrollbars when the size of the tree exceeds the dimensions of the view. Although a fully collapsed tree might be quite small, its expanded form may be quite large. By automatically adding scrollbars as needed, **TreeView** lets you use a smaller space than would ordinarily be possible.

**TreeView** is a generic class that is defined like this:

```java
class TreeView<T>
```

Here, `T` specifies the type of value held by an item in the tree. Often, this will be of type `String`. **TreeView** defines two constructors. This is the one we will use:

```
TreeView(TreeItem<T> rootNode)
```

Here, `rootNode` specifies the root of the tree. Because all nodes descend from the root, it is the only one that needs to be passed to **TreeView**.

The items that form the tree are objects of type **TreeItem**. At the outset, it is important to state that **TreeItem** does not inherit **Node**. Thus, **TreeItem**s are not general-purpose objects. They can be used in a **TreeView**, but not as stand-alone controls. **TreeItem** is a generic class, as shown here:

```java
class TreeItem<T>
```

Here, `T` specifies the type of value held by the **TreeItem**.

Before you can use a **TreeView**, you must construct the tree that it will display. To do this, you must first create the root. Next, add other nodes to that root. You do this by calling either `add()` or `addAll()` on the list returned by `getChildren()`. These other nodes can be leaf nodes or subtrees. After the tree has been constructed, you create the **TreeView** by passing the root node to its constructor.

You can handle selection events in the **TreeView** in a way similar to the way that you handle them in a **ListView**, through the use of a change listener. To do so, first, obtain the
selection model by calling `getSelectionModel()` . Then, call `selectedItemProperty()` to obtain the property for the selected item. On that return value, call `addListener()` to add a change listener. Each time a selection is made, a reference to the new selection will be passed to the `changed()` handler as the new value. (See `ListView` for more details on handling change events.)

You can obtain the value of a `TreeItem` by calling `getValue()` . You can also follow the tree path of an item in either the forward or backward direction. To obtain the parent, call `getParent()` . To obtain the children, call `getChildren()` .

The following example shows how to build and use a `TreeView` . The tree presents a hierarchy of food. The type of items stored in the tree are strings. The root is labeled Food. Under it are three direct descendent nodes: Fruit, Vegetables, and Nuts. Under Fruit are three child nodes: Apples, Pears, and Oranges. Under Apples are three leaf nodes: Fuji, Winesap, and Jonathan. Each time a selection is made, the name of the item is displayed. Also, the path from the root to the item is shown. This is done by the repeated use of `getParent()` .
// Demonstrate a TreeView

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.beans.value.*;
import javafx.geometry.*;

public class TreeViewDemo extends Application {

    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        Scene myScene = new Scene(rootNode, 310, 460);

        // Set the scene on the stage.
        myStage.setScene(myScene);
    }
}
// Create a label that will report the state of the
// selected tree item.
response = new Label("No Selection");

// Create tree items, starting with the root.
TreeItem<String> tRoot = new TreeItem<String>("Food");

// Now add subtrees, beginning with fruit.
TreeItem<String> tFruit = new TreeItem<String>("Fruit");

// Construct the Apple subtree.
TreeItem<String> tApples = new TreeItem<String>("Apples");

// Add child nodes to the Apple node.
tApples.getChildren().add(new TreeItem<String>("Fuji");
tApples.getChildren().add(new TreeItem<String>("Ripensap");
tApples.getChildren().add(new TreeItem<String>("Jonathan");

// Add varieties to the fruit node.
tFruit.getChildren().add(tApples);
tFruit.getChildren().add(new TreeItem<String>("Pears");
tFruit.getChildren().add(new TreeItem<String>("Oranges");

// Finally, add the fruit node to the root.
tRoot.getChildren().add(tFruit);

// Now, add vegetables subtree, using the same general process.
TreeItem<String> tVegetables = new TreeItem<String>("Vegetables");
tVegetables.getChildren().add(new TreeItem<String>("Corn");
tVegetables.getChildren().add(new TreeItem<String>("Peas");
tVegetables.getChildren().add(new TreeItem<String>("Broccoli");
tVegetables.getChildren().add(new TreeItem<String>("Beans");
tRoot.getChildren().add(tVegetables);

// Likewise, add nuts subtree.
TreeItem<String> tNuts = new TreeItem<String>("Nuts");
tNuts.getChildren().add(new TreeItem<String>("Walnuts");
tNuts.getChildren().add(new TreeItem<String>("Peanuts");
tNuts.getChildren().add(new TreeItem<String>("Pecans");
tRoot.getChildren().add(tNuts);

// Create tree view using the tree just created.
TreeView<String> tvFood = new TreeView<String>(tRoot);

// Get the tree view selection model.
MultipleSelectionModel<TreeItem<String>> tvSelModel =
tvFood.getSelectionModel();

// Use a change listener to respond to a selection within
// a tree view.
tvSelModel.selectedItemProperty().addListener(
    new ChangeListener<TreeItem<String>>() {
        public void changed(ObservableValue? extends TreeItem<String>? oldValue, TreeItem<String> oldVal, TreeItem<String> newVal) {
// Display the selection and its complete path from the root.
if(newVal != null) {
    // Construct the entire path to the selected item.
    String path = newVal.getValue();
    TreeItem<String> tmp = newVal.getParent();
    while(tmp != null) {
        path = tmp.getValue() + " - > " + path;
        tmp = tmp.getParent();
    }

    // Display the selection and the entire path.
    response.setText("Selection is " + newVal.getValue() + "
    \n    Complete path is " + path);
}
}

// Add controls to the scene graph.
rootNode.getChildren().addAll(tvFood, response);

// Show the stage and its scene.
myStage.show();
There are two things to pay special attention to in this program. First, notice how the tree is constructed. First, the root node is created by this statement:

```java
TreeItem<String> tiRoot = new TreeItem<String>("Food");
```

Next, the nodes under the root are constructed. These nodes consist of the root nodes of subtrees: one for fruit, one for vegetables, and one for nuts. Next, the leaves are added to these subtrees. However, one of these, the fruit subtree, consists of another subtree that contains varieties of apples. The point here is that each branch in a tree leads either to a leaf or to the root of a subtree. After all of the nodes have been constructed, the root nodes of each subtree are added to the root node of the tree. This is done by calling `add()` on the root node. For example, this is how the Nuts subtree is added to `tiRoot`.

```java
tiRoot.getChildren().add(tiNuts);
```

The process is the same for adding any child node to its parent node.

The second thing to notice in the program is the way the path from the root to the selected node is constructed within the change event handler. It is shown here:
String path = newVal.getValue();
TreeItem<String> tmp = newVal.getParent();
while (tmp != null) {
    path = tmp.getValue() + " -> " + path;
    tmp = tmp.getParent();
}

The code works like this: First, the value of the newly selected node is obtained. In this example, the value will be a string, which is the node’s name. This string is assigned to the path string. Then, a temporary variable of type TreeItem<String> is created and initialized to refer to the parent of the newly selected node. If the newly selected node does not have a parent, then tmp will be null. Otherwise, the loop is entered, within which each parent’s value (which is its name in this case) is added to path. This process continues until the root node of the tree (which has no parent) is found.

Although the preceding shows the basic mechanism required to handle a TreeView, it is important to point out that several customizations and options are supported. TreeView is a powerful control that you will want to examine fully on your own.

**Introducing Effects and Transforms**

A principal advantage of JavaFX is its ability to alter the precise look of a control (or any node in the scene graph) through the application of an effect and/or a transform. Both effects and transforms help give your GUI the sophisticated, modern look that users have come to expect. Although it is beyond the scope of this book to examine each effect and transform supported by JavaFX, the following introduction will give you an idea of the benefits they provide.

**Effects**

Effects are supported by the abstract Effect class and its concrete subclasses, which are packaged in javafx.scene.effect. Using these effects, you can customize the way a node in a scene graph looks. Several built-in effects are provided. Here is a sampling:

<table>
<thead>
<tr>
<th>Effect</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bloom</td>
<td>Increases the brightness of the brighter parts of a node.</td>
</tr>
<tr>
<td>BoxBlur</td>
<td>Blurs a node.</td>
</tr>
<tr>
<td>DropShadow</td>
<td>Displays a shadow that appears behind the node.</td>
</tr>
<tr>
<td>Glow</td>
<td>Produces a glowing effect.</td>
</tr>
<tr>
<td>InnerShadow</td>
<td>Displays a shadow inside a node.</td>
</tr>
<tr>
<td>Lighting</td>
<td>Creates shadow effects of a light source.</td>
</tr>
<tr>
<td>Reflection</td>
<td>Displays a reflection.</td>
</tr>
</tbody>
</table>
These, and the other effects, are easy to use and are available for use by any Node, including controls. Of course, depending on the control, some effects will be more appropriate than others.

To set an effect on a node, call setEffect( ), which is defined by Node. It is shown here:

```java
final void setEffect(Effect effect)
```

Here, effect is the effect that will be applied. To specify no effect, pass null. Thus, to add an effect to a node, first create an instance of that effect and then pass it to setEffect( ). Once this has been done, the effect will be used whenever the node is rendered (as long as the effect is supported by the environment). To demonstrate the power of effects, we will use two of them: Glow and InnerShadow. However, the process of adding an effect is essentially the same no matter what effect you choose.

**Glow** produces an effect that gives a node a glowing appearance. The amount of glow is under your control. To use a glow effect, you must first create a Glow instance. This is the constructor that we will use:

```java
Glow(double glowLevel)
```

Here, glowLevel specifies the amount of glowing, which must be a value between 0.0 and 1.0.

After a Glow instance has been created, the glow level can be changed by using setLevel( ), shown here:

```java
final void setLevel(double glowLevel)
```

As before, glowLevel specifies the glow level, which must be between 0.0 and 1.0.

**InnerShadow** produces an effect that simulates a shadow on the inside of the node. It supports various constructors. This is the one we will use:

```java
InnerShadow(double radius, Color shadowColor)
```

Here, radius specifies the radius of the shadow inside the node. In essence, the radius describes the size of the shadow. The color of the shadow is specified by shadowColor. Here, the type Color is the JavaFX type `javafx.scene.paint.Color`. It defines a large number of constants, such as Color.GREEN, Color.RED, and Color.BLUE, which makes it easy to use.

**Transforms**

Transforms are supported by the abstract Transform class, which is packaged in `javafx.scene.transform`. Four of its subclasses are Rotate, Scale, Shear, and Translate. Each does what its name suggests. (Another subclass is Affine, but typically you will use one or more of the preceding transform classes.) It is possible to perform more than one transform on a node. For example, you could rotate it and scale it. Transforms are supported by the Node class as described next.
One way to add a transform to a node is to add it to the list of transforms maintained by the node. This list is obtained by calling `getTransforms()`, which is defined by `Node`. It is shown here:

```java
final ObservableList<Transform> getTransforms()
```

It returns a reference to the list of transforms. To add a transform, simply add it to this list by calling `add()`. You can clear the list by calling `clear()`. You can use `remove()` to remove a specific element.

In some cases, you can specify a transform directly, by setting one of `Node`'s properties. For example, you can set the rotation angle of a node, with the pivot point being at the center of the node, by calling `setRotate()`, passing in the desired angle. You can set a scale by using `setScaleX()` and `setScaleY()`, and you can translate a node by using `setTranslateX()` and `setTranslateY()`. (Z axis translations may also be supported by the platform.) However, using the transforms list offers the greatest flexibility, and that is the approach demonstrated here.

---

**NOTE** Any transforms specified on a node directly will be applied after all transforms in the transforms list.

To demonstrate the use of transforms, we will use the `Rotate` and `Scale` classes. The other transforms are used in the same general way. `Rotate` rotates a node around a specified point. It defines several constructors. Here is one example:

```java
Rotate(double angle, double x, double y)
```

Here, `angle` specifies the number of degrees to rotate. The center of rotation, called the `pivot point`, is specified by `x` and `y`. It is also possible to use the default constructor and set these values after a `Rotate` object has been created, which is what the following demonstration program will do. This is done by using the `setAngle()`, `setPivotX()`, and `setPivotY()` methods, shown here:

```java
final void setAngle(double angle)
final void setPivotX(double x)
final void setPivotY(double y)
```

As before, `angle` specifies the number of degrees to rotate and the center of rotation is specified by `x` and `y`.

`Scale` scales a node as specified by a scale factor. `Scale` defines several constructors. This is the one we will use:
Scale(double widthFactor, double heightFactor)

Here, widthFactor specifies the scaling factor applied to the node’s width, and heightFactor specifies the scaling factor applied to the node’s height. These factors can be changed after a Scale instance has been created by using setX() and setY(), shown here:

final void setX(double widthFactor)
final void setY(double heightFactor)

As before, widthFactor specifies the scaling factor applied to the node’s width, and heightFactor specifies the scaling factor applied to the node’s height.

**Demonstrating Effects and Transforms**
The following program demonstrates the use of effects and transforms. It does so by creating four buttons called Rotate, Scale, Glow, and Shadow. Each time one of these buttons is pressed, the corresponding effect or transform is applied to the button. Sample output is shown here:

![Effects and Transforms Demo](image)

When you examine the program, you will see how easy it is to customize the look of your GUI. You might find it interesting to experiment with it, trying different transforms or effects, or trying the effects on different types of nodes other than buttons.

```java
// Demonstrate rotation, scaling, glowing, and inner shadow.
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.transform.*;
import javafx.scene.effect.*;
import javafx.scene.paint.*;

public class EffectsAndTransformsDemo extends Application {
    ...
double angle = 0.0;
double glowVal = 0.0;
boolean shadow = false;
double scaleFactor = 1.0;

// Create initial effects and transforms.
Glow glow = new Glow(0.0);
InnersShadow innersShadow = new InnersShadow(10.0, Color.RED);
Rotate rotate = new Rotate(0);
Scale scale = new Scale(scaleFactor, scaleFactor);

// Create four push buttons.
Button btnRotate = new Button("Rotate");
Button btnGlow = new Button("Glow");
Button btnShadow = new Button("Shadow off");
Button btnScale = new Button("Scale");

public static void main(String[] args) {
    // Start the JavaFX application by calling launch().
    launch(args);
}

// Override the start() method.
public void start(Stage myStage) {
    // Give the stage a title.
    myStage.setTitle("Effects and Transforms Demo");

    // Use a FlowPane for the root node. In this case,
    // vertical and horizontal gaps of 10 are used.
    FlowPane rootNode = new FlowPane(10, 10);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 100, 100);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // Set the initial glow effect.
    btnGlow.setEffect(glow);

    // Add rotation to the transform list for the Rotate button.
    btnRotate.getTransforms().add(rotate);

    // Add scaling to the transform list for the Scale button.
    btnScale.getTransforms().add(scale);

    // Handle the action events for the Rotate button.
    btnRotate.setOnAction(new EventHandler<ActionEvent>() {
Before leaving the topic of effects and transforms, it is useful to mention that several of
them are particularly pleasing when used on a **Text** node. **Text** is a class packaged in `javafx.scene.text`. It creates a node that consists of text. Because it is a node, the text can be easily manipulated as a unit and various effects and transforms can be applied.

**Adding Tooltips**

One very popular element in the modern GUI is the **tooltip**. A tooltip is a short message that is displayed when the mouse hovers over a control. In JavaFX, a tooltip can be easily added to any control. Frankly, because of the benefits that tooltips offer and the ease by which they can be incorporated into your GUI, there is virtually no reason not to use them where appropriate.

To add a tooltip, you call the `setTooltip()` method defined by **Control**. (**Control** is a base class for all controls.) The `setTooltip()` method is shown here:

```java
final void setTooltip(Tooltip tip)
```

In this case, `tip` is an instance of **Tooltip**, which specifies the tooltip. Once a tooltip has been set, it is automatically displayed when the mouse hovers over the control. No other action is required on your part.

The **Tooltip** class encapsulates a tooltip. This is the constructor that we will use:

```java
Tooltip(String str)
```

Here, `str` specifies the message that will be displayed by the tooltip.

To see tooltips in action, try adding the following statements to the **CheckboxDemo** program shown earlier.

