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1. Java Fundamentals
2. Introducing Data Types and Operators
3. Program Control Statements
4. Introducing Classes, Objects, and Methods
5. More Data Types and Operators
6. A Closer Look at Methods and Classes
7. Inheritance
8. Packages and Interfaces
9. Exception Handling
10. Using I/O
11. Multithreaded Programming
12. Enumerations, Autoboxing, Static Import, and Annotations
13. Generics
14. Lambda Expressions and Method References
15. Applets, Events, and Miscellaneous Topics
16. Introducing Swing
17. Introducing JavaFX
A. Answers to Self Tests
B. Using Java’s Documentation Comments

Index
INTRODUCTION

1 Java Fundamentals
The Origins of Java
   How Java Relates to C and C++
   How Java Relates to C#
Java’s Contribution to the Internet
   Java Applets
   Security
   Portability
Java’s Magic: The Bytecode
The Java Buzzwords
Object-Oriented Programming
   Encapsulation
   Polymorphism
   Inheritance
Obtaining the Java Development Kit
A First Simple Program
   Entering the Program
   Compiling the Program
   The First Sample Program Line by Line
Handling Syntax Errors
A Second Simple Program
Another Data Type
Try This 1-1: Converting Gallons to Liters
Two Control Statements
   The if Statement
   The for Loop
Create Blocks of Code
Semicolons and Positioning
Indentation Practices
Try This 1-2: Improving the Gallons-to-Liters Converter
The Java Keywords
Identifiers in Java
The Java Class Libraries
Chapter 1 Self Test

2 Introducing Data Types and Operators
Why Data Types Are Important
Java’s Primitive Types
   Integers
   Floating-Point Types
3 Program Control Statements

Input Characters from the Keyboard
The if Statement
Nested ifs
The if-else-if Ladder
The switch Statement
Nested switch Statements
Try This 3-1: Start Building a Java Help System
The for Loop
Some Variations on the for Loop
Missing Pieces
  The Infinite Loop
Loops with No Body
Declaring Loop Control Variables Inside the for Loop
The Enhanced for Loop
The while Loop
The do-while Loop
Try This 3-2: Improve the Java Help System
Use break to Exit a Loop
Use break as a Form of goto
Use continue
Try This 3-3: Finish the Java Help System
Nested Loops
Chapter 3 Self Test

4 Introducing Classes, Objects, and Methods
Class Fundamentals
   The General Form of a Class
   Defining a Class
How Objects Are Created
Reference Variables and Assignment
Methods
   Adding a Method to the Vehicle Class
Returning from a Method
Returning a Value
Using Parameters
   Adding a Parameterized Method to Vehicle
Try This 4-1: Creating a Help Class
Constructors
Parameterized Constructors
Adding a Constructor to the Vehicle Class
The new Operator Revisited
Garbage Collection
The finalize( ) Method
Try This 4-2: Demonstrate Garbage Collection and Finalization
The this Keyword
Chapter 4 Self Test

5 More Data Types and Operators
Arrays
   One-Dimensional Arrays
Try This 5-1: Sorting an Array
Multidimensional Arrays
   Two-Dimensional Arrays
Irregular Arrays
   Arrays of Three or More Dimensions
   Initializing Multidimensional Arrays
Alternative Array Declaration Syntax
Assigning Array References
Using the length Member
Try This 5-2: A Queue Class
The For-Each Style for Loop
   Iterating Over Multidimensional Arrays
Applying the Enhanced for Strings
Constructing Strings
Operating on Strings
Arrays of Strings
Strings Are Immutable
Using a String to Control a switch Statement
Using Command-Line Arguments
The Bitwise Operators
The Bitwise AND, OR, XOR, and NOT Operators
The Shift Operators
Bitwise Shorthand Assignments
Try This 5-3: A ShowBits Class
The ? Operator
Chapter 5 Self Test

6 A Closer Look at Methods and Classes
Controlling Access to Class Members
Java’s Access Modifiers
Try This 6-1: Improving the Queue Class
Pass Objects to Methods
How Arguments Are Passed
Returning Objects
Method Overloading
Overloading Constructors
Try This 6-2: Overloading the Queue Constructor
Recursion
Understanding static
Static Blocks
Try This 6-3: The Quicksort
Introducing Nested and Inner Classes
Varargs: Variable-Length Arguments
Varargs Basics
Overloading Varargs Methods
Varargs and Ambiguity
Chapter 6 Self Test

7 Inheritance
Inheritance Basics
Member Access and Inheritance
Constructors and Inheritance
Using super to Call Superclass Constructors
Using super to Access Superclass Members
Try This 7-1: Extending the Vehicle Class
Creating a Multilevel Hierarchy
8 Packages and Interfaces

Packages
  Defining a Package
  Finding Packages and CLASSPATH
  A Short Package Example

Packages and Member Access
  A Package Access Example

Understanding Protected Members

Importing Packages

Java’s Class Library Is Contained in Packages

Interfaces

Implementing Interfaces

Using Interface References

Try This 8-1: Creating a Queue Interface

Variables in Interfaces

Interfaces Can Be Extended

Default Interface Methods
  Default Method Fundamentals
  A More Practical Example of a Default Method

Multiple Inheritance Issues

Use static Methods in an Interface

Final Thoughts on Packages and Interfaces

Chapter 8 Self Test

9 Exception Handling

The Exception Hierarchy

Exception Handling Fundamentals
  Using try and catch
    A Simple Exception Example

The Consequences of an Uncaught Exception
  Exceptions Enable You to Handle Errors Gracefully
Using Multiple catch Statements
Catching Subclass Exceptions
Try Blocks Can Be Nested
Throwing an Exception
  Rethrowing an Exception
A Closer Look at Throwable
Using finally
Using throws
Three Recently Added Exception Features
Java’s Built-in Exceptions
Creating Exception Subclasses
Try This 9-1: Adding Exceptions to the Queue Class
Chapter 9 Self Test

10 Using I/O
Java’s I/O Is Built upon Streams
Byte Streams and Character Streams
The Byte Stream Classes
The Character Stream Classes
The Predefined Streams
Using the Byte Streams
  Reading Console Input
  Writing Console Output
Reading and Writing Files Using Byte Streams
  Inputting from a File
  Writing to a File
Automatically Closing a File
Reading and Writing Binary Data
Try This 10-1: A File Comparison Utility
Random-Access Files
Using Java’s Character-Based Streams
  Console Input Using Character Streams
  Console Output Using Character Streams
File I/O Using Character Streams
  Using a FileWriter
  Using a FileReader
Using Java’s Type Wrappers to Convert Numeric Strings
Try This 10-2: Creating a Disk-Based Help System
Chapter 10 Self Test

11 Multithreaded Programming
Multithreading Fundamentals
The Thread Class and Runnable Interface
Creating a Thread
  Some Simple Improvements
Try This 11-1: Extending Thread
Creating Multiple Threads
Determining When a Thread Ends
Thread Priorities
Synchronization
Using Synchronized Methods
The synchronized Statement
Thread Communication Using notify(), wait(), and notifyAll()
  An Example That Uses wait() and notify()
Suspending, Resuming, and Stopping Threads
Try This 11-2: Using the Main Thread
Chapter 11 Self Test

12  Enumerations, Autoboxing, Static Import, and Annotations
Enumerations
  Enumeration Fundamentals
Java Enumerations Are Class Types
The values() and valueOf() Methods
Constructors, Methods, Instance Variables, and Enumerations
  Two Important Restrictions
Enumerations Inherit Enum
Try This 12-1: A Computer-Controlled Traffic Light
Autoboxing
Type Wrappers
Autoboxing Fundamentals
Autoboxing and Methods
Autoboxing/Unboxing Occurs in Expressions
  A Word of Warning
Static Import
Annotations (Metadata)
Chapter 12 Self Test

13  Generics
Generics Fundamentals
A Simple Generics Example
  Generics Work Only with Reference Types
  Generic Types Differ Based on Their Type Arguments
  A Generic Class with Two Type Parameters
  The General Form of a Generic Class
Bounded Types
Using Wildcard Arguments
Bounded Wildcards
Generic Methods
Generic Constructors
Generic Interfaces
16 Introducing Swing
The Origins and Design Philosophy of Swing
Components and Containers
   Components
   Containers
   The Top-Level Container Panes
Layout Managers
A First Simple Swing Program
   The First Swing Example Line by Line
Use JButton
Work with JTextField
Create a JCheckBox
Work with JList
Try This 16-1: A Swing-Based File Comparison Utility
Use Anonymous Inner Classes or Lambda Expressions to Handle Events
Create a Swing Applet
Chapter 16 Self Test

17 Introducing JavaFX
JavaFX Basic Concepts
   The JavaFX Packages
   The Stage and Scene Classes
   Nodes and Scene Graphs
Layouts
   The Application Class and the Life-cycle Methods
Launching a JavaFX Application
A JavaFX Application Skeleton
Compiling and Running a JavaFX Program
The Application Thread
A Simple JavaFX Control: Label
Using Buttons and Events
  Event Basics
    Introducing the Button Control
    Demonstrating Event Handling and the Button
Three More JavaFX Controls
  CheckBox
Try This 17-1: Use the CheckBox Indeterminate State
  ListView
  TextField
Introducing Effects and Transforms
  Effects
  Transforms
    Demonstrating Effects and Transforms
What Next?
Chapter 17 Self Test

A Answers to Self Tests
  Chapter 1: Java Fundamentals
  Chapter 2: Introducing Data Types and Operators
  Chapter 3: Program Control Statements
  Chapter 4: Introducing Classes, Objects, and Methods
  Chapter 5: More Data Types and Operators
  Chapter 6: A Closer Look at Methods and Classes
  Chapter 7: Inheritance
  Chapter 8: Packages and Interfaces
  Chapter 9: Exception Handling
  Chapter 10: Using I/O
  Chapter 11: Multithreaded Programming
  Chapter 12: Enumerations, Autoboxing, Static Import, and Annotations
  Chapter 13: Generics
  Chapter 14: Lambda Expressions and Method References
  Chapter 15: Applets, Events, and Miscellaneous Topics
  Chapter 16: Introducing Swing
  Chapter 17: Introducing JavaFX

B Using Java’s Documentation Comments
  The javadoc Tags
    @author
    {@code}
    @deprecated
    {@docRoot}
    @exception
    {@inheritDoc}
    {@link}
    {@linkplain}
The General Form of a Documentation Comment
What javadoc Outputs
An Example That Uses Documentation Comments

Index
Introduction

The purpose of this book is to teach you the fundamentals of Java programming. It uses a step-by-step approach complete with numerous examples, self tests, and projects. It assumes no previous programming experience. The book starts with the basics, such as how to compile and run a Java program. It then discusses the keywords, features, and constructs that form the core of the Java language. You’ll also find coverage of some of Java’s most advanced features, including multithreaded programming and generics. An introduction to the fundamentals of Swing and JavaFX concludes the book. By the time you finish, you will have a firm grasp of the essentials of Java programming.

It is important to state at the outset that this book is just a starting point. Java is more than just the elements that define the language. Java also includes extensive libraries and tools that aid in the development of programs. To be a top-notch Java programmer implies mastery of these areas, too. After completing this book, you will have the knowledge to pursue any and all other aspects of Java.

The Evolution of Java

Only a few languages have fundamentally reshaped the very essence of programming. In this elite group, one stands out because its impact was both rapid and widespread. This language is, of course, Java. It is not an overstatement to say that the original release of Java 1.0 in 1995 by Sun Microsystems, Inc., caused a revolution in programming. This revolution radically transformed the Web into a highly interactive environment. In the process, Java set a new standard in computer language design.

Over the years, Java has continued to grow, evolve, and otherwise redefine itself. Unlike many other languages, which are slow to incorporate new features, Java has often been at the forefront of computer language development. One reason for this is the culture of innovation and change that came to surround Java. As a result, Java has gone through several upgrades—some relatively small, others more significant.

The first major update to Java was version 1.1. The features added by Java 1.1 were more substantial than the increase in the minor revision number would have you think. For example, Java 1.1 added many new library elements, redefined the way events are handled, and reconfigured many features of the original 1.0 library.

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, itself. 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.

The next upgrade of Java was J2SE 1.3. This version of Java 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. The release of J2SE 1.4 further enhanced Java. This release contained several important new features, including chained exceptions, channel-based I/O, and the assert
The release of J2SE 5 created nothing short of a second Java revolution. Unlike most of the previous Java upgrades, which offered important but incremental improvements, J2SE 5 fundamentally expanded the scope, power, and range of the language. To give you an idea of the magnitude of the changes caused by J2SE 5, here is a list of its major new features:

- Generics
- Autoboxing/unboxing
- Enumerations
- The enhanced “for-each” style `for` loop
- Variable-length arguments (varargs)
- Static import
- Annotations

This is not a list of minor tweaks or incremental upgrades. Each item in the list represents a significant addition to the Java language. Some, such as generics, the enhanced `for` loop, 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.

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 Java Development Kit (JDK) was called JDK 5. In order to maintain consistency, however, 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, and Sun once again decided to change the name of the Java platform. First, notice that the “2” has been dropped. Thus, the platform now had the name Java SE, and the official product name was Java Platform, Standard Edition 6, with the development kit being 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 run time. It also went through several updates during its long (in Java terms) life cycle, with several upgrades added along the way. In general, Java SE 6 served to further solidify the advances made by J2SE 5.

The next release of Java was called Java SE 7, with the development kit being called JDK 7. It has an internal version number of 1.7. Java SE 7 was the first major release of Java after Sun Microsystems was acquired by Oracle. Java SE 7 added several new features, including significant additions to the language and the API libraries. Some of the most important features added by Java SE 7 were those 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, including

- A `String` can control a `switch` statement.
- Binary integer literals.
- Underscores in numeric literals.
- An expanded `try` statement, called `try-with-resources`, that supports automatic resource management.
- 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` (multicatch) and better type checking for exceptions that are rethrown.

As you can see, even though the Project Coin features were considered to be small changes to the language, their benefits were much larger than the qualifier “small” would suggest. In particular, the `try-with-resources` statement profoundly affects the way that a substantial amount of code is written.

**Java SE 8**

The newest release of Java is Java SE 8, with the development 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. In the process, lambda expressions can simplify and reduce the amount of source code needed to create certain constructs. 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.

In addition to lambda expressions, JDK 8 adds many other important new features. For example, beginning with JDK 8, it is now possible to define a default implementation for a method specified by an interface. JDK 8 also bundles support for JavaFX, Java’s new GUI framework. JavaFX is expected to soon play an important part in nearly all Java applications, ultimately replacing Swing for most GUI-based projects. 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. The material in this book has been updated to reflect Java SE 8, with many new features, updates, and additions indicated throughout.

**How This Book Is Organized**

This book presents an evenly paced tutorial in which each section builds upon the previous one. It contains 17 chapters, each discussing an aspect of Java. This book is unique because it includes several special elements that reinforce what you are learning.

**Key Skills & Concepts**

Each chapter begins with a set of critical skills that you will be learning.

**Self Test**

Each chapter concludes with a Self Test that lets you test your knowledge. The answers are in Appendix A.
Ask the Expert
Sprinkled throughout the book are special “Ask the Expert” boxes. These contain additional information or interesting commentary about a topic. They use a Question/Answer format.

Try This Elements
Each chapter contains one or more Try This elements, which are projects that show you how to apply what you are learning. In many cases, these are real-world examples that you can use as starting points for your own programs.

No Previous Programming Experience Required
This book assumes no previous programming experience. Thus, if you have never programmed before, you can use this book. If you do have some previous programming experience, you will be able to advance a bit more quickly. Keep in mind, however, that Java differs in several key ways from other popular computer languages. It is important not to jump to conclusions. Thus, even for the experienced programmer, a careful reading is advised.

Required Software
To compile and run all of the programs in this book, you will need the latest Java Development Kit (JDK) from Oracle, which, at the time of this writing, is JDK 8. This is the JDK for Java SE 8. Instructions for obtaining the Java JDK are given in Chapter 1.

If you are using an earlier version of Java, you will still be able to use this book, but you won’t be able to compile and run the programs that use Java’s newer features.

Don’t Forget: Code on the Web
Remember, the source code for all of the examples and projects in this book is available free of charge on the Web at www.oraclepressbooks.com.

Special Thanks
Special thanks to Danny Coward, the technical editor for this edition of the book. Danny has worked on several of my books and his advice, insights, and suggestions have always been of great value and much appreciated.
For Further Study

*Java: A Beginner’s Guide* is your gateway to the Herb Schildt series of Java programming books. Here are some others that you will find of interest:

*Java: The Complete Reference*

*Herb Schildt’s Java Programming Cookbook*

*The Art of Java*

*Swing: A Beginner’s Guide*
Chapter 1
Java Fundamentals

Key Skills & Concepts

- Know the history and philosophy of Java
- Understand Java’s contribution to the Internet
- Understand the importance of bytecode
- Know the Java buzzwords
- Understand the foundational principles of object-oriented programming
- Create, compile, and run a simple Java program
- Use variables
- Use the if and for control statements
- Create blocks of code
- Understand how statements are positioned, indented, and terminated
- Know the Java keywords
- Understand the rules for Java identifiers

The rise of the Internet and the World Wide Web fundamentally reshaped computing. Prior to the Web, the cyber landscape was dominated by stand-alone PCs. Today, nearly all computers are
connected to the Internet. The Internet, itself, was transformed—originally offering a convenient way to share files and information. Today it is a vast, distributed computing universe. With these changes came a new way to program: Java.

Java is the preeminent language of the Internet, but it is more than that. Java revolutionized programming, changing the way that we think about both the form and the function of a program. To be a professional programmer today implies the ability to program in Java—it is that important. In the course of this book, you will learn the skills needed to master it.

The purpose of this chapter is to introduce you to Java, including its history, its design philosophy, and several of its most important features. By far, the hardest thing about learning a programming language is the fact that no element exists in isolation. Instead, the components of the language work in conjunction with each other. This interrelatedness is especially pronounced in Java. In fact, it is difficult to discuss one aspect of Java without involving others. To help overcome this problem, this chapter provides a brief overview of several Java features, including the general form of a Java program, some basic control structures, and operators. It does not go into too many details but, rather, concentrates on the general concepts common to any Java program.

The Origins of Java

Computer language innovation is driven forward by two factors: improvements in the art of programming and changes in the computing environment. Java is no exception. Building upon the rich legacy inherited from C and C++, Java adds refinements and features that reflect the current state of the art in programming. Responding to the rise of the online environment, Java offers features that streamline programming for a highly distributed architecture.

Java was conceived by James Gosling, Patrick Naughton, Chris Warth, Ed Frank, and Mike Sheridan at Sun Microsystems in 1991. This language was initially called “Oak” but was renamed “Java” in 1995. Somewhat surprisingly, the original impetus for Java was not the Internet! Instead, the primary motivation was the need for a platform-independent language that could be used to create software to be embedded in various consumer electronic devices, such as toasters, microwave ovens, and remote controls. As you can probably guess, many different types of CPUs are used as controllers. The trouble was that (at that time) most computer languages were designed to be compiled for a specific target. For example, consider C++.

Although it was possible to compile a C++ program for just about any type of CPU, to do so required a full C++ compiler targeted for that CPU. The problem, however, is that compilers are expensive and time-consuming to create. In an attempt to find a better solution, Gosling and others worked on a portable, cross-platform language that could 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 emerged 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 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. 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 many types of computers, operating systems, and CPUs.

What was once an irritating but a 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. This realization caused the focus of Java to switch from consumer electronics to Internet programming. So, while it was the desire for an architecture-neutral programming language that provided the initial spark, it was the Internet that ultimately led to Java’s large-scale success.

**How Java Relates to C and C++**

Java is directly related to both C and C++. Java inherits its syntax from C. Its object model is adapted from C++. Java’s relationship with C and C++ is important for several reasons. First, many programmers are familiar with the C/C++ syntax. This makes it easy for a C/C++ programmer to learn Java and, conversely, for a Java programmer to learn C/C++.

Second, Java’s designers did not “reinvent the wheel.” Instead, they further refined an already highly successful programming paradigm. The modern age of programming began with C. It moved to C++, and now to Java. By inheriting and building upon that rich heritage, Java provides a powerful, logically consistent programming environment that takes the best of the past and adds new features required by the online environment. Perhaps most important, because of their similarities, C, C++, and Java define a common, conceptual framework for the professional programmer. Programmers do not face major rifts when switching from one language to another.

One of the central design philosophies of both C and C++ is that the programmer is in charge! Java also inherits this philosophy. 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.

Java has one other attribute in common with C and C++: it 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. There is no better way to produce a top-flight professional programming language.

Because of the similarities between Java and C++, especially their support for object-oriented programming, it is tempting to think of Java as simply the “Internet version of C++.” However, to do so would be a mistake. Java has significant practical and philosophical differences. Although Java was influenced by C++, it is not an enhanced version of C++. For example, it is neither upwardly nor downwardly compatible with C++. Of course, the similarities with C++ are significant, and if you are a C++ programmer, you will feel right at home with Java. Another 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. They will coexist for many years to come.

**How Java Relates to C#**

A few years after the creation of Java, Microsoft developed the C# language. This is important because C# is closely related to Java. In fact, many of C#’s features directly parallel Java. Both Java and C# share the same general C++-style 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 means that if you already know C#, then learning Java will be especially easy. Conversely, if C# is in your future, then your knowledge of Java will come in handy.

Given the similarity between Java and C#, one might naturally ask, “Will C# replace Java?” The answer is No. Java and C# are optimized for two different types of computing environments. Just as C++ and Java will coexist for a long time to come, so will C# and Java.

Java’s Contribution to 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 that 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 safely downloaded and executed on the client computer, 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 is considered by many to be 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 different 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 in 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 run-time 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 because many modern languages are designed to be compiled into executable code due to 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. Safety is also enhanced by certain restrictions that exist in the Java language.

When a program is interpreted, it generally runs slower than the same program 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.

Ask the Expert

Q: I have heard about a special type of Java program called a servlet. What is it?

A: A servlet is a small program that executes on a server. Just as applets dynamically extend the functionality of a web browser, servlets dynamically extend the functionality of a web server. It is helpful to understand that 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. Thus, with the advent of the servlet, Java spanned both sides of the client/server connection. Although the creation of servlets is beyond the scope of this beginner’s guide, they are something that you will want to study further as you advance in Java programming. (Coverage of servlets can be found in my book Java: The Complete Reference, published by Oracle Press/McGraw-Hill Education.)

The Java Buzzwords

No overview of Java 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 played an important role in molding the final form of the language. The key considerations were summed up by the Java design team in the following list of buzzwords.

<table>
<thead>
<tr>
<th>Simple</th>
<th>Java has a concise, cohesive set of features that makes it easy to learn and use.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Secure</td>
<td>Java provides a secure means of creating Internet applications.</td>
</tr>
<tr>
<td>Portable</td>
<td>Java programs can execute in any environment for which there is a Java run-time system.</td>
</tr>
<tr>
<td>Object-oriented</td>
<td>Java embodies the modern, object-oriented programming philosophy.</td>
</tr>
<tr>
<td>Robust</td>
<td>Java encourages error-free programming by being strictly typed and performing run-time checks.</td>
</tr>
<tr>
<td>Multithreaded</td>
<td>Java provides integrated support for multithreaded programming.</td>
</tr>
<tr>
<td>Architecture-neutral</td>
<td>Java is not tied to a specific machine or operating system architecture.</td>
</tr>
</tbody>
</table>
Java supports cross-platform code through the use of Java bytecode.

High performance

The Java bytecode is highly optimized for speed of execution.

Distributed

Java was designed with the distributed environment of the Internet in mind.

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.

---

**Ask the Expert**

**Q:** To address the issues of portability and security, why was it necessary to create a new computer language such as Java; couldn’t a language like C++ be adapted? In other words, couldn’t a C++ compiler that outputs bytecode be created?

**A:** While it would be possible for a C++ compiler to generate something similar to bytecode rather than executable code, C++ has features that discourage its use for the creation of Internet programs—the most important feature being C++’s support for pointers. A pointer is the address of some object stored in memory. Using a pointer, it would be possible to access resources outside the program itself, resulting in a security breach. Java does not support pointers, thus eliminating this problem.

---

**Object-Oriented Programming**

At the center of Java is object-oriented programming (OOP). The object-oriented methodology is inseparable from Java, and all Java programs are, to at least some extent, object-oriented. Because of OOP’s importance to Java, it is useful to understand in a general way OOP’s basic principles before you write even a simple Java program. Later in this book, you will see how to put these concepts into practice.

OOP is a powerful way to approach the job of programming. Programming methodologies have changed dramatically since the invention of the computer, primarily to accommodate the increasing complexity of programs. For example, when computers were first invented, programming was done by toggling in the binary machine instructions using the computer’s 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, 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. Although FORTRAN was a very impressive first step, it is hardly a language that encourages clear, easy-to-understand programs.

The 1960s gave birth to structured programming. This is the method encouraged by languages such as C and Pascal. The use of structured languages made it possible to write moderately complex programs fairly easily. Structured languages are characterized by their support for stand-alone subroutines, local variables, rich control constructs, and their lack of reliance upon the GOTO.
Although structured languages are a powerful tool, even they reach their limit when a project becomes too large.

Consider this: At each milestone in the development of programming, techniques and tools were created to allow the programmer to deal with increasingly greater complexity. Each step of the way, the new approach took the best elements of the previous methods and moved forward. Prior to the invention of OOP, many projects were nearing (or exceeding) the point where the structured approach no longer works. Object-oriented methods were created to help programmers break through these barriers.

Object-oriented programming took the best ideas of structured programming and combined them with several new concepts. The result was a different way of organizing a program. In the most general sense, a program can be organized in one of two ways: around its code (what is happening) or around its data (what is being affected). Using only structured programming techniques, programs are typically organized around code. This approach can be thought of as “code acting on data.”

Object-oriented programs work the other way around. They are organized around data, with the key principle being “data controlling access to code.” In an object-oriented language, you define the data and the routines that are permitted to act on that data. Thus, a data type defines precisely what sort of operations can be applied to that data.

To support the principles of object-oriented programming, all OOP languages, including Java, have three traits in common: encapsulation, polymorphism, and inheritance. Let’s examine each.

Encapsulation
Encapsulation is a programming mechanism that binds together code and the data it manipulates, and that keeps both safe from outside interference and misuse. In an object-oriented language, code and data can be bound together in such a way that a self-contained black box is created. Within the box are all necessary data and code. When code and data are linked together in this fashion, an object is created. In other words, an object is the device that supports encapsulation.

Within an object, code, data, or both may be private to that object or public. Private code or data is known to and accessible by only another part of the object. That is, private code or data cannot be accessed by a piece of the program that exists outside the object. When code or data is public, other parts of your program can access it even though it is defined within an object. Typically, the public parts of an object are used to provide a controlled interface to the private elements of the object.

Java’s basic unit 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 form of an object. It specifies both the data and the code that will operate on that data. Java uses a class specification to construct objects. Objects are instances of a class. Thus, a class is essentially a set of plans that specify how to build an object.

The code and data that constitute a class 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. Method is Java’s term for a subroutine. 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.

Polymorphism
Polymorphism (from Greek, meaning “many forms”) is the quality that allows one interface to access
A general class of actions. The specific action is determined by the exact nature of the situation. A simple example of polymorphism is found in the steering wheel of an automobile. The steering wheel (i.e., the interface) is the same no matter what type of actual steering mechanism is used. That is, the steering wheel works the same whether your car has manual steering, power steering, or rack-and-pinion steering. Therefore, once you know how to operate the steering wheel, you can drive any type of car.

The same principle can also apply to programming. For example, consider a stack (which is a first-in, last-out list). You might have a program that requires three different types of stacks. One stack is used for integer values, one for floating-point values, and one for characters. In this case, 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 create one general set of stack routines that works for all three specific situations. This way, once you know how to use one stack, you can use them all.

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. Polymorphism 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 (i.e., method) as it applies to each situation. You, the programmer, don’t need to do this selection manually. You need only remember and utilize the general interface.

**Inheritance**

Inheritance is the process by which one object can acquire the properties of another object. This is important because it supports the concept of hierarchical classification. If you think about it, most knowledge is made manageable by hierarchical (i.e., top-down) classifications. For example, a Red Delicious apple is part of the classification apple, which in turn is part of the fruit class, which is under the larger class food. That is, the food class possesses certain qualities (edible, nutritious, etc.) which also, logically, apply to its subclass, fruit. In addition to these qualities, the fruit class has specific characteristics (juicy, sweet, etc.) that distinguish it from other food. The apple class defines those qualities specific to an apple (grows on trees, not tropical, etc.). A Red Delicious apple would, in turn, inherit all the qualities of all preceding classes, and would define only those qualities that make it unique.

Without the use of hierarchies, each object would have to explicitly define all of its characteristics. Using 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.

**Obtaining the Java Development Kit**

Now that the theoretical underpinning of Java has been explained, it is time to start writing Java programs. Before you can compile and run those programs, however, you must have the Java Development Kit (JDK) installed on your computer. The JDK is available free of charge from Oracle. At the time of this writing, the current release of the JDK is JDK 8. This is the version used by Java SE 8. (SE stands for Standard Edition.) Because JDK 8 contains many new features that are not supported by earlier versions of Java, it is recommended that you use JDK 8 (or later) to compile
and run the programs in this book. If you use an earlier version, then programs containing new features will not compile.

The JDK can be downloaded from www.oracle.com/technetwork/java/javase/downloads/index.html. Just go to the download page and follow the instructions for the type of computer that you have. After you have installed the JDK, you will be able to compile and run programs. The JDK supplies two primary programs. The first is javac, which is the Java compiler. The second is java, which is the standard Java interpreter and is also referred to as the application launcher.

One other point: The JDK runs in the command prompt environment and uses command-line tools. It is not a windowed application. It is also not an integrated development environment (IDE).

NOTE

In addition to the basic command-line tools supplied with the JDK, there are several high-quality IDEs available for Java, such as NetBeans and Eclipse. An IDE can be very helpful when developing and deploying commercial applications. As a general rule, you can also use an IDE to compile and run the programs in this book if you so choose. However, the instructions presented in this book for compiling and running a Java program describe only the JDK command-line tools. The reasons for this are easy to understand. First, the JDK is readily available to all readers. Second, the instructions for using the JDK will be the same for all readers. Furthermore, for the simple programs presented in this book, using the JDK command-line tools is usually the easiest approach. If you are using an IDE, you will need to follow its instructions. Because of differences between IDEs, no general set of instructions can be given.

Ask the Expert

Q: You state that object-oriented programming is an effective way to manage large programs. However, it seems that it might add substantial overhead to relatively small ones. Since you say that all Java programs are, to some extent, object-oriented, does this impose a penalty for smaller programs?

A: No. As you will see, for small programs, Java’s object-oriented features are nearly transparent. Although it is true that Java follows a strict object model, you have wide latitude as to the degree to which you employ it. For smaller programs, their “object-orientedness” is barely perceptible. As your programs grow, you will integrate more object-oriented features effortlessly.

A First Simple Program

Let’s start by compiling and running the short sample program shown here:
You will follow these three steps:

1. Enter the program.
2. Compile the program.
3. Run the program.

**Entering the Program**
The programs shown in this book are available from McGraw-Hill Education’s website: [www.oraclepressbooks.com](http://www.oraclepressbooks.com). However, if you want to enter the programs by hand, you are free to do so. In this case, you must enter the program into your computer using a text editor, not a word processor. Word processors typically store format information along with text. This format information will confuse the Java compiler. If you are using a Windows platform, you can use WordPad or any other programming editor that you like.

For most computer languages, the name of the file that holds the source code to a program is arbitrary. 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:

```
javac Example.java
```
The `javac` compiler creates a file called `Example.class` that contains the bytecode version of the program. Remember, bytecode is not executable code. Bytecode must be executed by a Java Virtual Machine. Thus, the output of `javac` is not code that can be directly executed.

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

```
java Example
```

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

```
Java drives the Web.
```

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 the Java interpreter as just shown, you are actually specifying the name of the class that you want the interpreter 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.

**NOTE**

If, when you try to compile the program, the computer cannot find `javac` (and assuming that you have installed the JDK correctly), you may need to specify the path to the command-line tools. In Windows, for example, this means that you will need to add the path to the command-line tools to the paths defined for the `PATH` environmental variable. For example, if JDK 8 was installed under the Program Files directory, then the path to the command-line tools will be similar to `C:\Program Files\Java\jdk1.8.0\bin`. (Of course, you will need to find the path to Java on your computer, which may differ from the one just shown. Also the specific version of the JDK may differ.) You will need to consult the documentation for your operating system on how to set the path, because this procedure differs between OSes.

**The First Sample Program Line by Line**

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:

```
/*
   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:

class Example {

This line uses the keyword class to declare that a new class is being defined. As mentioned, the class is Java’s basic unit of encapsulation. Example is the name of the class. The class definition begins with the opening curly brace ({) and ends with the closing curly brace (}). The elements between the two braces are members of the class. 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 in the program is the *single-line comment*, shown here:

// A Java 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 next line of code is shown here:

public static void main (String args[]) {

This line begins the main() method. As mentioned earlier, in Java, a subroutine is called a 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 exact meaning of each part of this line cannot be given now, since it involves a detailed understanding of several other of Java’s features. However, since many of the examples in 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*. An access modifier determines how other parts of the program can access the members of the class. When a class member is preceded by public, then that member can 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 before an object of the class has been created. This is necessary because main() is called by the JVM 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. 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 no parameters are required for a given method, you still need to include the empty parentheses. In `main()` there is only one parameter, `String args[ ]`, which declares a parameter named `args`. This is an array of objects of type `String`. (Arrays are collections of similar objects.) Objects of type `String` store sequences of characters. 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 included in a method will occur between the method’s opening curly brace and its closing curly brace.

The next line of code is shown here. Notice that it occurs inside `main()`.

```
System.out.println("Java drives the Web.");
```

This line outputs the string "Java drives the Web." 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 that 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. Thus, `System.out` is an object that encapsulates console output. The fact that Java uses an object to define console output is further evidence of its object-oriented nature.

As you have probably guessed, console output (and input) is not used frequently in 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, for demonstration programs, and for 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.

One last point: Java is case sensitive. Forgetting this can cause you serious problems. For example, if you accidentally type `Main` instead of `main`, or `PrintLn` instead of `println`, the preceding program will be incorrect. Furthermore, although the Java compiler will compile classes that do not contain a `main()` method, it has no way to execute them. So, if you had mistyped `main`, the compiler would still compile your program. However, the Java interpreter would report an error because it would be unable to find the `main()` method.

### Handling Syntax Errors

If you have not yet done so, enter, compile, and run the preceding program. As you may know from your previous programming experience, it is quite easy to accidentally type something incorrectly when entering code into your computer. Fortunately, if you enter something incorrectly into your program, the compiler will report a *syntax error* message when it tries to compile it. The Java compiler attempts to make sense out of your source code no matter what you have written. For this reason, the error that is reported may not always reflect the actual cause of the problem. In the preceding program, for example, an accidental omission of the opening curly brace after the `main()`
method causes the compiler to report the following two errors:

```
Example.java:8: ';' expected
   public static void main(String args[])
Example.java:11: class, interface, or enum expected
```

Clearly, the first error message is completely wrong because what is missing is not a semicolon, but a curly brace.

The point of this discussion is that when your program contains a syntax error, you shouldn’t necessarily take the compiler’s messages at face value. The messages may be misleading. You may need to “second-guess” an error message in order to find the real problem. Also, look at the last few lines of code in your program that precede the line being flagged. Sometimes an error will not be reported until several lines after the point at which the error actually occurred.

A Second Simple Program

Perhaps no other construct is as important to a programming language as the assignment of a value to a variable. A variable is a named memory location that can be assigned a value. Further, the value of a variable can be changed during the execution of a program. That is, the content of a variable is changeable, not fixed. The following program creates two variables called `var1` and `var2`:

```java
class Example2 {
   public static void main(String args[]) {
      int var1; // this declares a variable
      int var2; // this declares another variable
      var1 = 1024; // this assigns 1024 to var1
      System.out.println("var1 contains " + var1);
      var2 = var1 / 2;
      System.out.print("var2 contains var1 / 2: ");
      System.out.println(var2);
   }
}
```

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

```
var1 contains 1024
var2 contains var1 / 2: 512
```

This program introduces several new concepts. First, the statement
int var1; // this declares a variable called var1 of type integer. In Java, all variables must be declared before they are used. Further, the type of values that the variable can hold must also be specified. This is called the type of the variable. In this case, var1 can hold integer values. These are whole number values. In Java, to declare a variable to be of type integer, precede its name with the keyword int. Thus, the preceding statement declares a variable called var1 of type int.

The next line declares a second variable called var2:

int var2; // this declares another variable

Notice that this line uses the same format as the first line except that the name of the variable is different.

In general, to declare a variable you will use a statement like this:

```java
type var-name;
```

Here, type specifies the type of variable being declared, and var-name is the name of the variable. In addition to int, Java supports several other data types.

The following line of code assigns var1 the value 1024:

```java
var1 = 1024; // this assigns 1024 to var1
```

In Java, the assignment operator is the single equal sign. It copies the value on its right side into the variable on its left.

The next line of code outputs the value of var1 preceded by the string "var1 contains ":

```java
System.out.println("var1 contains " + var1);
```

In this statement, the plus sign causes the value of var1 to be displayed after the string that precedes it. This approach can be generalized. Using the + operator, you can chain together as many items as you want within a single println( ) statement.

The next line of code assigns var2 the value of var1 divided by 2:

```java
var2 = var1 / 2;
```

This line divides the value in var1 by 2 and then stores that result in var2. Thus, after the line executes, var2 will contain the value 512. The value of var1 will be unchanged. Like most other computer languages, Java supports a full range of arithmetic operators, including those shown here:

```
+ Addition
- Subtraction
* Multiplication
/ Division
```

Here are the next two lines in the program:
Two new things are occurring here. First, the built-in method `print()` is used to display the string "var2 contains var1 / 2: ". This string is not followed by a new line. 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 new line after each call. Second, in the call to `println()`, notice that `var2` is used by itself. Both `print()` and `println()` can be used to output values of any of Java’s built-in types.

One more point about declaring variables before we move on: It is possible to declare two or more variables using the same declaration statement. Just separate their names by commas. For example, `var1` and `var2` could have been declared like this:

```java
int var1, var2; // both declared using one statement
```

### Another Data Type

In the preceding program, a variable of type `int` was used. However, a variable of type `int` can hold only whole numbers. Thus, it cannot be used when a fractional component is required. For example, an `int` variable can hold the value 18, but not the value 18.3. Fortunately, `int` is only one of several data types defined by Java. To allow numbers with fractional components, Java defines two floating-point types: `float` and `double`, which represent single- and double-precision values, respectively. Of the two, `double` is the most commonly used.

To declare a variable of type `double`, use a statement similar to that shown here:

```java
double x;
```

Here, `x` is the name of the variable, which is of type `double`. Because `x` has a floating-point type, it can hold values such as 122.23, 0.034, or –19.0.

To better understand the difference between `int` and `double`, try the following program:
The output from this program is shown here:

Original value of var: 10
Original value of x: 10.0

var after division: 2 ← Fractional component lost
x after division: 2.5 ← Fractional component preserved

As you can see, when var is divided by 4, a whole-number division is performed, and the outcome is 2—the fractional component is lost. However, when x is divided by 4, the fractional component is preserved, and the proper answer is displayed.

There is one other new thing to notice in the program. To print a blank line, simply call println( ) without any arguments.

Ask the Expert

Q: Why does Java have different data types for integers and floating-point values? That is, why aren’t all numeric values just the same type?

A: Java supplies different data types so that you can write efficient programs. For example, integer arithmetic is faster than floating-point calculations. Thus, if you don’t need fractional values, then you don’t need to incur the overhead associated with types float or double. Second, the amount of memory required for one type of data might be less than that required for another. By
supplying different types, Java enables you to make best use of system resources. Finally, some algorithms require (or at least benefit from) the use of a specific type of data. In general, Java supplies a number of built-in types to give you the greatest flexibility.

Try This 1-1  Converting Gallons to Liters

Although the preceding sample programs illustrate several important features of the Java language, they are not very useful. Even though you do not know much about Java at this point, you can still put what you have learned to work to create a practical program. In this project, we will create a program that converts gallons to liters. The program will work by declaring two double variables. One will hold the number of the gallons, and the second will hold the number of liters after the conversion. There are 3.7854 liters in a gallon. Thus, to convert gallons to liters, the gallon value is multiplied by 3.7854. The program displays both the number of gallons and the equivalent number of liters.

1. Create a new file called GalToLit.java.
2. Enter the following program into the file:

```java
/*
   Try This 1-1
   This program converts gallons to liters.
   Call this program GalToLit.java.
*/

class GalToLit {
    public static void main(String args[]) {
        double gallons; // holds the number of gallons
        double liters; // holds conversion to liters

        gallons = 10; // start with 10 gallons
        liters = gallons * 3.7854; // convert to liters

        System.out.println(gallons + " gallons is " + liters + " liters.");
    }
}
```

3. Compile the program using the following command line:

    javac GalToLit.java

4. Run the program using this command:

    java GalToLit

You will see this output:

    10.0 gallons is 37.854 liters.
5. As it stands, this program converts 10 gallons to liters. However, by changing the value assigned to **gallons**, you can have the program convert a different number of gallons into its equivalent number of liters.

## Two Control Statements

Inside a method, execution proceeds from one statement to the next, top to bottom. However, it is possible to alter this flow through the use of the various program control statements supported by Java. Although we will look closely at control statements later, two are briefly introduced here because we will be using them to write sample programs.

### The if Statement

You can selectively execute part of a program through the use of Java’s conditional statement: the **if**. The Java **if** statement works much like the IF statement in any other language. 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(10 < 11) System.out.println("10 is less than 11");
```

In this case, since 10 is less than 11, the conditional expression is true, and **println( )** will execute. However, consider the following:

```
if(10 < 9) System.out.println("this won't be displayed");
```

In this case, 10 is not less than 9. Thus, the call to **println( )** will not take place.

Java defines a full complement of relational operators that may be used in a conditional expression. They are shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;</td>
<td>Less than</td>
</tr>
<tr>
<td>&lt;=</td>
<td>Less than or equal</td>
</tr>
<tr>
<td>&gt;</td>
<td>Greater than</td>
</tr>
<tr>
<td>&gt;=</td>
<td>Greater than or equal</td>
</tr>
<tr>
<td>==</td>
<td>Equal to</td>
</tr>
<tr>
<td>!=</td>
<td>Not equal</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
int gallons = 10;
if(gallons < 10) {
    System.out.println("Less than 10 gallons");
} else {
    System.out.println("10 gallons or more");
}
```
Demonstrate the if.

Call this file IfDemo.java.

```java
class IfDemo {
    public static void main(String args[]) {
        int a, b, c;

        a = 2;
        b = 3;

        if(a < b) System.out.println("a is less than b");

        // this won't display anything
        if(a == b) System.out.println("you won't see this");

        System.out.println();

        c = a - b; // c contains -1

        System.out.println("c contains -1");
        if(c >= 0) System.out.println("c is non-negative");
        if(c < 0) System.out.println("c is negative");

        System.out.println();

        c = b - a; // c now contains 1

        System.out.println("c contains 1");
        if(c >= 0) System.out.println("c is non-negative");
        if(c < 0) System.out.println("c is negative");
    }
}
```

The output generated by this program is shown here:

```
a is less than b

c contains -1
c is negative

c contains 1
c is non-negative
```

Notice one other thing in this program. The line

```java
int a, b, c;
```
declares three variables, \texttt{a}, \texttt{b}, and \texttt{c}, by use of a comma-separated list. As mentioned earlier, when you need two or more variables of the same type, they can be declared in one statement. Just separate the variable names by commas.

The for Loop

You can repeatedly execute a sequence of code by creating a loop. Java supplies a powerful assortment of loop constructs. The one we will look at here is the \texttt{for} loop. The simplest form of the \texttt{for} loop is shown here:

\begin{verbatim}
for(initialization; condition; iteration) statement;
\end{verbatim}

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

Here is a short program that illustrates the \texttt{for} loop:

\begin{verbatim}
public class ForDemo {
    public static void main(String args[]) {
        int count;
        for(count = 0; count < 5; count = count + 1) \-- This loop iterates five times.
            System.out.println("This is count: " + count);
        System.out.println("Done!");
    }
}
\end{verbatim}

The output generated by the program is shown here:

\begin{verbatim}
This is count: 0
This is count: 1
This is count: 2
This is count: 3
This is count: 4
Done!
\end{verbatim}

In this example, \texttt{count} is the loop control variable. It is set to zero in the initialization portion of the \texttt{for}. At the start of each iteration (including the first one), the conditional test \texttt{count < 5} 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 \texttt{count} by 1. This process continues until the conditional test is false, at which point execution picks up at the bottom of the loop. 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:
The reason is that Java includes a special increment operator that performs this operation more efficiently. The increment operator is `++` (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:

```java
count++;
```

Thus, the `for` in the preceding program will usually be written like this:

```java
for(count = 0; count < 5; count++)
```

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 `--`. This operator decreases its operand by one.

---

**Create Blocks of Code**

Another key element of Java is the *code block*. A code block is a grouping of two or more statements. 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(w < h) {
    v = w * h;
    w = 0;
}
```

Here, if `w` is less than `h`, 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. Code blocks allow many algorithms to be implemented with greater clarity and efficiency.

Here is a program that uses a block of code to prevent a division by zero:
The output generated by this program is shown here:

```
i does not equal zero
j / i is 2.0
```

In this case, the target of the `if` statement is a block of code and not just a single statement. If the condition controlling the `if` is true (as it is in this case), the three statements inside the block will be executed. Try setting `i` to zero and observe the result. You will see that the entire block is skipped.

---

**Ask the Expert**

**Q:** Does the use of a code block introduce any run-time inefficiencies? In other words, does Java actually execute the `{ and `}?  

**A:** No. Code blocks do not add any overhead whatsoever. In fact, because of their ability to simplify the coding of certain algorithms, their use generally increases speed and efficiency. Also, the `{ and `} exist only in your program’s source code. Java does not, per se, execute the `{ or `}.

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.

---

**Semicolons and Positioning**

In Java, the semicolon is a separator that is used to terminate a statement. That is, each individual statement must be ended with a semicolon. It indicates the end of one logical entity.

As you know, a block is a set of logically connected statements that are surrounded by opening and
closing braces. A block is not terminated with a semicolon. Since a block is a group of statements, with a semicolon after each statement, it makes sense that a block is not terminated by a semicolon; instead, the end of the block is indicated by the closing brace.

Java does not recognize the end of the line as a terminator. For this reason, it does not matter where on a line you put a statement. For example,

```java
x = y;
y = y + 1;
System.out.println(x + " " + y);
```

is the same as the following, to Java:

```java
x = y; y = y + 1; System.out.println(x + " " + y);
```

Furthermore, the individual elements of a statement can also be put on separate lines. For example, the following is perfectly acceptable:

```java
System.out.println("This is a long line of output" + x + y + z + 
"more output");
```

Breaking long lines in this fashion is often used to make programs more readable. It can also help prevent excessively long lines from wrapping.

**Indentation Practices**

You may have noticed in the previous examples that certain statements were indented. Java is a free-form language, meaning that it does not matter where you place statements relative to each other on a line. However, over the years, a common and accepted indentation style has developed that allows for very readable programs. This book follows that style, and it is recommended that you do so as well. Using this style, you indent one level after each opening brace, and move back out one level after each closing brace. Certain statements encourage some additional indenting; these will be covered later.

**Try This 1-2 Improving the Gallons-to-Liters Converter**

You can use the `for` loop, the `if` statement, and code blocks to create an improved version of the gallons-to-liters converter that you developed in the first project. This new version will print a table of conversions, beginning with 1 gallon and ending at 100 gallons. After every 10 gallons, a blank line will be output. This is accomplished through the use of a variable called `counter` that counts the number of lines that have been output. Pay special attention to its use.

1. Create a new file called `GalToLitTable.java`.

```java
GalToLitTable.java
```

You can use the `for` loop, the `if` statement, and code blocks to create an improved version of the gallons-to-liters converter that you developed in the first project. This new version will print a table of conversions, beginning with 1 gallon and ending at 100 gallons. After every 10 gallons, a blank line will be output. This is accomplished through the use of a variable called `counter` that counts the number of lines that have been output. Pay special attention to its use.

1. Create a new file called `GalToLitTable.java`.
2. Enter the following program into the file:

```java
/*
 Try This 1-2

This program displays a conversion
table of gallons to liters.

Call this program "GalToLitTable.java".
*/
class GalToLitTable {
    public static void main(String args[]) {
        double gallons, liters;
        int counter;

        counter = 0;  // Line counter is initially set to zero.
        for(gallons = 1; gallons <= 100; gallons++) {
            liters = gallons * 3.7854; // convert to liters
            System.out.println(gallons + " gallons is " +
                                liters + " liters.");

            counter++;  // Increment the line counter
            // every 10th line, print a blank line
            if(counter == 10) {
                System.out.println();
                counter = 0;  // reset the line counter
            }
        }
    }
}
```

3. Compile the program using the following command line:

```
javac GalToLitTable.java
```

4. Run the program using this command:

```
java GalToLitTable
```

Here is a portion of the output that you will see:
The Java Keywords

Fifty keywords are currently defined in the Java language (see Table 1-1). These keywords, combined with the syntax of the operators and separators, form the definition of the Java language. These keywords cannot be used as names for a variable, class, or method.
Table 1-1   The Java Keywords

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 1-1.

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.

**Identifiers in Java**

In Java an identifier is a name given to a method, a variable, or any other user-defined item. Identifiers can be from one to several characters long. Variable names may start with any letter of the alphabet, an underscore, or a dollar sign. Next may be either a letter, a digit, a dollar sign, or an underscore. The underscore can be used to enhance the readability of a variable name, as in `line_count`. Uppercase and lowercase are different; that is, to Java, `myvar` and `MyVar` are separate names. Here are some examples of acceptable identifiers:

<table>
<thead>
<tr>
<th>Test</th>
<th>x</th>
<th>y2</th>
<th>MaxLoad</th>
</tr>
</thead>
<tbody>
<tr>
<td>$up</td>
<td>_top</td>
<td>my_var</td>
<td>sample23</td>
</tr>
</tbody>
</table>

Remember, you can’t start an identifier with a digit. Thus, **12x** is invalid, for example.

You cannot use any of the Java keywords as identifier names. Also, you should not use the name of any standard method, such as **println**, as an identifier. Beyond these two restrictions, good programming practice dictates that you use identifier names that reflect the meaning or usage of the items being named.

**The Java Class Libraries**

The sample programs shown in this chapter make use of two of Java’s built-in methods: **println**() and **print**(). These methods are accessed 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 this book, various elements of the standard library classes and methods are described. However, the Java library is something that you will also want to explore more on your own.

Chapter 1 Self Test

1. What is bytecode and why is it important to Java’s use for Internet programming?
2. What are the three main principles of object-oriented programming?
3. Where do Java programs begin execution?
4. What is a variable?
5. Which of the following variable names is invalid?
   A. count
   B. $count
   C. count27
   D. 67count
6. How do you create a single-line comment? How do you create a multiline comment?
7. Show the general form of the if statement. Show the general form of the for loop.
8. How do you create a block of code?
9. The moon’s gravity is about 17 percent that of earth’s. Write a program that computes your effective weight on the moon.
10. Adapt Try This 1-2 so that it prints a conversion table of inches to meters. Display 12 feet of conversions, inch by inch. Output a blank line every 12 inches. (One meter equals approximately 39.37 inches.)
11. If you make a typing mistake when entering your program, what sort of error will result?
12. Does it matter where on a line you put a statement?
Chapter 2
Introducing Data Types and Operators

Key Skills & Concepts
- Know Java’s primitive types
- Use literals
- Initialize variables
- Know the scope rules of variables within a method
- Use the arithmetic operators
- Use the relational and logical operators
- Understand the assignment operators
- Use shorthand assignments
- Understand type conversion in assignments
- Cast incompatible types
- Understand type conversion in expressions

At the foundation of any programming language are its data types and operators, and Java is no exception. These elements define the limits of a language and determine the kind of tasks to which it can be applied. Fortunately, Java supports a rich assortment of both data types and operators, making it suitable for any type of programming.
Data types and operators are a large subject. We will begin here with an examination of Java’s foundational data types and its most commonly used operators. We will also take a closer look at variables and examine the expression.

Why Data Types Are Important
Data types are especially important in Java because it is a strongly typed language. This means that all operations are type-checked by the compiler for type compatibility. Illegal operations will not be compiled. Thus, strong type checking helps prevent errors and enhances reliability. To enable strong type checking, all variables, expressions, and values have a type. There is no concept of a “type-less” variable, for example. Furthermore, the type of a value determines what operations are allowed on it. An operation allowed on one type might not be allowed on another.

Java’s Primitive Types
Java contains two general categories of built-in data types: object-oriented and non-object-oriented. Java’s object-oriented types are defined by classes, and a discussion of classes is deferred until later. However, at the core of Java are eight primitive (also called elemental or simple) types of data, which are shown in Table 2-1. The term primitive is used here to indicate that these types are not objects in an object-oriented sense, but rather, normal binary values. These primitive types are not objects because of efficiency concerns. All of Java’s other data types are constructed from these primitive types.

<table>
<thead>
<tr>
<th>Type</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean</td>
<td>Represents true/false values</td>
</tr>
<tr>
<td>byte</td>
<td>8-bit integer</td>
</tr>
<tr>
<td>char</td>
<td>Character</td>
</tr>
<tr>
<td>double</td>
<td>Double-precision floating point</td>
</tr>
<tr>
<td>float</td>
<td>Single-precision floating point</td>
</tr>
<tr>
<td>int</td>
<td>Integer</td>
</tr>
<tr>
<td>long</td>
<td>Long integer</td>
</tr>
<tr>
<td>short</td>
<td>Short integer</td>
</tr>
</tbody>
</table>

Table 2-1 Java’s Built-in Primitive Data Types

Java strictly specifies a range and behavior for each primitive type, which all implementations of the Java Virtual Machine must support. Because of Java’s portability requirement, Java is uncompromising on this account. For example, an int is the same in all execution environments. This allows programs to be fully portable. There is no need to rewrite code to fit a specific platform. Although strictly specifying the range of the primitive types may cause a small loss of performance in some environments, it is necessary in order to achieve portability.

Integers
Java defines four integer types: byte, short, int, and long, which are shown here:
As the table shows, all of the integer types 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.

**NOTE**
Technically, the Java run-time system can use any size it wants to store a primitive type. However, in all cases, types must act as specified.

The most commonly used integer type is `int`. Variables of type `int` are often employed to control loops, to index arrays, and to perform general-purpose integer math.

When you need an integer that has a range greater than `int`, use `long`. For example, here is a program that computes the number of cubic inches contained in a cube that is one mile by one mile, by one mile:

```java
/*
   Compute the number of cubic inches
in 1 cubic mile.
*/
class Inches {
    public static void main(String args[]) {
        long ci;
        long im;

        im = 5280 * 12;
        ci = im * im * im;

        System.out.println("There are "+ ci +
                        " cubic inches in cubic mile.");
    }
}
```

Here is the output from the program:

```
There are 254358061056000 cubic inches in cubic mile.
```

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

The smallest integer type is `byte`. Variables of type `byte` are especially useful when working with raw binary data that may not be directly compatible with Java’s other built-in types. The `short` type
creates a short integer. Variables of type `short` are appropriate when you don’t need the larger range offered by `int`.

---

### Ask the Expert

**Q:** You say that there are four integer types: `int`, `short`, `long`, and `byte`. However, I have heard that `char` can also be categorized as an integer type in Java. Can you explain?

**A:** The formal specification for Java defines a type category called integral types, which includes `byte`, `short`, `int`, `long`, and `char`. They are called integral types because they all hold whole-number, binary values. However, the purpose of the first four is to represent numeric integer quantities. The purpose of `char` is to represent characters. Therefore, the principal uses of `char` and the principal uses of the other integral types are fundamentally different. Because of the differences, the `char` type is treated separately in this book.