```java
cbWeb.setTooltip(new Tooltip("Deploy to Web"));
cbDesktop.setTooltip(new Tooltip("Deploy to Desktop"));
cbMobile.setTooltip(new Tooltip("Deploy to Mobile"));
```

After these additions, the tooltips will be displayed for each check box.

**Disabling a Control**

Before leaving the subject of controls, it is useful to describe one more feature. Any node in the scene graph, including a control, can be disabled under program control. To disable a control, use `setDisable()`, defined by **Node**. It is shown here:

```java
final void setDisable(boolean disable)
```

If `disable` is **true**, the control is disabled; otherwise, it is enabled. Thus, using `setDisable()`, you can disable a control and then enable it later.
Chapter 36: Introducing JavaFX Menus

Menus are an important part of many GUIs because they give the user access to a program’s core functionally. Furthermore, the proper implementation of an application’s menus is a necessary part of creating a successful GUI. Because of the key role they play in many applications, JavaFX provides extensive support for menus. Fortunately, JavaFX’s approach to menus is both powerful and streamlined.

As you will see throughout the course of this chapter, JavaFX menus have several parallels with Swing menus, which were described in Chapter 33. As a result, if you already know how to create Swing menus, learning how to create menus in JavaFX is easy. That said, there are also several differences, so it is important not to jump to conclusions about the JavaFX menu system.

The JavaFX menu system supports several key elements, including

- The menu bar, which is the main menu for an application.
- The standard menu, which can contain either items to be selected or other menus (submenus).
- The context menu, which is often activated by right-clicking the mouse. Context menus are also called popup menus.

JavaFX menus also support accelerator keys, which enable menu items to be selected without having to activate the menu, and mnemonics, which allow a menu item to be selected by the keyboard once the menu options are displayed. In addition to “normal” menus, JavaFX also supports the toolbar, which provides rapid access to program functionality, often paralleling menu items.

Menu Basics

The JavaFX menu system is supported by a group of related classes packaged in javafx.scene.control. The ones used in this chapter are shown in Table 36-1, and they represent the core of the menu system. Although JavaFX allows a high degree of customization if desired, normally you will simply use the menu classes as-is because their default look and feel is generally what you will want.
Here is brief overview of how the classes fit together. To create a main menu for an application, you first need an instance of `MenuBar`. This class is, loosely speaking, a container for menus. To the `MenuBar` you add instances of `Menu`. Each `Menu` object defines a menu. That is, each `Menu` object contains one or more selectable items. The items displayed by a `Menu` are objects of type `MenuItem`. Thus, a `MenuItem` defines a selection that can be chosen by the user.

In addition to “standard” menu items, you can also include check and radio menu items in a menu. Their operation parallels check box and radio button controls. A check menu item is created by `CheckMenuItem`. A radio menu item is created by `RadioMenuItem`. Both of these classes extend `MenuItem`.

`SeparatorMenuItem` is a convenience class that creates a separator line in a menu. It inherits `CustomMenuItem`, which is a class that facilitates embedding other types of controls in a menu item. `CustomMenuItem` extends `MenuItem`.

One key point about JavaFX menus is that `MenuItem` does not inherit `Node`. Thus, instances of `MenuItem` can only be used in a menu. They cannot be otherwise incorporated into a scene graph. However, `MenuBar` does inherit `Node`, which does allow the menu bar to be added to the scene graph.

Another key point is that `MenuItem` is a superclass of `Menu`. This allows the creation of submenus, which are, essentially, menus within menus. To create a submenu, you first create and populate a `Menu` object with `MenuItem`s and then add it to another `Menu` object. You will see this process in action in the examples that follow.

When a menu item is selected, an action event is generated. The text associated with the selection will be the name of the selection. Thus, when using one action event handler to process all menu selections, one way you can determine which item was selected is by examining the name. Of course, you can also use separate anonymous inner classes or lambda expressions to handle each menu item’s action events. In this case, the menu selection is already known and there is no need to examine the name to determine which item was selected.

As an alternative or adjunct to menus that descend from the menu bar, you can also create stand-alone, context menus, which pop up when activated. To create a context menu, first
create an object of type ContextMenu. Then, add MenuItem objects to it. A context menu is often activated by clicking the right mouse button when the mouse is over a control for which a context menu has been defined. It is important to point out that ContextMenu is not derived from MenuItem. Rather, it inherits PopupControl.

A feature related to the menu is the toolbar. In JavaFX, toolbars are supported by the ToolBar class. It creates a stand-alone component that is often used to provide fast access to functionality contained within the menus of the application. For example, a toolbar might provide fast access to the formatting commands supported by a word processor.

An Overview of MenuBar, Menu, and MenuItem
Before you can create a menu, you need to know some specifics about MenuBar, Menu, and MenuItem. These form the minimum set of classes needed to construct a main menu for an application. MenuItems are also used by context (i.e., popup) menus. Thus, these classes form the foundation of the menu system.

MenuBar
MenuBar is essentially a container for menus. It is the control that supplies the main menu of an application. Like all JavaFX controls, it inherits Node. Thus, it can be added to a scene graph. MenuBar has only one constructor, which is the default constructor. Therefore, initially, the menu bar will be empty, and you will need to populate it with menus prior to use. As a general rule, an application has one and only one menu bar. MenuBar defines several methods, but often you will use only one: getMenus(). It returns a list of the menus managed by the menu bar. It is to this list that you will add the menus that you create. The getMenus() method is shown here:

```java
final ObservableList<Menu> getMenus()
```

A Menu instance is added to this list of menus by calling add(). You can also use addAll() to add two or more Menu instances in a single call. The added menus are positioned in the bar from left to right, in the order in which they are added. If you want to add a menu at a specific location, then use this version of add():

```java
void add(int idx, Menu menu)
```

Here, menu is added at the index specified by idx. Indexing begins at 0, with 0 being the left-most menu.

In some cases, you might want to remove a menu that is no longer needed. You can do this by calling remove() on the ObservableList returned by getMenus(). Here are two of its forms:

```java
void remove(Menu menu)
void remove(int idx)
```

Here, menu is a reference to the menu to remove, and idx is the index of the menu to remove. Indexing begins at zero.
It is sometimes useful to obtain a count of the number of items in a menu bar. To do this, call `size()` on the list returned by `getMenus()`.

NOTE Recall that `ObservableList` implements the `List` collections interface, which gives you access to all the methods defined by `List`.

Once a menu bar has been created and populated, it is added to the scene graph in the normal way.

**Menu**

`Menu` encapsulates a menu, which is populated with `MenuItems`. As mentioned, `Menu` is derived from `MenuItem`. This means that one `Menu` can be a selection in another `Menu`. This enables one menu to be submenu of another. `Menu` defines three constructors.

Perhaps the most commonly used is shown here:

```java
Menu(String name)
```

It creates a menu that has the name specified by `name`. You can specify an image along with text with this constructor:

```java
Menu(String name, Node image)
```

Here, `image` specifies the image that is displayed. In all cases, the menu is empty until menu items are added to it. Finally, you don’t have to give a menu a name when it is constructed. To create an unnamed menu, you can use the default constructor:

```java
Menu()
```

In this case, you can add a name and/or image after the fact by calling `setText()` or `setGraphic()`.

Each menu maintains a list of menu items that it contains. To add an item to the menu, add items to this list. To do so, first call `getItems()`, shown here:

```java
final ObservableList<MenuItem> getItems()
```

It returns the list of items currently associated with the menu. To this list, add menu items by calling either `add()` or `addAll()`. Among other actions, you can remove an item by calling `remove()` and obtain the size of the list by calling `size()`.

One other point: You can add a menu separator to the list of menu items, which is an object of type `SeparatorMenuItem`. Separators help organize long menus by allowing you to
group related items together. A separator can also help set off an important item, such as the Exit selection in a menu.

**MenuItem**

**MenuItem** encapsulates an element in a menu. This element can be either a selection linked to some program action, such as Save or Close, or it can cause a submenu to be displayed. **MenuItem** defines the following three constructors.

```
MenuItem()
MenuItem(String name)
MenuItem(String name, Node image)
```

The first creates an empty menu item. The second lets you specify the name of the item, and the third enables you to include an image.

A **MenuItem** generates an action event when selected. You can register an action event handler for such an event by calling `setOnAction()`, just as you did when handling button events. It is shown again for your convenience:

```
final void setOnAction(EventHandler<ActionEvent> handler)
```

Here, `handler` specifies the event handler. You can fire an action event on a menu item by calling `fire()`.

**MenuItem** defines several methods. One that is often useful is `setDisable()`, which you can use to enable or disable a menu item. It is shown here:

```
final void setDisable(boolean disable)
```

If `disable` is `true`, the menu item is disabled and cannot be selected. If `disable` is `false`, the item is enabled. Using `setDisable()`, you can turn menu items on or off, depending on program conditions.

**Create a Main Menu**

As a general rule, the most commonly used menu is the main menu. This is the menu defined by the menu bar, and it is the menu that defines all (or nearly all) of the functionality of an application. As you will see, JavaFX streamlines the process of creating and managing the main menu. Here, you will see how to construct a simple main menu. Subsequent sections will show various options.

---

**NOTE** As a way of clearly illustrating the similarities and differences between the Swing and JavaFX menu systems, the examples in this chapter rework the menu examples from Chapter 33. If you already know Swing, you might find it helpful to compare the two different approaches.
Constructing the main menu requires several steps. First, create the **MenuBar** instance that will hold the menus. Next, construct each menu that will be in the menu bar. In general, a menu is constructed by first creating a **Menu** object and then adding **MenuItem**s to it. After the menus have been created, add them to the menu bar. Then, the menu bar, itself, must be added to the scene graph. Finally, for each menu item, you must add an action event handler that responds to the action event fired when a menu item is selected.

A good way to understand the process of creating and managing menus is to work through an example. Here is a program that creates a simple menu bar that contains three menus. The first is a standard File menu that contains Open, Close, Save, and Exit selections. The second menu is called Options, and it contains two submenus called Colors and Priority. The third menu is called Help, and it has one item: About. When a menu item is selected, the name of the selection is displayed in a label.

```java
// Demonstrate Menus
import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
```
import javafx.event.*;
import javafx.geometry.*;

public class MenuDemo extends Application {
    Label response;

    public static void main(String[] args) {
        // Start the JavaFX application by calling launch()
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {
        // Give the stage a title.
        myStage.setTitle("Demonstrate Menus");

        // Use a BorderPane for the root node.
        BorderPane rootNode = new BorderPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 100, 300);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        // Create a label that will report the selection.
        response = new Label("Menu Demo");

        // Create the menu bar.
        MenuBar mb = new MenuBar();

        // Create the File menu.
        Menu fileMenu = new Menu("File");
        MenuItem open = new MenuItem("Open");
        MenuItem close = new MenuItem("Close");
        MenuItem save = new MenuItem("Save");
        MenuItem exit = new MenuItem("Exit");
        fileMenu.getItems().addAll(open, close, save,
                                  new SeparatorMenuItem(), exit);

        // Add File menu to the menu bar.
        mb.getMenus().add(fileMenu);

        // Create the Options menu.
        Menu optionsMenu = new Menu("Options");

        // Create the Colors submenu.
        Menu colorsMenu = new Menu("Colors");
        MenuItem red = new MenuItem("Red");
        MenuItem green = new MenuItem("Green");
        MenuItem blue = new MenuItem("Blue");

        // Add the Colors menu to the Options menu.
        optionsMenu.getItems().add(colorsMenu);

        // Add the Options menu to the menu bar.
        mb.getMenus().add(optionsMenu);
    }
}

colorsMenu.getItems().addAll(red, green, blue);
optionsMenu.getItems().addAll(colorsMenu);

// Create the Priority submenu.
Menu priorityMenu = new Menu("Priority");
MenuItem high = new MenuItem("High");
MenuItem low = new MenuItem("Low");
priorityMenu.getItems().addAll(high, low);
optionsMenu.getItems().add(priorityMenu);

// Add a separator.
optionsMenu.getItems().add(new SeparatorMenuItem());

// Create the Reset menu item.
MenuItem reset = new MenuItem("Reset");
optionsMenu.getItems().add(reset);

// Add Options menu to the menu bar.
nb.getMenu().add(optionsMenu);

// Create the Help menu.
Menu helpMenu = new Menu("Help");
MenuItem about = new MenuItem("About");
helpMenu.getItems().add(about);

// Add Help menu to the menu bar.
nb.getMenu().add(helpMenu);

// Create one event handler that will handle menu action events.
EventHandler<ActionEvent> MHhandler =
    new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            String name = ((MenuItem)ae.getTarget()).getText();

            // If Exit is chosen, the program is terminated.
            if (name.equals("Exit")) Platform.exit();

            response.setText(" name + " selected");
        }
    };

// Set action event handlers for the menu items.
open.setOnAction(MHhandler);
close.setOnAction(MHhandler);
save.setOnAction(MHhandler);
exit.setOnAction(MHhandler);
red.setOnAction(MHhandler);
green.setOnAction(MHhandler);
blue.setOnAction(MHhandler);
high.setOnAction(MHhandler);
low.setOnAction(MHhandler);
reset.setOnAction(MHhandler);
about.setOnAction(MHhandler);
Let’s examine, in detail, how the menus in this program are created. First, note that 
**MenuDemo** uses a **BorderPane** instance for the root node. **BorderPane** is similar to 
the AWT’s **BorderLayout** discussed in Chapter 26. It defines a window that has five areas: 
top, bottom, left, right, and center. The following methods set the node assigned to these 
areas:

```java
final void setTop(Node node)
final void setBottom(Node node)
final void setLeft(Node node)
final void setRight(Node node)
final void setCenter(Node node)
```

Here, *node* specifies the element, such as a control, that will be shown in each 
location. Later in the program, the menu bar is positioned in the top location and a 
label that displays the menu selection is set to the center position. Setting the 
menu bar to the top position ensures that it will be shown at the top of the
application and will automatically be resized to fit the horizontal width of the window. This is why BorderPane is used in the menu examples. Of course, other approaches, such as using a VBox, are also valid.

Much of the code in the program is used to construct the menu bar, its menus, and menu items, and this code warrants a close inspection. First, the menu bar is constructed and a reference to it is assigned to mb by this statement:

```java
// Create the menu bar.
MenuBar mb = new MenuBar();
```

At this point, the menu bar is empty. It will be populated by the menus that follow.

Next, the File menu and its menu entries are created by this sequence:

```java
// Create the File menu.
Menu fileMenu = new Menu("File");
MenuItem open = new MenuItem("Open");
MenuItem close = new MenuItem("Close");
MenuItem save = new MenuItem("Save");
MenuItem exit = new MenuItem("Exit");
```

The names Open, Close, Save, and Exit will be shown as selections in the menu. The menu entries are added to the File menu by this call to `addAll()` on the list of menu items returned by `getItems()`:

```java
fileMenu.getItems().addAll(open, close, save, new SeparatorMenuItem(), exit);
```

Recall that `getItems()` returns the menu items associated with a Menu instance. To add menu items to a menu, you will add them to this list. Notice that a separator is used to separate visually the Exit entry from the others.

Finally, the File menu is added to the menu bar by this line:

```java
// Add File menu to the menu bar.
mb.getMenus().add(fileMenu);
```

Once the preceding code sequence completes, the menu bar will contain one entry: File. The File menu will contain four selections in this order: Open, Close, Save, and Exit.

The Options menu is constructed using the same basic process as the File menu. However, the Options menu consists of two submenus, Colors and Priority, and a Reset entry. The submenus are first constructed individually and then added to the Options menu. As explained, because Menu inherits MenuItem, a Menu can be added as an entry into another Menu. This is the way the submenus are created. The Reset item is added last. Then, the Options menu is added to the menu bar. The Help menu is constructed using the
same process.

After all of the menus have been constructed, an **ActionEvent** handler called **MEHandler** is created that will process menu selections. For demonstration purposes, a single handler will process all selections, but in a real-world application, it is often easier to specify a separate handler for each individual selection by using anonymous inner classes or lambda expressions. The **ActionEvent** handler for the menu items is shown here:

```java
// Create one event handler that will handle all menu events.
EventHandler<ActionEvent> MEHandler = new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        String name = (MenuItem) ae.getTarget()).getText();

        // If Exit is chosen, the program is terminated.
        if (name.equals("Exit")) Platform.exit();

        response.setText( name + " selected");
    }
};
```

Inside **handle()**, the target of the event is obtained by calling **getTarget()**. The returned reference is cast to **MenuItem**, and its name is returned by calling **getText()**. This string is then assigned to **name**. If **name** contains the string "Exit", the application is terminated by calling **Platform.exit()**. Otherwise, the name is displayed in the **response** label.

Before continuing, it must be pointed out that a JavaFX application must call **Platform.exit()**, not **System.exit()**. The **Platform** class is defined by JavaFX and packaged in **javafx.application**. Its **exit()** method causes the **stop()** life-cycle method to be called. **System.exit()** does not.

Finally, **MEHandler** is registered as the action event handler for each menu item by the following statements:

```java
// Set action event handlers for the menu items.
open.setOnAction(MEHandler);
close.setOnAction(MEHandler);
save.setOnAction(MEHandler);
exit.setOnAction(MEHandler);
red.setOnAction(MEHandler);
green.setOnAction(MEHandler);
blue.setOnAction(MEHandler);
high.setOnAction(MEHandler);
low.setOnAction(MEHandler);
reset.setOnAction(MEHandler);
about.setOnAction(MEHandler);
```

Notice that no listeners are added to the Colors or Priority items because they are not actually selections. They simply activate submenus.

Finally, the menu bar is added to the root node by the following line:
This causes the menu bar to be placed at the top of the window.

At this point, you might want to experiment a bit with the MenuDemo program. Try adding another menu or adding additional items to an existing menu. It is important that you understand the basic menu concepts before moving on because this program will evolve throughout the remainder of this chapter.

**Add Mnemonics and Accelerators to Menu Items**

The menu created in the preceding example is functional, but it is possible to make it better. In real applications, a menu usually includes support for keyboard shortcuts. These come in two forms: accelerators and mnemonics. An accelerator is a key combination that lets you select a menu item without having to first activate the menu. As it applies to menus, a mnemonic defines a key that lets you select an item from an active menu by typing the key. Thus, a mnemonic allows you to use the keyboard to select an item from a menu that is already being displayed.

An accelerator can be associated with a `Menu` or `MenuItem`. It is specified by calling `setAccelerator( )`, shown next:

```java
final void setAccelerator(KeyCombination keyComb)
```

Here, `keyComb` is the key combination that is pressed to select the menu item.

**KeyCombination** is class that encapsulates a key combination, such as CTRL-S. It is packaged in `javafx.scene.input`.

`KeyCombination` defines two `protected` constructors, but often you will use the `keyCombination( )` factory method, shown here:

```java
static KeyCombination keyCombination(String keys)
```

In this case, `keys` is a string that specifies the key combination. It typically consists of a modifier, such as CTRL, ALT, SHIFT, or META, and a letter, such as s. There is a special value, called `shortcut`, which can be used to specify the CTRL key in a Windows system and the META key on a Mac. (It also maps to the typically used shortcut key on other types of systems.) Therefore, if you want to specify CTRL-S as the key combination for Save, then use the string ”shortcut+S”. This way, it will work for both Windows and Mac and elsewhere.

The following sequence adds accelerators to the File menu created by the MenuDemo program in the previous section. After making this change, you can directly select a File menu option by pressing CTRL-O, CTRL-C, CTRL-S, or CTRL-E.
A mnemonic can be specified for both MenuItem and Menu objects, and it is very easy to do. Simply precede the letter in the name of the menu or menu item with an underscore.

For example, in the preceding example, to add the mnemonic F to the File menu, declare fileMenu as shown here:

```java
Menu fileMenu = new Menu("_File"); // now defines a mnemonic
```

After making this change, you can select the File menu by typing ALT then F. However, mnemonics are active only if mnemonic parsing is true (as it is by default). You can turn mnemonic parsing on or off by using setMnemonicParsing(), shown here:

```java
final void setMnemonicParsing(boolean enable)
```

In this case, if enable is true, then mnemonic parsing is turned on. Otherwise, it is turned off.

After making these changes, the File menu will now look like this:

![File menu with mnemonic](image)

**Add Images to Menu Items**

You can add images to menu items or use images instead of text. The easiest way to add an image is to specify it when the menu item is being constructed using this constructor:

```java
MenuItem(String name, Node image)
```

It creates a menu item with the name specified by name and the image specified by
image. For example, here the About menu item is associated with an image when it is created.

```
ImageView aboutIV = new ImageView("aboutIcon.gif");
MenuItem about = new MenuItem("About", aboutIV);
```

After this addition, the image specified by `aboutIV` will be displayed next to the text “About” when the Help menu is displayed, as shown here:

![Demonstrating Menus](image)

One last point: You can also add an image to a menu item after the item has been created by calling `setGraphic()`. This lets you change the image during program execution.

### Use RadioMenuItem and CheckMenuItem

Although the type of menu items used by the preceding examples are, as a general rule, the most commonly used, JavaFX defines two others: check menu items and radio menu items. These elements can streamline a GUI by allowing a menu to provide functionality that would otherwise require additional, stand-alone components. Also, sometimes including check or radio menu items simply seems most natural for a specific set of features. Whatever your reason, it is easy to use check and/or radio menu items in menus, and both are examined here.

To add a check menu item to a menu, use `CheckMenuItem`. It defines three constructors, which parallel the ones defined by `MenuItem`. The one used in this chapter is shown here:

```
CheckMenuItem(String name)
```

Here, `name` specifies the name of the item. The initial state of the item is unchecked. If you want to check a check menu item under program control, call `setSelected()`, shown here:
final void setSelected(boolean selected)

If selected is true, the menu item is checked. Otherwise, it is unchecked. Like stand-alone check boxes, check menu items generate action events when their state is changed. Check menu items are especially appropriate in menus when you have options that can be selected and you want to display their selected/deselected status. A radio menu item can be added to a menu by creating an object of type RadioMenuItem. **RadioMenuItem** defines a number of constructors. The one used in this chapter is shown here:

RadioMenuItem(String name)

It creates a radio menu item that has the name passed in name. The item is not selected. As with the case of check menu items, to select a radio menu item, call setSelected(), passing true as an argument. **RadioMenuItem** works like a stand-alone radio button, generating both change and action events. Like stand-alone radio buttons, menu radio items must be put into a toggle group in order for them to exhibit mutually exclusive selection behavior. Because both CheckMenuItem and RadioMenuItem inherit MenuItem, each has all of the functionality provided by MenuItem. Aside from having the extra capabilities of check boxes and radio buttons, they act like and are used like other menu items. To try check and radio menu items, first remove the code that creates the Options menu in the MenuDemo example program. Then substitute the following code sequence, which uses check menu items for the Colors submenu and radio menu items for the Priority submenu.

```java
// Create the Options menu.
Menu optionsMenu = new Menu("Options");
```
After making the substitution, the check menu items in the Colors submenu look like those shown here:
Here is how the radio menu items in the Priority submenu now look:

Create a Context Menu

A popular alternative or addition to the menu bar is the popup menu, which in JavaFX is referred to as a context menu. Typically, a context menu is activated by clicking the right mouse button when over a control. Popup menus are supported in JavaFX by the ContextMenu class. The direct superclass of ContextMenu is PopupControl. An indirect superclass of ContextMenu is javafx.stage.PopupWindow, which supplies much of its basic functionality.

ContextMenu has two constructors. The one used in this chapter is shown here:
ContextMenu(MenuItem ... menuItems)

Here, menuItems specify the menu items that will constitute the context menu. The second ContextMenu constructor creates an empty menu to which items must be added.

In general, context menus are constructed like regular menus. Menu items are created and added to the menu. Menu item selections are also handled in the same way: by handling action events. The main difference between a context menu and a regular menu is the activation process.

To associate a context menu with a control is amazingly easy. Simply call setContextMenu( ) on the control, passing in a reference to the menu that you want to pop up. When you right-click on that control, the associated context menu will be shown.

The setContextMenu( ) method is shown here:

```java
final void setContextMenu(ContextMenu menu)
```

In this case, menu specifies the context menu associated with the invoking control.

To demonstrate a context menu, we will add one to the MenuDemo program. The context menu will present a standard “Edit” menu that includes the Cut, Copy, and Paste entries. It will be set on a text field control. When the mouse is right-clicked while in the text field, the context menu will pop up. To begin, create the context menu, as shown here:

```java
// Create the context menu items
MenuItem cut = new MenuItem("Cut");
MenuItem copy = new MenuItem("Copy");
MenuItem paste = new MenuItem("Paste");

// Create a context (i.e., popup) menu that shows edit options.
final ContextMenu editMenu = new ContextMenu(cut, copy, paste);
```

This sequence begins by constructing the MenuItems that will form the menu. It then creates an instance of ContextMenu called editMenu that contains the items.

Next, add the action event handler to these menu items, as shown here:

```java
cut.setOnAction(MEHandler);
copy.setOnAction(MEHandler);
paste.setOnAction(MEHandler);
```

This finishes the construction of the context menu, but the menu has not yet been associated with a control.

Now, add the following sequence that creates the text field:

```java
// Create a text field and set its column width to 20.
TextField tf = new TextField();
tf.setPrefColumnCount(20);
```
Next, set the context menu on the text field:

```java
// Add the context menu to the textfield.
tf.setContextMenu(editMenu);
```

Now, when the mouse is right-clicked over the text field, the context menu will pop up. To add the text field to the program, you must create a flow pane that will hold both the text field and the response label. This pane will then be added to the center of the **BorderPane**. This step is necessary because only one node can be added to any single location within a **BorderPane**. First, remove this line of code:

```java
rootNode.setCenter(response);
```

Replace it with the following code:

```java
// Create a flow pane that will hold both the response label and the text field.
FlowPane fpRoot = new FlowPane(10, 10);

// Center the controls in the scene.
fpRoot.setAlignment(Pos.CENTER);

// Add both the label and the text field to the flow pane.
fpRoot.getChildren().addAll(response, tf);

// Add the flow pane to the center of the border layout.
rootNode.setCenter(fpRoot);
```

Of course, the menu bar is still added to the top position of the border pane. After making these changes, when you right-click over the text field, the context menu will pop up, as shown here:
It is also possible to associate a context menu with a scene. One way to do this is by calling `setOnContextMenuRequested()` on the root node of the scene. This method is defined by `Node` and is shown here:

```java
final void setOnContextMenuRequested(
    EventHandler<? super ContextMenuEvent> eventHandler)
```

Here, `eventHandler` specifies the handler that will be called when a popup request has been received for the context menu. In this case, the handler must call the `show()` method defined by `ContextMenu` to cause the context menu to be displayed. This is the version we will use:

```java
final void show(Node node, double upperX, double upperY)
```

Here, `node` is the element on which the context menu is linked. The values of `upperX` and `upperY` define the X,Y location of the upper-left corner of the menu, relative to the screen. Typically, you will pass the screen coordinates at which the right-click occurred. To do this, you will call the `getScreenX()` and `getScreenY()` methods defined by `ContextMenuEvent`. They are shown here:

```java
final double getScreenX()
final double getScreenY()
```

Thus, you will typically pass the results of these methods to the `show()` method.

The preceding theory can be put into practice by adding the context menu to the root node of the scene graph. After doing so, right-clicking anywhere in the scene will cause the menu to pop up. To do this, first add the following sequence to the `MenuDemo` program:
Second, declare `rootNode final` so that it can be accessed within the anonymous inner class. After you have made these additions and changes, the context menu can be activated by clicking the right mouse button anywhere inside the application scene. For example, here is the menu displayed after right-clicking in the upper-left portion of the window.

![Screenshot of the menu](image)

**Create a Toolbar**

A toolbar is a component that can serve as both an alternative and as an adjunct to a menu. Typically, a toolbar contains a list of buttons that give the user immediate access to various program options. For example, a toolbar might contain buttons that select various font options, such as bold, italics, highlight, or underline. These options can be selected without the need to drop through a menu. As a general rule, toolbar buttons show images rather than text, although either or both are allowed. Furthermore, often tooltips are associated with image-based toolbar buttons.

In JavaFX, toolbars are instances of the `ToolBar` class. It defines the two constructors, shown here:

```java
ToolBar()
ToolBar(Node ... nodes)
```
The first constructor creates an empty, horizontal toolbar. The second creates a horizontal toolbar that contains the specified nodes, which are usually some form of button. If you want to create a vertical toolbar, call `setOrientation()` on the toolbar. It is shown here:

```java
final void setOrientation(Orientation how)
```

The value of `how` must be either `Orientation.VERTICAL` or `Orientation.HORIZONTAL`.

You add buttons (or other controls) to a toolbar in much the same way that you add them to a menu bar: call `add()` on the reference returned by the `getItems()` method. Often, however, it is easier to specify the items in the `ToolBar` constructor, and that is the approach used in this chapter. Once you have created a toolbar, add it to the scene graph. For example, when using a border layout, it could be added to the bottom location. Of course, other approaches are commonly used. For example, it could be added to a location directly under the menu bar or at the side of the window.

To illustrate a toolbar, we will add one to the `MenuDemo` program. The toolbar will present three debugging options: Set Breakpoint, Clear Breakpoint, and Resume Execution. We will also add tooltips to the menu items. Recall from the previous chapter, a tooltip is a small message that describes an item. It is automatically displayed if the mouse hovers over the item for moment. You can add a tooltip to the menu item in the same way as you add it to a control: by calling `setTooltip()`. Tooltips are especially useful when applied to image-based toolbar controls because sometimes it’s hard to design images that are intuitive to all users.

First, add the following code, which creates the debugging toolbar:

```java
// Define a toolbar. First, create toolbar items.
Button btnSet = new Button("Set Breakpoint",
    new ImageView("setBP.gif"));
Button btnClear = new Button("Clear Breakpoint",
    new ImageView("clearBP.gif"));
Button btnResume = new Button("Resume Execution",
    new ImageView("resume.gif"));

// Now, turn off text in the buttons.
btnSet.setTextDisplay(ContentDisplay графический только);
btnClear.setTextDisplay(ContentDisplay графический только);
btnResume.setTextDisplay(ContentDisplay графический только);
```
Let's look at this code closely. First, three buttons are created that correspond to the debug actions. Notice that each has an image associated with it. Next, each button deactivates the text display by calling `setContentDisplay()`. As a point of interest, it would have been possible to leave the text displayed, but the toolbar would have had a somewhat nonstandard look. (The text for each button is still needed, however, because it will be used by the action event handler for the buttons.) Tooltips are then set for each button. Finally, the toolbar is created, with the buttons specified as the contents.

Next, add the following sequence, which defines an action event handler for the toolbar buttons:

```java
// Create a handler for the toolbar buttons.
{
    public void handle(ActionEvent ae) {
        response.setText(((Button)ae.getTarget()).getText());
    }
};

// Set the toolbar button action event handlers.
btnSet.setAction(btnHandler);
btnClear.setAction(btnHandler);
btnResume.setAction(btnHandler);
```

Finally, add the toolbar to the bottom of the border layout by using this statement:

```java
rootNode.setBottom(tbDebug);
```

After making these additions, each time the user presses a toolbar button, an action event is fired, and it is handled by displaying the button’s text in the `response` label. The following output shows the toolbar in action.
Put the Entire MenuDemo Program Together

Throughout the course of this discussion, many changes and additions have been made to the MenuDemo program shown at the start of the chapter. Before concluding, it will be helpful to assemble all the pieces. Doing so not only eliminates any ambiguity about the way the pieces fit together, but it also gives you a complete menu demonstration program that you can experiment with.

The following version of MenuDemo includes all of the additions and enhancements described in this chapter. For clarity, the program has been reorganized, with separate methods being used to construct the various menus and toolbar. Notice that several of the menu-related variables, such as mb and tbDebug, have been made into instance variables so they can be directly accessed by any part of the class.
// Demonstrate Menus -- Final Version

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import javafx.scene.input.*;
import javafx.scene.image.*;
import javafx.beans.value.*;

public class MenuDemoFinal extends Application {

    MenuBar mb;
    EventHandler<ActionEvent> MSHandler;
    ContextMenu editMenu;
    ToolBar tbDebug;
    Label response;

    public static void main(String[] args) {

        // Start the JavaFX application by calling launch().
        launch(args);
    }

    // Override the start() method.
    public void start(Stage myStage) {

        // Give the stage a title.
        myStage.setTitle("Demonstrate Menus -- Final Version");

        // Use a BorderPane for the root node.
        final BorderPane rootNode = new BorderPane();

        // Create a scene.
        Scene myScene = new Scene(rootNode, 300, 300);
    }
}
// Set the scene on the stage.
myStage.setScene(myScene);

// Create a label that will report the selection.
response = new Label();

// Create one event handler for all menu action events.
MenuHandler = new EventHandler<ActionEvent>()
   public void handle(ActionEvent ae)
   {
      String name = ((MenuItem) ae.getTarget()).getText();
      if (name.equals("Exit")) Platform.exit();
      response.setText(name + " selected");
   }

// Create the menu bar.
mb = new MenuBar();

// Create the File menu.
makeFileMenu();

// Create the Options menu.
makeOptionsMenu();

// Create the Help menu.
makeHelpMenu();

// Create the context menu.
makeContextMenu();

// Create a text field and set its column width to 20.
TextField tf = new TextField();
   tf.setPrefColumnCount(20);

// Add the context menu to the text field.
   tf.setContextMenu(editMenu);

// create the toolbar.
makeToolBar();

// Add the context menu to the entire scene graph.
rootNode.setOnContextMenuRequested( new EventHandler<ContextMenuEvent>()
   public void handle(ContextMenuEvent ae)
   {
      // Pop up menu at the location of the right click.
      editMenu.show(rootNode, ae.getScreenX(), ae.getScreenY());
   }));

// Add the menu bar to the top of the border pane.
rootNode.setTop(mb);
// Create a flow pane that will hold both the response
// label and the text field.
FlowPane fpRoot = new FlowPane(10, 10);

// Center the controls in the scene.
fpRoot.setAlignment(Pos.CENTER);

// Use a separator to better organize the layout.
Separator separator = new Separator();
separator.setPrefWidth(250);

// Add the label, separator, and text field to the flow pane.
fpRoot.getChildren().addAll(response, separator, tf);

// Add the toolbar to the bottom of the border pane.
rootNode.setBottom(tbDebug);

// Add the flow pane to the center of the border layout.
rootNode.setCenter(fpRoot);

// Show the stage and its scene.
myStage.show();

// Create the File menu.
void makeFileMenu() {
    // Create the File menu, including a mnemonic.
    Menu fileMenu = new Menu("_File");

    // Create the File menu items.
    MenuItem open = new MenuItem("Open");
    MenuItem close = new MenuItem("Close");
    MenuItem save = new MenuItem("Save");
    MenuItem exit = new MenuItem("Exit");

    // Add items to File menu.
    fileMenu.getItems().addAll(open, close, save,
                                new SeparatorMenuItem(), exit);

    // Add keyboard accelerators for the File menu.
    open.setAccelerator(KeyCombination.getKeyCombination("shortcut+O"));
    close.setAccelerator(KeyCombination.getKeyCombination("shortcut+C"));
    save.setAccelerator(KeyCombination.getKeyCombination("shortcut+S"));
    exit.setAccelerator(KeyCombination.getKeyCombination("shortcut+E"));

    // Set action event handlers.
    open.setOnAction(handler);
    close.setOnAction(handler);
    save.setOnAction(handler);
    exit.setOnAction(handler);

    // Add File menu to the menu bar.
    mb.getItems().add(fileMenu);
}
// Create the Options menu.
void makeOptionsMenu() {
    Menu optionsMenu = new Menu("Options");

    // Create the Colors submenu.
    Menu colorsMenu = new Menu("Colors");

    // Use check menu items for colors. This allows
    // the user to select more than one color.
    CheckMenuItem red = new CheckMenuItem("Red");
    CheckMenuItem green = new CheckMenuItem("Green");
    CheckMenuItem blue = new CheckMenuItem("Blue");

    // Add the check menu items for the Colors menu and
    // add the colors menu to the Options menu.
    colorsMenu.getItems().addAll(red, green, blue);
    optionsMenu.getItems().add(colorsMenu);

    // Select green as the default color selection.
    green.setSelected(true);

    // Create the Priority submenu.
    Menu priorityMenu = new Menu("Priority");

    // Use radio menu items for the priority setting.
    // This lets the menu show which priority is used
    // and also ensures that one and only one priority
    // can be selected at any one time.
    RadioMenuItem high = new RadioMenuItem("High");
    RadioMenuItem low = new RadioMenuItem("Low");

    // Create a toggle group and use it for the radio menu items.
    ToggleGroup tg = new ToggleGroup();
    high.setToggleGroup(tg);
    low.setToggleGroup(tg);

    // Select High priority for the default selection.
    high.setSelected(true);

    // Add the radio menu items to the Priority menu and
    // add the Priority menu to the Options menu.
    priorityMenu.getItems().addAll(high, low);
    optionsMenu.getItems().add(priorityMenu);

    // Add a separator.
    optionsMenu.getItems().add(new SeparatorMenuItem());

    // Create the Reset menu item and add it to the Options menu.
    MenuItem reset = new MenuItem("Reset");
    optionsMenu.getItems().add(reset);

    // Set action event handlers.
    red.setAction(MENHandler);
    green.setAction(MENHandler);
    blue.setAction(MENHandler);
high.setOnAction(MEHandler);
low.setOnAction(MEHandler);
reset.setOnAction(MEHandler);

// Use a change listener to respond to changes in the radio
// menu item setting.
tg.selectedToggleProperty().addListener(new ChangeListener<Toggle>()
    public void changed(ObservableValue<? extends Toggle> toggle, Toggle oldVal, Toggle newVal) {
        if (newVal == null) return;

        // Cast newVal to RadioButton.
        RadioButton rbtn = (RadioButton) newVal;

        // Display the selection.
        response.setText("Priority selected is " + rbtn.getText());
    });

// Add Options menu to the menu bar.
mb.getMenus().add(optionsMenu);

// Create the Help menu.
void makeHelpMenu() {

    // Create an ImageView for the Image.
    ImageView aboutIV = new ImageView("aboutIcon.gif");

    // Create the Help menu.
    Menu helpMenu = new Menu("Help");

    // Create the About menu item and add it to the Help menu.
    MenuItem about = new MenuItem("About", aboutIV);
    helpMenu.getItems().add(about);

    // Set action event handler.
    about.setOnAction(MEHandler);

    // Add Help menu to the menu bar.
    mb.getMenus().add(helpMenu);
}

// Create the context menu items.
void makeContextMenu() {

    // Create the edit context menu items.
    MenuItem cut = new MenuItem("Cut");
    MenuItem copy = new MenuItem("Copy");
    MenuItem paste = new MenuItem("Paste");

    // Create a context (i.e., popup) menu that shows edit options.
    editMenu = new ContextMenu(cut, copy, paste);
}
Continuing Your Exploration of JavaFX

JavaFX represents a major advance in GUI frameworks for Java. It also redefines aspects of the Java platform. The preceding three chapters have introduced several of its core features, but there is much left to explore. For example, JavaFX supplies several more controls, such as sliders, stand-alone scrollbars, and tables. You will want to experiment with its layouts, such as VBox and Hbox. You will also want to explore, in detail, the various effects in javafx.scene.effect and the various transforms in javafx.scene.transform. Another exciting class is WebView, which gives you an easy way to integrate web content into a scene graph. Frankly, all of JavaFX is worthy of serious study. In many ways, it is charting the future course of Java.
This chapter provides an overview of Java Beans. Beans are important because they allow you to build complex systems from software components. These components may be provided by you or supplied by one or more different vendors. Java Beans defines an architecture that specifies how these building blocks can operate together.

To better understand the value of Beans, consider the following. Hardware designers have a wide variety of components that can be integrated together to construct a system. Resistors, capacitors, and inductors are examples of simple building blocks. Integrated circuits provide more advanced functionality. All of these different parts can be reused. It is not necessary or possible to rebuild these capabilities each time a new system is needed. Also, the same pieces can be used in different types of circuits. This is possible because the behavior of these components is understood and documented.

The software industry has also been seeking the benefits of reusability and interoperability of a component-based approach. To realize these benefits, a component architecture is needed that allows programs to be assembled from software building blocks, perhaps provided by different vendors. It must also be possible for a designer to select a component, understand its capabilities, and incorporate it into an application. When a new version of a component becomes available, it should be easy to incorporate this functionality into existing code. Fortunately, Java Beans provides just such an architecture.

What Is a Java Bean?

A *Java Bean* is a software component that has been designed to be reusable in a variety of different environments. There is no restriction on the capability of a Bean. It may perform a simple function, such as obtaining an inventory value, or a complex function, such as forecasting the performance of a stock portfolio. A Bean may be visible to an end user. One example of this is a button on a graphical user interface. A Bean may also be invisible to a user. Software to decode a stream of multimedia information in real time is an example of this type of building block. Finally, a Bean may be designed to work autonomously on a user’s workstation or to work in cooperation with a set of other distributed components. Software to generate a pie chart from a set of data points is an example of a Bean that can execute locally. However, a Bean that provides real-time price information from a stock or
commodities exchange would need to work in cooperation with other distributed software to obtain its data.

**Advantages of Java Beans**
The following list enumerates some of the benefits that Java Bean technology provides for a component developer:

- A Bean obtains all the benefits of Java’s “write-once, run-anywhere” paradigm.
- The properties, events, and methods of a Bean that are exposed to another application can be controlled.
- Auxiliary software can be provided to help configure a Bean. This software is only needed when the design-time parameters for that component are being set. It does not need to be included in the run-time environment.
- The state of a Bean can be saved in persistent storage and restored at a later time.
- A Bean may register to receive events from other objects and can generate events that are sent to other objects.

**Introspection**
At the core of Java Beans is introspection. This is the process of analyzing a Bean to determine its capabilities. This is an essential feature of the Java Beans API because it allows another application, such as a design tool, to obtain information about a component. Without introspection, the Java Beans technology could not operate.

There are two ways in which the developer of a Bean can indicate which of its properties, events, and methods should be exposed. With the first method, simple naming conventions are used. These allow the introspection mechanisms to infer information about a Bean. In the second way, an additional class that extends the `BeanInfo` interface is provided that explicitly supplies this information. Both approaches are examined here.

**Design Patterns for Properties**
A property is a subset of a Bean’s state. The values assigned to the properties determine the behavior and appearance of that component. A property is set through a setter method. A property is obtained by a getter method. There are two types of properties: simple and indexed.

**Simple Properties**
A simple property has a single value. It can be identified by the following design patterns, where `N` is the name of the property and `T` is its type:

```java
public T getN()  
public void setN(T arg)
```
A read/write property has both of these methods to access its values. A read-only property has only a get method. A write-only property has only a set method.

Here are three read/write simple properties along with their getter and setter methods:

```java
private double depth, height, width;

public double getDepth() {
    return depth;
}
public void setDepth(double d) {
    depth = d;
}

public double getHeight() {
    return height;
}
public void setHeight(double h) {
    height = h;
}

public double getWidth() {
    return width;
}
public void setWidth(double w) {
    width = w;
}
```

**NOTE** For a boolean property, a method of the form `isPropertyName()` can also be used as an accessor.

**Indexed Properties**

An indexed property consists of multiple values. It can be identified by the following design patterns, where `N` is the name of the property and `T` is its type:

```java
public T getN(int index);
public void setN(int index, T value);
public T[] getN();
public void setN(T values[]);
```

Here is an indexed property called `data` along with its getter and setter methods:
Beans use the delegation event model that was discussed earlier in this book. Beans can generate events and send them to other objects. These can be identified by the following design patterns, where T is the type of the event:

```java
private double data[];

public double getData(int index) {
    return data[index];
}

public void setData(int index, double value) {
    data[index] = value;
}

public double[] getData() {
    return data;
}

public void setData(double[] values) {
    data = new double[values.length];
    System.arraycopy(values, 0, data, 0, values.length);
}
```

**Design Patterns for Events**

These methods are used to add or remove a listener for the specified event. The version of `addTListener( )` that does not throw an exception can be used to *multicast* an event, which means that more than one listener can register for the event notification. The version that throws `TooManyListenersException` *unicasts* the event, which means that the number of listeners can be restricted to one. In either case, `removeTListener( )` is used to remove the listener. For example, assuming an event interface type called `TemperatureListener`, a Bean that monitors temperature might supply the following methods:

```java
public void addTemperatureListener(TemperatureListener tl) {
    ...
}

public void removeTemperatureListener(TemperatureListener tl) {
    ...
}
```

**Methods and Design Patterns**

Design patterns are not used for naming nonproperty methods. The introspection mechanism finds all of the public methods of a Bean. Protected and private methods are not
Using the BeanInfo Interface

As the preceding discussion shows, design patterns implicitly determine what information is available to the user of a Bean. The BeanInfo interface enables you to explicitly control what information is available. The BeanInfo interface defines several methods, including these:

- PropertyDescriptor[] getPropertyDescriptors()
- EventSetDescriptor[] getEventSetDescriptors()
- MethodDescriptor[] getMethodDescriptors()

They return arrays of objects that provide information about the properties, events, and methods of a Bean. The classes PropertyDescriptor, EventSetDescriptor, and MethodDescriptor are defined within the java.beans package, and they describe the indicated elements. By implementing these methods, a developer can designate exactly what is presented to a user, bypassing introspection based on design patterns.

When creating a class that implements BeanInfo, you must call that class bnameBeanInfo, where bname is the name of the Bean. For example, if the Bean is called MyBean, then the information class must be called MyBeanBeanInfo.

To simplify the use of BeanInfo, JavaBeans supplies the SimpleBeanInfo class. It provides default implementations of the BeanInfo interface, including the three methods just shown. You can extend this class and override one or more of the methods to explicitly control what aspects of a Bean are exposed. If you don’t override a method, then design-pattern introspection will be used. For example, if you don’t override getPropertyDescriptors(), then design patterns are used to discover a Bean’s properties. You will see SimpleBeanInfo in action later in this chapter.

Bound and Constrained Properties

A Bean that has a bound property generates an event when the property is changed. The event is of type PropertyChangeEvent and is sent to objects that previously registered an interest in receiving such notifications. A class that handles this event must implement the PropertyChangeListener interface.

A Bean that has a constrained property generates an event when an attempt is made to change its value. It also generates an event of type PropertyChangeEvent. It too is sent to objects that previously registered an interest in receiving such notifications. However, those other objects have the ability to veto the proposed change by throwing a PropertyVetoException. This capability allows a Bean to operate differently according to its run-time environment. A class that handles this event must implement the VetoableChangeListener interface.

Persistence
Persistence is the ability to save the current state of a Bean, including the values of a Bean’s properties and instance variables, to nonvolatile storage and to retrieve them at a later time. The object serialization capabilities provided by the Java class libraries are used to provide persistence for Beans. The easiest way to serialize a Bean is to have it implement the java.io.Serializable interface, which is simply a marker interface. Implementing java.io.Serializable makes serialization automatic. Your Bean need take no other action. Automatic serialization can also be inherited. Therefore, if any superclass of a Bean implements java.io.Serializable, then automatic serialization is obtained.

When using automatic serialization, you can selectively prevent a field from being saved through the use of the transient keyword. Thus, data members of a Bean specified as transient will not be serialized.

If a Bean does not implement java.io.Serializable, you must provide serialization yourself, such as by implementing java.io.Externalizable. Otherwise, containers cannot save the configuration of your component.

Customizers
A Bean developer can provide a customizer that helps another developer configure the Bean. A customizer can provide a step-by-step guide through the process that must be followed to use the component in a specific context. Online documentation can also be provided. A Bean developer has great flexibility to develop a customizer that can differentiate his or her product in the marketplace.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ApplicationInitializer</td>
<td>Methods in this interface are used to initialize Beans that are also applets.</td>
</tr>
<tr>
<td>BeanInfo</td>
<td>This interface allows a designer to specify information about the properties, events, and methods of a Bean.</td>
</tr>
<tr>
<td>Customizer</td>
<td>This interface allows a designer to provide a graphical user interface through which a Bean may be configured.</td>
</tr>
<tr>
<td>DesignMode</td>
<td>Methods in this interface determine if a Bean is executing in design mode.</td>
</tr>
<tr>
<td>ExceptionListener</td>
<td>A method in this interface is invoked when an exception has occurred.</td>
</tr>
<tr>
<td>PropertyChangeListener</td>
<td>A method in this interface is invoked when a bound property is changed.</td>
</tr>
<tr>
<td>PropertyEditor</td>
<td>Objects that implement this interface allow designers to change and display property values.</td>
</tr>
<tr>
<td>ValueChangeEvent</td>
<td>A method in this interface is invoked when a constrained property is changed.</td>
</tr>
<tr>
<td>Visibility</td>
<td>Methods in this interface allow a Bean to execute in environments where a graphical user interface is not available.</td>
</tr>
</tbody>
</table>

Table 37-1 The Interfaces in java.beans

The Java Beans API
The Java Beans functionality is provided by a set of classes and interfaces in the
The `java.beans` package. This section provides a brief overview of its contents. Table 37-1 lists the interfaces in `java.beans` and provides a brief description of their functionality. Table 37-2 lists the classes in `java.beans`.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BeanDescriptor</td>
<td>This class provides information about a Bean. It also allows you to associate a customizer with a Bean.</td>
</tr>
<tr>
<td>DefaultPersistenceDelegate</td>
<td>A concrete subclass of PersistenceDelegate.</td>
</tr>
<tr>
<td>Encoder</td>
<td>Encodes the state of a set of Beans. Can be used to write that information to a stream.</td>
</tr>
<tr>
<td>EventHandler</td>
<td>Supports dynamic event listener creation.</td>
</tr>
<tr>
<td>EventSetDescriptor</td>
<td>Instances of this class describe an event that can be generated by a Bean.</td>
</tr>
<tr>
<td>Expression</td>
<td>Encapsulates a call to a method that returns a result.</td>
</tr>
<tr>
<td>FeatureDescriptor</td>
<td>This is the superset of the PropertyDescriptor, EventSetDescriptor, and MethodDescriptor classes, among others.</td>
</tr>
<tr>
<td>IndexedPropertyChangeEvent</td>
<td>An subclass of PropertyChangeEvent that represents a change to an indexed property.</td>
</tr>
<tr>
<td>IndexedPropertyDescriptor</td>
<td>Instances of this class describe an indexed property of a Bean.</td>
</tr>
<tr>
<td>IntrospectionException</td>
<td>An exception of this type is generated if a problem occurs when analyzing a Bean.</td>
</tr>
<tr>
<td>Introspector</td>
<td>This class analyzes a Bean and constructs a BeanInfo object that describes the component.</td>
</tr>
<tr>
<td>MethodDescriptor</td>
<td>Instances of this class describe a method of a Bean.</td>
</tr>
<tr>
<td>ParameterDescriptor</td>
<td>Instances of this class describe a method parameter.</td>
</tr>
<tr>
<td>PersistenceDelegate</td>
<td>Handles the state information of an object.</td>
</tr>
<tr>
<td>PropertyChangeEvent</td>
<td>This event is generated when bound or constrained properties are changed. It is sent to objects that registered an interest in these events and that implement either the PropertyChangeListener or VetoableChangeListener interfaces.</td>
</tr>
<tr>
<td>PropertyChangeListenerProxy</td>
<td>Extends EventListenerProxy and implements PropertyChangeListener.</td>
</tr>
<tr>
<td>PropertyChangeSupport</td>
<td>Beans that support bound properties can use this class to notify PropertyChangeListener objects.</td>
</tr>
<tr>
<td>PropertyDescriptor</td>
<td>Instances of this class describe a property of a Bean.</td>
</tr>
<tr>
<td>PropertyEditorManager</td>
<td>This class locates a PropertyEditor object for a given type.</td>
</tr>
<tr>
<td>PropertyEditorSupport</td>
<td>This class provides functionality that can be used when writing property editors.</td>
</tr>
<tr>
<td>PropertyVetoException</td>
<td>An exception of this type is generated if a change to a constrained property is vetoed.</td>
</tr>
<tr>
<td>SimpleBeanInfo</td>
<td>This class provides functionality that can be used when writing BeanInfo classes.</td>
</tr>
<tr>
<td>Statement</td>
<td>Encapsulates a call to a method.</td>
</tr>
<tr>
<td>VetoableChangeListenerProxy</td>
<td>Extends EventListenerProxy and implements VetoableChangeListener.</td>
</tr>
<tr>
<td>VetoableChangeSupport</td>
<td>Beans that support constrained properties can use this class to notify VetoableChangeListener objects.</td>
</tr>
<tr>
<td>XMLDecoder</td>
<td>Used to read a Bean from an XML document.</td>
</tr>
<tr>
<td>XMLEncoder</td>
<td>Used to write a Bean to an XML document.</td>
</tr>
</tbody>
</table>

Table 37-2 The Classes in `java.beans`
Although it is beyond the scope of this chapter to discuss all of the classes, four are of particular interest: **Introspector**, **PropertyDescriptor**, **EventSetDescriptor**, and **MethodDescriptor**. Each is briefly examined here.

**Introspector**
The **Introspector** class provides several static methods that support introspection. Of most interest is **getBeanInfo()**. This method returns a **BeanInfo** object that can be used to obtain information about the Bean. The **getBeanInfo()** method has several forms, including the one shown here:

```java
static BeanInfo getBeanInfo(Class<?> bean) throws IntrospectionException
```
The returned object contains information about the Bean specified by `bean`.

**PropertyDescriptor**
The **PropertyDescriptor** class describes the characteristics of a Bean property. It supports several methods that manage and describe properties. For example, you can determine if a property is bound by calling **isBound()**. To determine if a property is constrained, call **isConstrained()**. You can obtain the name of a property by calling **getName()**.

**EventSetDescriptor**
The **EventSetDescriptor** class represents a Bean event. It supports several methods that obtain the methods that a Bean uses to add or remove event listeners, and to otherwise manage events. For example, to obtain the method used to add listeners, call **getAddListenerMethod()**. To obtain the method used to remove listeners, call **getRemoveListenerMethod()**. To obtain the type of a listener, call **getListenerType()**. You can obtain the name of an event by calling **getName()**.

**MethodDescriptor**
The **MethodDescriptor** class represents a Bean method. To obtain the name of the method, call **getName()**. You can obtain information about the method by calling **getMethod()**, shown here:

```java
Method getMethod()
```
An object of type **Method** that describes the method is returned.

**A Bean Example**
This chapter concludes with an example that illustrates various aspects of Bean programming, including introspection and using a **BeanInfo** class. It also makes use of the **Introspector**, **PropertyDescriptor**, and **EventSetDescriptor** classes. The example uses three classes. The first is a Bean called **Colors**, shown here:
// A simple Bean.
import java.awt.*;
import java.awt.event.*;
import java.io.Serializable;

public class Colors extends Canvas implements Serializable {
    transient private Color color; // not persistent
    private boolean rectangular; // is persistent
The Colors Bean displays a colored object within a frame. The color of the component is determined by the private Color variable color, and its shape is determined by the private boolean variable rectangular. The constructor defines an anonymous inner class that extends MouseAdapter and overrides its mousePressed( ) method. The change( ) method is invoked in response to mouse presses. It selects a random color and then repaints the component. The getRectangular( ) and setRectangular( ) methods provide
access to the one property of this Bean. The `change()` method calls `randomColor()` to choose a color and then calls `repaint()` to make the change visible. Notice that the `paint()` method uses the `rectangular` and `color` variables to determine how to present the Bean. The next class is `ColorsBeanInfo`. It is a subclass of `SimpleBeanInfo` that provides explicit information about `Colors`. It overrides `getPropertyDescriptors()` in order to designate which properties are presented to a Bean user. In this case, the only property exposed is `rectangular`. The method creates and returns a `PropertyDescriptor` object for the `rectangular` property. The `PropertyDescriptor` constructor that is used is shown here:

```java
PropertyDescriptor(String property, Class<? super beanCls>)
   throws IntrospectionException
```

Here, the first argument is the name of the property, and the second argument is the class of the Bean.

```java
// A Bean information class.
import java.beans.*;
public class ColorsBeanInfo extends SimpleBeanInfo {
   public PropertyDescriptor[] getPropertyDescriptors() {
      try {
         PropertyDescriptor rectangular = new
            PropertyDescriptor("rectangular", Colors.class);
         PropertyDescriptor pd[] = {rectangular};
         return pd;
      }
      catch(Exception e) {
         System.out.println("Exception caught. " + e);
      }
      return null;
   }
}
```

The final class is called `IntrospectorDemo`. It uses introspection to display the properties and events that are available within the `Colors` Bean.
The output from this program is the following:

Properties:
  rectangular

Events:
  mouseWheel
  mouse
  mouseMotion
  component
  hierarchyBounds
  focus
  hierarchy
  propertyChange
  inputMethod
  key

Notice two things in the output. First, because `ColorsBeanInfo` overrides `getPropertyDescriptors()` such that the only property returned is `rectangular`, only the `rectangular` property is displayed. However, because `getEventSetDescriptors()` is not overridden by `ColorsBeanInfo`, design-pattern introspection is used, and all events...
are found, including those in **Colors**' superclass, **Canvas**. Remember, if you don’t override one of the “get” methods defined by **SimpleBeanInfo**, then the default, design-pattern introspection is used. To observe the difference that **ColorsBeanInfo** makes, erase its class file and then run **IntrospectorDemo** again. This time it will report more properties.
This chapter presents an introduction to servlets. Servlets are small programs that execute on the server side of a web connection. Just as applets dynamically extend the functionality of a web browser, servlets dynamically extend the functionality of a web server. The topic of servlets is quite large, and it is beyond the scope of this chapter to cover it all. Instead, we will focus on the core concepts, interfaces, and classes, and develop several examples.

Background

In order to understand the advantages of servlets, you must have a basic understanding of how web browsers and servers cooperate to provide content to a user. Consider a request for a static web page. A user enters a Uniform Resource Locator (URL) into a browser. The browser generates an HTTP request to the appropriate web server. The web server maps this request to a specific file. That file is returned in an HTTP response to the browser. The HTTP header in the response indicates the type of the content. The Multipurpose Internet Mail Extensions (MIME) are used for this purpose. For example, ordinary ASCII text has a MIME type of text/plain. The Hypertext Markup Language (HTML) source code of a web page has a MIME type of text/html.

Now consider dynamic content. Assume that an online store uses a database to store information about its business. This would include items for sale, prices, availability, orders, and so forth. It wishes to make this information accessible to customers via web pages. The contents of those web pages must be dynamically generated to reflect the latest information in the database.

In the early days of the Web, a server could dynamically construct a page by creating a separate process to handle each client request. The process would open connections to one or more databases in order to obtain the necessary information. It communicated with the web server via an interface known as the Common Gateway Interface (CGI). CGI allowed the separate process to read data from the HTTP request and write data to the HTTP response. A variety of different languages were used to build CGI programs. These included C, C++, and Perl.

However, CGI suffered serious performance problems. It was expensive in terms of processor and memory resources to create a separate process for each client request. It was
also expensive to open and close database connections for each client request. In addition, the CGI programs were not platform-independent. Therefore, other techniques were introduced. Among these are servlets.

Servlets offer several advantages in comparison with CGI. First, performance is significantly better. Servlets execute within the address space of a web server. It is not necessary to create a separate process to handle each client request. Second, servlets are platform-independent because they are written in Java. Third, the Java security manager on the server enforces a set of restrictions to protect the resources on a server machine. Finally, the full functionality of the Java class libraries is available to a servlet. It can communicate with applets, databases, or other software via the sockets and RMI mechanisms that you have seen already.

The Life Cycle of a Servlet

Three methods are central to the life cycle of a servlet. These are `init()`, `service()`, and `destroy()`. They are implemented by every servlet and are invoked at specific times by the server. Let us consider a typical user scenario to understand when these methods are called. First, assume that a user enters a Uniform Resource Locator (URL) to a web browser. The browser then generates an HTTP request for this URL. This request is then sent to the appropriate server.

Second, this HTTP request is received by the web server. The server maps this request to a particular servlet. The servlet is dynamically retrieved and loaded into the address space of the server.

Third, the server invokes the `init()` method of the servlet. This method is invoked only when the servlet is first loaded into memory. It is possible to pass initialization parameters to the servlet so it may configure itself.

Fourth, the server invokes the `service()` method of the servlet. This method is called to process the HTTP request. You will see that it is possible for the servlet to read data that has been provided in the HTTP request. It may also formulate an HTTP response for the client. The servlet remains in the server’s address space and is available to process any other HTTP requests received from clients. The `service()` method is called for each HTTP request.

Finally, the server may decide to unload the servlet from its memory. The algorithms by which this determination is made are specific to each server. The server calls the `destroy()` method to relinquish any resources such as file handles that are allocated for the servlet. Important data may be saved to a persistent store. The memory allocated for the servlet and its objects can then be garbage collected.

Servlet Development Options

To create servlets, you will need access to a servlet container/server. Two popular ones are Glassfish and Tomcat. Glassfish is from Oracle and is provided by the Java EE SDK. It is supported by NetBeans. Tomcat is an open-source product maintained by the Apache Software Foundation. It can also be used by NetBeans. Both Tomcat and Glassfish can also
be used with other IDEs, such as Eclipse. The examples and descriptions in this chapter use Tomcat for reasons that will soon be apparent.

Although IDEs such as NetBeans and Eclipse are very useful and can streamline the creation of servlets, they are not used in this chapter. The way you develop and deploy servlets differs among IDEs, and it is simply not possible for this book to address each environment.

Furthermore, many readers will be using the command-line tools rather than an IDE. Therefore, if you are using an IDE, you must refer to the instructions for that environment for information concerning the development and deployment of servlets. For this reason, the instructions given here and elsewhere in this chapter assume that only the command-line tools are employed. Thus, they will work for nearly any reader.

Tomcat is used in this chapter because, in the opinion of this author, it makes it relatively easy to run the example servlets using only command-line tools and a text editor. It is also widely available in various programming environments. Furthermore, since only command-line tools are used, you don’t need to download and install an IDE just to experiment with servlets. Understand, however, that even if you are developing in an environment that uses Glassfish, the concepts presented here still apply. It is just that the mechanics of preparing a servlet for testing will be slightly different.

---

**REMEMBER** The instructions for developing and deploying servlets in this chapter are based on Tomcat and use only command-line tools. If you are using an IDE and different servlet container/server, consult the documentation for your environment.

**Using Tomcat**

Tomcat contains the class libraries, documentation, and run-time support that you will need to create and test servlets. At the time of this writing, several versions of Tomcat are available. The instructions that follow use 7.0.47. You can download Tomcat from [tomcat.apache.org](http://tomcat.apache.org). You should choose a version appropriate to your environment.

The examples in this chapter assume a 64-bit Windows environment. Assuming that a 64-bit version of Tomcat 7.0.47 was unpacked from the root directly, the default location is