---

### Floating-Point Types

As explained in Chapter 1, the floating-point types can represent numbers that have fractional components. There are two kinds of floating-point types, `float` and `double`, which represent single- and double-precision numbers, respectively. Type `float` is 32 bits wide and type `double` is 64 bits wide.

Of the two, `double` is the most commonly used because all of the math functions in Java’s class library use `double` values. For example, the `sqrt( )` method (which is defined by the standard `Math` class) returns a `double` value that is the square root of its `double` argument. Here, `sqrt( )` is used to compute the length of the hypotenuse, given the lengths of the two opposing sides:
The output from the program is shown here:

```java
Hypotenuse is 5.0
```

One other point about the preceding example: As mentioned, `sqrt()` is a member of the standard `Math` class. Notice how `sqrt()` is called; it is preceded by the name `Math`. This is similar to the way `System.out` precedes `println()`. Although not all standard methods are called by specifying their class name first, several are.

### Characters

In Java, characters are not 8-bit quantities like they are in many other computer languages. Instead, Java uses Unicode. Unicode defines a character set that can represent all of the characters found in all human languages. In Java, `char` is an unsigned 16-bit type having a range of 0 to 65,536. The standard 8-bit ASCII character set is a subset of Unicode and ranges from 0 to 127. Thus, the ASCII characters are still valid Java characters.

A character variable can be assigned a value by enclosing the character in single quotes. For example, this assigns the variable `ch` the letter X:

```java
char ch;
ch = 'X';
```

You can output a `char` value using a `println()` statement. For example, this line outputs the value in `ch`:

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

Since `char` is an unsigned 16-bit type, it is possible to perform various arithmetic manipulations on a `char` variable. For example, consider the following program:
The output generated by this program is shown here:

ch contains X
ch is now Y
ch is now Z

In the program, ch is first given the value X. Next, ch is incremented. This results in ch containing Y, the next character in the ASCII (and Unicode) sequence. Next, ch is assigned the value 90, which is the ASCII (and Unicode) value that corresponds to the letter Z. Since the ASCII character set occupies the first 127 values in the Unicode character set, all the “old tricks” that you may have used with characters in other languages will work in Java, too.

Ask the Expert

Q: Why does Java use Unicode?

A: Java was designed for worldwide use. Thus, it needs to use a character set that can represent all the world’s languages. Unicode is the standard character set designed expressly for this purpose. Of course, the use of Unicode is inefficient for languages such as English, German, Spanish, or French, whose characters can be contained within 8 bits. But such is the price that must be paid for global portability.

The Boolean Type

The boolean type represents true/false values. Java defines the values true and false using the reserved words true and false. Thus, a variable or expression of type boolean will be one of these two values.

Here is a program that demonstrates the boolean type:
// Demonstrate boolean values.
class BoolDemo {
    public static void main(String args[]) {
        boolean b;

        b = false;
        System.out.println("b is " + b);
        b = true;
        System.out.println("b is " + b);

        // a boolean value can control the if statement
        if(b) System.out.println("This is executed.");

        b = false;
        if(b) System.out.println("This is not executed.");

        // outcome of a relational operator is a boolean value
        System.out.println("10 > 9 is " + (10 > 9));
    }
}

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 >.

Try This 2-1 How Far Away Is the Lightning?

In this project, you will create a program that computes how far away, in feet, a listener is from a lightning strike. Sound travels approximately 1,100 feet per second through air. Thus, knowing the interval between the time you see a lightning bolt and the time the sound reaches you enables you to compute the distance to the lightning. For this project, assume that the time interval is 7.2 seconds.
1. Create a new file called **Sound.java**.

2. To compute the distance, you will need to use floating-point values. Why? Because the time interval, 7.2, has a fractional component. Although it would be permissible to use a value of type `float`, we will use `double` in the example.

3. To compute the distance, you will multiply 7.2 by 1,100. You will then assign this value to a variable.

4. Finally, you will display the result.

Here is the entire **Sound.java** program listing:

```java
/*
   Try This 2-1
   Compute the distance to a lightning
   strike whose sound takes 7.2 seconds
   to reach you.
*/

class Sound {
   public static void main(String args[]) {
      double dist;

      dist = 7.2 * 1100;

      System.out.println("The lightning is " + dist + 
                      " feet away.");
   }
}
```

5. Compile and run the program. The following result is displayed:

   The lightning is 7920.0 feet away.

6. Extra challenge: You can compute the distance to a large object, such as a rock wall, by timing the echo. For example, if you clap your hands and time how long it takes for you to hear the echo, then you know the total round-trip time. Dividing this value by two yields the time it takes the sound to go one way. You can then use this value to compute the distance to the object. Modify the preceding program so that it computes the distance, assuming that the time interval is that of an echo.

**Literals**

In Java, literals refer to fixed values that are represented in their human-readable form. For example, the number 100 is a literal. Literals are also commonly called *constants*. For the most part, literals, and their usage, are so intuitive that they have been used in one form or another by all the preceding sample programs. Now the time has come to explain them formally.

Java literals can be of any of the primitive data types. The way each literal is represented depends upon its type. As explained earlier, character constants are enclosed in single quotes. For example, 'a'
and ' %' are both character constants.

Integer literals are specified as numbers without fractional components. For example, 10 and –100 are integer literals. Floating-point literals require the use of the decimal point followed by the number’s fractional component. For example, 11.123 is a floating-point literal. Java also allows you to use scientific notation for floating-point numbers.

By default, integer literals are of type int. If you want to specify a long literal, append an l or an L. For example, 12 is an int, but 12L is a long.

By default, floating-point literals are of type double. To specify a float literal, append an F or f to the constant. For example, 10.19F is of type float.

Although integer literals create an int value by default, they can still be assigned to variables of type char, byte, or short as long as the value being assigned can be represented by the target type. An integer literal can always be assigned to a long variable.

Beginning with JDK 7, you can embed one or more underscores into an integer or floating-point literal. Doing so can make it easier to read values consisting of many digits. When the literal is compiled, the underscores are simply discarded. Here is an example:

```
123_45_1234
```

This specifies the value 123,451,234. The use of underscores is particularly useful when encoding things like part numbers, customer IDs, and status codes that are commonly thought of as consisting of subgroups of digits.

### Hexadecimal, Octal, and Binary Literals

As you may know, in programming it is sometimes easier to use a number system based on 8 or 16 instead of 10. The number system based on 8 is called octal, and it uses the digits 0 through 7. In octal the number 10 is the same as 8 in decimal. The base 16 number system is called hexadecimal and uses the digits 0 through 9 plus the letters A through F, which stand for 10, 11, 12, 13, 14, and 15. For example, the hexadecimal number 10 is 16 in decimal. Because of the frequency with which these two number systems are used, Java allows you to specify integer literals in hexadecimal or octal instead of decimal. A hexadecimal literal must begin with 0x or 0X (a zero followed by an x or X). An octal literal begins with a zero. Here are some examples:

```java
hex = 0xFF; // 255 in decimal
cnt = 011; // 9 in decimal
```

As a point of interest, Java also allows hexadecimal floating-point literals, but they are seldom used.

Beginning with JDK 7, it is possible to specify an integer literal by use of binary. To do so, precede the binary number with a 0b or 0B. For example, this specifies the value 12 in binary: 0b1100.

### Character Escape Sequences

Enclosing character constants in single quotes works for most printing characters, but a few characters, such as the carriage return, pose a special problem when a text editor is used. In addition, certain other characters, such as the single and double quotes, have special meaning in Java, so you
cannot use them directly. For these reasons, Java provides special *escape sequences*, sometimes referred to as backslash character constants, shown in Table 2-2. These sequences are used in place of the characters that they represent.

<table>
<thead>
<tr>
<th>Escape Sequence</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>\</code></td>
<td>Single quote</td>
</tr>
<tr>
<td><code>\'</code></td>
<td>Double quote</td>
</tr>
<tr>
<td><code>\\</code></td>
<td>Backslash</td>
</tr>
<tr>
<td><code>\r</code></td>
<td>Carriage return</td>
</tr>
<tr>
<td><code>\n</code></td>
<td>New line</td>
</tr>
<tr>
<td><code>\f</code></td>
<td>Form feed</td>
</tr>
<tr>
<td><code>\t</code></td>
<td>Horizontal tab</td>
</tr>
<tr>
<td><code>\b</code></td>
<td>Backspace</td>
</tr>
<tr>
<td><code>\ddd</code></td>
<td>Octal constant (where ddd is an octal constant)</td>
</tr>
<tr>
<td><code>\xooo</code></td>
<td>Hexadecimal constant (where xooo is a hexadecimal constant)</td>
</tr>
</tbody>
</table>

Table 2-2  Character Escape Sequences

For example, this assigns *ch* the tab character:

```java
ch = '\t';
```

The next example assigns a single quote to *ch*:

```java
ch = '\';
```

**String Literals**

Java supports one other type of literal: the string. A *string* is a set of characters enclosed by double quotes. For example,

"this is a test"

is a string. You have seen examples of strings in many of the `println()` statements in the preceding sample programs.

In addition to normal characters, a string literal can also contain one or more of the escape sequences just described. For example, consider the following program. It uses the `\n` and `\t` escape sequences.
Ask the Expert

Q: Is a string consisting of a single character the same as a character literal? For example, is "k" the same as 'k'?

A: No. You must not confuse strings with characters. A character literal represents a single letter of type char. A string containing only one letter is still a string. Although strings consist of characters, they are not the same type.

Notice how the \n escape sequence is used to generate a new line. You don’t need to use multiple println() statements to get multiline output. Just embed \n within a longer string at the points where you want the new lines to occur.

A Closer Look at Variables

Variables were introduced in Chapter 1. Here, we will take a closer look at them. As you learned earlier, variables are declared using this form of statement,

type var-name;

where type is the data type of the variable, and var-name is its name. You can declare a variable of any valid type, including the simple types just described, and every variable will have a type. Thus, the capabilities of a variable are determined by its type. For example, a variable of type boolean cannot be used to store floating-point values. Furthermore, the type of a variable cannot change during its lifetime. An int variable cannot turn into a char variable, for example.

All variables in Java must be declared prior to their use. This is necessary because the compiler must know what type of data a variable contains before it can properly compile any statement that uses the variable. It also enables Java to perform strict type checking.
Initializing a Variable
In general, you must give a variable a value prior to using it. One way to give a variable a value is through an assignment statement, as you have already seen. Another way is by giving it an initial value when it is declared. To do this, follow the variable’s name with an equal sign and the value being assigned. The general form of initialization is shown here:

```
type var = value;
```

Here, `value` is the value that is given to `var` when `var` is created. The value must be compatible with the specified type. Here are some examples:

```java
int count = 10; // give count an initial value of 10
char ch = 'X'; // initialize ch with the letter X
float f = 1.2F; // f is initialized with 1.2
```

When declaring two or more variables of the same type using a comma-separated list, you can give one or more of those variables an initial value. For example:

```java
int a, b = 8, c = 19, d; // b and c have initializations
```

In this case, only `b` and `c` are initialized.

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 volume of a cylinder given the radius of its base and its height:

```java
// Demonstrate dynamic initialization.
class DynInit {
    public static void main(String args[]) {
        double radius = 4, height = 5;
        // dynamically initialize volume
        double volume = 3.1416 * radius * radius * height;
        System.out.println("Volume is " + volume);
    }
}
```

Here, three local variables—`radius`, `height`, and `volume`—are declared. The first two, `radius` and `height`, are initialized by constants. However, `volume` is initialized dynamically to the volume of the cylinder. The key point here is that the initialization expression can 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 that we have been using were declared at the start of the `main()` method. However, Java allows variables to be declared within any block. As explained in Chapter 1, 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.

Some other computer languages define two general categories of scopes: global and local. Although supported by Java, these are not the best ways to categorize Java’s scopes. The most important scopes in Java are those defined by a class and those defined by a method. A discussion of class scope (and variables declared within it) is deferred until later in this book, when classes are described. For now, we will examine only 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.

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
class ScopeDemo {
    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 Here, y is outside of its scope.
        // 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 visible only 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` 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.

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, that variable will be reinitialized each time the block in which it is declared is entered. For example, consider this program:

```java
// Demonstrate lifetime of a variable.
class VarInitDemo {
    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 always reinitialized to -1 each time the inner `for` loop is entered. Even though it is subsequently assigned the value 100, this value is lost.

There is one quirk to Java’s scope rules that may surprise you: although blocks can be nested, no variable declared within an inner scope can have the same name as a variable declared by an enclosing scope. For example, the following program, which tries to declare two separate variables with the same name, will not compile.
If you come from a C/C++ background, you know that there is no restriction on the names that you give variables declared in an inner scope. Thus, in C/C++ the declaration of `count` within the block of the outer `for` loop is completely valid, and such a declaration hides the outer variable. The designers of Java felt that this name hiding could easily lead to programming errors and disallowed it.

**Operators**

Java provides a rich operator environment. An *operator* is a symbol that tells the compiler to perform a specific mathematical or logical manipulation. Java has four general classes of operators: arithmetic, bitwise, relational, and logical. Java also defines some additional operators that handle certain special situations. This chapter will examine the arithmetic, relational, and logical operators. We will also examine the assignment operator. The bitwise and other special operators are examined later.

**Arithmetic Operators**

Java defines the following arithmetic operators:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</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>Decrement</td>
</tr>
</tbody>
</table>

The operators `+`, `–`, `*`, and `/` all work the same way in Java as they do in any other computer.
language (or algebra, for that matter). These can be applied to any built-in numeric data type. They can also be used on objects of type char.

Although the actions of arithmetic operators are well known to all readers, a few special situations warrant some explanation. First, remember that when / is applied to an integer, any remainder will be truncated; for example, 10/3 will equal 3 in integer division. You can obtain the remainder of this division by using the modulus operator %. It works in Java the way it does in other languages: it yields the remainder of an integer division. For example, 10 % 3 is 1. In Java, the % can be applied to both integer and floating-point types. Thus, 10.0 % 3.0 is also 1. The following program demonstrates the modulus operator.

```java
// Demonstrate the % operator.
class ModDemo {
    public static void main(String args[]) {
        int iresult, irem;
        double dresult, drem;

        iresult = 10 / 3;
        irem = 10 % 3;
        dresult = 10.0 / 3.0;
        drem = 10.0 % 3.0;

        System.out.println("Result and remainder of 10 / 3: " +
                iresult + " " + irem);
        System.out.println("Result and remainder of 10.0 / 3.0: " +
                dresult + " " + drem);
    }
}
```

The output from the program is shown here:

```
Result and remainder of 10 / 3: 3 1
Result and remainder of 10.0 / 3.0: 3.333333333333335 1.0
```

As you can see, the % yields a remainder of 1 for both integer and floating-point operations.

### Increment and Decrement

Introduced in Chapter 1, the ++ and the -- are Java’s increment and decrement operators. 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 adds 1 to its operand, and the decrement operator subtracts 1. Therefore,

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

is the same as

```
x++;
```
Both the increment and decrement operators can either precede (prefix) or follow (postfix) the operand. For example,

\[
x = x + 1;
\]

can be written as

\[
++x; // prefix form
\]
or as

\[
x++; // postfix form
\]

In the foregoing example, there is no difference whether the increment is applied as a prefix or a postfix. However, when an increment or decrement is used as part of a larger expression, there is an important difference. When an increment or decrement operator precedes its operand, Java will perform the corresponding operation prior to obtaining the operand’s value for use by the rest of the expression. If the operator follows its operand, Java will obtain the operand’s value before incrementing or decrementing it. Consider the following:

\[
x = 10;
y = ++x;
\]

In this case, \(y\) will be set to 11. However, if the code is written as

\[
x = 10;
y = x++;
\]

then \(y\) will be set to 10. In both cases, \(x\) is still set to 11; the difference is when it happens. There are significant advantages in being able to control when the increment or decrement operation takes place.

**Relational and Logical Operators**

In the terms *relational operator* and *logical operator*, *relational* refers to the relationships that values can have with one another, and *logical* refers to the ways in which true and false values can be connected together. Since the relational operators produce true or false results, they often work with the logical operators. For this reason they will be discussed together here.

The relational operators are shown here:
The logical operators are shown next:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>&amp;</td>
<td>AND</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
<tr>
<td>^</td>
<td>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>NOT</td>
</tr>
</tbody>
</table>

The outcome of the relational and logical operators is a boolean value.

In Java, all objects can be compared for equality or inequality using = = and !=. However, the comparison operators, <, >, <=, or >=, can be applied only to those types that support an ordering relationship. Therefore, all of the relational operators can be applied to all numeric types and to type char. However, values of type boolean can only be compared for equality or inequality, since the true and false values are not ordered. For example, true > false has no meaning in Java.

For the logical operators, the operands must be of type boolean, and the result of a logical operation is of type boolean. The logical operators, &, |, ^, and !, support the basic logical operations AND, OR, XOR, and NOT, according to the following truth table:

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

As the table shows, the outcome of an exclusive OR operation is true when exactly one and only one operand is true.

Here is a program that demonstrates several of the relational and logical operators:
The output from the program is shown here:

```java
// Demonstrate the relational and logical operators.
class RelLogOps {
    public static void main(String args[]) {
        int i, j;
        boolean b1, b2;

        i = 10;
        j = 11;
        if(i < j) System.out.println("i < j");
        if(i <= j) System.out.println("i <= j");
        if(i != j) System.out.println("i != j");
        if(i == j) System.out.println("this won't execute");
        if(i >= j) System.out.println("this won't execute");
        if(i > j) System.out.println("this won't execute");

        b1 = true;
        b2 = false;
        if(b1 & b2) System.out.println("this won't execute");
        if(!(b1 & b2)) System.out.println("!(b1 & b2) is true");
        if(b1 | b2) System.out.println("b1 | b2 is true");
        if(b1 ^ b2) System.out.println("b1 ^ b2 is true");
    }
}
```

The output from the program is shown here:

```
i < j
i <= j
i != j
!(b1 & b2) is true
b1 | b2 is true
b1 ^ b2 is true
```

**Short-Circuit Logical Operators**

Java supplies special *short-circuit* versions of its AND and OR logical operators that can be used to produce more efficient code. To understand why, consider the following. In an AND operation, if the first operand is false, the outcome is false no matter what value the second operand has. In an OR operation, if the first operand is true, the outcome of the operation is true no matter what the value of the second operand. Thus, in these two cases there is no need to evaluate the second operand. By not evaluating the second operand, time is saved and more efficient code is produced.

The short-circuit AND operator is `&&`, and the short-circuit OR operator is `||`. Their normal counterparts are `&` and `|`. The only difference between the normal and short-circuit versions is that the normal operands will always evaluate each operand, but short-circuit versions will evaluate the second operand only when necessary.

Here is a program that demonstrates the short-circuit AND operator. The program determines whether the value in `d` is a factor of `n`. It does this by performing a modulus operation. If the remainder of `n / d` is zero, then `d` is a factor. However, since the modulus operation involves a division, the short-circuit form of the AND is used to prevent a divide-by-zero error.
To prevent a divide-by-zero, the if statement first checks to see if d is equal to zero. If it is, the short-circuit AND stops at that point and does not perform the modulus division. Thus, in the first test, d is 2 and the modulus operation is performed. The second test fails because d is set to zero, and the modulus operation is skipped, avoiding a divide-by-zero error. Finally, the normal AND operator is tried. This causes both operands to be evaluated, which leads to a run-time error when the division by zero occurs.

One last point: The formal specification for Java refers to the short-circuit operators as the conditional-or and the conditional-and operators, but the term “short-circuit” is commonly used.

The Assignment Operator

You have been using the assignment operator since Chapter 1. Now it is time to take a formal look at it. The assignment operator is the single equal sign, =. This 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 var must be compatible with the type of 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 x, y, and 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 z = 100 is 100, which is then assigned to y, which in turn is assigned to x. Using a “chain of assignment” is an easy
way to set a group of variables to a common value.

**Shorthand Assignments**

Java provides special *shorthand* assignment operators that simplify the coding of certain assignment statements. Let’s begin with an example. The assignment statement shown here

```java
x = x + 10;
```

can be written, using Java shorthand, as

```java
x += 10;
```

---

**Ask the Expert**

**Q:** Since the short-circuit operators are, in some cases, more efficient than their normal counterparts, why does Java still offer the normal AND and OR operators?

**A:** In some cases you will want both operands of an AND or OR operation to be evaluated because of the side effects produced. Consider the following:

```java
// Side effects can be important.
class SideEffects {
    public static void main(String args[]) {
        int i;
        i = 0;

        /* Here, i is still incremented even though 
           the if statement fails. */
        if(false & (++i < 100))
            System.out.println("this won't be displayed");
        System.out.println("if statement executed: "+ i); // displays 1

        /* In this case, i is not incremented because 
           the short-circuit operator skips the increment. */
        if(false && (++i < 100))
            System.out.println("this won't be displayed");
        System.out.println("if statement executed: "+ i); // still 1 !!
    }
}
```

As the comments indicate, in the first `if` statement, `i` is incremented whether the `if` succeeds or not. However, when the short-circuit operator is used, the variable `i` is not incremented when the first operand is false. The lesson here is that if your code expects the right-hand operand of an AND or OR operation to be evaluated, you must use Java’s non-short-circuit forms of these operations.
The operator pair `+=` tells the compiler to assign to `x` the value of `x` plus 10. Here is another example.

The statement

\[ x = x - 100; \]

is the same as

\[ x -= 100; \]

Both statements assign to `x` the value of `x` minus 100.

This shorthand will work for all the binary operators in Java (that is, those that require two operands). The general form of the shorthand is

\[ var \ op = expression; \]

Thus, the arithmetic and logical shorthand assignment operators are the following:

\[ \begin{array}{c|c|c|c|c} \hline \ + & - & * & / & \% \\ \hline & \ & = & = & \& \\ \hline \ \hline \end{array} \]

Because these operators combine an operation with an assignment, they are formally referred to as *compound assignment* operators.

The compound assignment operators provide two benefits. First, they are more compact than their "longhand" equivalents. Second, in some cases, they are more efficient. For these reasons, you will often see the compound assignment operators used in professionally written Java programs.

**Type Conversion in Assignments**

In programming, it is common to assign one type of variable to another. For example, you might want to assign an `int` value to a `float` variable, as shown here:

```java
int i;
float f;

i = 10;
f = i; // assign an int to a float
```

When compatible types are mixed in an assignment, the value of the right side is automatically converted to the type of the left side. Thus, in the preceding fragment, the value in `i` is converted into a `float` and then assigned to `f`. However, because of Java’s strict type checking, not all types are compatible, and thus, not all type conversions are implicitly allowed. For example, `boolean` and `int` are not compatible.

When one type of data is assigned to another type of variable, an *automatic type conversion* will take place if

- 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, and both `int` and `byte` are integer types, so an automatic conversion from `byte` to `int` can be applied.

For widening conversions, the numeric types, including integer and floating-point types, are compatible with each other. For example, the following program is perfectly valid since `long` to `double` is a widening conversion that is automatically performed.

```
// Demonstrate automatic conversion from long to double.
class LtoD {
    public static void main(String args[]) {
        long L;
        double D;

        L = 100123285L;
        D = L; // Automatic conversion from long to double

        System.out.println("L and D: "+L+" "+D);
    }
}
```

Although there is an automatic conversion from `long` to `double`, there is no automatic conversion from `double` to `long`, since this is not a widening conversion. Thus, the following version of the preceding program is invalid.

```
// *** This program will not compile. ***
class LtoD {
    public static void main(String args[]) {
        long L;
        double D;

        D = 100123285.0;
        L = D; // Illegal!!!

        System.out.println("L and D: "+L+" "+D);
    }
}
```

There are no automatic conversions from the numeric types to `char` or `boolean`. Also, `char` and `boolean` are not compatible with each other. However, an integer literal can be assigned to `char`.

### Casting Incompatible Types

Although the automatic type conversions are helpful, they will not fulfill all programming needs because they apply only to widening conversions between compatible types. For all other cases you must employ a cast. A cast is an instruction to the compiler to convert one type into another. Thus, it requests an explicit type conversion. A cast has this general form:
Here, \textit{target-type} specifies the desired type to convert the specified expression to. For example, if you want to convert the type of the expression $x/y$ to \textbf{int}, you can write

\begin{verbatim}
double x, y;
// ...
(int) (x / y)
\end{verbatim}

Here, even though \texttt{x} and \texttt{y} are of type \textbf{double}, the cast converts the outcome of the expression to \textbf{int}. The parentheses surrounding \texttt{x / y} are necessary. Otherwise, the cast to \textbf{int} would apply only to the \texttt{x} and not to the outcome of the division. The cast is necessary here because there is no automatic conversion from \textbf{double} to \textbf{int}.

When a cast involves a \textit{narrowing conversion}, information might be lost. For example, when casting a \textbf{long} into a \textbf{short}, information will be lost if the \textbf{long}'s value is greater than the range of a \textbf{short} because its high-order bits are removed. When a floating-point value is cast to an integer type, the fractional component will also be lost due to truncation. For example, if the value 1.23 is assigned to an integer, the resulting value will simply be 1. The 0.23 is lost.

The following program demonstrates some type conversions that require casts:

\begin{verbatim}
// Demonstrate casting.
class CastDemo {
    public static void main(String args[]) {
        double x, y;
        byte b;
        int i;
        char ch;

        x = 10.0;
        y = 3.0;  // Truncation will occur in this conversion.

        i = (int) (x / y); // cast double to int
        System.out.println("Integer outcome of x / y: " + i);

        i = 100;
        b = (byte) i; // No loss of info here. A byte can hold the value 100.
        System.out.println("Value of b: " + b);

        i = 257;
        b = (byte) i; // Information loss this time. A byte cannot hold the value 257.
        System.out.println("Value of b: " + b);

        b = 88; // ASCII code for X
        ch = (char) b; // Cast between incompatible types
        System.out.println("ch: " + ch);
    }
}
\end{verbatim}

The output from the program is shown here:
In the program, the cast of $(x / y)$ to `int` results in the truncation of the fractional component, and information is lost. Next, no loss of information occurs when `b` is assigned the value 100 because a `byte` can hold the value 100. However, when the attempt is made to assign `b` the value 257, information loss occurs because 257 exceeds a `byte`’s maximum value. Finally, no information is lost, but a cast is needed when assigning a `byte` value to a `char`.

**Operator Precedence**

Table 2-3 shows the order of precedence for all Java operators, from highest to lowest. This table includes several operators that will be discussed later in this book. Although technically separators, the [], (), and . can also act like operators. In that capacity, they would have the highest precedence.

<table>
<thead>
<tr>
<th>Highest</th>
<th>++ (prefix)</th>
<th>-- (prefix)</th>
<th>~</th>
<th>!</th>
<th>+ (unary)</th>
<th>- (unary)</th>
<th>(type-cast)</th>
</tr>
</thead>
<tbody>
<tr>
<td>++ (postfix)</td>
<td>++ (postfix)</td>
<td>-- (postfix)</td>
<td>~</td>
<td>!</td>
<td>+ (unary)</td>
<td>- (unary)</td>
<td>(type-cast)</td>
</tr>
<tr>
<td>*</td>
<td>/</td>
<td>%</td>
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<td>&gt;=</td>
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<td>&gt;</td>
<td>=</td>
<td>&lt;=</td>
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<td></td>
<td></td>
<td>instanceof</td>
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<tr>
<td>&amp;=</td>
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<td>=&gt;</td>
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<td>?::</td>
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</tr>
</tbody>
</table>

Table 2-3 The Precedence of the Java Operators

**Try This 2-2** Display a Truth Table for the Logical Operators

```java
LogicalOpTable.java
```

In this project, you will create a program that displays the truth table for Java’s logical operators. You must make the columns in the table line up. This project makes use of several features covered in this chapter, including one of Java’s escape sequences and the logical operators. It also illustrates the
differences in the precedence between the arithmetic + operator and the logical operators.

1. Create a new file called **LogicalOpTable.java**.

2. To ensure that the columns line up, you will use the \t escape sequence to embed tabs into each output string. For example, this `println()` statement displays the header for the table:

   ```java
   System.out.println("P\tQ\tAND\tOR\tXOR\tNOT");
   ```

3. Each subsequent line in the table will use tabs to position the outcome of each operation under its proper heading.

4. Here is the entire **LogicalOpTable.java** program listing. Enter it at this time.

   ```java
   // Try This 2-2: a truth table for the logical operators.
   class LogicalOpTable {
       public static void main(String args[]) {

           boolean p, q;

           System.out.println("P\tQ\tAND\tOR\tXOR\tNOT");

           p = true; q = true;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));

           p = true; q = false;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));

           p = false; q = true;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));

           p = false; q = false;
           System.out.print(p + "\t" + q +"\t");
           System.out.print((p&q) + "\t" + (p|q) + "\t");
           System.out.println((p^q) + "\t" + (!p));
       }
   }
   ```

Notice the parentheses surrounding the logical operations inside the `println()` statements. They are necessary because of the precedence of Java’s operators. The + operator is higher than the logical operators.

5. Compile and run the program. The following table is displayed.
Expressions
Operators, variables, and literals are constituents of *expressions*. You probably already know the general form of an expression from your other programming experience, or from algebra. However, a few aspects of expressions will be discussed now.

Type Conversion in Expressions
Within an expression, it is possible to mix two or more different types of data as long as they are compatible with each other. For example, you can mix short and long within an expression because they are both numeric types. When different types of data are mixed within an expression, they are all converted to the same type. This is accomplished through the use of Java’s *type promotion rules*.

First, all *char*, byte, and short values are promoted to int. Then, if one operand is a long, the whole expression is promoted to long. If one operand is a float operand, the entire expression is promoted to float. If any of the operands is double, the result is double.

It is important to understand that type promotions apply only to the values operated upon when an expression is evaluated. For example, if the value of a byte variable is promoted to int inside an expression, outside the expression, the variable is still a byte. Type promotion only affects the evaluation of an expression.

Type promotion can, however, lead to somewhat unexpected results. For example, when an arithmetic operation involves two byte values, the following sequence occurs: First, the byte operands are promoted to int. Then the operation takes place, yielding an int result. Thus, the outcome of an operation involving two byte values will be an int. This is not what you might intuitively expect. Consider the following program:

```java
// A promotion surprise!
class PromDemo {
    public static void main(String args[]) {
        byte b;
        int i;

        b = 10;  // No cast needed because result is already elevated to int.
        i = b * b;  // OK, no cast needed

        b = 10;
        b = (byte) (b * b);  // Cast is needed here to assign an int to a byte!

        System.out.println("i and b: "+i+" " +b);
    }
}
```
Somewhat counterintuitively, no cast is needed when assigning \(b^2\) to \(i\), because \(b\) is promoted to \(\text{int}\) when the expression is evaluated. However, when you try to assign \(b \cdot b\) to \(b\), you do need a cast—back to \(\text{byte}\)! Keep this in mind if you get unexpected type-incompatibility error messages on expressions that would otherwise seem perfectly OK.

This same sort of situation also occurs when performing operations on \texttt{chars}. For example, in the following fragment, the cast back to \texttt{char} is needed because of the promotion of \(\texttt{ch1}\) and \(\texttt{ch2}\) to \texttt{int} within the expression:

```java
char ch1 = 'a', ch2 = 'b';
ch1 = (char) (ch1 + ch2);
```

Without the cast, the result of adding \(\texttt{ch1}\) to \(\texttt{ch2}\) would be \texttt{int}, which can’t be assigned to a \texttt{char}.

Casts are not only useful when converting between types in an assignment. For example, consider the following program. It uses a cast to \texttt{double} to obtain a fractional component from an otherwise integer division.

```java
// Using a cast.
class UseCast {
    public static void main(String args[]) {
        int i;

        for(i = 0; i < 5; i++) {
            System.out.println(i + " / 3: " + i / 3);
            System.out.println(i + " / 3 with fractions: " + (double) i / 3);
            System.out.println();
        }
    }
}
```

The output from the program is shown here:

```
0 / 3: 0
0 / 3 with fractions: 0.0
1 / 3: 0
1 / 3 with fractions: 0.3333333333333333
2 / 3: 0
2 / 3 with fractions: 0.6666666666666666
3 / 3: 1
3 / 3 with fractions: 1.0
4 / 3: 1
4 / 3 with fractions: 1.3333333333333333
```
Spacing and Parentheses
An expression in Java may have tabs and spaces in it to make it more readable. For example, the following two expressions are the same, but the second is easier to read:

```
x = 10 / y * (127 / x);
```

```
x = 10 / y * (127 / x);
```

Parentheses increase the precedence of the operations contained within them, just like in algebra. Use of redundant or additional parentheses will not cause errors or slow down the execution of the expression. You are encouraged to use parentheses to make clear the exact order of evaluation, both for yourself and for others who may have to figure out your program later. For example, which of the following two expressions is easier to read?

```
x = y / 3 - 34 * temp + 127;
```

```
x = (y / 3) - (34 * temp) + 127;
```

✔️ Chapter 2 Self Test

1. Why does Java strictly specify the range and behavior of its primitive types?

2. What is Java’s character type, and how does it differ from the character type used by some other programming languages?

3. A boolean value can have any value you like because any non-zero value is true. True or False?

4. Given this output,
   One
   Two
   Three
   using a single string, show the `println()` statement that produced it.

5. What is wrong with this fragment?
   ```
   for(i = 0; i < 10; i++) {
       int sum;

       sum = sum + i;
   }
   System.out.println("Sum is: " + sum);
   ```

6. Explain the difference between the prefix and postfix forms of the increment operator.

7. Show how a short-circuit AND can be used to prevent a divide-by-zero error.

8. In an expression, what type are `byte` and `short` promoted to?
9. In general, when is a cast needed?
10. Write a program that finds all of the prime numbers between 2 and 100.
11. Does the use of redundant parentheses affect program performance?
12. Does a block define a scope?
Chapter 3
Program Control Statements

Key Skills & Concepts
- Input characters from the keyboard
- Know the complete form of the `if` statement
- Use the `switch` statement
- Know the complete form of the `for` loop
- Use the `while` loop
- Use the `do-while` loop
- Use `break` to exit a loop
- Use `break` as a form of `goto`
- Apply `continue`
- Nest loops

In this chapter, you will learn about the statements that control a program’s flow of execution. There are three categories of program control statements: selection statements, which include the `if` and the `switch`; iteration statements, which include the `for`, `while`, and `do-while` loops; and jump statements, which include `break`, `continue`, and `return`. Except for `return`, which is discussed later in this book, the remaining control statements, including the `if` and `for` statements to which you have already had a
brief introduction, are examined in detail here. The chapter begins by explaining how to perform some simple keyboard input.

Input Characters from the Keyboard
Before examining Java’s control statements, we will make a short digression that will allow you to begin writing interactive programs. Up to this point, the sample programs in this book have displayed information to the user, but they have not received information from the user. Thus, you have been using console output, but not console (keyboard) input. The main reason for this is that Java’s input capabilities rely on or make use of features not discussed until later in this book. Also, most real-world Java programs and applets will be graphical and window based, not console based. For these reasons, not much use of console input is found in this book. However, there is one type of console input that is relatively easy to use: reading a character from the keyboard. Since several of the examples in this chapter will make use of this feature, it is discussed here.

To read a character from the keyboard, we will use `System.in.read()`. `System.in` is the complement to `System.out`. It is the input object attached to the keyboard. The `read()` method waits until the user presses a key and then returns the result. The character is returned as an integer, so it must be cast into a `char` to assign it to a `char` variable. By default, console input is *line buffered*. Here, the term buffer refers to a small portion of memory that is used to hold the characters before they are read by your program. In this case, the buffer holds a complete line of text. As a result, you must press ENTER before any character that you type will be sent to your program. Here is a program that reads a character from the keyboard:

```java
// Read a character from the keyboard.
public class KbiIn {
    public static void main(String args[])
        throws java.io.IOException {
        char ch;
        System.out.print("Press a key followed by ENTER: ");
        ch = (char) System.in.read(); // get a char
        System.out.println("Your key is: " + ch);
    }
}
```

Here is a sample run:

```
Press a key followed by ENTER: t
Your key is: t
```

In the program, notice that `main()` begins like this:

```java
public static void main(String args[])
    throws java.io.IOException {
```

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
mechanism, which is discussed in Chapter 9. For now, don’t worry about its precise meaning.

The fact that System.in is line buffered is a source of annoyance at times. When you press ENTER, a carriage return, line feed sequence is entered into the input stream. Furthermore, these characters are left pending in the input buffer until you read them. Thus, for some applications, you may need to remove them (by reading them) before the next input operation. You will see an example of this later in this chapter.

The if Statement

Chapter 1 introduced the if statement. It is examined in detail here. The complete form of the if statement is

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

where the targets of the if and else are single statements. The else clause is optional. The targets of both the if and else can be blocks of statements. The general form of the if, using blocks of statements, is

```java
if(condition)
{
    statement sequence
}
else
{
    statement sequence
}
```

If the conditional expression is true, the target of the if will be executed; otherwise, if it exists, the target of the else will be executed. At no time will both of them be executed. The conditional expression controlling the if must produce a boolean result.

To demonstrate the if (and several other control statements), we will create and develop a simple computerized guessing game that would be suitable for young children. In the first version of the game, the program asks the player for a letter between A and Z. If the player presses the correct letter on the keyboard, the program responds by printing the message ** Right **. The program is shown here:
This program prompts the player and then reads a character from the keyboard. Using an if statement, it then checks that character against the answer, which is K in this case. If K was entered, the message is displayed. When you try this program, remember that the K must be entered in uppercase.

Taking the guessing game further, the next version uses the else to print a message when the wrong letter is picked.

```java
// Guess the letter game.
class Guess {
    public static void main(String args[])
        throws java.io.IOException {
        char ch, answer = 'K';

        System.out.println("I'm thinking of a letter between A and Z.");
        System.out.print("Can you guess it: ");

        ch = (char) System.in.read(); // read a char from the keyboard

        if(ch == answer) System.out.println("** Right **");
    }
}
```

This program prompts the player and then reads a character from the keyboard. Using an if statement, it then checks that character against the answer, which is K in this case. If K was entered, the message is displayed. When you try this program, remember that the K must be entered in uppercase.

Taking the guessing game further, the next version uses the else to print a message when the wrong letter is picked.

```java
// Guess the letter game, 2nd version.
class Guess2 {
    public static void main(String args[])
        throws java.io.IOException {
        char ch, answer = 'K';

        System.out.println("I'm thinking of a letter between A and Z.");
        System.out.print("Can you guess it: ");

        ch = (char) System.in.read(); // get a char

        if(ch == answer) System.out.println("** Right **");
        else System.out.println("...Sorry, you're wrong.");
    }
}
```

**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. The main thing to remember about nested ifs in Java is that an else statement always refers to the nearest if statement that is within the same block as the else and not already associated with an else. Here is an example:

```java
if(i == 10) {
    if(j < 20) a = b;
    if(k > 100) c = d;
    else a = c; // this else refers to if(k > 100)
} else a = d; // this else refers to if(i == 10)
```
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.

You can use a nested if to add a further improvement to the guessing game. This addition provides the player with feedback about a wrong guess.

A sample run is shown here:

I'm thinking of a letter between A and Z.
Can you guess it: Z
...Sorry, you're too high

The if-else-if Ladder
A common programming construct that is based upon the nested if is the if-else-if ladder. It looks like this:
The conditional expressions are evaluated from the top downward. As soon as a true condition is found, the statement associated with it is executed, and the rest of the ladder is bypassed. If none of the conditions are true, the final `else` statement will be executed. The final `else` often acts as a default condition; that is, if all other conditional tests fail, the last `else` statement is performed. If there is no final `else` and all other conditions are false, no action will take place.

The following program demonstrates the `if-else-if` ladder:

```java
// Demonstrate an if-else-if ladder.
class Ladder {
    public static void main(String args[]) {
        int x;
        for(x=0; x<6; x++) {
            if(x==1)
                System.out.println("x is one");
            else if(x==2)
                System.out.println("x is two");
            else if(x==3)
                System.out.println("x is three");
            else if(x==4)
                System.out.println("x is four");
            else
                System.out.println("x is not between 1 and 4"); // This is the default statement.
        }
    }
}
```

The program produces the following output:

```
x is not between 1 and 4
x is one
x is two
x is three
x is four
x is not between 1 and 4
```

As you can see, the default `else` is executed only if none of the preceding `if` statements succeeds.

**The switch Statement**
The second of Java’s selection statements is the **switch**. The **switch** provides for a multiway branch. Thus, it enables a program to select among several alternatives. Although a series of nested **if** statements can perform multiway tests, for many situations the **switch** is a more efficient approach. It works like this: the value of an expression is successively tested against a list of constants. When a match is found, the statement sequence associated with that match is executed. The general form of the **switch** statement is

```java
switch(expression) {
    case constant1:
        statement sequence
        break;
    case constant2:
        statement sequence
        break;
    case constant3:
        statement sequence
        break;
    .
    .
    .
    default:
        statement sequence
}
```

For versions of Java prior to JDK 7, the **expression** controlling the **switch** 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**. This means that modern versions of Java can use a string to control a **switch**. (This technique is demonstrated in Chapter 5, when **String** is described.) Frequently, the expression controlling a **switch** is simply a variable rather than a larger expression.

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 **default** statement sequence is executed if no **case** constant matches the expression. The **default** is optional; if it is not present, no action takes place if all matches fail. When a match is found, the statements associated with that **case** are executed until the **break** is encountered or, in the case of **default** or the last **case**, until the end of the **switch** is reached.

The following program demonstrates the **switch**:

```java
switch(expression) {
    case constant1:
        statement sequence
        break;
    case constant2:
        statement sequence
        break;
    case constant3:
        statement sequence
        break;
    .
    .
    .
    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 four
i is five or more
i is five or more
i is five or more
i is five or more
```

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. When i is five or greater, no case statements match, so the default statement is executed.

Technically, the break statement is optional, although most applications of the switch will use it. When encountered within the statement sequence of a case, the break statement causes program flow to exit from the entire switch statement and resume at the next statement outside the switch. However, if a break statement does not end the statement sequence associated with a case, then all the
statements at and following the matching case will be executed until a break (or the end of the switch) is encountered.

For example, study the following program carefully. Before looking at the output, can you figure out what it will display on the screen?

```java
// Demonstrate the switch without break statements.
class NoBreak {
    public static void main(String args[]) {
        int i;
        for(i=0; i<=5; i++) {
            switch(i) {
                case 0:
                    System.out.println("i is less than one");
                case 1:
                    System.out.println("i is less than two");
                case 2:
                    System.out.println("i is less than three");
                case 3:
                    System.out.println("i is less than four");
                case 4:
                    System.out.println("i is less than five");
            }
        }
        System.out.println();
    }
}
```

This program displays the following output:

```
i is less than one
i is less than two
i is less than three
i is less than four
i is less than five
i is less than two
i is less than three
i is less than four
i is less than five
i is less than three
i is less than four
i is less than five
i is less than four
i is less than five
i is less than five
```

As this program illustrates, execution will continue into the next case if no break statement is
You can have empty cases, as shown in this example:

```java
switch(i) {
    case 1:
    case 2:
    case 3: System.out.println("i is 1, 2 or 3");
            break;
    case 4: System.out.println("i is 4");
            break;
}
```

In this fragment, if `i` has the value 1, 2, or 3, the first `println()` statement executes. If it is 4, the second `println()` statement executes. The “stacking” of cases, as shown in this example, is common when several cases share common code.

### Nested switch Statements

It is possible to have a `switch` as part of the statement sequence of an outer `switch`. This is called a nested `switch`. Even if the case constants of the inner and outer `switch` contain common values, no conflicts will arise. For example, the following code fragment is perfectly acceptable:

```java
switch(ch1) {
    case 'A': System.out.println("This A is part of outer switch.");
    switch(ch2) {
        case 'A':
            System.out.println("This A is part of inner switch");
            break;
        case 'B': // ...
    } // end of inner switch
    break;
    case 'B': // ...
}
```

### Try This 3-1 Start Building a Java Help System

This project builds a simple help system that displays the syntax for the Java control statements. The program displays a menu containing the control statements and then waits for you to choose one. After one is chosen, the syntax of the statement is displayed. In this first version of the program, help is available for only the `if` and `switch` statements. The other control statements are added in subsequent projects.

1. Create a file called `Help.java`.
2. The program begins by displaying the following menu:
To accomplish this, you will use the statement sequence shown here:

```java
System.out.println("Help on:");
System.out.println("  1. if");
System.out.println("  2. switch");
System.out.print("Choose one: ");
```

3. Next, the program obtains the user’s selection by calling `System.in.read()`, as shown here:

   ```java
   choice = (char) System.in.read();
   ```

4. Once the selection has been obtained, the program uses the `switch` statement shown here to display the syntax for the selected statement.

   ```java
   switch(choice) {
   case '1':
      System.out.println("The if:\n");
      System.out.println("if(condition) statement; ");
      System.out.println("else statement; ");
      break;
   case '2':
      System.out.println("The switch:\n");
      System.out.println("switch(expression) {");
      System.out.println("  case constant:");
      System.out.println("    statement sequence");
      System.out.println("  break;"');
      System.out.println("  // ..."'),
      System.out.println("}"");
      break;
   default:
      System.out.print("Selection not found.");
   }
   ```

Notice how the `default` clause catches invalid choices. For example, if the user enters 3, no `case` constants will match, causing the `default` sequence to execute.

5. Here is the entire `Help.java` program listing:
6. Here is a sample run.

Help on:
  1. if
  2. switch
Choose one: 1

The if:

if(condition) statement;
else statement;
The for Loop
You have been using a simple form of the for loop since Chapter 1. You might be surprised at just how powerful and flexible the for loop is. Let’s begin by reviewing the basics, starting with the most traditional forms of the for.

The general form of the for loop for repeating a single statement is

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

For repeating a block, the general form is

```c
for(initialization; condition; iteration)
{
    statement sequence
}
```

Ask the Expert

**Q:** Under what conditions should I use an if-else-if ladder rather than a switch when coding a multiway branch?

**A:** In general, use an if-else-if ladder when the conditions controlling the selection process do not rely upon a single value. For example, consider the following if-else-if sequence:

```c
if(x < 10) // ...
else if(y != 0) // ...
else if(!done) // ...
```

This sequence cannot be recoded into a switch because all three conditions involve different variables—and differing types. What variable would control the switch? Also, you will need to use an if-else-if ladder when testing floating-point values or other objects that are not of types valid for use in a switch expression.

The initialization is usually an assignment statement that sets the initial value of the loop control variable, which acts as the counter that controls the loop. The condition is a Boolean expression that determines whether or not the loop will repeat. The iteration expression defines the amount by which the loop control variable will change each time the loop is repeated. Notice that these three major sections of the loop must be separated by semicolons. The for loop will continue to execute as long as the condition tests true. Once the condition becomes false, the loop will exit, and program execution will resume on the statement following the for.

The following program uses a for loop to print the square roots of the numbers between 1 and 99.
It also displays the rounding error present for each square root.

```java
// Show square roots of 1 to 99 and the rounding error.
class SqrRoot {  
    public static void main(String args[]) {  
        double num, sroot, rerr;  
        for(num = 1.0; num < 100.0; num++) {  
            sroot = Math.sqrt(num);  
            System.out.println("Square root of " + num +  
                " is " + sroot);  
            // compute rounding error  
            rerr = num - (sroot * sroot);  
            System.out.println("Rounding error is " + rerr);  
            System.out.println();  
        }  
    }  
}
```

Notice that the rounding error is computed by squaring the square root of each number. This result is then subtracted from the original number, thus yielding the rounding error.

The `for` loop can proceed in a positive or negative fashion, and it can change the loop control variable by any amount. For example, the following program prints the numbers 100 to −95, in decrements of 5:

```java
// A negatively running for loop.  
class DecrFor {  
    public static void main(String args[]) {  
        int x;  
        for(x = 100; x > -100; x -= 5)  
            System.out.println(x);  
    }  
}
```

An important point about `for` loops is that the conditional expression is always tested at the top of the loop. This means that the code inside the loop may not be executed at all if the condition is false to begin with. Here is an example:

```java
for(count=10; count < 5; count++)  
    x += count; // this statement will not execute
```

This loop will never execute because its control variable, `count`, is greater than 5 when the loop is first entered. This makes the conditional expression, `count < 5`, false from the outset; thus, not even one iteration of the loop will occur.

### Some Variations on the for Loop
The `for` is one of the most versatile statements in the Java language because it allows a wide range of variations. For example, multiple loop control variables can be used. Consider the following program:

```java
// Use commas in a for statement.
class Comma {
    public static void main(String args[]) {
        int i, j;

        for(i=0, j=10; i < j; i++, j--)  // Notice the two loop control variables.
            System.out.println("i and j: " + i + " " + j);
    }
}
```

The output from the program is shown here:

```
i and j: 0 10
i and j: 1 9
i and j: 2 8
i and j: 3 7
i and j: 4 6
```

Here, commas separate the two initialization statements and the two iteration expressions. When the loop begins, both `i` and `j` are initialized. Each time the loop repeats, `i` is incremented and `j` is decremented. Multiple loop control variables are often convenient and can simplify certain algorithms. You can have any number of initialization and iteration statements, but in practice, more than two or three make the `for` loop unwieldy.

The condition controlling the loop can be any valid Boolean expression. It does not need to involve the loop control variable. In the next example, the loop continues to execute until the user types the letter `S` at the keyboard:

```java
// Loop until an S is typed.
class ForTest {
    public static void main(String args[])
        throws java.io.IOException {

        int i;

        System.out.println("Press S to stop.");

        for(i = 0; (char) System.in.read() != 'S'; i++)
            System.out.println("Pass #" + i);
    }
}
```

**Missing Pieces**

Some interesting `for` loop variations are created by leaving pieces of the loop definition empty. In Java, it is possible for any or all of the initialization, condition, or iteration portions of the `for` loop to
be blank. For example, consider the following program:

```java
// Parts of the for can be empty.
class Empty {
    public static void main(String args[]) {
        int i;
        for(i = 0; i < 10; ) { // The iteration expression is missing.
            System.out.println("Pass "+i);
            i++; // increment loop control var
        }
    }
}
```

Here, the iteration expression of the `for` is empty. Instead, the loop control variable `i` is incremented inside the body of the loop. This means that each time the loop repeats, `i` is tested to see whether it equals 10, but no further action takes place. Of course, since `i` is still incremented within the body of the loop, the loop runs normally, displaying the following output:

Pass #0
Pass #1
Pass #2
Pass #3
Pass #4
Pass #5
Pass #6
Pass #7
Pass #8
Pass #9

In the next example, the initialization portion is also moved out of the `for`:

```java
// Move more out of the for loop.
class Empty2 {
    public static void main(String args[]) {
        int i;
        i = 0; // move initialization out of loop
        for(; i < 10; ) {
            System.out.println("Pass "+i);
            i++; // increment loop control var
        }
    }
}
```

In this version, `i` is initialized before the loop begins, rather than as part of the `for`. Normally, you will want to initialize the loop control variable inside the `for`. Placing the initialization outside of the loop is generally done only when the initial value is derived through a complex process that does not lend itself to containment inside the `for` statement.
The Infinite Loop
You can create an infinite loop (a loop that never terminates) using the for by leaving the conditional expression empty. For example, the following fragment shows the way most Java programmers create an infinite loop:

```java
for (;;) // intentionally infinite loop
{
    //...
}
```

This loop will run forever. Although there are some programming tasks, such as operating system command processors, that require an infinite loop, most “infinite loops” are really just loops with special termination requirements. Near the end of this chapter, you will see how to halt a loop of this type. (Hint: It’s done using the break statement.)

Loops with No Body
In Java, the body associated with a for loop (or any other loop) can be empty. This is because a null statement is syntactically valid. Body-less loops are often useful. For example, the following program uses one to sum the numbers 1 through 5:

```java
// The body of a loop can be empty.
class Empty3 {
    public static void main(String args[]) {
        int i;
        int sum = 0;

        // sum the numbers through 5
        for(i = 1; i <= 5; sum += i++) ; // No body in this loop!

        System.out.println("Sum is " + sum);
    }
}
```

The output from the program is shown here:

```
Sum is 15
```

Notice that the summation process is handled entirely within the for statement, and no body is needed. Pay special attention to the iteration expression:

```
sum += i++
```

Don’t be intimidated by statements like this. They are common in professionally written Java programs and are easy to understand if you break them down into their parts. In other words, this statement says, “Add to sum the value of sum plus i, then increment i.” Thus, it is the same as this sequence of statements:
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, the following program computes both the summation and the factorial of the numbers 1 through 5. It declares its loop control variable i inside the for.

```java
sum = sum + i;
i++;
```

The Enhanced for Loop

Relatively recently, a new form of the for loop, called the enhanced for, was added to Java. The enhanced for provides a streamlined way to cycle through the contents of a collection of objects, such as an array. The enhanced for loop is discussed in Chapter 5, after arrays have been introduced.

The while Loop

Another of Java’s loops is the while. The general form of the while loop is

```java
while(condition) statement;
```

where statement may be a single statement or a block of statements, and condition defines the condition that controls the loop. The condition may be any valid Boolean expression. The loop
repeats while the condition is true. When the condition becomes false, program control passes to the line immediately following the loop.

Here is a simple example in which a while is used to print the alphabet:

```java
// Demonstrate the while loop.
class WhileDemo {
    public static void main(String args[]) {
        char ch;

        // print the alphabet using a while loop
        ch = 'a';
        while(ch <= 'z') {
            System.out.print(ch);
            ch++;
        }
    }
}
```

Here, ch is initialized to the letter a. Each time through the loop, ch is output and then incremented. This process continues until ch is greater than z.

As with the for loop, the while checks the conditional expression at the top of the loop, which means that the loop code may not execute at all. This eliminates the need for performing a separate test before the loop. The following program illustrates this characteristic of the while loop. It computes the integer powers of 2, from 0 to 9.

```java
// Compute integer powers of 2.
class Power {
    public static void main(String args[]) {
        int e;
        int result;
        for(int i=0; i < 10; i++) {
            result = 1;
            e = i;
            while(e > 0) {
                result *= 2;
                e--;
            }
            System.out.println("2 to the " + i + " power is " + result);
        }
    }
}
```

The output from the program is shown here:
Notice that the `while` loop executes only when `e` is greater than 0. Thus, when `e` is zero, as it is in the first iteration of the `for` loop, the `while` loop is skipped.

---

**Ask the Expert**

**Q:** Given the flexibility inherent in all of Java’s loops, what criteria should I use when selecting a loop? That is, how do I choose the right loop for a specific job?

**A:** Use a `for` loop when performing a known number of iterations. Use the `do-while` when you need a loop that will always perform at least one iteration. The `while` is best used when the loop will repeat an unknown number of times.

---

**The do-while Loop**

The last of Java’s loops is the `do-while`. Unlike the `for` and the `while` loops, in which the condition is tested at the top of the loop, the `do-while` loop checks its condition at the bottom of the loop. This means that a `do-while` loop will always execute at least once. The general form of the `do-while` loop is

```java
    do {
        statements;
    } while(condition);
```

Although the braces are not necessary when only one statement is present, they are often used to improve readability of the `do-while` construct, thus preventing confusion with the `while`. The `do-while` loop executes as long as the conditional expression is true.

The following program loops until the user enters the letter q:
Using a do-while loop, we can further improve the guessing game program from earlier in this chapter. This time, the program loops until you guess the letter.

```java
// Demonstrate the do-while loop.
class DWDemo {
    public static void main(String args[])
        throws java.io.IOException {

        char ch;

        do {
            System.out.print("Press a key followed by ENTER: ");
            ch = (char) System.in.read(); // get a char
        } while(ch != 'q');
    }
}

Using a do-while loop, we can further improve the guessing game program from earlier in this chapter. This time, the program loops until you guess the letter.