```
C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\
```

This is the location assumed by the examples in this book. If you load Tomcat in a different location (or use a different version of Tomcat), you will need to make appropriate changes to the examples. You may need to set the environmental variable `JAVA_HOME` to the top-level directory in which the Java Development Kit is installed.
NOTE All of the directories shown in this section assume Tomcat 7.0.47. If you install a different version of Tomcat, then you will need to adjust the directory names and paths to match those used by the version you installed.

Once installed, you start Tomcat by selecting `startup.bat` from the `bin` directly under the `apache-tomcat-7.0.47` directory. To stop Tomcat, execute `shutdown.bat`, also in the `bin` directory.

The classes and interfaces needed to build servlets are contained in `servlet-api.jar`, which is in the following directory:

```
C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\lib
```

To make `servlet-api.jar` accessible, update your `CLASSPATH` environment variable so that it includes

```
C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\lib\servlet-api.jar
```

Alternatively, you can specify this file when you compile the servlets. For example, the following command compiles the first servlet example:

```
javac HelloServlet.java -classpath "C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\lib\servlet-api.jar"
```

Once you have compiled a servlet, you must enable Tomcat to find it. For our purposes, this means putting it into a directory under Tomcat’s `webapps` directory and entering its name into a `web.xml` file. To keep things simple, the examples in this chapter use the directory and `web.xml` file that Tomcat supplies for its own example servlets. This way, you won’t have to create any files or directories just to experiment with the sample servlets. Here is the procedure that you will follow.

First, copy the servlet’s class file into the following directory:

```
C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\webapps\examples\WEB-INF\classes
```

Next, add the servlet’s name and mapping to the `web.xml` file in the following directory:

```
C:\apache-tomcat-7.0.47-windows-x64\apache-tomcat-7.0.47\webapps\examples\WEB-INF
```
For instance, assuming the first example, called **HelloServlet**, you will add the following lines in the section that defines the servlets:

```xml
<servelt>
  <servelt-name>HelloServlet</servelt-name>
  <servelt-class>HelloServlet</servelt-class>
</servelt>
```

Next, you will add the following lines to the section that defines the servlet mappings:

```xml
<servelt-mapping>
  <servelt-name>HelloServlet</servelt-name>
  <url-pattern>/servelt/HelloServlet</url-pattern>
</servelt-mapping>
```

Follow this same general procedure for all of the examples.

**A Simple Servlet**

To become familiar with the key servlet concepts, we will begin by building and testing a simple servlet. The basic steps are the following:

1. Create and compile the servlet source code. Then, copy the servlet’s class file to the proper directory, and add the servlet’s name and mappings to the proper **web.xml** file.
2. Start Tomcat.
3. Start a web browser and request the servlet.

Let us examine each of these steps in detail.

**Create and Compile the Servlet Source Code**

To begin, create a file named **HelloServlet.java** that contains the following program:
import java.io.*;
import javax.servlet.*;

public class HelloServlet extends GenericServlet {

    public void service(HttpServletRequest request, HttpServletResponse response)
        throws ServletException, IOException {
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>Hello!" );
        pw.close();
    }

Let’s look closely at this program. First, note that it imports the javax.servlet package. This package contains the classes and interfaces required to build servlets. You will learn more about these later in this chapter. Next, the program defines HelloServlet as a subclass of GenericServlet. The GenericServlet class provides functionality that simplifies the creation of a servlet. For example, it provides versions of init() and destroy(), which may be used as is. You need supply only the service() method.

Inside HelloServlet, the service() method (which is inherited from GenericServlet) is overridden. This method handles requests from a client. Notice that the first argument is a ServletRequest object. This enables the servlet to read data that is provided via the client request. The second argument is a ServletResponse object. This enables the servlet to formulate a response for the client.

The call to setContentType() establishes the MIME type of the HTTP response. In this program, the MIME type is text/html. This indicates that the browser should interpret the content as HTML source code.

Next, the getWriter() method obtains a PrintWriter. Anything written to this stream is sent to the client as part of the HTTP response. Then println() is used to write some simple HTML source code as the HTTP response.

Compile this source code and place the HelloServlet.class file in the proper Tomcat directory as described in the previous section. Also, add HelloServlet to the web.xml file, as described earlier.

Start Tomcat
Start Tomcat as explained earlier. Tomcat must be running before you try to execute a servlet.

Start a Web Browser and Request the Servlet
Start a web browser and enter the URL shown here:

http://localhost:8080/examples/servlets/servlet/HelloServlet
Alternatively, you may enter the URL shown here:

http://127.0.0.1:8080/examples/servlets/servlet/HelloServlet

This can be done because 127.0.0.1 is defined as the IP address of the local machine. You will observe the output of the servlet in the browser display area. It will contain the string **Hello!** in bold type.

**The Servlet API**

Two packages contain the classes and interfaces that are required to build the servlets described in this chapter. These are `javax.servlet` and `javax.servlet.http`. They constitute the core of the Servlet API. Keep in mind that these packages are not part of the Java core packages. Therefore, they are not included with Java SE. Instead, they are provided by Tomcat. They are also provided by Java EE.

The Servlet API has been in a process of ongoing development and enhancement. The current servlet specification is version 3.1. However, because changes happen fast in the world of Java, you will want to check for any additions or alterations. This chapter discusses the core of the Servlet API, which will be available to most readers and works with all modern versions of the servlet specification.

**The javax.servlet Package**

The `javax.servlet` package contains a number of interfaces and classes that establish the framework in which servlets operate. The following table summarizes several key interfaces that are provided in this package. The most significant of these is `Servlet`. All servlets must implement this interface or extend a class that implements the interface. The `ServletRequest` and `ServletResponse` interfaces are also very important.

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Servlet</td>
<td>Declares life cycle methods for a servlet.</td>
</tr>
<tr>
<td>ServletConfig</td>
<td>Allows servlets to get initialization parameters.</td>
</tr>
<tr>
<td>ServletContext</td>
<td>Enables servlets to log events and access information about their environment.</td>
</tr>
<tr>
<td>ServletRequest</td>
<td>Used to read data from a client request.</td>
</tr>
<tr>
<td>ServletResponse</td>
<td>Used to write data to a client response.</td>
</tr>
</tbody>
</table>

The following table summarizes the core classes that are provided in the `javax.servlet` package:
GenericServlet Implements the **Servlet** and **ServletConfig** interfaces.

ServletInputStream Encapsulates an input stream for reading requests from a client.

ServletOutputStream Encapsulates an output stream for writing responses to a client.

ServletException Indicates a servlet error occurred.

UnavailableException Indicates a servlet is unavailable.

Let us examine these interfaces and classes in more detail.

**The Servlet Interface**

All servlets must implement the **Servlet** interface. It declares the **init()**, **service()**, and **destroy()** methods that are called by the server during the life cycle of a servlet. A method is also provided that allows a servlet to obtain any initialization parameters. The methods defined by **Servlet** are shown in Table 38-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void destroy()</td>
<td>Called when the servlet is unloaded.</td>
</tr>
<tr>
<td>ServletConfig getServletConfig()</td>
<td>Returns a ServletConfig object that contains any initialization parameters.</td>
</tr>
<tr>
<td>String getServletInfo()</td>
<td>Returns a string describing the servlet.</td>
</tr>
<tr>
<td>void init(ServletConfig config) throws ServletException</td>
<td>Called when the servlet is initialized. Initialization parameters for the servlet can be obtained from config. A ServletException should be thrown if the servlet cannot be initialized.</td>
</tr>
<tr>
<td>void service(ServletRequest request, ServletResponse response) throws ServletException, IOException</td>
<td>Called to process a request from a client. The request from the client can be read from request. The response to the client can be written to response. An exception is generated if a servlet or IO problem occurs.</td>
</tr>
</tbody>
</table>

**Table 38-1** The Methods Defined by **Servlet**

The **init()**, **service()**, and **destroy()** methods are the life cycle methods of the servlet. These are invoked by the server. The **getServletConfig()** method is called by the servlet to obtain initialization parameters. A servlet developer overrides the **getServletInfo()** method to provide a string with useful information (for example, the version number). This method is also invoked by the server.

**The ServletConfig Interface**

The **ServletConfig** interface allows a servlet to obtain configuration data when it is loaded. The methods declared by this interface are summarized here:

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
</table>
The ServletContext Interface

The ServletContext interface enables servlets to obtain information about their environment. Several of its methods are summarized in Table 38-2.

```
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Object getAttribute(String attr)</td>
<td>Returns the value of the server attribute named attr.</td>
</tr>
<tr>
<td>String getMimeType(String file)</td>
<td>Returns the MIME type of file.</td>
</tr>
<tr>
<td>String getRealPath(String path)</td>
<td>Returns the real (i.e., absolute) path that corresponds to the relative path path.</td>
</tr>
<tr>
<td>String getServerInfo()</td>
<td>Returns information about the server.</td>
</tr>
<tr>
<td>void log(String s)</td>
<td>Writes s to the servlet log.</td>
</tr>
<tr>
<td>void log(String s, Throwable e)</td>
<td>Writes s and the stack trace for e to the servlet log.</td>
</tr>
<tr>
<td>void setAttribute(String attr, Object value)</td>
<td>Sets the attribute specified by attr to the value passed in value.</td>
</tr>
</tbody>
</table>
```

Table 38-2 Various Methods Defined by ServletContext

The ServletRequest Interface

The ServletRequest interface enables a servlet to obtain information about a client request. Several of its methods are summarized in Table 38-3.
The ServletResponse Interface

The ServletResponse interface enables a servlet to formulate a response for a client. Several of its methods are summarized in Table 38-4.

The GenericServlet Class

The GenericServlet class provides implementations of the basic life cycle methods for a servlet. GenericServlet implements the Servlet and ServletConfig interfaces. In addition, a method to append a string to the server log file is available. The signatures of
The method are shown here:

```java
void log(String s)
void log(String s, Throwable e)
```

Here, s is the string to be appended to the log, and e is an exception that occurred.

**The ServletInputStream Class**
The `ServletInputStream` class extends `InputStream`. It is implemented by the servlet container and provides an input stream that a servlet developer can use to read the data from a client request. In addition to the input methods inherited from `InputStream`, a method is provided to read bytes from the stream. It is shown here:

```java
int readLine(byte[] buffer, int offset, int size) throws IOException
```

Here, `buffer` is the array into which `size` bytes are placed starting at `offset`. The method returns the actual number of bytes read or -1 if an end-of-stream condition is encountered.

**The ServletOutputStream Class**
The `ServletOutputStream` class extends `OutputStream`. It is implemented by the servlet container and provides an output stream that a servlet developer can use to write data to a client response. In addition to the output methods provided by `OutputStream`, it also defines the `print()` and `println()` methods, which output data to the stream.

**The Servlet Exception Classes**
`javax.servlet` defines two exceptions. The first is `ServletException`, which indicates that a servlet problem has occurred. The second is `UnavailableException`, which extends `ServletException`. It indicates that a servlet is unavailable.

**Reading Servlet Parameters**
The `ServletRequest` interface includes methods that allow you to read the names and values of parameters that are included in a client request. We will develop a servlet that illustrates their use. The example contains two files. A web page is defined in `PostParameters.html`, and a servlet is defined in `PostParametersServlet.java`. The HTML source code for `PostParameters.html` is shown in the following listing. It defines a table that contains two labels and two text fields. One of the labels is employee and the other is phone. There is also a submit button. Notice that the action parameter of the form tag specifies a URL. The URL identifies the servlet to process the HTTP POST request.
The source code for PostParametersServlet.java is shown in the following listing. The service() method is overridden to process client requests. The getParameterNames() method returns an enumeration of the parameter names. These are processed in a loop. You can see that the parameter name and value are output to the client. The parameter value is obtained via the getParameter() method.
import java.io.*;
import java.util.*;
import javax.servlet.*;

public class PostParametersServlet
extends GenericServlet {

    public void service(ServletRequest request,
                        ServletResponse response)
        throws ServletException, IOException {

        // Get print writer.
        PrintWriter pw = response.getWriter();

        // Get enumeration of parameter names.
        Enumeration e = request.getParameterNames();

        // Display parameter names and values.
        while (e.hasMoreElements()) {
            String pname = (String) e.nextElement();
            pw.print(pname + " = ");
            String pvalue = request.getParameter(pname);
            pw.println(pvalue);
        }
        pw.close();
    }
}

Compile the servlet. Next, copy it to the appropriate directory, and update the web.xml file, as previously described. Then, perform these steps to test this example:

1. Start Tomcat (if it is not already running).
2. Display the web page in a browser.
3. Enter an employee name and phone number in the text fields.
4. Submit the web page.

After following these steps, the browser will display a response that is dynamically generated by the servlet.

The javax.servlet.http Package
The preceding examples have used the classes and interfaces defined in javax.servlet, such as ServletRequest, ServletResponse, and GenericServlet, to illustrate the basic functionality of servlets. However, when working with HTTP, you will normally use the interfaces and classes in javax.servlet.http. As you will see, its functionality makes it easy to build servlets that work with HTTP requests and responses.
The following table summarizes the interfaces used in this chapter:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>HttpServletRequest</td>
<td>Enables servlets to read data from an HTTP request.</td>
</tr>
<tr>
<td>HttpServletResponse</td>
<td>Enables servlets to write data to an HTTP response.</td>
</tr>
<tr>
<td>HttpSession</td>
<td>Allows session data to be read and written.</td>
</tr>
</tbody>
</table>

The following table summarizes the classes used in this chapter. The most important of these is **HttpServletRequest**. Servlet developers typically extend this class in order to process HTTP requests.

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cookie</td>
<td>Allows state information to be stored on a client machine.</td>
</tr>
<tr>
<td>HttpServlet</td>
<td>Provides methods to handle HTTP requests and responses.</td>
</tr>
</tbody>
</table>

**The HttpServletRequest Interface**

The **HttpServletRequest** interface enables a servlet to obtain information about a client request. Several of its methods are shown in Table 38-5.
The HttpServletResponse Interface

The HttpServletResponse interface enables a servlet to formulate an HTTP response to a client. Several constants are defined. These correspond to the different status codes that can be assigned to an HTTP response. For example, SC_OK indicates that the HTTP request succeeded, and SC_NOT_FOUND indicates that the requested resource is not available. Several methods of this interface are summarized in Table 38-6.

---

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String getAuthType( )</td>
<td>Returns authentication scheme.</td>
</tr>
<tr>
<td>Cookie[] getCookie( )</td>
<td>Returns an array of the cookies in this request.</td>
</tr>
<tr>
<td>Long getDateHeader(String field)</td>
<td>Returns the value of the date header field named field.</td>
</tr>
<tr>
<td>String getHeaderValue(String field)</td>
<td>Returns the value of the header field named field.</td>
</tr>
<tr>
<td>Enumeration&lt;String&gt; getHeaderNames( )</td>
<td>Returns an enumeration of the header names.</td>
</tr>
<tr>
<td>int getHeader(String field)</td>
<td>Returns the int equivalent of the header field named field.</td>
</tr>
<tr>
<td>String getMethod( )</td>
<td>Returns the HTTP method for this request.</td>
</tr>
<tr>
<td>String getPathInfo( )</td>
<td>Returns any path information that is located after the servlet path and before a query string of the URL.</td>
</tr>
<tr>
<td>String getPathTranslated( )</td>
<td>Returns any path information that is located after the servlet path and before a query string of the URL after translating it to a real path.</td>
</tr>
<tr>
<td>String getQueryString( )</td>
<td>Returns any query string in the URL.</td>
</tr>
<tr>
<td>String getRemoteUser( )</td>
<td>Returns the name of the user who issued this request.</td>
</tr>
<tr>
<td>String getRequestedSessionId( )</td>
<td>Returns the ID of the session.</td>
</tr>
<tr>
<td>String getRequestedURL( )</td>
<td>Returns the URL.</td>
</tr>
<tr>
<td>StringBuffer getRequestedURL( )</td>
<td>Returns the URL.</td>
</tr>
<tr>
<td>String getServletPath( )</td>
<td>Returns the part of the URL that identifies the servlet.</td>
</tr>
<tr>
<td>HttpSession getSession( )</td>
<td>Returns the session for this request. If a session does not exist, one is created and then returned.</td>
</tr>
<tr>
<td>HttpSession getSession(boolean create)</td>
<td>If create is true and no session exists, creates and returns a session for this request. Otherwise, returns the existing session for this request.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdFromCookie( )</td>
<td>Returns true if a cookie contains the session ID. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdFromURL( )</td>
<td>Returns true if the URL contains the session ID. Otherwise, returns false.</td>
</tr>
<tr>
<td>boolean isRequestedSessionIdValid( )</td>
<td>Returns true if the requested session ID is valid in the current session context.</td>
</tr>
</tbody>
</table>

Table 38-5 Various Methods Defined by HttpServletRequest
The `HttpSession` Interface

The `HttpSession` interface enables a servlet to read and write the state information that is associated with an HTTP session. Several of its methods are summarized in Table 38-7. All of these methods throw an `IllegalStateException` if the session has already been invalidated.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void addCookie(Cookie cookie)</code></td>
<td>Adds cookie to the HTTP response.</td>
</tr>
<tr>
<td><code>boolean containsHeader(String field)</code></td>
<td>Determines if the HTTP response header contains a field named <code>field</code>.</td>
</tr>
<tr>
<td><code>String encodeURL(String url)</code></td>
<td>Determines if the session ID must be encoded in the URL identified as <code>url</code>. Otherwise, returns <code>url</code>. All URLs generated by a servlet should be processed by this method.</td>
</tr>
<tr>
<td><code>String encodeRedirectURL(String url)</code></td>
<td>Determines if the session ID must be encoded in the URL identified as <code>url</code>. Otherwise, returns <code>url</code>. All URLs passed to <code>sendRedirect()</code> should be processed by this method.</td>
</tr>
<tr>
<td><code>void sendError(int code)</code></td>
<td>Sends the error code <code>code</code> to the client.</td>
</tr>
<tr>
<td><code>void sendRedirect(String url)</code></td>
<td>Sends the error code <code>code</code> and message <code>message</code> to the client.</td>
</tr>
<tr>
<td><code>void setDateHeader(String field, long millis)</code></td>
<td>Adds <code>field</code> to the header with date value equal to <code>millis</code> (milliseconds since midnight, January 1, 1970, GMT).</td>
</tr>
<tr>
<td><code>void setHeader(String field, String value)</code></td>
<td>Adds <code>field</code> to the header with value equal to <code>value</code>.</td>
</tr>
<tr>
<td><code>void setHeader(String field, int value)</code></td>
<td>Adds <code>field</code> to the header with value equal to <code>value</code>.</td>
</tr>
<tr>
<td><code>void setRedirectError(int code)</code></td>
<td>Sets the status code for this response to <code>code</code>.</td>
</tr>
</tbody>
</table>

Table 38-6 Various Methods Defined by `HttpServletResponse`
The Cookie Class

The **Cookie** class encapsulates a cookie. A *cookie* is stored on a client and contains state information. Cookies are valuable for tracking user activities. For example, assume that a user visits an online store. A cookie can save the user’s name, address, and other information. The user does not need to enter this data each time he or she visits the store. A servlet can write a cookie to a user’s machine via the `addCookie()` method of the `HttpServletResponse` interface. The data for that cookie is then included in the header of the HTTP response that is sent to the browser.

The names and values of cookies are stored on the user’s machine. Some of the information that can be saved for each cookie includes the following:

- The name of the cookie
- The value of the cookie
- The expiration date of the cookie
- The domain and path of the cookie

The expiration date determines when this cookie is deleted from the user’s machine. If an expiration date is not explicitly assigned to a cookie, it is deleted when the current browser session ends.

The domain and path of the cookie determine when it is included in the header of an HTTP request. If the user enters a URL whose domain and path match these values, the cookie is then supplied to the web server. Otherwise, it is not.

There is one constructor for **Cookie**. It has the signature shown here:

```
Cookie(String name, String value)
```

Here, the name and value of the cookie are supplied as arguments to the constructor. The methods of the **Cookie** class are summarized in Table 38-8.
### The HttpServlet Class

The **HttpServlet** class extends **GenericServlet**. It is commonly used when developing servlets that receive and process HTTP requests. The methods defined by the **HttpServlet** class are summarized in Table 38-9.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>void doDelete(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP DELETE request.</td>
</tr>
<tr>
<td>void doGet(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP GET request.</td>
</tr>
<tr>
<td>void doHead(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP HEAD request.</td>
</tr>
<tr>
<td>void doOptions(HttpServletRequest req, HttpServletResponse res) throws IOException, ServletException</td>
<td>Handles an HTTP OPTIONS request.</td>
</tr>
</tbody>
</table>

**Table 38-8** The Methods Defined by Cookie

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>String clone()</td>
<td>Returns a copy of this object.</td>
</tr>
<tr>
<td>String getComment()</td>
<td>Returns the comment.</td>
</tr>
<tr>
<td>String getDomain()</td>
<td>Returns the domain.</td>
</tr>
<tr>
<td>int getMaxAge()</td>
<td>Returns the maximum age (in seconds).</td>
</tr>
<tr>
<td>String getName()</td>
<td>Returns the name.</td>
</tr>
<tr>
<td>String getPath()</td>
<td>Returns the path.</td>
</tr>
<tr>
<td>boolean getSecure()</td>
<td>Returns true if the cookie is secure. Otherwise, returns false.</td>
</tr>
<tr>
<td>String getValue()</td>
<td>Returns the value.</td>
</tr>
<tr>
<td>int getVersion()</td>
<td>Returns the version.</td>
</tr>
<tr>
<td>boolean isHttpOnly()</td>
<td>Returns true if the cookie has the HttpOnly attribute.</td>
</tr>
<tr>
<td>void setComment(String c)</td>
<td>Sets the comment to ( c ).</td>
</tr>
<tr>
<td>void setDomain(String d)</td>
<td>Sets the domain to ( d ).</td>
</tr>
<tr>
<td>void setHttpOnly(boolean hOnly)</td>
<td>If ( hOnly ) is true, then the HttpOnly attribute is added to the cookie. If ( hOnly ) is false, the HttpOnly attribute is removed.</td>
</tr>
<tr>
<td>voidsetMaxAge(int sec)</td>
<td>Sets the maximum age of the cookie to ( sec ). This is the number of seconds after which the cookie is deleted.</td>
</tr>
<tr>
<td>void setPath(String p)</td>
<td>Sets the path to ( p ).</td>
</tr>
<tr>
<td>void setSecure(boolean secure)</td>
<td>Sets the security flag to ( secure ).</td>
</tr>
<tr>
<td>void setValue(String v)</td>
<td>Sets the value to ( v ).</td>
</tr>
<tr>
<td>void setVersion(int v)</td>
<td>Sets the version to ( v ).</td>
</tr>
</tbody>
</table>
Table 38-9  The Methods Defined by HttpServlet

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>doGet( )</td>
<td>Handles an HTTP GET request.</td>
</tr>
<tr>
<td>doPost( )</td>
<td>Handles an HTTP POST request.</td>
</tr>
<tr>
<td>doPut( )</td>
<td>Handles an HTTP PUT request.</td>
</tr>
<tr>
<td>doHead( )</td>
<td>Handles an HTTP HEAD request.</td>
</tr>
<tr>
<td>doOptions( )</td>
<td>Handles an HTTP OPTIONS request.</td>
</tr>
<tr>
<td>doTrace( )</td>
<td>Handles an HTTP TRACE request.</td>
</tr>
<tr>
<td>getLastModified( )</td>
<td>Returns the time (in milliseconds since midnight, January 1, 1970, GMT) when the requested resource was last modified.</td>
</tr>
<tr>
<td>service( )</td>
<td>Called by the server when an HTTP request arrives for this servlet. The arguments provide access to the HTTP request and response, respectively.</td>
</tr>
</tbody>
</table>

Handling HTTP Requests and Responses

The HttpServlet class provides specialized methods that handle the various types of HTTP requests. A servlet developer typically overrides one of these methods. These methods are doGet( ), doPost( ), doHead( ), doOptions( ), doPut( ), doPost( ), doPut( ), and doTrace( ). A complete description of the different types of HTTP requests is beyond the scope of this book. However, the GET and POST requests are commonly used when handling form input. Therefore, this section presents examples of these cases.

Handling HTTP GET Requests

Here we will develop a servlet that handles an HTTP GET request. The servlet is invoked when a form on a web page is submitted. The example contains two files. A web page is defined in ColorGet.html, and a servlet is defined in ColorGetServlet.java. The HTML source code for ColorGet.html is shown in the following listing. It defines a form that contains a select element and a submit button. Notice that the action parameter of the form tag specifies a URL. The URL identifies a servlet to process the HTTP GET request.

```html
<html>
<head>
</head>
<body>
<center>
<form name="Form1" action="http://localhost:8080/examples/servlets/servlet/ColorGetServlet">
  <b>Color:</b>
  <select name="color" size="1">
    <option value="Red">Red</option>
    <option value="Green">Green</option>
    <option value="Blue">Blue</option>
  </select>
  <br>
  <input type="submit" value="Submit">
</form>
</center>
</body>
</html>
```

The source code for ColorGetServlet.java is shown in the following listing. The doGet( )
method is overridden to process any HTTP GET requests that are sent to this servlet. It uses
the `getParameter()` method of `HttpServletRequest` to obtain the selection that was
made by the user. A response is then formulated.

```java
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class ColorGetServlet extends HttpServlet {

    public void doGet(HttpServletRequest request,
                       HttpServletResponse response)
                   throws ServletException, IOException {

        String color = request.getParameter("color");
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>The selected color is: ");
        pw.println(color);
        pw.close();
    }
}
```

Compile the servlet. Next, copy it to the appropriate directory, and update the `web.xml` file,
as previously described. Then, perform these steps to test this example:

1. Start Tomcat, if it is not already running.
2. Display the web page in a browser.
3. Select a color.
4. Submit the web page.

After completing these steps, the browser will display the response that is
dynamically generated by the servlet.

One other point: Parameters for an HTTP GET request are included as part of the URL that
is sent to the web server. Assume that the user selects the red option and submits the form.
The URL sent from the browser to the server is

```
```

The characters to the right of the question mark are known as the *query string*.

**Handling HTTP POST Requests**

Here we will develop a servlet that handles an HTTP POST request. The servlet is invoked
when a form on a web page is submitted. The example contains two files. A web page is
defined in `ColorPost.html`, and a servlet is defined in `ColorPostServlet.java`. 
The HTML source code for **ColorPost.html** is shown in the following listing. It is identical to **ColorGet.html** except that the method parameter for the form tag explicitly specifies that the POST method should be used, and the action parameter for the form tag specifies a different servlet.

```html
<html>
<body>
<form name="Form1" method="post" action="http://localhost:8080/examples/servlets/servlet/ColorPostServlet">
<B>Color:</B>
<select name="color" size="1">
<option value="Red">Red</option>
<option value="Green">Green</option>
<option value="Blue">Blue</option>
</select>
<br><br>
<input type="submit" value="Submit"/>
</form>
</body>
</html>
```

The source code for **ColorPostServlet.java** is shown in the following listing. The **doPost()** method is overridden to process any HTTP POST requests that are sent to this servlet. It uses the **getParameter()** method of **HttpServletRequest** to obtain the selection that was made by the user. A response is then formulated.