// Guess the letter game, 4th version.
class Guess4 {
    public static void main(String args[])
        throws java.io.IOException {

    char ch, ignore, answer = 'K';

    do {
        System.out.println("I'm thinking of a letter between A and Z. ");
        System.out.print("Can you guess it: ");

        // read a character
        ch = (char) System.in.read();

        // discard any other characters in the input buffer
        do {
            ignore = (char) System.in.read();
        } while(ignore != '\n');

        if(ch == answer) System.out.println("** Right **");
        else {
            System.out.print("...Sorry, you're ");
            if(ch < answer) System.out.println("too low");
            else System.out.println("too high");
            System.out.println("Try again!\n");
        }
    } while(answer != ch);
}
}

Here is a sample run:

I'm thinking of a letter between A and Z. Can you guess it: A
...Sorry, you're too low
Try again!

I'm thinking of a letter between A and Z. Can you guess it: Z
...Sorry, you're too high
Try again!

I'm thinking of a letter between A and Z. Can you guess it: K
** Right **

Notice one other thing of interest in this program. There are two do-while loops in the program. The first loops until the user guesses the letter. Its operation and meaning should be clear. The second do-while loop, shown again here, warrants some explanation:

```java
// discard any other characters in the input buffer
do {
    ignore = (char) System.in.read();
} while(ignore != '\n');
```

As explained earlier, console input is line buffered—you have to press ENTER before characters are sent. Pressing ENTER causes a carriage return and a line feed (newline) sequence to be generated. These characters are left pending in the input buffer. Also, if you typed more than one key before pressing ENTER, they too would still be in the input buffer. This loop discards those characters by continuing to read input until the end of the line is reached. If they were not discarded, then those characters would also be sent to the program as guesses, which is not what is wanted. (To see the effect of this, you might try removing the inner do-while loop.) In Chapter 10, after you have learned more about Java, some other, higher-level ways of handling console input are described. However, the use of read() here gives you insight into how the foundation of Java's I/O system operates. It also shows another example of Java's loops in action.

Try This 3-2 Improve the Java Help System

This project expands on the Java help system that was created in Try This 3-1. This version adds the syntax for the for, while, and do-while loops. It also checks the user’s menu selection, looping until a valid response is entered.

1. Copy Help.java to a new file called Help2.java.
2. Change the first part of main() so that it uses a loop to display the choices, as shown here:
Notice that a nested do-while loop is used to discard any unwanted characters remaining in the input buffer. After making this change, the program will loop, displaying the menu until the user enters a response that is between 1 and 5.

3. Expand the switch statement to include the for, while, and do-while loops, as shown here:
Notice that no `default` statement is present in this version of the `switch`. Since the menu loop ensures that a valid response will be entered, it is no longer necessary to include a `default` statement to handle an invalid choice.

4. Here is the entire `Help2.java` program listing:
Try This 3-2

An improved Help system that uses a do-while to process a menu selection.

*/
class Help2 {
    public static void main(String args[])
        throws java.io.IOException {
        char choice, ignore;

        do {
            System.out.println("Help on:");
            System.out.println("  1. if");
            System.out.println("  2. switch");
            System.out.println("  3. for");
            System.out.println("  4. while");
            System.out.println("  5. do-while
            System.out.print("Choose one: ");
Use break to Exit a Loop

It is possible to force an immediate exit from a loop, bypassing any remaining code in the body of the loop and the loop’s conditional test, by using the `break` statement. 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
choice = (char) System.in.read();

do {
    ignore = (char) System.in.read();
} while(ignore != '\n');
} while( choice < '1' | choice > '5');

System.out.println("\n");

switch(choice) {
    case '1':
        System.out.println("The if:");
        System.out.println("if(condition) statement;";
        System.out.println("else statement;");
        break;
    case '2':
        System.out.println("The switch:");
        System.out.println("switch(expression) {");
        System.out.println("    case constant:");
        System.out.println("        statement sequence";
        System.out.println("    break;");
        System.out.println("    // ...";
        System.out.println("}"");
        break;
    case '3':
        System.out.println("The for:");
        System.out.print("for(init; condition; iteration)";
        System.out.println(" statement;";
        break;
    case '4':
        System.out.println("The while:");
        System.out.println("while(condition) statement;";
        break;
    case '5':
        System.out.println("The do-while:");
        System.out.println("do {");
        System.out.println("    statement;";
        System.out.println("} while (condition);";
        break;
}
```
This program generates the following output:

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

As you can see, although the for loop is designed to run from 0 to num (which in this case is 100), the break statement causes it to terminate early, when i squared is greater than or equal to num.

The break statement can be used with any of Java’s loops, including intentionally infinite loops. For example, the following program simply reads input until the user types the letter q:

```java
// Read input until a q is received.
class Break2 {
    public static void main(String args[]) throws java.io.IOException {
        char ch;

        for( ; ; ) { // This "infinite" loop is terminated by the break.
            ch = (char) System.in.read(); // get a char
            if(ch == 'q') break;
        }
        System.out.println("You pressed q!");
    }
}
```

When used inside a set of nested loops, the break statement will break out of only the innermost loop. For example:
This program generates the following output:

Outer loop count: 0
   Inner loop count: 0 1 2 3 4 5 6 7 8 9
Outer loop count: 1
   Inner loop count: 0 1 2 3 4 5 6 7 8 9
Outer loop count: 2
   Inner loop count: 0 1 2 3 4 5 6 7 8 9
Loops complete.

As you can see, the break statement in the inner loop causes the termination of only 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.

Use break as a Form of goto

In addition to its uses with the switch statement and loops, the break statement can be employed by itself to provide a “civilized” form of the goto statement. Java does not have a goto statement, because it provides an unstructured way to alter the flow of program execution. Programs that make extensive use of the goto are usually hard to understand and hard to maintain. There are, however, a few places where the goto is a useful and legitimate device. For example, the goto can be helpful when 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:

```java
break label;
```

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

To name a block, put a label at the start of it. The block being labeled can be a stand-alone block, or a statement that has a block as its target. 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:

```java
// Using break with a label.
class Break4 {
    public static void main(String args[]) {
        int i;

        for(i=1; i<4; i++) {
            one: {
                two: {
                    three: {
                        System.out.println("\ni is "+i);
                        if(i==1) break one; // Break to a label.
                        if(i==2) break two;
                        if(i==3) break three;

                        // this is never reached
                        System.out.println("won't print");
                    }
                    System.out.println("After block three.");
                }
                System.out.println("After block two.");
            }
            System.out.println("After block one.");
        }
        System.out.println("After for.");
    }
}
```

The output from the program is shown here:
Let's look closely at the program to understand precisely why this output is produced. When \(i\) is 1, the first \(\text{if}\) statement succeeds, causing a \texttt{break} to the end of the block of code defined by label \texttt{one}. This causes \textit{After block one.} to print. When \(i\) is 2, the second \(\text{if}\) succeeds, causing control to be transferred to the end of the block labeled by \texttt{two}. This causes the messages \textit{After block two.} and \textit{After block one.} to be printed, in that order. When \(i\) is 3, the third \(\text{if}\) succeeds, and control is transferred to the end of the block labeled by \texttt{three}. Now, all three messages are displayed.

Here is another example. This time, \texttt{break} is being used to jump outside of a series of nested \texttt{for} loops. When the \texttt{break} statement in the inner loop is executed, program control jumps to the end of the block defined by the outer \texttt{for} loop, which is labeled by \texttt{done}. This causes the remainder of all three loops to be bypassed.

```java
// Another example of using break with a label.
class Break5 {
    public static void main(String args[]) {
        done:
        for(int i=0; i<10; i++) {
            for(int j=0; j<10; j++) {
                for(int k=0; k<10; k++) {
                    System.out.println(k + " ");
                    if(k == 5) break done; // jump to done
                }
            }
        }
        System.out.println("After k loop"); // won't execute
        System.out.println("After j loop"); // won't execute
        System.out.println("After i loop");
    }
}
```

The output from the program is shown here:
Precisely where you put a label is very important—especially when working with loops. For example, consider the following program:

```java
// Where you put a label is important.
class Break6 {
    public static void main(String args[]) {
        int x=0, y=0;

        // here, put label before for statement.
        for(x=0; x < 5; x++) {
            for(y = 0; y < 5; y++) {
                if(y == 2) break stop1;
                System.out.println("x and y: "+x+" "+y);
            }
        }
        System.out.println();

        // now, put label immediately before {
        for(x=0; x < 5; x++)
        stop2: {
            for(y = 0; y < 5; y++) {
                if(y == 2) break stop2;
                System.out.println("x and y: "+x+" "+y);
            }
        }
    }
}
```

The output from this program is shown here:
In the program, both sets of nested loops are the same except for one point. In the first set, the label precedes the outer for loop. In this case, when the break executes, it transfers control to the end of the entire for block, skipping the rest of the outer loop's iterations. In the second set, the label precedes the outer for's opening curly brace. Thus, when break stop2 executes, control is transferred to the end of the outer for's block, causing the next iteration to occur.

Keep in mind that you cannot break to any label that 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 to that block.

---

Ask the Expert

Q: You say that the goto is unstructured and that the break with a label offers a better alternative. But really, doesn’t breaking to a label, which might be many lines of code and
Use continue

It is possible to force an early iteration of a loop, bypassing the loop’s normal control structure. This is accomplished using **continue**. The **continue** statement forces the next iteration of the loop to take place, skipping any code between itself and the conditional expression that controls the loop. Thus, **continue** is essentially the complement of **break**. For example, the following program uses **continue** to help print the even numbers between 0 and 100:

```java
// Use continue.
class ContDemo {
    public static void main(String args[]) {
        int i;

        // print even numbers between 0 and 100
        for(i = 0; i<=100; i++) {
            if((i%2) != 0) continue; // iterate
            System.out.println(i);
        }
    }
}
```

Only even numbers are printed, because an odd one will cause the loop to iterate early, bypassing the call to **println( )**.

In **while** and **do-while** loops, a **continue** statement will cause control to go directly to the conditional expression and then continue the looping process. In the case of the **for**, the iteration expression of the loop is evaluated, then the conditional expression is executed, and then the loop continues.

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** with a label:
The output from the program is shown here:

```
Outer loop pass 1, Inner loop: 1234
Outer loop pass 2, Inner loop: 1234
Outer loop pass 3, Inner loop: 1234
Outer loop pass 4, Inner loop: 1234
Outer loop pass 5, Inner loop: 1234
Outer loop pass 6, Inner loop: 1234
Outer loop pass 7, Inner loop: 1234
Outer loop pass 8, Inner loop: 1234
Outer loop pass 9, Inner loop: 1234
```

As the output shows, when the `continue` executes, control passes to the outer loop, skipping the remainder of the inner loop.

Good uses of `continue` are rare. One reason is that Java provides a rich set of loop statements that fit most applications. However, for those special circumstances in which early iteration is needed, the `continue` statement provides a structured way to accomplish it.

**Try This 3-3 Finish the Java Help System**

```java
Help3.java
```

This project puts the finishing touches on the Java help system that was created in the previous projects. This version adds the syntax for `break` and `continue`. It also allows the user to request the syntax for more than one statement. It does this by adding an outer loop that runs until the user enters `q` as a menu selection.

1. Copy `Help2.java` to a new file called `Help3.java`.
2. Surround all of the program code with an infinite `for` loop. Break out of this loop, using `break`, when a letter `q` is entered. Since this loop surrounds all of the program code, breaking out of this
3. Change the menu loop as shown here:

```java
do {
    System.out.println("Help on:");
    System.out.println("  1. if");
    System.out.println("  2. switch");
    System.out.println("  3. for");
    System.out.println("  4. while");
    System.out.println("  5. do-while");
    System.out.println("  6. break");
    System.out.println("  7. continue
");
    System.out.print("Choose one (q to quit): ");

    choice = (char) System.in.read();
    do {
        ignore = (char) System.in.read();
    } while(ignore != '\n');
} while( choice < '1' | choice > '7' & choice != 'q');
```

Notice that this loop now includes the `break` and `continue` statements. It also accepts the letter q as a valid choice.

4. Expand the `switch` statement to include the `break` and `continue` statements, as shown here:

```java
case '6':
    System.out.println("The break:\n");
    System.out.println("break; or break label; ");
    break;
case '7':
    System.out.println("The continue:\n");
    System.out.println("continue; or continue label; ");
    break;
```

5. Here is the entire Help3.java program listing:
Try This 3-3

The finished Java statement Help system that processes multiple requests.

*/
class Help3 {
    public static void main(String args[])
        throws java.io.IOException {
        char choice, ignore;

        for(;;) {
            do {
                System.out.println("Help on:");
                System.out.println("  1. if");
                System.out.println("  2. switch");
                System.out.println("  3. for");
                System.out.println("  4. while");
                System.out.println("  5. do-while");
                System.out.println("  6. break");
                System.out.println("  7. continue\n");
                System.out.print("Choose one (q to quit): ");

                choice = (char) System.in.read();

                do {
                    ignore = (char) System.in.read();
                } while(ignore != '\n');
            }
        }
    }
}
Here is a sample run:

```java
6. while( choice < '1' | choice > '7' & choice != 'q') {
    if(choice == 'q') break;
    System.out.println("\n");
    switch(choice) {
      case '1':
        System.out.println("The if:\n");
        System.out.println("if(condition) statement;");
        System.out.println("else statement;");
        break;
      case '2':
        System.out.println("The switch:\n");
        System.out.println("switch(expression) {");
        System.out.println("  case constant:");
        System.out.println("    statement sequence");
        System.out.println("  break;");
        System.out.println("  // ..." );
        System.out.println("    }" );
        break;
      case '3':
        System.out.println("The for:\n");
        System.out.println("for(init; condition; iteration)" );
        System.out.println(" statement;" );
        break;
      case '4':
        System.out.println("The while:\n");
        System.out.println("while(condition) statement;" );
        break;
      case '5':
        System.out.println("The do-while:\n");
        System.out.println("do {");
        System.out.println("  statement;" );
        System.out.println("} while (condition);" );
        break;
      case '6':
        System.out.println("The break:\n");
        System.out.println("break; or break label;" );
        break;
      case '7':
        System.out.println("The continue:\n");
        System.out.println("continue; or continue label;" );
        break;
    }
    System.out.println();
  }
}
```
Nested Loops

As you have seen in some of the preceding examples, one loop can be nested inside of another. Nested loops are used to solve a wide variety of programming problems and are an essential part of...
programming. So, before leaving the topic of Java's loop statements, let's look at one more nested loop example. The following program uses a nested for loop to find the factors of the numbers from 2 to 100:

```java
/*
 * Use nested loops to find factors of numbers between 2 and 100.
 */

class FindFac {
    public static void main(String args[]) {
        for(int i=2; i <= 100; i++) {
            System.out.print("Factors of " + i + ": ");
            for(int j = 2; j < i; j++)
                if((i%j) == 0) System.out.print(j + " ");
            System.out.println();
        }
    }
}
```

Here is a portion of the output produced by the program:

```
Factors of 2:
Factors of 3:
Factors of 4: 2
Factors of 5:
Factors of 6: 2 3
Factors of 7:
Factors of 8: 2 4
Factors of 9: 3
Factors of 10: 2 5
Factors of 11:
Factors of 12: 2 3 4 6
Factors of 13:
Factors of 14: 2 7
Factors of 15: 3 5
Factors of 16: 2 4 8
Factors of 17:
Factors of 18: 2 3 6 9
Factors of 19:
Factors of 20: 2 4 5 10
```

In the program, the outer loop runs i from 2 through 100. The inner loop successively tests all numbers from 2 up to i, printing those that evenly divide i. Extra challenge: The preceding program can be made more efficient. Can you see how? (Hint: The number of iterations in the inner loop can be reduced.)
Chapter 3 Self Test

1. Write a program that reads characters from the keyboard until a period is received. Have the program count the number of spaces. Report the total at the end of the program.

2. Show the general form of the if-else-if ladder.

3. Given
   
   ```java
   if(x < 10)
       if(y > 100) {
           if(!done) x = z;
           else y = z;
       }
   else System.out.println("error"); // what if? to what if does the last else associate?
   ```

4. Show the for statement for a loop that counts from 1000 to 0 by –2.

5. Is the following fragment valid?
   ```java
   for(int i = 0; i < num; i++)
       sum += i;
   
   count = i;
   ```

6. Explain what break does. Be sure to explain both of its forms.

7. In the following fragment, after the break statement executes, what is displayed?
   ```java
   for(i = 0; i < 10; i++) {
       while(running) {
           if(x<y) break;
           // ...
       }
   }
   System.out.println("after while");
   ```

8. What does the following fragment print?
   ```java
   for(int i = 0; i<10; i++) {
       System.out.print(i + " ");
       if((i%2) == 0) continue;
       System.out.println();
   }
   ```

9. The iteration expression in a for loop need not always alter the loop control variable by a fixed amount. Instead, the loop control variable can change in any arbitrary way. Using this concept, write a program that uses a for loop to generate and display the progression 1, 2, 4, 8, 16, 32, and so on.

10. The ASCII lowercase letters are separated from the uppercase letters by 32. Thus, to convert a lowercase letter to uppercase, subtract 32 from it. Use this information to write a program that
reads characters from the keyboard. Have it convert all lowercase letters to uppercase, and all uppercase letters to lowercase, displaying the result. Make no changes to any other character. Have the program stop when the user enters a period. At the end, have the program display the number of case changes that have taken place.

11. What is an infinite loop?

12. When using break with a label, must the label be on a block that contains the break?
Chapter 4
Introducing Classes, Objects, and Methods

Key Skills & Concepts
- Know the fundamentals of the class
- Understand how objects are created
- Understand how reference variables are assigned
- Create methods, return values, and use parameters
- Use the `return` keyword
- Return a value from a method
- Add parameters to a method
- Utilize constructors
- Create parameterized constructors
- Understand `new`
- Understand garbage collection and finalizers
- Use the `this` keyword

Before you can go much further in your study of Java, you need to learn about the class. The class is the essence of Java. It is the foundation upon which the entire Java language is built because the class
defines the nature of an object. As such, the class forms the basis for object-oriented programming in Java. Within a class are defined data and code that acts upon that data. The code is contained in methods. Because classes, objects, and methods are fundamental to Java, they are introduced in this chapter. Having a basic understanding of these features will allow you to write more sophisticated programs and better understand certain key Java elements described in the following chapter.

Class Fundamentals
Since all Java program activity occurs within a class, we have been using classes since the start of this book. Of course, only extremely simple classes have been used, and we have not taken advantage of the majority of their features. As you will see, classes are substantially more powerful than the limited ones presented so far.

Let’s begin by reviewing the basics. A class is a template that defines the form of an object. It specifies both the data and the code that will operate on that data. Java uses a class specification to construct objects. Objects are instances of a class. Thus, a class is essentially a set of plans that specify how to build an object. It is important to be clear on one issue: a class is a logical abstraction. It is not until an object of that class has been created that a physical representation of that class exists in memory.

One other point: Recall that the methods and variables that constitute a class are called members of the class. The data members are also referred to as instance variables.

The General Form of a Class
When you define a class, you declare its exact form and nature. You do this by specifying the instance variables that it contains and the methods that operate on them. Although very simple classes might contain only methods or only instance variables, most real-world classes contain both.

A class is created by using the keyword class. A simplified general form of a class definition is shown here:
Although there is no syntactic rule that enforces it, a well-designed class should define one and only one logical entity. For example, a class that stores names and telephone numbers will not normally also store information about the stock market, average rainfall, sunspot cycles, or other unrelated information. The point here is that well-designed class groups logically connected information. Putting unrelated information into the same class will quickly destruct your code!

Up to this point, the classes that we have been using have had only one method: main(). Soon you will see how to create others. However, notice that the general form of a class does not specify a main() method. A main() method is required only if that class is the starting point for your program. Also, some types of Java applications, such as applets, don’t require a main().

### Defining a Class

To illustrate classes, we will develop a class that encapsulates information about vehicles, such as cars, vans, and trucks. This class is called Vehicle, and it will store three items of information about a vehicle: the number of passengers that it can carry, its fuel capacity, and its average fuel consumption (in miles per gallon).

The first version of Vehicle is shown next. It defines three instance variables: passengers, fuelcap, and mpg. Notice that Vehicle does not contain any methods. Thus, it is currently a data-only class. (Subsequent sections will add methods to it.)

```java
class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon
}
```
A class definition creates a new data type. In this case, the new data type is called Vehicle. You will use this name to declare objects of type Vehicle. Remember that a class declaration is only a type description; it does not create an actual object. Thus, the preceding code does not cause any objects of type Vehicle to come into existence.

To actually create a Vehicle object, you will use a statement like the following:

```java
Vehicle minivan = new Vehicle(); // create a Vehicle object called minivan
```

After this statement executes, minivan will be an instance of Vehicle. Thus, it will have “physical” reality. For the moment, don’t worry about the details of this statement.

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 Vehicle object will contain its own copies of the instance variables passengers, fuelcap, and mpg. To access these variables, you will use the dot (.) operator. The dot operator links the name of an object with the name of a member. The general form of the dot operator is shown here:

```
object.member
```

Thus, the object is specified on the left, and the member is put on the right. For example, to assign the fuelcap variable of minivan the value 16, use the following statement:

```java
minivan.fuelcap = 16;
```

In general, you can use the dot operator to access both instance variables and methods.

Here is a complete program that uses the Vehicle class:

```java
/* A program that uses the Vehicle class.

Call this file VehicleDemo.java
*/
class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;       // fuel consumption in miles per gallon
}

// This class declares an object of type Vehicle.
class VehicleDemo {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        int range;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16; // Notice the use of the dot operator to access a member.
        minivan.mpg = 21;

        // compute the range assuming a full tank of gas
        range = minivan.fuelcap * minivan.mpg;
        System.out.println("Minivan can carry "+ minivan.passengers + " with a range of "+ range);
    }
}
```
You should call the file that contains this program `VehicleDemo.java` because the `main()` method is in the class called `VehicleDemo`, not the class called `Vehicle`. When you compile this program, you will find that two `.class` files have been created, one for `Vehicle` and one for `VehicleDemo`. The Java compiler automatically puts each class into its own `.class` file. It is not necessary for both the `Vehicle` and the `VehicleDemo` class to be in the same source file. You could put each class in its own file, called `Vehicle.java` and `VehicleDemo.java`, respectively.

To run this program, you must execute `VehicleDemo.class`. The following output is displayed:

```
Minivan can carry 7 with a range of 336
```

Before moving on, let’s review a fundamental principle: each object has its own copies of the instance variables defined by its class. Thus, the contents of the variables in one object can differ from the contents of the variables in another. There is no connection between the two objects except for the fact that they are both objects of the same type. For example, if you have two `Vehicle` objects, each has its own copy of `passengers`, `fuelcap`, and `mpg`, and the contents of these can differ between the two objects. The following program demonstrates this fact. (Notice that the class with `main()` is now called `TwoVehicles`.)
The output produced by this program is shown here:

Minivan can carry 7 with a range of 336
Sportscar can carry 2 with a range of 168

As you can see, **minivan**'s data is completely separate from the data contained in **sportscar**. The following illustration depicts this situation.
How Objects Are Created

In the preceding programs, the following line was used to declare an object of type `Vehicle`:

```java
Vehicle minivan = new Vehicle();
```

This declaration performs two functions. First, it declares a variable called `minivan` of the class type `Vehicle`. This variable does not define an object. Instead, it is simply a variable that can refer to an object. Second, the declaration creates a physical copy of the object and assigns to `minivan` a reference to that object. This is done by 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 a variable. Thus, in Java, all class objects must be dynamically allocated.

The two steps combined in the preceding statement can be rewritten like this to show each step individually:

```java
Vehicle minivan; // declare reference to object
minivan = new Vehicle(); // allocate a Vehicle object
```

The first line declares `minivan` as a reference to an object of type `Vehicle`. Thus, `minivan` is a variable that can refer to an object, but it is not an object itself. At this point, `minivan` does not refer to an object. The next line creates a new `Vehicle` object and assigns a reference to it to `minivan`. Now, `minivan` is linked with an object.

Reference Variables and Assignment

In an assignment operation, object reference variables act differently than do variables of a primitive type, such as `int`. When you assign one primitive-type variable to another, the situation is straightforward. The variable on the left receives a copy of the value of the variable on the right. When you assign one object reference variable to another, the situation is a bit more complicated because you are changing the object that the reference variable refers to. The effect of this difference can cause some counterintuitive results. For example, consider the following fragment:

```java
Vehicle car1 = new Vehicle();
Vehicle car2 = car1;
```

At first glance, it is easy to think that `car1` and `car2` refer to different objects, but this is not the case. Instead, `car1` and `car2` will both refer to the same object. The assignment of `car1` to `car2` simply makes `car2` refer to the same object as does `car1`. Thus, the object can be acted upon by either `car1` or `car2`. For example, after the assignment

```java
car1.mpg = 26;
```

executes, both of these `println()` statements

```java
System.out.println(car1.mpg);
System.out.println(car2.mpg);
```
Although car1 and car2 both refer to the same object, they are not linked in any other way. For example, a subsequent assignment to car2 simply changes the object to which car2 refers. For example:

```java
Vehicle car1 = new Vehicle();
Vehicle car2 = car1;
Vehicle car3 = new Vehicle();

car2 = car3; // now car2 and car3 refer to the same object.
```

After this sequence executes, car2 refers to the same object as car3. The object referred to by car1 is unchanged.

### Methods

As explained, instance variables and methods are constituents of classes. So far, the Vehicle class contains data, but no methods. Although data-only classes are perfectly valid, most classes will have methods. Methods are subroutines that manipulate the data defined by the class and, in many cases, provide access to that data. In most cases, other parts of your program will interact with a class through its methods.

A method contains one or more statements. In well-written Java code, each method performs only one task. Each method has a name, and it is this name that is used to call the method. In general, you can give a method whatever name you please. However, remember that main() is reserved for the method that begins execution of your program. Also, don’t use Java’s keywords for method names.

When denoting methods in text, this book has used and will continue to use a convention that has become common when writing about Java. A method will have parentheses after its name. For example, if a method’s name is `getval`, it will be written `getval()` when its name is used in a sentence. This notation will help you distinguish variable names from method names in this book.

The general form of a method is shown here:

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

Here, `ret-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 `void`. The name of the method is specified by `name`. This can be any legal identifier other than those already used by other items within the current scope. The `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, the parameter list will be empty.

### Adding a Method to the Vehicle Class

As just explained, the methods of a class typically manipulate and provide access to the data of the
class. With this in mind, recall that main() in the preceding examples computed the range of a vehicle by multiplying its fuel consumption rate by its fuel capacity. While technically correct, this is not the best way to handle this computation. The calculation of a vehicle’s range is something that is best handled by the Vehicle class itself. The reason for this conclusion is easy to understand: the range of a vehicle is dependent upon the capacity of the fuel tank and the rate of fuel consumption, and both of these quantities are encapsulated by Vehicle. By adding a method to Vehicle that computes the range, you are enhancing its object-oriented structure. To add a method to Vehicle, specify it within Vehicle’s declaration. For example, the following version of Vehicle contains a method called range() that displays the range of the vehicle.

```java
// Add range to Vehicle.

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;   // fuel capacity in gallons
    int mpg;       // fuel consumption in miles per gallon

    // Display the range.
    void range() {
        System.out.println("Range is " + fuelcap * mpg);
    }
}

class AddMeth {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        Vehicle sportscar = new Vehicle();

        int range1, range2;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16;
        minivan.mpg = 21;

        // assign values to fields in sportscar
        sportscar.passengers = 2;
        sportscar.fuelcap = 14;
        sportscar.mpg = 12;

        System.out.print("Minivan can carry " + minivan.passengers + ". ");
        minivan.range(); // display range of minivan
        System.out.print("Sportscar can carry " + sportscar.passengers + ". ");
        sportscar.range(); // display range of sportscar.
    }
}
```

This program generates the following output:
Let's look at the key elements of this program, beginning with the `range()` method itself. The first line of `range()` is:

```java
void range() {
```

This line declares a method called `range` that has no parameters. Its return type is `void`. Thus, `range()` does not return a value to the caller. The line ends with the opening curly brace of the method body.

The body of `range()` consists solely of this line:

```java
System.out.println("Range is " + fuelcap * mpg);
```

This statement displays the range of the vehicle by multiplying `fuelcap` by `mpg`. Since each object of type `Vehicle` has its own copy of `fuelcap` and `mpg`, when `range()` is called, the range computation uses the calling object's copies of those variables.

The `range()` method ends when its closing curly brace is encountered. This causes program control to transfer back to the caller.

Next, look closely at this line of code from inside `main()`:

```java
minivan.range();
```

This statement invokes the `range()` method on `minivan`. That is, it calls `range()` relative to the `minivan` object, using the object's name followed by the dot operator. When a method is called, program control is transferred to the method. When the method terminates, control is transferred back to the caller, and execution resumes with the line of code following the call.

In this case, the call to `minivan.range()` displays the range of the vehicle defined by `minivan`. In similar fashion, the call to `sportscar.range()` displays the range of the vehicle defined by `sportscar`. Each time `range()` is invoked, it displays the range for the specified object.

There is something very important to notice inside the `range()` method: the instance variables `fuelcap` and `mpg` 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 `fuelcap` and `mpg` inside `range()` implicitly refer to the copies of those variables found in the object that invokes `range()`.

**Returning from a Method**

In general, there are two conditions that cause a method to return—first, as the `range()` method in the preceding example shows, when the method’s closing curly brace is encountered. The second is when a `return` statement is executed. There are two forms of `return`—one for use in `void` methods (those that do not return a value) and one for returning values. The first form is examined here. The next section explains how to return values.

In a `void` method, you can cause the immediate termination of a method by using this form of
return;

When this statement executes, program control returns to the caller, skipping any remaining code in the method. For example, consider this method:

```java
void myMeth() {
    int i;

    for(i=0; i<10; i++) {
        if(i == 5) return; // stop at 5
        System.out.println();
    }
}
```

Here, the for loop will only run from 0 to 5, because once i equals 5, the method returns. It is permissible to have multiple return statements in a method, especially when there are two or more routes out of it. For example:

```java
void myMeth() {
    // ...
    if(done) return;
    // ...
    if(error) return;
    // ...
}
```

Here, the method returns if it is done or if an error occurs. Be careful, however, because having too many exit points in a method can destruct the code; so avoid using them casually. A well-designed method has well-defined exit points.

To review: A void method can return in one of two ways—its closing curly brace is reached, or a return statement is executed.

### Returning a Value

Although methods with a return type of void are not rare, most methods will return a value. In fact, the ability to return a value is one of the most useful features of a method. You have already seen one example of a return value: when we used the `sqrt()` function to obtain a square root.

Return values are used for a variety of purposes in programming. In some cases, such as with `sqrt()`, the return value contains the outcome of some calculation. In other cases, the return value may simply indicate success or failure. In still others, it may contain a status code. Whatever the purpose, using method return values is an integral part of Java programming.

Methods return a value to the calling routine using this form of return:

```java
return value;
```
Here, value is the value returned. This form of return can be used only with methods that have a non-void return type. Furthermore, a non-void method must return a value by using this form of return.

You can use a return value to improve the implementation of range( ). Instead of displaying the range, a better approach is to have range( ) compute the range and return this value. Among the advantages to this approach is that you can use the value for other calculations. The following example modifies range( ) to return the range rather than displaying it.

```java
// Use a return value.

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon

    // Return the range.
    int range() {
        return mpg * fuelcap; ← Return the range for a given vehicle.
    }
}

class RetMeth {
    public static void main(String args[]) {
        Vehicle minivan = new Vehicle();
        Vehicle sportscar = new Vehicle();

        int rangel, range2;

        // assign values to fields in minivan
        minivan.passengers = 7;
        minivan.fuelcap = 16;
        minivan.mpg = 21;

        // assign values to fields in sportscar
        sportscar.passengers = 2;
        sportscar.fuelcap = 14;
        sportscar.mpg = 12;

        // get the ranges
        rangel = minivan.range(); ← Assign the value returned to a variable.
        range2 = sportscar.range();

        System.out.println("Minivan can carry " + minivan.passengers + " with range of " + rangel + " Miles");

        System.out.println("Sportscar can carry " + sportscar.passengers + " with range of " + range2 + " miles");
    }
}
```

The output is shown here:

Minivan can carry 7 with range of 336 Miles
Sportscar can carry 2 with range of 168 miles
In the program, notice that when \texttt{range( )} is called, it is put on the right side of an assignment statement. On the left is a variable that will receive the value returned by \texttt{range( )}. Thus, after
\begin{verbatim}
range1 = minivan.range();
\end{verbatim}

executes, the range of the \texttt{minivan} object is stored in \texttt{range1}.

Notice that \texttt{range( )} now has a return type of \texttt{int}. This means that it will return an integer value to the caller. The return type of a method is important because the type of data returned by a method must be compatible with the return type specified by the method. Thus, if you want a method to return data of type \texttt{double}, its return type must be type \texttt{double}.

Although the preceding program is correct, it is not written as efficiently as it could be. Specifically, there is no need for the \texttt{range1} or \texttt{range2} variables. A call to \texttt{range( )} can be used in the \texttt{println( )} statement directly, as shown here:
\begin{verbatim}
System.out.println("Minivan can carry " + minivan.passengers + " with range of " + minivan.range() + " Miles");
\end{verbatim}

In this case, when \texttt{println( )} is executed, \texttt{minivan.range( )} is called automatically and its value will be passed to \texttt{println( )}. Furthermore, you can use a call to \texttt{range( )} whenever the range of a \texttt{Vehicle} object is needed. For example, this statement compares the ranges of two vehicles:
\begin{verbatim}
if(v1.range() > v2.range()) System.out.println("v1 has greater range");
\end{verbatim}

### Using Parameters

It is possible to pass one or more values to a method when the method is called. Recall that a value passed to a method is called an \textit{argument}. Inside the method, the variable that receives the argument is called a \textit{parameter}. Parameters are declared inside the parentheses that follow the method’s name. The parameter declaration syntax is the same as that used for variables. A parameter is within the scope of its method, and aside from its special task of receiving an argument, it acts like any other local variable.

Here is a simple example that uses a parameter. Inside the \texttt{ChkNum} class, the method \texttt{isEven( )} returns \texttt{true} if the value that it is passed is even. It returns \texttt{false} otherwise. Therefore, \texttt{isEven( )} has a return type of \texttt{boolean}.
In the program, `isEven()` is called three times, and each time a different value is passed. Let’s look at this process closely. First, notice how `isEven()` is called. The argument is specified between the parentheses. When `isEven()` is called the first time, it is passed the value 10. Thus, when `isEven()` begins executing, the parameter `x` receives the value 10. In the second call, 9 is the argument, and `x`, then, has the value 9. In the third call, the argument is 8, which is the value that `x` receives. The point is that the value passed as an argument when `isEven()` is called is the value received by its parameter, `x`.

A method can have more than one parameter. Simply declare each parameter, separating one from the next with a comma. For example, the `Factor` class defines a method called `isFactor()` that determines whether the first parameter is a factor of the second.
Notice that when \texttt{isFactor()} is called, the arguments are also separated by commas.

When using multiple parameters, each parameter specifies its own type, which can differ from the others. For example, this is perfectly valid:

\begin{verbatim}
int myMeth(int a, double b, float c) {
    // ...
}
\end{verbatim}

**Adding a Parameterized Method to Vehicle**

You can use a parameterized method to add a new feature to the \texttt{Vehicle} class: the ability to compute the amount of fuel needed for a given distance. This new method is called \texttt{fuelneeded()}. This method takes the number of miles that you want to drive and returns the number of gallons of gas required. The \texttt{fuelneeded()} method is defined like this:

\begin{verbatim}
define fuelneeded(int miles) {
    return (double) miles / mpg;
}
\end{verbatim}

Notice that this method returns a value of type \texttt{double}. This is useful since the amount of fuel needed for a given distance might not be a whole number. The entire \texttt{Vehicle} class that includes \texttt{fuelneeded()} is shown here:

\begin{verbatim}
/*
   Add a parameterized method that computes the fuel required for a given distance.
*/

class Vehicle {
    int passengers; // number of passengers
    int fuelcap;    // fuel capacity in gallons
    int mpg;        // fuel consumption in miles per gallon
}
\end{verbatim}
The output from the program is shown here:

To go 252 miles minivan needs 12.0 gallons of fuel.
To go 252 miles sportscar needs 21.0 gallons of fuel.

Try This 4-1 Creating a Help Class

If one were to try to summarize the essence of the class in one sentence, it might be this: a class encapsulates functionality. Of course, sometimes the trick is knowing where one "functionality" ends and another begins. As a general rule, you will want your classes to be the building blocks of your
larger application. In order to do this, each class must represent a single functional unit that performs clearly delineated actions. Thus, you will want your classes to be as small as possible—but no smaller! That is, classes that contain extraneous functionality confuse and destructure code, but classes that contain too little functionality are fragmented. What is the balance? It is at this point that the science of programming becomes the art of programming. Fortunately, most programmers find that this balancing act becomes easier with experience.

To begin to gain that experience you will convert the help system from Try This 3-3 in the preceding chapter into a Help class. Let’s examine why this is a good idea. First, the help system defines one logical unit. It simply displays the syntax for Java’s control statements. Thus, its functionality is compact and well defined. Second, putting help in a class is an esthetically pleasing approach. Whenever you want to offer the help system to a user, simply instantiate a help-system object. Finally, because help is encapsulated, it can be upgraded or changed without causing unwanted side effects in the programs that use it.

1. Create a new file called HelpClassDemo.java. To save you some typing, you might want to copy the file from Try This 3-3, Help3.java, into HelpClassDemo.java.

2. To convert the help system into a class, you must first determine precisely what constitutes the help system. For example, in Help3.java, there is code to display a menu, input the user’s choice, check for a valid response, and display information about the item selected. The program also loops until the letter q is pressed. If you think about it, it is clear that the menu, the check for a valid response, and the display of the information are integral to the help system. How user input is obtained, and whether repeated requests should be processed, are not. Thus, you will create a class that displays the help information, the help menu, and checks for a valid selection. Its methods will be called helpOn(), showMenu(), and isValid(), respectively.

3. Create the helpOn() method as shown here:
void helpOn(int what) {
  switch (what) {
    case '1':
      System.out.println("The if: \\
");
      System.out.println("if (condition) statement;");
      System.out.println("else statement; \\
");
      break;
    case '2':
      System.out.println("The switch: \\
");
      System.out.println("switch (expression) { \\
");
      System.out.println("  case constant: \\
");
      System.out.println("    statement sequence \\
");
      System.out.println("    break; \\
");
      System.out.println("  // ... \\
");
      System.out.println("} \\
");
      break;
    case '3':
      System.out.println("The for: \\
");
      System.out.println("for (init; condition; iteration) \\
");
      System.out.println("  statement; \\
");
      break;
    case '4':
      System.out.println("The while: \\
");
      System.out.println("while (condition) statement; \\
");
      break;
    case '5':
      System.out.println("The do-while: \\
");
      System.out.println("do \\
");
      System.out.println("  statement; \\
");
      System.out.println("} while (condition); \\
");
      break;
    case '6':
      System.out.println("The break: \\
");
      System.out.println("break; or break label; \\
");
      break;
    case '7':
      System.out.println("The continue: \\
");
      System.out.println("continue; or continue label; \\
");
      break;
  }
  System.out.println();
}

4. Next, create the showMenu() method:
5. Create the `isValid()` method, shown here:

   ```java
   boolean isValid(int ch) {
      if(ch < '1' | ch > '7' & ch != 'q') return false;
      else return true;
   }
   ```

6. Assemble the foregoing methods into the `Help` class, shown here:
class Help {
    void helpOn(int what) {
        switch (what) {
            case '1':
                System.out.println("The if:\n");
                System.out.println("if(condition) statement;\n");
                System.out.println("else statement;\n");
                break;
            case '2':
                System.out.println("The switch:\n");
                System.out.println("switch(expression) {\n");
                System.out.println("    case constant:\n");
                System.out.println("        statement sequence\n");
                System.out.println("    break;\n");
                System.out.println("    // ...\n");
                System.out.println("}\n");
                break;
            case '3':
                System.out.println("The for:\n");
                System.out.println("for(init; condition; iteration)\n");
                System.out.println("    statement;\n");
                break;
            case '4':
                System.out.println("The while:\n");
                System.out.println("while(condition) statement;\n");
                break;
            case '5':
                System.out.println("The do-while:\n");
                System.out.println("do {\n");
                System.out.println("    statement;\n");
                System.out.println("} while (condition);\n");
                break;
            case '6':
                System.out.println("The break:\n");
                System.out.println("break; or break label;\n");
                break;
        }
    }
}

7. Finally, rewrite the `main()` method from Try This 3-3 so that it uses the new `Help` class. Call this class `HelpClassDemo.java`. The entire listing for `HelpClassDemo.java` is shown here:

```java
/*
 * Try This 4-1
 * Convert the help system from Try This 3-3 into a Help class.
 */

class Help {
    void helpOn(int what) {
        switch(what) {
            case '1':
                System.out.println("The if:
                    System.out.println("if(condition) statement;"));
                System.out.println("else statement;");
                break;
```
case '2':
    System.out.println("The switch:
    System.out.println("switch(expression) {");
    System.out.println( "    case constant:");
    System.out.println("    statement sequence");
    System.out.println("    break;");
    System.out.println("    // ...");
    System.out.println("}"");
    break;

case '3':
    System.out.println("The for:
    System.out.println("for(init; condition; iteration)"");
    System.out.println("    statement;");
    break;

case '4':
    System.out.println("The while:
    System.out.println("while(condition) statement;");
    break;

case '5':
    System.out.println("The do-while:
    System.out.println("do {");
    System.out.println("    statement;");
    System.out.println("} while (condition);");
    break;

case '6':
    System.out.println("The break:
    System.out.println("break; or break label;");
    break;

case '7':
    System.out.println("The continue:
    System.out.println("continue; or continue label;");
    break;
}
System.out.println();
}

void showMenu() {
    System.out.println("Help on:");
    System.out.println("  1. if");
    System.out.println("  2. switch");
    System.out.println("  3. for");
    System.out.println("  4. while");
    System.out.println("  5. do-while");
    System.out.println("  6. break");
    System.out.println("  7. continue
    System.out.print("Choose one (q to quit): ");
}
When you try the program, you will find that it is functionally the same as before. The advantage to this approach is that you now have a help system component that can be reused whenever it is needed.

Constructors
In the preceding examples, the instance variables of each Vehicle object had to be set manually using a sequence of statements, such as:

```java
minivan.passengers = 7;
minivan.fuelcap = 16;
minivan.mpg = 21;
```
An approach like this would never be used in professionally written Java code. Aside from being error prone (you might forget to set one of the fields), there is simply a better way to accomplish this task: the constructor.

A constructor initializes an object when it is created. It has the same name as its class and is syntactically similar to a method. However, constructors have no explicit return type. Typically, you will use a constructor to give initial values to the instance variables defined by the class, or to perform any other startup procedures required to create a fully formed object.

All classes have constructors, whether you define one or not, because Java automatically provides a default constructor that initializes all member variables to their default values, which are zero, `null`, and `false`, for numeric types, reference types, and `boolean`s, respectively. However, once you define your own constructor, the default constructor is no longer used.

Here is a simple example that uses a constructor:

```java
// A simple constructor.

class MyClass {
    int x;

    MyClass() { // This is the constructor for MyClass.
        x = 10;
    }
}

class ConsDemo {
    public static void main(String args[]) {
        MyClass t1 = new MyClass();
        MyClass t2 = new MyClass();

        System.out.println(t1.x + " " + t2.x);
    }
}

In this example, the constructor for `MyClass` is

```java
MyClass() {
    x = 10;
}
```

This constructor assigns the instance variable `x` of `MyClass` the value 10. This constructor is called by `new` when an object is created. For example, in the line

```java
MyClass t1 = new MyClass();
```

the constructor `MyClass()` is called on the `t1` object, giving `t1.x` the value 10. The same is true for `t2`. After construction, `t2.x` has the value 10. Thus, the output from the program is

```
10 10
```
Parameterized Constructors

In the preceding example, a parameter-less constructor was used. Although this is fine for some situations, most often you will need a constructor that accepts one or more parameters. Parameters are added to a constructor in the same way that they are added to a method: just declare them inside the parentheses after the constructor’s name. For example, here, `MyClass` is given a parameterized constructor:

```java
// A parameterized constructor.

class MyClass {
    int x;

    MyClass(int i) {   // This constructor has a parameter.
        x = i;
    }
}

class ParmConsDemo {
    public static void main(String args[]) {
        MyClass t1 = new MyClass(10);
        MyClass t2 = new MyClass(88);

        System.out.println(t1.x + " " + t2.x);
    }
}
```

The output from this program is shown here:

```
10 88
```

In this version of the program, the `MyClass()` constructor defines one parameter called `i`, which is used to initialize the instance variable, `x`. Thus, when the line

```java
MyClass t1 = new MyClass(10);
```

executes, the value 10 is passed to `i`, which is then assigned to `x`.

Adding a Constructor to the Vehicle Class

We can improve the `Vehicle` class by adding a constructor that automatically initializes the `passengers`, `fuelcap`, and `mpg` fields when an object is constructed. Pay special attention to how `Vehicle` objects are created.
Both minivan and sportscar are initialized by the Vehicle() constructor when they are created. Each object is initialized as specified in the parameters to its constructor. For example, in the following line,

Vehicle minivan = new Vehicle(7, 16, 21);

the values 7, 16, and 21 are passed to the Vehicle() constructor when new creates the object. Thus, minivan's copy of passengers, fuelcap, and mpg will contain the values 7, 16, and 21, respectively. The output from this program is the same as the previous version.
The new Operator Revisited

Now that you know more about classes and their constructors, let’s take a closer look at the `new` operator. In the context of an assignment, the `new` operator has this general form:

```java
class-var = new class-name(arg-list);
```

Here, `class-var` is a variable of the class type being created. The `class-name` is the name of the class that is being instantiated. The class name followed by a parenthesized argument list (which can be empty) specifies the constructor for the class. If a class does not define its own constructor, `new` will use the default constructor supplied by Java. Thus, `new` can be used to create an object of any class type. The `new` operator returns a reference to the newly created object, which (in this case) is assigned to `class-var`.

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 about exceptions in Chapter 9.) 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.

Garbage Collection

As you have seen, objects are dynamically allocated from a pool of free memory by using the `new` operator. As explained, memory is not infinite, and the free memory can be exhausted. Thus, it is possible for `new` to fail because there is insufficient free memory to create the desired object. For this reason, a key component of any dynamic allocation scheme is the recovery of free memory from unused objects, making that memory available for subsequent reallocation. In some programming languages, the release of previously allocated memory is handled manually. However, Java uses a different, more trouble-free approach: garbage collection.

Java’s garbage collection system reclaims objects automatically—occurring transparently, behind the scenes, without any programmer intervention. 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 is released. This recycled memory can then be used for a subsequent allocation.

Ask the Expert

Q: Why don’t I need to use `new` for variables of the primitive types, such as `int` or `float`?

A: Java’s primitive types are not implemented as objects. Rather, because of efficiency concerns, they are implemented as “normal” variables. A variable of a primitive type actually contains the value that you have given it. As explained, object variables are references to the object. This layer of indirection (and other object features) adds overhead to an object that is avoided by a primitive type.
Garbage collection occurs only sporadically during the execution of your program. It will not occur simply because one or more objects exist that are no longer used. For efficiency, the garbage collector will usually run only when two conditions are met: there are objects to recycle, and there is a need to recycle them. Remember, garbage collection takes time, so the Java run-time system does it only when it is appropriate. Thus, you can’t know precisely when garbage collection will take place.

The finalize( ) Method
It is possible to define a method that will be called just before an object’s final destruction by the garbage collector. This method is called finalize( ), and it can be used to ensure that an object terminates cleanly. For example, you might use finalize( ) to make sure that an open file owned by that object is closed.

To add a finalizer to a class, you simply define the finalize( ) method. The Java run-time system 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 finalize( ) method has this general form:

```java
protected void finalize( )
{
    // finalization code here
}
```

Here, the keyword protected is a specifier that limits access to finalize( ). This and the other access specifiers are explained in Chapter 6.

It is important to understand that finalize( ) is called just before 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. For example, if your program ends before garbage collection occurs, finalize( ) will not execute. Therefore, it should be used as a “backup” procedure to ensure the proper handling of some resource, or for special-use applications, not as the means that your program uses in its normal operation. In short, finalize( ) is a specialized method that is seldom needed by most programs.

Ask the Expert

Q: I know that C++ defines things called destructors, which are automatically executed when an object is destroyed. Is finalize( ) similar to a destructor?

A: Java does not have destructors. Although it is true that the finalize( ) method approximates the function of a destructor, it is not the same. For example, a C++ destructor is always called just before an object goes out of scope, but you can’t know when finalize( ) will be called for any specific object. Frankly, because of Java’s use of garbage collection, there is little need for a destructor.
Try This 4-2  Demonstrate Garbage Collection and Finalization

```
Finalize.java
```

Because garbage collection runs sporadically in the background, it is not trivial to demonstrate it. However, one way it can be done is through the use of the `finalize()` method. Recall that `finalize()` is called when an object is about to be recycled. As explained, objects are not necessarily recycled as soon as they are no longer needed. Instead, the garbage collector waits until it can perform its collection efficiently, usually when there are many unused objects. Thus, to demonstrate garbage collection via the `finalize()` method, you often need to create and destroy a large number of objects—and this is precisely what you will do in this project.

1. Create a new file called `Finalize.java`.
2. Create the `FDemo` class shown here:

   ```java
class FDemo {
    int x;

    FDemo(int i) {
        x = i;
    }

    // called when object is recycled
    protected void finalize() {
        System.out.println("Finalizing " + x);
    }

    // generates an object that is immediately destroyed
    void generator(int i) {
        FDemo o = new FDemo(i);
    }
}
```

The constructor sets the instance variable `x` to a known value. In this example, `x` is used as an object ID. The `finalize()` method displays the value of `x` when an object is recycled. Of special interest is `generator()`. This method creates and then promptly discards an `FDemo` object. You will see how this is used in the next step.
3. Create the `Finalize` class, shown here:
class Finalize {
    public static void main(String[] args) {
        int count;

        FDemo ob = new FDemo(0);

        /* Now, generate a large number of objects. At
        some point, garbage collection will occur.
        Note: you might need to increase the number
        of objects generated in order to force
        garbage collection. */

        for (count = 1; count < 100000; count++)
            ob.generator(count);
    }
}

This class creates an initial FDemo object called ob. Then, using ob, it creates 100,000 objects by calling generator( ) on ob. This has the net effect of creating and discarding 100,000 objects. At various points in the middle of this process, garbage collection will take place. Precisely how often or when depends upon several factors, such as the initial amount of free memory and the operating system. However, at some point, you will start to see the messages generated by finalize( ). If you don't see the messages, try increasing the number of objects being generated by raising the count in the for loop.

4. Here is the entire Finalize.java program:
Before concluding this chapter, it is necessary to introduce **this**. When a method is called, it is automatically passed an implicit argument that is a reference to the invoking object (that is, the object on which the method is called). This reference is called **this**. To understand **this**, first consider a program that creates a class called `Pwr` that computes the result of a number raised to some integer power:

```java
/*
 Try This 4-2
 Demonstrate garbage collection and the finalize() method.
 */

class FDemo {
    int x;

    FDemo(int i) {
        x = i;
    }

    // called when object is recycled
    protected void finalize() {
        System.out.println("Finalizing "+x);
    }

    // generates an object that is immediately destroyed
    void generator(int i) {
        FDemo o = new FDemo(i);
    }
}

class Finalize {
    public static void main(String args[]) {
        int count;
        FDemo ob = new FDemo(0);

        /* Now, generate a large number of objects. At some point, garbage collection will occur.
        Note: you might need to increase the number of objects generated in order to force
garbage collection. */

        for(count=1; count < 100000; count++)
            ob.generator(count);
    }
}
```
As you know, within a method, the other members of a class can be accessed directly, without any object or class qualification. Thus, inside `get_pwr()`, the statement

```
return val;
```

means that the copy of `val` associated with the invoking object will be returned. However, the same statement can also be written like this:

```
return this.val;
```

Here, `this` refers to the object on which `get_pwr()` was called. Thus, `this.val` refers to that object’s copy of `val`. For example, if `get_pwr()` had been invoked on `x`, then `this` in the preceding statement would have been referring to `x`. Writing the statement without using `this` is really just shorthand.

Here is the entire `Pwr` class written using the `this` reference:
Actually, no Java programmer would write `Pwr` as just shown because nothing is gained, and the standard form is easier. However, `this` has some important uses. For example, the Java syntax permits the name of a parameter or a local variable to be the same as the name of an instance variable. When this happens, the local name hides the instance variable. You can gain access to the hidden instance variable by referring to it through `this`. For example, the following is a syntactically valid way to write the `Pwr()` constructor.

```java
class Pwr {
    double b;
    int e;
    double val;

    Pwr(double base, int exp) {
        this.b = base;
        this.e = exp;

        this.val = 1;
        if(exp==0) return;
        for( ; exp>0; exp--) this.val = this.val * base;
    }

double get_pwr() {
    return this.val;
}
}
```

In this version, the names of the parameters are the same as the names of the instance variables, thus hiding them. However, `this` is used to “uncover” the instance variables.

---

**Chapter 4 Self Test**

1. What is the difference between a class and an object?
2. How is a class defined?
3. What does each object have its own copy of?
4. Using two separate statements, show how to declare an object called `counter` of a class called `MyCounter`. 

5. Show how a method called `myMeth()` is declared if it has a return type of `double` and has two `int` parameters called `a` and `b`.

6. How must a method return if it returns a value?

7. What name does a constructor have?

8. What does `new` do?

9. What is garbage collection, and how does it work? What is `finalize()`?

10. What is `this`?

11. Can a constructor have one or more parameters?

12. If a method returns no value, what must its return type be?
Chapter 5
More Data Types and Operators

Key Skills & Concepts

- Understand and create arrays
- Create multidimensional arrays
- Create irregular arrays
- Know the alternative array declaration syntax
- Assign array references
- Use the `length` array member
- Use the for-each style `for` loop
- Work with strings
- Apply command-line arguments
- Use the bitwise operators
- Apply the `?` operator

This chapter returns to the subject of Java’s data types and operators. It discusses arrays, the `String` type, the bitwise operators, and the `?` ternary operator. It also covers Java’s for-each style `for` loop. Along the way, command-line arguments are described.
Arrays

An array is a collection of variables of the same type, referred to by a common name. In Java, arrays can have one or more dimensions, although the one-dimensional array is the most common. Arrays are used for a variety of purposes because they offer a convenient means of grouping together related variables. For example, you might use an array to hold a record of the daily high temperature for a month, a list of stock price averages, or a list of your collection of programming books.

The principal advantage of an array is that it organizes data in such a way that it can be easily manipulated. For example, if you have an array containing the incomes for a selected group of households, it is easy to compute the average income by cycling through the array. Also, arrays organize data in such a way that it can be easily sorted.

Although arrays in Java can be used just like arrays in other programming languages, they have one special attribute: they are implemented as objects. This fact is one reason that a discussion of arrays was deferred until objects had been introduced. By implementing arrays as objects, several important advantages are gained, not the least of which is that unused arrays can be garbage collected.

One-Dimensional Arrays

A one-dimensional array is a list of related variables. Such lists are common in programming. For example, you might use a one-dimensional array to store the account numbers of the active users on a network. Another array might be used to store the current batting averages for a baseball team.

To declare a one-dimensional array, you can use this general form:

```
type array-name[ ] = new type[size];
```

Here, `type` declares the element type of the array. (The element type is also commonly referred to as the base type.) The element type determines the data type of each element contained in the array. The number of elements that the array will hold is determined by `size`. Since arrays are implemented as objects, the creation of an array is a two-step process. First, you declare an array reference variable. Second, you allocate memory for the array, assigning a reference to that memory to the array variable. Thus, arrays in Java are dynamically allocated using the `new` operator.

Here is an example. The following creates an `int` array of 10 elements and links it to an array reference variable named `sample`:

```
int sample[] = new int[10];
```

This declaration works just like an object declaration. The `sample` variable holds a reference to the memory allocated by `new`. This memory is large enough to hold 10 elements of type `int`. As with objects, it is possible to break the preceding declaration in two. For example:

```
int sample[];
sample = new int[10];
```

In this case, when `sample` is first created, it refers to no physical object. It is only after the second statement executes that `sample` is linked with an array.