```java
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class ColorPostServlet extends HttpServlet {

    public void doPost(HttpServletRequest request,
                        HttpServletResponse response)
        throws ServletException, IOException {

        String color = request.getParameter("color");
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>The selected color is: ");
        pw.println(color);
        pw.close();
    }
}
```

Compile the servlet and perform the same steps as described in the previous section to test it.
Parameters for an HTTP POST request are not included as part of the URL that is sent to the web server. In this example, the URL sent from the browser to the server is http://localhost:8080/examples/servlets/servlet/ColorPostServlet. The parameter names and values are sent in the body of the HTTP request.

Using Cookies

Now, let's develop a servlet that illustrates how to use cookies. The servlet is invoked when a form on a web page is submitted. The example contains three files as summarized here:

<table>
<thead>
<tr>
<th>File</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>AddCookie.html</td>
<td>Allows a user to specify a value for the cookie named MyCookie.</td>
</tr>
<tr>
<td>AddCookieServlet.java</td>
<td>Processes the submission of AddCookie.html.</td>
</tr>
<tr>
<td>GetCookiesServlet.java</td>
<td>Displays cookie values.</td>
</tr>
</tbody>
</table>

The HTML source code for AddCookie.html is shown in the following listing. This page contains a text field in which a value can be entered. There is also a submit button on the page. When this button is pressed, the value in the text field is sent to AddCookieServlet via an HTTP POST request.

```html
<html>
<body>
<center>
<form name="Form1" method="post" action="http://localhost:8080/examples/servlets/servlet/AddCookieServlet">
  <B>Enter a value for MyCookie:</B>
  <input type="text" name="data" size=25 value="" />
  <input type="submit" value="Submit" />
</form>
</body>
</html>
```

The source code for AddCookieServlet.java is shown in the following listing. It gets the value of the parameter named "data". It then creates a Cookie object that has the name "MyCookie" and contains the value of the "data" parameter. The cookie is then added to the header of the HTTP response via the addCookie( ) method. A feedback message is then written to the browser.
The source code for GetCookiesServlet.java is shown in the following listing. It invokes the `getCookies()` method to read any cookies that are included in the HTTP GET request. The names and values of these cookies are then written to the HTTP response. Observe that the `getName()` and `getValue()` methods are called to obtain this information.
import java.io.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class GetCookiesServlet extends HttpServlet {

    public void doGet(HttpServletRequest request,
            HttpServletResponse response)
            throws ServletException, IOException {

        // Get cookies from header of HTTP request.
        Cookie[] cookies = request.getCookies();

        // Display these cookies.
        response.setContentType("text/html");
        PrintWriter pw = response.getWriter();
        pw.println("<B>");
        for(int i = 0; i < cookies.length; i++) {
            String name = cookies[i].getName();
            String value = cookies[i].getValue();
            pw.println("name = "+name+
"; value = "+value);
        }
        pw.close();
    }
}

Compile the servlets. Next, copy them to the appropriate directory, and update the
web.xml file, as previously described. Then, perform these steps to test this example:

1. Start Tomcat, if it is not already running.
2. Display AddCookie.html in a browser.
3. Enter a value for MyCookie.
4. Submit the web page.

After completing these steps, you will observe that a feedback message is displayed
by the browser.

Next, request the following URL via the browser:

http://localhost:9080/examples/servlets/servlet/GetCookiesServlet

Observe that the name and value of the cookie are displayed in the browser. In this example, an expiration date is not explicitly assigned to the cookie via the
setMaxAge( ) method of Cookie. Therefore, the cookie expires when the browser session
ends. You can experiment by using setMaxAge( ) and observe that the cookie is then saved
Session Tracking

HTTP is a stateless protocol. Each request is independent of the previous one. However, in some applications, it is necessary to save state information so that information can be collected from several interactions between a browser and a server. Sessions provide such a mechanism.

A session can be created via the `getSession()` method of `HttpServletRequest`. An `HttpSession` object is returned. This object can store a set of bindings that associate names with objects. The `setAttribute()`, `getAttribute()`, `getAttributeNames()`, and `removeAttribute()` methods of `HttpSession` manage these bindings. Session state is shared by all servlets that are associated with a client.

The following servlet illustrates how to use session state. The `getSession()` method gets the current session. A new session is created if one does not already exist. The `getAttribute()` method is called to obtain the object that is bound to the name "date". That object is a `Date` object that encapsulates the date and time when this page was last accessed. (Of course, there is no such binding when the page is first accessed.) A `Date` object encapsulating the current date and time is then created. The `setAttribute()` method is called to bind the name "date" to this object.

```java
import java.io.*;
import java.util.*;
import javax.servlet.*;
import javax.servlet.http.*;

public class DateServlet extends HttpServlet {
```
public void doGet(HttpServletRequest request, 
HttpServletRequest response) 
throws ServletException, IOException {

    // Get the HttpSession object.
    HttpSession hs = request.getSession(true);

    // Get writer.
    response.setContentType("text/html");
    PrintWriter pw = response.getWriter();
    pw.print("<B>");

    // Display date/time of last access.
    Date date = (Date)hs.getAttribute("date");
    if (date != null) {
        pw.println("Last access: " + date + "<br>");
    }

    // Display current date/time.
    date = new Date();
    hs.setAttribute("date", date);
    pw.println("Current date: " + date);
}

When you first request this servlet, the browser displays one line with the current date and time information. On subsequent invocations, two lines are displayed. The first line shows the date and time when the servlet was last accessed. The second line shows the current date and time.
As explained in Part I, Java supports three types of comments. The first two are the // and the /* */. The third type is called a documentation comment. It begins with the character sequence /***. It ends with */. Documentation comments allow you to embed information about your program into the program itself. You can then use the javadoc utility program (supplied with the JDK) to extract the information and put it into an HTML file. Documentation comments make it convenient to document your programs. You have almost certainly seen documentation generated with javadoc, because that is the way the Java API library was documented.

**The javadoc Tags**
The javadoc utility recognizes the following tags:

<table>
<thead>
<tr>
<th>Tag</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>@author</td>
<td>Identifies the author.</td>
</tr>
<tr>
<td>{@code}</td>
<td>Displays information as-is, without processing HTML styles, in code font.</td>
</tr>
<tr>
<td>@deprecated</td>
<td>Specifies that a program element is deprecated.</td>
</tr>
<tr>
<td>{@docRoot}</td>
<td>Specifies the path to the root directory of the current documentation.</td>
</tr>
<tr>
<td>@exception</td>
<td>Identifies an exception thrown by a method or constructor.</td>
</tr>
<tr>
<td>{@inheritDoc}</td>
<td>Inherits a comment from the immediate superclass.</td>
</tr>
<tr>
<td>{@link}</td>
<td>Inserts an in-line link to another topic.</td>
</tr>
<tr>
<td>{@linkplain}</td>
<td>Inserts an in-line link to another topic, but the link is displayed in plaintext font.</td>
</tr>
<tr>
<td>{@literal}</td>
<td>Displays information as-is, without processing HTML styles.</td>
</tr>
<tr>
<td>@param</td>
<td>Documents a parameter.</td>
</tr>
<tr>
<td>@return</td>
<td>Documents a method’s return value.</td>
</tr>
<tr>
<td>@see</td>
<td>Specifies a link to another topic.</td>
</tr>
<tr>
<td>Tag</td>
<td>Description</td>
</tr>
<tr>
<td>-----------</td>
<td>-----------------------------------------------------------------------------</td>
</tr>
<tr>
<td>@serial</td>
<td>Documents a default serializable field.</td>
</tr>
<tr>
<td>@serialData</td>
<td>Documents the data written by the writeObject() or writeExternal() methods.</td>
</tr>
<tr>
<td>@serialField</td>
<td>Documents an ObjectStreamField component.</td>
</tr>
<tr>
<td>@since</td>
<td>States the release when a specific change was introduced.</td>
</tr>
<tr>
<td>@throws</td>
<td>Same as @exception.</td>
</tr>
<tr>
<td>{@value}</td>
<td>Displays the value of a constant, which must be a static field.</td>
</tr>
<tr>
<td>@version</td>
<td>Specifies the version of a class.</td>
</tr>
</tbody>
</table>

Document tags that begin with an “at” sign (@) are called stand-alone tags (also called block tags), and they must be used on their own line. Tags that begin with a brace, such as {@code}, are called in-line tags, and they can be used within a larger description. You may also use other, standard HTML tags in a documentation comment. However, some tags, such as headings, should not be used because they disrupt the look of the HTML file produced by javadoc.

As it relates to documenting source code, you can use documentation comments to document classes, interfaces, fields, constructors, and methods. In all cases, the documentation comment must immediately precede the item being documented. Some tags, such as @see, @since, and @deprecated, can be used to document any element. Other tags apply only to the relevant elements. Each tag is examined next.

---

**NOTE** Documentation comments can also be used for documenting a package and preparing an overview, but the procedures differ from those used to document source code. See the javadoc documentation for details on these uses.

@author
The @author tag documents the author of a class or interface. It has the following syntax:

```
@author description
```

Here, description will usually be the name of the author. You will need to specify the -author option when executing javadoc in order for the @author field to be included in the HTML documentation.

{@code}
The {@code} tag enables you to embed text, such as a snippet of code, into a comment.
That text is then displayed as-is in code font, without any further processing, such as HTML rendering. It has the following syntax:

```code
code-snippet
```

@deprecated
The `@deprecated` tag specifies that a program element is deprecated. It is recommended that you include `@see` or `{@link}` tags to inform the programmer about available alternatives. The syntax is the following:

```code
@deprecated description
```

Here, `description` is the message that describes the deprecation. The `@deprecated` tag can be used in documentation for fields, methods, constructors, classes, and interfaces.

```docRoot```
`{@docRoot}` specifies the path to the root directory of the current documentation.

@exception
The `@exception` tag describes an exception to a method. It has the following syntax:

```code
@exception exception-name explanation
```

Here, the fully qualified name of the exception is specified by `exception-name`, and `explanation` is a string that describes how the exception can occur. The `@exception` tag can only be used in documentation for a method or constructor.

```inheritDoc```
This tag inherits a comment from the immediate superclass.

```link```
The `@link` tag provides an in-line link to additional information. It has the following syntax:

```code
@link pkg.class#member text
```

Here, `pkg.class#member` specifies the name of a class or method to which a link is added, and `text` is the string that is displayed.

```linkplain```
Inserts an in-line link to another topic. The link is displayed in plain-text font. Otherwise, it is similar to `@link`.

```literal```
The `@literal` tag enables you to embed text into a comment. That text is then displayed as-is, without any further processing, such as HTML rendering. It has the following syntax:

```code
description
```
Here, *description* is the text that is embedded.

@param
The @param tag documents a parameter. It has the following syntax:

```
@param parameter-name explanation
```

Here, *parameter-name* specifies the name of a parameter. The meaning of that parameter is described by *explanation*. The @param tag can be used only in documentation for a method or constructor, or a generic class or interface.

@return
The @return tag describes the return value of a method. It has the following syntax:

```
@return explanation
```

Here, *explanation* describes the type and meaning of the value returned by a method. The @return tag can be used only in documentation for a method.

@see
The @see tag provides a reference to additional information. Two commonly used forms are shown here:

```
@see anchor
@see pkg.class#member text
```

In the first form, *anchor* is a link to an absolute or relative URL. In the second form, *pkg.class#member* specifies the name of the item, and *text* is the text displayed for that item. The text parameter is optional, and if not used, then the item specified by *pkg.class#member* is displayed. The member name, too, is optional. Thus, you can specify a reference to a package, class, or interface in addition to a reference to a specific method or field. The name can be fully qualified or partially qualified. However, the dot that precedes the member name (if it exists) must be replaced by a hash character.

@serial
The @serial tag defines the comment for a default serializable field. It has the following syntax:

```
@serial description
```

Here, *description* is the comment for that field.

@serialData
The @serialData tag documents the data written by the *writeObject*() and *writeExternal*() methods. It has the following syntax:

```
@serialData description
```
Here, *description* is the comment for that data.

@serialField
For a class that implements *Serializable*, the @serialField tag provides comments for an *ObjectStreamField* component. It has the following syntax:

@serialField name type description

Here, *name* is the name of the field, *type* is its type, and *description* is the comment for that field.

@since
The @since tag states that an element was introduced in a specific release. It has the following syntax:

@since release

Here, *release* is a string that designates the release or version in which this feature became available.

@throws
The @throws tag has the same meaning as the @exception tag.

{@value}

{@value} has two forms. The first displays the value of the constant that it precedes, which must be a *static* field. It has this form:

{@value}

The second form displays the value of a specified *static* field. It has this form:

{@value pkg.class#field}

Here, *pkg.class#field* specifies the name of the *static* field.

@version
The @version tag specifies the version of a class or interface. It has the following syntax:

@version info

Here, *info* is a string that contains version information, typically a version number, such as 2.2. You will need to specify the -version option when executing javadoc in order for the @version field to be included in the HTML documentation.

The General Form of a Documentation Comment

After the beginning /***, the first line or lines become the main description of your class, interface, field, constructor, or method. After that, you can include one or more of the various @ tags. Each @ tag must start at the beginning of a new line or follow one or more asterisks (*) that are at the start of a line. Multiple tags of the same type should be grouped together. For example, if you have three @see tags, put them one after the other. In-line
tags (those that begin with a brace) can be used within any description. Here is an example of a documentation comment for a class:

```java
/**
 * This class draws a bar chart.
 * @author Herbert Schildt
 * @version 3.2
 */
```

**What javadoc Outputs**
The *javadoc* program takes as input your Java program’s source file and outputs several HTML files that contain the program’s documentation. Information about each class will be in its own HTML file. *javadoc* will also output an index and a hierarchy tree. Other HTML files can be generated.

**An Example that Uses Documentation Comments**
Following is a sample program that uses documentation comments. Notice the way each comment immediately precedes the item that it describes. After being processed by *javadoc*, the documentation about the *SquareNum* class will be found in *SquareNum.html*. 
import java.io.*;
/**
 * This class demonstrates documentation comments.
 * @author Herbert Schildt
 * @version 1.2
 */
public class SquareNum {
    /**
     * This method returns the square of num.
     * This is a multiline description. You can use
     * as many lines as you like.
     * @param num The value to be squared.
     * @return num squared.
     */
    public double square(double num) {
        return num * num;
    }

    /**
     * This method inputs a number from the user.
     * @return The value input as a double.
     * @exception IOException On input error.
     * @see IOException
     */
    public double getNumber() throws IOException {
        // create a BufferedReader using System.in
        InputStreamReader isr = new InputStreamReader(System.in);
        BufferedReader inData = new BufferedReader(isr);
        String str;
        str = inData.readLine();
        return (new Double(str)).doubleValue();
    }

    /**
     * This method demonstrates square().
     * @param args Unused.
     * @exception IOException On input error.
     * @see IOException
     */
    public static void main(String args[])
        throws IOException {
        SquareNum ob = new SquareNum();
        double val;
```java
System.out.println("Enter value to be squared: ");
val = ob.getNumber();
val = ob.square(val);
System.out.println("Squared value is " + val);
```

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