An individual element within an array is accessed by use of an index. An index describes the position of an element within an array. In Java, all arrays have zero as the index of their first element.
Because **sample** has 10 elements, it has index values of 0 through 9. To index an array, specify the number of the element you want, surrounded by square brackets. Thus, the first element in **sample** is **sample[0]**, and the last element is **sample[9]**. For example, the following program loads **sample** with the numbers 0 through 9:

```java
// Demonstrate a one-dimensional array.
class ArrayDemo {
    public static void main(String args[]) {
        int sample[] = new int[10];
        int i;

        for(i = 0; i < 10; i = i+1)
            sample[i] = i;

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

The output from the program is shown here:

This is sample[0]: 0
This is sample[1]: 1
This is sample[2]: 2
This is sample[3]: 3
This is sample[4]: 4
This is sample[5]: 5
This is sample[6]: 6
This is sample[7]: 7
This is sample[8]: 8
This is sample[9]: 9

Conceptually, the **sample** array looks like this:

![Conceptual representation of sample array]

Arrays are common in programming because they let you deal easily with large numbers of related variables. For example, the following program finds the minimum and maximum values stored in the **nums** array by cycling through the array using a **for** loop:
The output from the program is shown here:

```
min and max: -978 100123
```

In the preceding program, the `nums` array was given values by hand, using 10 separate assignment statements. Although perfectly correct, there is an easier way to accomplish this. Arrays can be initialized when they are created. The general form for initializing a one-dimensional array is shown here:

```
type array-name[] = { val1, val2, val3, ..., valN };
```

Here, the initial values are specified by `val1` through `valN`. They are assigned in sequence, left to right, in index order. Java automatically allocates an array large enough to hold the initializers that you specify. There is no need to explicitly use the `new` operator. For example, here is a better way to write the `MinMax` program:
Array boundaries are strictly enforced in Java; it is a run-time error to overrun or underrun the end of an array. If you want to confirm this for yourself, try the following program that purposely overruns an array:

```java
// Use array initializers.
class MinMax2 {
    public static void main(String args[]) {
        int nums[] = { 99, -10, 100123, 18, -978, 5623, 463, -9, 287, 49 }; // Array initializers
        int min, max;
        min = max = nums[0];
        for(int i=1; i < 10; i++) {
            if(nums[i] < min) min = nums[i];
            if(nums[i] > max) max = nums[i];
        }
        System.out.println("Min and max: " + min + " " + max);
    }
}
```

As soon as \( i \) reaches 10, an \texttt{ArrayIndexOutOfBoundsException} is generated and the program is terminated.

**Try This 5-1 Sorting an Array**

Because a one-dimensional array organizes data into an indexable linear list, it is the perfect data structure for sorting. In this project you will learn a simple way to sort an array. As you may know, there are a number of different sorting algorithms. There are the quick sort, the shaker sort, and the shell sort, to name just three. However, the best known, simplest, and easiest to understand is called the Bubble sort. Although the Bubble sort is not very efficient—in fact, its performance is unacceptable for sorting large arrays—it may be used effectively for sorting small arrays.

1. Create a file called \texttt{Bubble.java}.
The Bubble sort gets its name from the way it performs the sorting operation. It uses the repeated comparison and, if necessary, exchange of adjacent elements in the array. In this process, small values move toward one end and large ones toward the other end. The process is conceptually similar to bubbles finding their own level in a tank of water. The Bubble sort operates by making several passes through the array, exchanging out-of-place elements when necessary. The number of passes required to ensure that the array is sorted is equal to one less than the number of elements in the array.

Here is the code that forms the core of the Bubble sort. The array being sorted is called `nums`.

```c
// This is the Bubble sort.
for(a=1; a < size; a++)
    for(b=size-1; b >= a; b--)
    {
        if(nums[b-1] > nums[b]) { // if out of order
            // exchange elements
            t = nums[b-1];
            nums[b-1] = nums[b];
            nums[b] = t;
        }
    }
```

Notice that sort relies on two `for` loops. The inner loop checks adjacent elements in the array, looking for out-of-order elements. When an out-of-order element pair is found, the two elements are exchanged. With each pass, the smallest of the remaining elements moves into its proper location. The outer loop causes this process to repeat until the entire array has been sorted.

3. Here is the entire Bubble program:
class Bubble {
    public static void main(String args[]) {
        int nums[] = { 99, -10, 100123, 18, -978, 5623, 463, -9, 287, 49 };
        int a, b, t;
        int size;
        size = 10; // number of elements to sort

        // display original array
        System.out.print("Original array is:");
        for(int i=0; i < size; i++)
            System.out.print(" "+nums[i]);
        System.out.println();

        // This is the Bubble sort.
        for(a=1; a < size; a++)
            for(b=size-1; b >= a; b--){
                if(nums[b-1] > nums[b]) { // if out of order
                    // exchange elements
                    t = nums[b-1];
                    nums[b-1] = nums[b];
                    nums[b] = t;
                }
            }

        // display sorted array
        System.out.print("Sorted array is:");
        for(int i=0; i < size; i++)
            System.out.print(" "+nums[i]);
        System.out.println();
    }
}

The output from the program is shown here:

Original array is: 99 -10 100123 18 -978 5623 463 -9 287 49
Sorted array is: -978 -10 -9 18 49 99 287 463 5623 100123

4. Although the Bubble sort is good for small arrays, it is not efficient when used on larger ones. The best general-purpose sorting algorithm is the Quicksort. The Quicksort, however, relies on features of Java that you have not yet learned about.
Multidimensional Arrays
Although the one-dimensional array is the most commonly used array in programming, multidimensional arrays (arrays of two or more dimensions) are certainly not rare. In Java, a multidimensional array is an array of arrays.

Two-Dimensional Arrays
The simplest form of the multidimensional array is the two-dimensional array. A two-dimensional array is, in essence, a list of one-dimensional arrays. To declare a two-dimensional integer array `table` of size 10, 20 you would write

```java
int table[][] = new int[10][20];
```

Pay careful attention to the declaration. Unlike some other computer languages, which use commas to separate the array dimensions, Java places each dimension in its own set of brackets. Similarly, to access point 3, 5 of array `table`, you would use `table[3][5]`.

In the next example, a two-dimensional array is loaded with the numbers 1 through 12.

```java
// Demonstrate a two-dimensional array.
class TwoD {
    public static void main(String args[]) {
        int t, i;
        int table[][] = new int[3][4];

        for(t=0; t < 3; ++t) {
            for(i=0; i < 4; ++i) {
                table[t][i] = (t*4)+i+1;
                System.out.print(table[t][i] + " ");
            }
            System.out.println();
        }
    }
}
```

In this example, `table[0][0]` will have the value 1, `table[0][1]` the value 2, `table[0][2]` the value 3, and so on. The value of `table[2][3]` will be 12. Conceptually, the array will look like that shown in Figure 5-1.
Irregular Arrays

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

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

Although 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 separately, you do not need to allocate the same number of elements for each index. Since multidimensional arrays are implemented as arrays of arrays, the length of each array is under your control. For example, assume you are writing a program that stores the number of passengers that ride an airport shuttle. If the shuttle runs 10 times a day during the week and twice a day on Saturday and Sunday, you could use the `riders` array shown in the following program to store the information. Notice that the length of the second dimension for the first five indices is 10 and the length of the second dimension for the last two indices is 2.
The use of irregular (or ragged) multidimensional arrays is not recommended for most 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), an irregular array might be a perfect solution.

Arrays of Three or More Dimensions
Java allows arrays with more than two dimensions. Here is the general form of a multidimensional array declaration:
type name[ ][ ][ ] = new type[size1][size2][sizeN];

For example, the following declaration creates a $4 \times 10 \times 3$ three-dimensional integer array.

```
int multidim[][][] = new int[4][10][3];
```

**Initializing Multidimensional Arrays**

A multidimensional array can be initialized by enclosing each dimension's initializer list within its own set of curly braces. For example, the general form of array initialization for a two-dimensional array is shown here:

```
type-specifier array_name[][] = {
    { val, val, val, ..., val },
    { val, val, val, ..., val },
    ...
    { val, val, val, ..., val }
};
```

Here, `val` indicates an initialization value. Each inner block designates a row. Within each row, the first value will be stored in the first position of the subarray, the second value in the second position, and so on. Notice that commas separate the initializer blocks and that a semicolon follows the closing `}`.

For example, the following program initializes an array called `sqrs` with the numbers 1 through 10 and their squares:
Here is the output from the program:

```
1 1
2 4
3 9
4 16
5 25
6 36
7 49
8 64
9 81
10 100
```

**Alternative Array Declaration Syntax**

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

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

Here, the square brackets follow the type specifier, not the name of the array variable. For example, the following two declarations are equivalent:
int counter[] = new int[3];
int[] counter = new int[3];

The following declarations are also equivalent:

char table[][] = new char[3][4];
char[][] table = new char[3][4];

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

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

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

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

The alternative declaration form is also useful when specifying an array as a return type for a method. For example,

int[] someMeth() { ... }

This declares that someMeth() returns an array of type int.

Because both forms of array declarations are in widespread use, both are used in this book.

Assigning Array References
As with other objects, when you assign one array reference variable to another, you are simply changing what object that variable refers to. You are not causing a copy of the array to be made, nor are you causing the contents of one array to be copied to the other. For example, consider this program:
As the output shows, after the assignment of `nums1` to `nums2`, both array reference variables refer to the same object.

**Using the length Member**

Because arrays are implemented as objects, each array has associated with it a `length` instance variable that contains the number of elements that the array can hold. (In other words, `length` contains the size of the array.) Here is a program that demonstrates this property:
// Use the length array member.
class LengthDemo {
    public static void main(String args[]) {
        int list[] = new int[10];
        int nums[] = { 1, 2, 3};
        int table[][] = { // a variable-length table
            {1, 2, 3},
            {4, 5},
            {6, 7, 8, 9}
        };

        System.out.println("length of list is " + list.length);
        System.out.println("length of nums is " + nums.length);
        System.out.println("length of table is " + table.length);
        System.out.println("length of table[0] is " + table[0].length);
        System.out.println("length of table[1] is " + table[1].length);
        System.out.println("length of table[2] is " + table[2].length);
        System.out.println();

        // use length to initialize list
        for(int i=0; i < list.length; i++)
            list[i] = i * i;

        System.out.print("Here is list: ");
        // now use length to display list
        for(int i=0; i < list.length; i++)
            System.out.print(list[i] + " ");
        System.out.println();
    }
}

This program displays the following output:

length of list is 10
length of nums is 3
length of table is 3
length of table[0] is 3
length of table[1] is 2
length of table[2] is 4

Here is list: 0 1 4 9 16 25 36 49 64 81

Pay special attention to the way length is used with the two-dimensional array table. As explained, a two-dimensional array is an array of arrays. Thus, when the expression

```
    table.length
```

is used, it obtains the number of arrays stored in table, which is 3 in this case. To obtain the length of any individual array in table, you will use an expression such as this,

```
    table[0].length
```
which, in this case, obtains the length of the first array.

One other thing to notice in LengthDemo is the way that list.length is used by the for loops to govern the number of iterations that take place. Since each array carries with it its own length, you can use this information rather than manually keeping track of an array’s size. Keep in mind that the value of list.length has nothing to do with the number of elements that are actually in use. It contains the number of elements that the array is capable of holding.

The inclusion of the list.length member simplifies many algorithms by making certain types of array operations easier—and safer—to perform. For example, the following program uses list.length to copy one array to another while preventing an array overrun and its attendant runtime exception.

```java
// Use length variable to help copy an array.
class ACopy {
    public static void main(String args[]) {
        int i;
        int nums1[] = new int[10];
        int nums2[] = new int[10];

        for(i=0; i < nums1.length; i++)
            nums1[i] = i;

        // copy nums1 to nums2
        if(nums2.length >= nums1.length) // Use length to compare array sizes.
            for(i = 0; i < nums1.length; i++)
                nums2[i] = nums1[i];

        for(i=0; i < nums2.length; i++)
            System.out.print(nums2[i] + " ");
    }
}
```

Here, list.length helps perform two important functions. First, it is used to confirm that the target array is large enough to hold the contents of the source array. Second, it provides the termination condition of the for loop that performs the copy. Of course, in this simple example, the sizes of the arrays are easily known, but this same approach can be applied to a wide range of more challenging situations.

---

**Try This 5-2 A Queue Class**

As you may know, a data structure is a means of organizing data. The simplest data structure is the array, which is a linear list that supports random access to its elements. Arrays are often used as the underpinning for more sophisticated data structures, such as stacks and queues. A stack is a list in which elements can be accessed in first-in, last-out (FILO) order only. A queue is a list in which elements can be accessed in first-in, first-out (FIFO) order only. Thus, a stack is like a stack of plates on a table—the first down is the last to be used. A queue is like a line at a bank—the first in line is the first served.

What makes data structures such as stacks and queues interesting is that they combine storage for
information with the methods that access that information. Thus, stacks and queues are data engines in which storage and retrieval are provided by the data structure itself, not manually by your program. Such a combination is, obviously, an excellent choice for a class, and in this project you will create a simple queue class.

In general, queues support two basic operations: put and get. Each put operation places a new element on the end of the queue. Each get operation retrieves the next element from the front of the queue. Queue operations are consumptive: once an element has been retrieved, it cannot be retrieved again. The queue can also become full, if there is no space available to store an item, and it can become empty, if all of the elements have been removed.

One last point: There are two basic types of queues—circular and noncircular. A circular queue reuses locations in the underlying array when elements are removed. A noncircular queue does not reuse locations and eventually becomes exhausted. For the sake of simplicity, this example creates a noncircular queue, but with a little thought and effort, you can easily transform it into a circular queue.

1. Create a file called `QDemo.java`.

2. Although there are other ways to support a queue, the method we will use is based upon an array. That is, an array will provide the storage for the items put into the queue. This array will be accessed through two indices. The put index determines where the next element of data will be stored. The get index indicates at what location the next element of data will be obtained. Keep in mind that the get operation is consumptive, and it is not possible to retrieve the same element twice. Although the queue that we will be creating stores characters, the same logic can be used to store any type of object. Begin creating the `Queue` class with these lines:

   ```java
class Queue {
    char q[]; // this array holds the queue
    int putloc, getloc; // the put and get indices

    Queue(int size) {
        q = new char[size]; // allocate memory for queue
        putloc = getloc = 0;
    }

    Notice that the put and get indices are initially set to zero.

4. The `put()` method, which stores elements, is shown next:

   ```java
   // put a character into the queue
   void put(char ch) {
      if(putloc==q.length) {
         System.out.println(" - Queue is full.");
         return;
      }

      q[putloc++] = ch;
   }
   ```

   The method begins by checking for a queue-full condition. If `putloc` is equal to one past the last
location in the q array, there is no more room in which to store elements. Otherwise, the new element is stored at that location and putloc is incremented. Thus, putloc is always the index where the next element will be stored.

5. To retrieve elements, use the get( ) method, shown next:

```java
// get a character from the queue
char get() {
    if(getloc == putloc) {
        System.out.println(" - Queue is empty.");
        return (char) 0;
    }
    return q[getloc++];
}
```

Notice first the check for queue-empty. If getloc and putloc both index the same element, the queue is assumed to be empty. This is why getloc and putloc were both initialized to zero by the Queue constructor. Then, the next element is returned. In the process, getloc is incremented. Thus, getloc always indicates the location of the next element to be retrieved.

6. Here is the entire QDemo.java program:

```java
/*
   Try This 5-2

   A queue class for characters.
*/

class Queue {
    char q[]; // this array holds the queue
    int putloc, getloc; // the put and get indices

    Queue(int size) {
        q = new char[size]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // put a character into the queue
    void put(char ch) {
        if(putloc == q.length) {
            System.out.println(" - Queue is full.");
            return;
        }
    }
```
q[putloc++] = ch;
}

// get a character from the queue
char get() {
  if(getloc == putloc) {
    System.out.println(" - Queue is empty.");
    return (char) 0;
  }

  return q[getloc++];
}

// Demonstrate the Queue class.
class QDemo {
  public static void main(String args[]) {
    Queue bigQ = new Queue(100);
    Queue smallQ = new Queue(4);
    char ch;
    int i;

    System.out.println("Using bigQ to store the alphabet.");
    // put some numbers into bigQ
    for(i=0; i < 26; i++)
      bigQ.put((char) ('A' + i));

    // retrieve and display elements from bigQ
    System.out.println("Contents of bigQ: ");
    for(i=0; i < 26; i++) {
      ch = bigQ.get();
      if(ch != (char) 0) System.out.print(ch);
    }

    System.out.println("\\n");

    System.out.println("Using smallQ to generate errors.");
    // Now, use smallQ to generate some errors
    for(i=0; i < 5; i++) {
      System.out.println("Attempting to store " +
                        (char) ('Z' - i));
      smallQ.put((char) ('Z' - i));
    }
    System.out.println();

    // more errors on smallQ
    System.out.println("Contents of smallQ: ");
    for(i=0; i < 5; i++) {
      ch = smallQ.get();
      if(ch != (char) 0) System.out.print(ch);
    }
  }
}
7. The output produced by the program is shown here:

Using bigQ to store the alphabet.
Contents of bigQ: ABCDEFGHIJKLMNOPQRSTUVWXYZ

Using smallQ to generate errors.

Attempting to store Z
Attempting to store Y
Attempting to store X
Attempting to store W
Attempting to store V - Queue is full.

Contents of smallQ: ZYXW - Queue is empty.

8. On your own, try modifying Queue so that it stores other types of objects. For example, have it store ints or doubles.

The For-Each Style for Loop

When working with arrays, it is common to encounter situations in which each element in an array must be examined, from start to finish. For example, to compute the sum of the values held in an array, each element in the array must be examined. The same situation occurs when computing an average, searching for a value, copying an array, and so on. Because such “start to finish” operations are so common, Java defines a second form of the for loop that streamlines this operation.

The second form of the for implements a “for-each” style loop. A for-each loop cycles through a collection of objects, such as an array, in strictly sequential fashion, from start to finish. In recent years, for-each style loops have gained popularity among both computer language designers and programmers. Originally, Java did not offer a for-each style loop. However, with the release of JDK 5, the for loop was enhanced to provide this option. The for-each style of for is also referred to as the enhanced for loop. Both terms are used in this book.

The general form of the for-each style for is shown here.

for(type itr-var : collection) statement-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 book is the array. 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. Thus, when iterating over an array of size N, the enhanced for obtains the elements in the array in index order, from 0 to N–1.

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. Furthermore, the starting and ending value for the loop control variable, and its increment, must be explicitly specified.

### Ask the Expert

**Q:** Aside from arrays, what other types of collections can the for-each style for loop cycle through?

**A:** One of the most important uses of the for-each style for is to cycle through the contents of a collection defined by the Collections Framework. The Collections Framework is a set of classes that implement various data structures, such as lists, vectors, sets, and maps. A discussion of the Collections Framework is beyond the scope of this book, but complete coverage of the Collections Framework can be found in my book *Java: The Complete Reference, Ninth Edition* (Oracle Press/McGraw-Hill Education, 2014).

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 `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, it also prevents boundary errors.

Here is an entire program that demonstrates the for-each version of the for just described:
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 for automatically cycles through an array in sequence from the lowest index to the highest.

Although the for-each for loop iterates until all elements in an array have been examined, it is possible to terminate the loop early by using a break statement. For example, this loop sums only the first five elements of nums:

```
    // Sum only the first 5 elements.
    for(int x : nums) {
        System.out.println("Value is: " + x);
        sum += x;
        if(x == 5) break; // stop the loop when 5 is obtained
    }
```

There is one important point to understand about the for-each style for 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:
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 `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.
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:

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. However, 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.
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.

Now that the for-each style for has been introduced, it will be used where appropriate throughout the remainder of this book.

Strings

From a day-to-day programming standpoint, one of the most important of Java’s data types is String. String defines and supports character strings. In many other programming languages, a string is an array of characters. This is not the case with Java. In Java, strings are objects.

Actually, you have been using the String class since Chapter 1, but you did not know it. When you create a string literal, you are actually creating a String object. For example, in the statement

```java
System.out.println("In Java, strings are objects.");
```

the string "In Java, strings are objects." is automatically made into a String object by Java. Thus, the use of the String class has been “below the surface” in the preceding programs. In the following
sections, you will learn to handle it explicitly. Be aware, however, that the String class is quite large, and we will only scratch its surface here. It is a class that you will want to explore on its own.

**Constructing Strings**

You can construct a String just like you construct any other type of object: by using `new` and calling the String constructor. For example:

```java
String str = new String("Hello");
```

This creates a String object called `str` that contains the character string "Hello". You can also construct a String from another String. For example:

```java
String str = new String("Hello");
String str2 = new String(str);
```

After this sequence executes, `str2` will also contain the character string "Hello".

Another easy way to create a String is shown here:

```java
String str = "Java strings are powerful."
```

In this case, `str` is initialized to the character sequence "Java strings are powerful."

Once you have created a String object, you can use it anywhere that a quoted string is allowed. For example, you can use a String object as an argument to `println()`, as shown in this example:

```java
// Introduce String.
class StringDemo {
    public static void main(String args[]) {
        // declare strings in various ways
        String str1 = new String("Java strings are objects.");
        String str2 = "They are constructed various ways."
        String str3 = new String(str2);

        System.out.println(str1);
        System.out.println(str2);
        System.out.println(str3);
    }
}
```

The output from the program is shown here:

Java strings are objects.
They are constructed various ways.
They are constructed various ways.

**Operating on Strings**

The String class contains several methods that operate on strings. Here are the general forms for a few:
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean equals(str)</td>
<td>Returns true if the invoking string contains the same character sequence as str.</td>
</tr>
<tr>
<td>int length()</td>
<td>Obtains the length of a string.</td>
</tr>
<tr>
<td>char charAt(index)</td>
<td>Obtains the character at the index specified by index.</td>
</tr>
<tr>
<td>int compareTo(str)</td>
<td>Returns less than zero if the invoking string is less than str, greater than zero if the invoking string is greater than str, and zero if the strings are equal.</td>
</tr>
<tr>
<td>int indexOf(str)</td>
<td>Searches the invoking string for the substring specified by str. Returns the index of the first match or –1 on failure.</td>
</tr>
<tr>
<td>int lastIndexOf(str)</td>
<td>Searches the invoking string for the substring specified by str. Returns the index of the last match or –1 on failure.</td>
</tr>
</tbody>
</table>

Here is a program that demonstrates these methods:
This program generates the following output:

Length of str1: 45
When it comes to Web programming, Java is #1.
str1 equals str2
str1 does not equal str3
str1 is greater than str3
Index of first occurrence of One: 0
Index of last occurrence of One: 14

You can concatenate (join together) two strings using the + operator. For example, this statement
String str1 = "One";
String str2 = "Two";
String str3 = "Three";
String str4 = str1 + str2 + str3;

initializes str4 with the string "OneTwoThree".

Ask the Expert

Q: Why does String define the equals() method? Can’t I just use ==?

A: The equals() method compares the character sequences of two String objects for equality. Applying the == to two String references simply determines whether the two references refer to the same object.

Arrays of Strings

Like any other data type, strings can be assembled into arrays. For example:

```java
// Demonstrate String arrays.
class StringArrays {

    public static void main(String args[]) {
        String strs[] = { "This", "is", "a", "test." };

        System.out.println("Original array: ");
        for(String s : strs)
            System.out.print(s + " ");
        System.out.println("\n");

        // change a string
        strs[1] = "was";
        strs[3] = "test, too!";

        System.out.println("Modified array: ");
        for(String s : strs)
            System.out.print(s + " ");
    }
}
```

Here is the output from this program:
Strings Are Immutable

The contents of a String object are immutable. That is, once created, the character sequence that makes up the string cannot be altered. This restriction allows Java to implement strings more efficiently. Even though this probably sounds like a serious drawback, it isn’t. When you need a string that is a variation on one that already exists, simply create a new string that contains the desired changes. Since unused String objects are automatically garbage collected, you don’t even need to worry about what happens to the discarded strings. It must be made clear, however, that String reference variables may, of course, change the object to which they refer. It is just that the contents of a specific String object cannot be changed after it is created.

Ask the Expert

Q: You say that once created, String objects are immutable. I understand that, from a practical point of view, this is not a serious restriction, but what if I want to create a string that can be changed?

A: You’re in luck. Java offers a class called StringBuffer, which creates string objects that can be changed. For example, in addition to the charAt() method, which obtains the character at a specific location, StringBuffer defines setCharAt(), which sets a character within the string. Java also supplies StringBuilder, which is related to StringBuffer, and also supports strings that can be changed. However, for most purposes you will want to use String, not StringBuffer or StringBuilder.

To fully understand why immutable strings are not a hindrance, we will use another of String’s methods: substring(). The substring() method returns a new string that contains a specified portion of the invoking string. Because a new String object is manufactured that contains the substring, the original string is unaltered, and the rule of immutability remains intact. The form of substring() that we will be using is shown here:

String substring(int startIndex, int endIndex)

Here, startIndex specifies the beginning index, and endIndex specifies the stopping point. Here is a program that demonstrates substring() and the principle of immutable strings:
Here is an example that demonstrates controlling a `switch` with a `String`:
As you would expect, the output from the program is

```
Canceling
```

The string contained in `command` (which is "cancel" 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 can be very convenient and can improve the readability of some code. 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 less efficient 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.

**Using Command-Line Arguments**

Now that you know about the `String` class, you can understand the `args` parameter to `main( )` that has been in every program shown so far. Many programs accept what are called *command-line arguments*. 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 the `String` array passed to `main( )`. For example, the following program displays all of the command-line arguments that it is called with:
If `CLDemo` is executed like this,

```java
class CLDemo {
    public static void main(String args[]) {
        System.out.println("There are " + args.length + " command-line arguments.");
        System.out.println("They are: ");
        for(int i=0; i<args.length; i++)
            System.out.println("arg[" + i + "]: " + args[i]);
    }
}
```

you will see the following output:

```
There are 3 command-line arguments.
They are:
arg[0]: one
arg[1]: two
arg[2]: three
```

Notice that the first argument is stored at index 0, the second argument is stored at index 1, and so on.

To get a taste of the way command-line arguments can be used, consider the next program. It takes one command-line argument that specifies a person’s name. It then searches through a two-dimensional array of strings for that name. If it finds a match, it displays that person’s telephone number.
Here is a sample run:

```
java Phone Mary
Mary: 555-8976
```

The Bitwise Operators

In Chapter 2 you learned about Java’s arithmetic, relational, and logical operators. Although these are the most commonly used, Java provides additional operators that expand the set of problems to which Java can be applied: the bitwise operators. The bitwise operators can be used on values of type `long`, `int`, `short`, `char`, or `byte`. Bitwise operations cannot be used on `boolean`, `float`, `double`, or class types. They are called the bitwise operators because they are used to test, set, or shift the individual bits that make up a value. Bitwise operations are important to a wide variety of systems-level programming tasks in which status information from a device must be interrogated or constructed. Table 5-1 lists the bitwise operators.
The Bitwise AND, OR, XOR, and NOT Operators

The bitwise operators AND, OR, XOR, and NOT are &, |, ^, and ~. They perform the same operations as their Boolean logical equivalents described in Chapter 2. The difference is that the bitwise operators work on a bit-by-bit basis. The following table shows the outcome of each operation using 1’s and 0’s:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<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>Unsigned shift right</td>
</tr>
<tr>
<td>&lt;&lt;</td>
<td>Shift left</td>
</tr>
<tr>
<td>~</td>
<td>One’s complement (unary NOT)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>p</th>
<th>q</th>
<th>p &amp; q</th>
<th>p</th>
<th>q</th>
<th>p</th>
<th>q</th>
<th>p</th>
<th>q</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
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<td>1</td>
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<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

In terms of its most common usage, you can think of the bitwise AND as a way to turn bits off. That is, any bit that is 0 in either operand will cause the corresponding bit in the outcome to be set to 0. For example:

```
  1 1 0 1 0 0 1 1
&  1 0 1 0 1 0 1 0
  1 0 0 0 0 0 1 0
```

The following program demonstrates the & by turning any lowercase letter into uppercase by resetting the 6th bit to 0. As the Unicode/ASCII character set is defined, the lowercase letters are the same as the uppercase ones except that the lowercase ones are greater in value by exactly 32. Therefore, to transform a lowercase letter to uppercase, just turn off the 6th bit, as this program illustrates:
The output from this program is shown here:

```
// Uppercase letters.
class UpCase {
    public static void main(String args[]) {
        char ch;

        for(int i=0; i < 10; i++) {
            ch = (char) ('a' + i);
            System.out.print(ch);

            // This statement turns off the 6th bit.
            ch = (char) ((int) ch & 65503); // ch is now uppercase
            System.out.print(ch + " ");
        }
    }
}
```

The output is shown here:
aA bB cC dD eE fF gG hH iI jJ

The value 65,503 used in the AND statement is the decimal representation of 1111 1111 1101 1111. Thus, the AND operation leaves all bits in `ch` unchanged except for the 6th one, which is set to 0.

The AND operator is also useful when you want to determine whether a bit is on or off. For example, this statement determines whether bit 4 in `status` is set:

```java
if((status & 8) != 0) System.out.println("bit 4 is on");
```

The number 8 is used because it translates into a binary value that has only the 4th bit set. Therefore, the if statement can succeed only when bit 4 of `status` is also on. An interesting use of this concept is to show the bits of a `byte` value in binary format.

```
// Display the bits within a byte.
class ShowBits {
    public static void main(String args[]) {
        int t;
        byte val;

        val = 123;
        for(t=128; t > 0; t = t/2) {
            if((val & t) != 0) System.out.print("1 ");
            else System.out.print("0 ");
        }
    }
}
```

The output is shown here:

```
0 1 1 1 1 0 1 1
```
The for loop successively tests each bit in val, using the bitwise AND, to determine whether it is on or off. If the bit is on, the digit 1 is displayed; otherwise, 0 is displayed. In Try This 5-3, you will see how this basic concept can be expanded to create a class that will display the bits in any type of integer.

The bitwise OR, as the reverse of AND, can be used to turn bits on. Any bit that is set to 1 in either operand will cause the corresponding bit in the result to be set to 1. For example:

\[
\begin{array}{c|c}
1 & 0 \\
\hline
1 & 0 \\
\end{array}
\begin{array}{c|c}
1 & 1 \\
\hline
1 & 1 \\
\end{array}
\begin{array}{c|c}
1 & 1 \\
\hline
1 & 1 \\
\end{array}
\]

We can make use of the OR to change the uppercasing program into a lowercasing program, as shown here:

```java
// Lowercase letters.
class LowCase {
    public static void main(String args[]) {
        char ch;

        for(int i=0; i < 10; i++) {
            ch = (char) ('A' + i);
            System.out.print(ch);

            // This statement turns on the 6th bit.
            ch = (char) ((int) ch | 32); // ch is now lowercase
            System.out.print(ch + " ");
        }
    }
}
```

The output from this program is shown here:

Aa Bb Cc Dd Ee Ff Gg Hh Ii Jj

The program works by ORing each character with the value 32, which is 0000 0000 0010 0000 in binary. Thus, 32 is the value that produces a value in binary in which only the 6th bit is set. When this value is ORed with any other value, it produces a result in which the 6th bit is set and all other bits remain unchanged. As explained, for characters this means that each uppercase letter is transformed into its lowercase equivalent.

An exclusive OR, usually abbreviated XOR, will set a bit on if, and only if, the bits being compared are different, as illustrated here:

\[
\begin{array}{c|c|c|c}
0 & 1 & 1 & 1 \\
\hline
1 & 0 & 1 & 1 \\
\hline
1 & 1 & 0 & 0 \\
\hline
1 & 1 & 0 & 0 \\
\end{array}
\]

The XOR operator has an interesting property that makes it a simple way to encode a message.
When some value X is XORed with another value Y, and then that result is XORed with Y again, X is produced. That is, given the sequence

\[ R1 = X \oplus Y; \ R2 = R1 \oplus Y; \]

then R2 is the same value as X. Thus, the outcome of a sequence of two XORs can produce the original value.

You can use this principle to create a simple cipher program in which some integer is the key that is used to both encode and decode a message by XORing the characters in that message. To encode, the XOR operation is applied the first time, yielding the cipher text. To decode, the XOR is applied a second time, yielding the plain text. Of course, such a cipher has no practical value, being trivially easy to break. It does, however, provide an interesting way to demonstrate the XOR. Here is a program that uses this approach to encode and decode a short message:

```java
// Use XOR to encode and decode a message.
class Encode {
    public static void main(String args[]) {
        String msg = "This is a test";
        String encmsg = "";
        String decmsg = "";
        int key = 88;

        System.out.print("Original message: ");
        System.out.println(msg);

        // encode the message
        for(int i=0; i < msg.length(); i++)
            encmsg = encmsg + (char) (msg.charAt(i) ^ key);

        System.out.print("Encoded message: ");
        System.out.println(encmsg);

        // decode the message
        for(int i=0; i < msg.length(); i++)
            decmsg = decmsg + (char) (encmsg.charAt(i) ^ key);

        System.out.print("Decoded message: ");
        System.out.println(decmsg);
    }
}
```

Here is the output:

Original message: This is a test
Encoded message: 01+x1+x9x,=+, Decoded message: This is a test

As you can see, the result of two XORs using the same key produces the decoded message.

The unary one's complement (NOT) operator reverses the state of all the bits of the operand. For example, if some integer called \(A\) has the bit pattern 1001 0110, then \(\neg A\) produces a result with the bit pattern 0110 1001.

The following program demonstrates the NOT operator by displaying a number and its complement.
in binary:

```java
// Demonstrate the bitwise NOT.
class NotDemo {
    public static void main(String args[]) {
        byte b = -34;
        for (int t = 128; t > 0; t = t/2) {
            if ((b & t) != 0) System.out.print("1 ");
            else System.out.print("0 ");
        }
        System.out.println();

        // reverse all bits
        b = (byte) ~b;
        for (int t = 128; t > 0; t = t/2) {
            if ((b & t) != 0) System.out.print("1 ");
            else System.out.print("0 ");
        }
    }
}
```

Here is the output:

```
1 1 0 1 1 1 1 0
0 0 1 0 0 0 0 1
```

**The Shift Operators**

In Java it is possible to shift the bits that make up a value to the left or to the right by a specified amount. Java defines the three bit-shift operators shown here:

<table>
<thead>
<tr>
<th>Operator</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>&lt;&lt;</code></td>
<td>Left shift</td>
</tr>
<tr>
<td><code>&gt;&gt;&gt;</code></td>
<td>Right shift</td>
</tr>
<tr>
<td><code>&gt;&gt;&gt;&gt;&gt;</code></td>
<td>Unsigned right shift</td>
</tr>
</tbody>
</table>

The general forms for these operators are shown here:

```
value << num-bits
value >> num-bits
value >>> num-bits
```

Here, `value` is the value being shifted by the number of bit positions specified by `num-bits`.

Each left shift causes all bits within the specified value to be shifted left one position and a 0 bit to be brought in on the right. Each right shift shifts all bits to the right one position and preserves the sign bit. As you may know, negative numbers are usually represented by setting the high-order bit of an integer value to 1, and this is the approach used by Java. Thus, if the value being shifted is negative,
each right shift brings in a 1 on the left. If the value is positive, each right shift brings in a 0 on the left.

In addition to the sign bit, there is something else to be aware of when right shifting. Java uses two's complement to represent negative values. In this approach negative values are stored by first reversing the bits in the value and then adding 1. Thus, the byte value for -1 in binary is 1111 1111. Right shifting this value will always produce -1!

If you don’t want to preserve the sign bit when shifting right, you can use an unsigned right shift (>>>), which always brings in a 0 on the left. For this reason, the >>> is also called the zero-fill right shift. You will use the unsigned right shift when shifting bit patterns, such as status codes, that do not represent integers.

For all of the shifts, the bits shifted out are lost. Thus, a shift is not a rotate, and there is no way to retrieve a bit that has been shifted out.

Shown next is a program that graphically illustrates the effect of a left and right shift. Here, an integer is given an initial value of 1, which means that its low-order bit is set. Then, a series of eight shifts are performed on the integer. After each shift, the lower 8 bits of the value are shown. The process is then repeated, except that a 1 is put in the 8th bit position, and right shifts are performed.

```java
// Demonstrate the shift << and >> operators.
class ShiftDemo {
    public static void main(String args[]) {
        int val = 1;

        for(int i = 0; i < 8; i++) {
            for(int t=128; t > 0; t = t/2) {
                if((val & t) != 0) System.out.print("1 ");
                else System.out.print("0 ");
            }
            System.out.println();
            val = val << 1; // left shift
        }
        System.out.println();

        val = 128;
        for(int i = 0; i < 8; i++) {
            for(int t=128; t > 0; t = t/2) {
                if((val & t) != 0) System.out.print("1 ");
                else System.out.print("0 ");
            }
            System.out.println();
            val = val >> 1; // right shift
        }
    }
}
```

The output from the program is shown here:
You need to be careful when shifting byte and short values because Java will automatically promote these types to int when evaluating an expression. For example, if you right shift a byte value, it will first be promoted to int and then shifted. The result of the shift will also be of type int. Often this conversion is of no consequence. However, if you shift a negative byte or short value, it will be sign-extended when it is promoted to int. Thus, the high-order bits of the resulting integer value will be filled with ones. This is fine when performing a normal right shift. But when you perform a zero-fill right shift, there are 24 ones to be shifted before the byte value begins to see zeros.

Bitwise Shorthand Assignments
All of the binary bitwise operators have a shorthand form that combines an assignment with the bitwise operation. For example, the following two statements both assign to x the outcome of an XOR of x with the value 127.

```java
x = x ^ 127;
```

```java
x ^= 127;
```

Ask the Expert

Q: Since binary is based on powers of two, can the shift operators be used as a shortcut for multiplying or dividing an integer by two?

A: Yes. The bitwise shift operators can be used to perform very fast multiplication or division by two. A shift left doubles a value. A shift right halves it.
Try This 5-3 A ShowBits Class

This project creates a class called **ShowBits** that enables you to display in binary the bit pattern for any integer value. Such a class can be quite useful in programming. For example, if you are debugging device-driver code, then being able to monitor the data stream in binary is often a benefit.

1. Create a file called **ShowBitsDemo.java**.
2. Begin the **ShowBits** class as shown here:

   ```java
   class ShowBits {
       int numbits;

       ShowBits(int n) {
           numbits = n;
       }
   }
   ``

   **ShowBits** creates objects that display a specified number of bits. For example, to create an object that will display the low-order 8 bits of some value, use

   ```java
   ShowBits byteval = new ShowBits(8)
   ``

   The number of bits to display is stored in **numbits**.
3. To actually display the bit pattern, **ShowBits** provides the method **show( )**, which is shown here:

   ```java
   void show(long val) {
       long mask = 1;

       // left-shift a 1 into the proper position
       mask <<= numbits-1;

       int spacer = 0;
       for(; mask != 0; mask >>= 1) {
           if((val & mask) != 0) System.out.print("1");
           else System.out.print("0");
           spacer++;
           if((spacer % 8) == 0) {
               System.out.print(" ");
               spacer = 0;
           }
       }
       System.out.println();
   }
   ``

   Notice that **show( )** specifies one **long** parameter. This does not mean that you always have to pass **show( )** a **long** value, however. Because of Java’s automatic type promotions, any integer
type can be passed to \texttt{show()}\,. The number of bits displayed is determined by the value stored in \texttt{numbits}. After each group of 8 bits, \texttt{show( )} outputs a space. This makes it easier to read the binary values of long bit patterns.

4. The \textbf{ShowBitsDemo} program is shown here:

```java
/*
 * Try This 5-3
 * A class that displays the binary representation of a value.
 */

class ShowBits {
    int numbites;

    ShowBits(int n) {
        numbites = n;
    }

    void show(long val) {
        long mask = 1;

        // left-shift a 1 into the proper position
        mask <<= numbites-1;

        int spacer = 0;
        for(; mask != 0; mask >>= 1) {
            if((val & mask) != 0) System.out.print("1");
            else System.out.print("0");
            spacer++;
            if((spacer % 8) == 0) {
                System.out.print(" ");
                spacer = 0;
            }
        }
        System.out.println();
    }
}

// Demonstrate ShowBits.
class ShowBitsDemo {
    public static void main(String args[]) {
        ShowBits b = new ShowBits(8);
        ShowBits i = new ShowBits(32);
        ShowBits li = new ShowBits(64);
    }
}
```
5. The output from ShowBitsDemo is shown here:

```
System.out.println("123 in binary: ");
b.show(123);

System.out.println("\n87987 in binary: ");
i.show(87987);

System.out.println("\n237658768 in binary: ");
li.show(237658768);

// you can also show low-order bits of any integer
System.out.println("Low order 8 bits of 87987 in binary: ");
b.show(87987);
```

The ? Operator
One of Java’s most fascinating operators is the ?. The ? operator is often used to replace if-else statements of this general form:

```java
if (condition)
    var = expression1;
else
    var = expression2;
```

Here, the value assigned to var depends upon the outcome of the condition controlling the if.

The ? is called a ternary operator because it requires three operands. It takes the general form

```
Exp1 ? Exp2 : Exp3;
```

where Exp1 is a boolean expression, and Exp2 and Exp3 are expressions of any type other than void. The type of Exp2 and Exp3 must be the same (or compatible), though. Notice the use and placement of the colon.

The value of a ? expression is determined like this: Exp1 is evaluated. If it is true, then Exp2 is
evaluated and becomes the value of the entire expression. If Exp1 is false, then Exp3 is evaluated and its value becomes the value of the expression. Consider this example, which assigns absval the absolute value of val:

```java
absval = val < 0 ? -val : val; // get absolute value of val
```

Here, absval will be assigned the value of val if val is zero or greater. If val is negative, then absval will be assigned the negative of that value (which yields a positive value). The same code written using the if-else structure would look like this:

```java
if(val < 0) absval = -val;
else absval = val;
```

Here is another example of the ? operator. This program divides two numbers, but will not allow a division by zero.

```java
// Prevent a division by zero using the ?.
class NoZeroDiv {
    public static void main(String args[]) {
        int result;

        for(int i = -5; i < 6; i++) {
            result = i != 0 ? 100 / i : 0; // This prevents a divide-by-zero.
            if(i != 0)
                System.out.println("100 / " + i + " is " + result);
        }
    }
}
```

The output from the program is shown here:

```
100 / -5 is -20
100 / -4 is -25
100 / -3 is -33
100 / -2 is -50
100 / -1 is -100
100 / 1 is 100
100 / 2 is 50
100 / 3 is 33
100 / 4 is 25
100 / 5 is 20
```

Pay special attention to this line from the program:

```java
result = i != 0 ? 100 / i : 0;
```

Here, result is assigned the outcome of the division of 100 by i. However, this division takes place only if i is not zero. When i is zero, a placeholder value of zero is assigned to result.

You don’t actually have to assign the value produced by the ? to some variable. For example, you could use the value as an argument in a call to a method. Or, if the expressions are all of type
boolean, the ? can be used as the conditional expression in a loop or if statement. For example, here is the preceding program rewritten a bit more efficiently. It produces the same output as before.

```java
// Prevent a division by zero using the ?.
class NoZeroDiv2 {
    public static void main(String args[]) {

        for(int i = -5; i < 6; i++)
            if(i != 0 ? true : false)
                System.out.println("100 / " + i +
                                      " is " + 100 / i);
    }
}
```

Notice the if statement. If i is zero, then the outcome of the if is false, the division by zero is prevented, and no result is displayed. Otherwise, the division takes place.

---

### Chapter 5 Self Test

1. Show two ways to declare a one-dimensional array of 12 doubles.

2. Show how to initialize a one-dimensional array of integers to the values 1 through 5.

3. Write a program that uses an array to find the average of 10 double values. Use any 10 values you like.

4. Change the sort in Try This 5-1 so that it sorts an array of strings. Demonstrate that it works.

5. What is the difference between the String methods indexOf() and lastIndexOf()?

6. Since all strings are objects of type String, show how you can call the length() and charAt() methods on this string literal: "I like Java".

7. Expanding on the Encode cipher class, modify it so that it uses an eight-character string as the key.

8. Can the bitwise operators be applied to the double type?

9. Show how this sequence can be rewritten using the ? operator.
   ```java
   if(x < 0) y = 10;
   else y = 20;
   ```

10. In the following fragment, is the & a bitwise or logical operator? Why?
   ```java
   boolean a, b;
   // ...
   if(a & b) ...
   ```

11. Is it an error to overrun the end of an array? Is it an error to index an array with a negative value?

12. What is the unsigned right-shift operator?
13. Rewrite the MinMax class shown earlier in this chapter so that it uses a for-each style for loop.

14. Can the for loops that perform sorting in the Bubble class shown in Try This 5-1 be converted into for-each style loops? If not, why not?

15. Can a String control a switch statement?
Chapter 6
A Closer Look at Methods and Classes

Key Skills & Concepts
- Control access to members
- Pass objects to a method
- Return objects from a method
- Overload methods
- Overload constructors
- Use recursion
- Apply static
- Use inner classes
- Use varargs

This chapter resumes our examination of classes and methods. It begins by explaining how to control access to the members of a class. It then discusses the passing and returning of objects, method overloading, recursion, and the use of the keyword static. Also described are nested classes and variable-length arguments.

Controlling Access to Class Members
In its support for encapsulation, the class provides two major benefits. First, it links data with the code that manipulates it. You have been taking advantage of this aspect of the class since Chapter 4. Second, it provides the means by which access to members can be controlled. It is this feature that is examined here.

Although Java’s approach is a bit more sophisticated, in essence, there are two basic types of class members: public and private. A public member can be freely accessed by code defined outside of its class. This is the type of class member that we have been using up to this point. A private member can be accessed only by other methods defined by its class. It is through the use of private members that access is controlled.

Restricting access to a class’ members is a fundamental part of object-oriented programming because it helps prevent the misuse of an object. By allowing access to private data only through a well-defined set of methods, you can prevent improper values from being assigned to that data—by performing a range check, for example. It is not possible for code outside the class to set the value of a private member directly. You can also control precisely how and when the data within an object is used. Thus, when correctly implemented, a class creates a “black box” that can be used, but the inner workings of which are not open to tampering.

Up to this point, you haven’t had to worry about access control because Java provides a default access setting in which, for the types of programs shown earlier, the members of a class are freely available to the other code in the program. (Thus, for the preceding examples, the default access setting is essentially public.) Although convenient for simple classes (and example programs in books such as this one), this default setting is inadequate for many real-world situations. Here you will see how to use Java’s other access control features.

### Java’s Access Modifiers

Member access control is achieved through the use of three access modifiers: public, private, and protected. As explained, if no access modifier is used, the default access setting is assumed. In this chapter, we will be concerned with public and private. The protected modifier applies only when inheritance is involved and is described in Chapter 8.

When a member of a class is modified by the public specifier, that member can be accessed by any other code in your program. This includes methods defined inside other classes.

When a member of a class is specified as private, that member can be accessed only by other members of its class. Thus, methods in other classes cannot access a private member of another class.

The default access setting (in which no access modifier is used) is the same as public unless your program is broken down into packages. A package is, essentially, a grouping of classes. Packages are both an organizational and an access control feature, but a discussion of packages must wait until Chapter 8. For the types of programs shown in this and the preceding chapters, public access is the same as default access.

An access modifier precedes the rest of a member’s type specification. That is, it must begin a member’s declaration statement. Here are some examples:

```java
public String errMsg;
private double accountBalance bal;
private boolean isError(byte status) { // ...
```
To understand the effects of **public** and **private**, consider the following program:

```java
// Public vs private access.
class MyClass {
    private int alpha; // private access
    public int beta;  // public access
    int gamma;       // default access

    /* Methods to access alpha. It is OK for a
        member of a class to access a private member
        of the same class.
    */
    void setAlpha(int a) {
        alpha = a;
    }
    int getAlpha() {
        return alpha;
    }
}

class AccessDemo {
    public static void main(String args[]) {
        MyClass ob = new MyClass();

        /* Access to alpha is allowed only through
           its accessor methods. */
        ob.setAlpha(-99);
        System.out.println("ob.alpha is " + ob.getAlpha());

        // You cannot access alpha like this:
        // ob.alpha = 10; // Wrong! alpha is private! ←Wrong—alpha is private!

        // These are OK because beta and gamma are public.
        ob.beta = 88;  ←OK because these are public.
        ob.gamma = 99;
    }
}
```

As you can see, inside the **MyClass** class, **alpha** is specified as **private**, **beta** is explicitly specified as **public**, and **gamma** uses the default access, which for this example is the same as specifying **public**. Because **alpha** is private, it cannot be accessed by code outside of its class. Therefore, inside the **AccessDemo** class, **alpha** cannot be used directly. It must be accessed through its public accessor methods: **setAlpha( )** and **getAlpha( )**. If you were to remove the comment symbol from the beginning of the following line,

```java
// ob.alpha = 10; // Wrong! alpha is private!
```

you would not be able to compile this program because of the access violation. Although access to **alpha** by code outside of **MyClass** is not allowed, methods defined within **MyClass** can freely access it, as the **setAlpha( )** and **getAlpha( )** methods show.

The key point is this: A private member can be used freely by other members of its class, but it cannot be accessed by code outside its class.
To see how access control can be applied to a more practical example, consider the following program that implements a “fail-soft” int array, in which boundary errors are prevented, thus avoiding a run-time exception from being generated. This is accomplished by encapsulating the array as a private member of a class, allowing access to the array only through member methods. With this approach, any attempt to access the array beyond its boundaries can be prevented, with such an attempt failing gracefully (resulting in a “soft” landing rather than a “crash”). The fail-soft array is implemented by the **FailSoftArray** class, shown here:

```java
/* This class implements a "fail-soft" array which prevents runtime errors. */
```
class FailSoftArray {
    private int a[]; // reference to array
    private int errval; // value to return if get() fails
    public int length; // length is public

    /* Construct array given its size and the value to
     * return if get() fails. */
    public FailSoftArray(int size, int errv) {
        a = new int[size];
        errval = errv;
        length = size;
    }

    // Return value at given index.
    public int get(int index) {
        if(indexOK(index)) return a[index];
        return errval;
    }

    // Put a value at an index. Return false on failure.
    public boolean put(int index, int val) {
        if(indexOK(index)) {
            a[index] = val;
            return true;
        }
        return false;
    }

    // Return true if index is within bounds.
    private boolean indexOK(int index) {
        if(index >= 0 & index < length) return true;
        return false;
    }
}

// Demonstrate the fail-soft array.
class FS Demo {
    public static void main(String args[]) {
        FailSoftArray fs = new FailSoftArray(5, -1);
        int x;

        // show quiet failures
        System.out.println("Fail quietly.");
        for(int i=0; i < (fs.length * 2); i++) {
            fs.put(i, i*10); // Access to array must be through its accessor methods.
        }
        for(int i=0; i < (fs.length * 2); i++) {
            x = fs.get(i);
        }
    }
Let's look closely at this example. Inside **FailSoftArray** are defined three private members. The first is **a**, which stores a reference to the array that will actually hold information. The second is **errval**, which is the value that will be returned when a call to get() fails. The third is the private method **indexOK()**, which determines whether an index is within bounds. Thus, these three members can be used only by other members of the **FailSoftArray** class. Specifically, **a** and **errval** can be used only by other methods in the class, and **indexOK()** can be called only by other members of **FailSoftArray**. The rest of the class members are public and can be called by any other code in a program that uses **FailSoftArray**.

When a **FailSoftArray** object is constructed, you must specify the size of the array and the value that you want to return if a call to get() fails. The error value must be a value that would otherwise not be stored in the array. Once constructed, the actual array referred to by **a** and the error value stored in **errval** cannot be accessed by users of the **FailSoftArray** object. Thus, they are not open to
misuse. For example, the user cannot try to index $a$ directly, possibly exceeding its bounds. Access is available only through the *get*() and *put*() methods.

The *indexOK*() method is *private* mostly for the sake of illustration. It would be harmless to make it *public* because it does not modify the object. However, since it is used internally by the *FailSoftArray* class, it can be *private*.

Notice that the *length* instance variable is *public*. This is in keeping with the way Java implements arrays. To obtain the length of a *FailSoftArray*, simply use its *length* member.

To use a *FailSoftArray* array, call *put*() to store a value at the specified index. Call *get*() to retrieve a value from a specified index. If the index is out-of-bounds, *put*() returns *false* and *get*() returns *errval*.

For the sake of convenience, the majority of the examples in this book will continue to use default access for most members. Remember, however, that in the real world, restricting access to members—especially instance variables—is an important part of successful object-oriented programming. As you will see in Chapter 7, access control is even more vital when inheritance is involved.

---

**Try This 6-1  Improving the Queue Class**

You can use the *private* modifier to make a rather important improvement to the *Queue* class developed in Chapter 5, Try This 5-2. In that version, all members of the *Queue* class use the default access, which is essentially public. This means that it would be possible for a program that uses a *Queue* to directly access the underlying array, possibly accessing its elements out of turn. Since the entire point of a queue is to provide a first-in, first-out list, allowing out-of-order access is not desirable. It would also be possible for a malicious programmer to alter the values stored in the *putloc* and *getloc* indices, thus corrupting the queue. Fortunately, these types of problems are easy to prevent by applying the *private* specifier.

1. Copy the original *Queue* class in Try This 5-2 to a new file called *Queue.java*.
2. In the *Queue* class, add the *private* modifier to the *q* array, and the indices *putloc* and *getloc*, as shown here:

```java
// An improved queue class for characters.
class Queue {
    // these members are now private
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    Queue(int size) {
        q = new char[size]; // allocate memory for queue
        putloc = getloc = 0;
    }
```

---
3. Changing \texttt{q}, \texttt{putloc}, and \texttt{getloc} from default access to private access has no effect on a program that properly uses \texttt{Queue}. For example, it still works fine with the \texttt{QDemo} class from Try This 5-2. However, it prevents the improper use of a \texttt{Queue}. For example, the following types of statements are illegal:

\begin{verbatim}
Queue test = new Queue(10);

test.q[0] = 99;  // wrong!
test.putloc = -100;  // won't work!
\end{verbatim}

4. Now that \texttt{q}, \texttt{putloc}, and \texttt{getloc} are private, the \texttt{Queue} class strictly enforces the first-in, first-out attribute of a queue.

\section*{Pass Objects to Methods}
Up to this point, the examples in this book have been using simple types as parameters to methods. However, it is both correct and common to pass objects to methods. For example, the following program defines a class called \texttt{Block} that stores the dimensions of a three-dimensional block:
This program generates the following output:

```java
ob1 same dimensions as ob2: true
ob1 same dimensions as ob3: false
ob1 same volume as ob3: true
```

The `sameBlock()` and `sameVolume()` methods compare the `Block` object passed as a parameter to the invoking object. For `sameBlock()`, the dimensions of the objects are compared and `true` is returned only if the two blocks are the same. For `sameVolume()`, the two blocks are compared only to determine whether they have the same volume. In both cases, notice that the parameter `ob` specifies `Block` as its type. Although `Block` is a class type created by the program, it is used in the same way as Java’s built-in types.

### How Arguments Are Passed

As the preceding example demonstrated, passing an object to a method is a straightforward task. However, there are some nuances of passing an object that are not shown in the example. In certain
cases, the effects of passing an object will be different from those experienced when passing non-object arguments. To see why, you need to understand in a general sense the two ways in which an argument can be passed 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 in the call. 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 arguments, the precise effect differs between whether a primitive type or a reference type is passed.

When you pass a primitive type, such as int or double, 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:

```java
// Primitive types are passed by value.
class Test {
    /* This method causes no change to the arguments used in the call. */
    void noChange(int i, int j) {
        i = i + j;
        j = -j;
    }
}

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.noChange(a, b);

        System.out.println("a and b after call: " +
                          a + " " + b);
    }
}
```

The output from this program is shown here:

```
a and b before call: 15 20
a and b after call: 15 20
```

As you can see, the operations that occur inside noChange() have no effect on the values of a and b used in the call.
When you pass an object to a method, the situation changes dramatically, because objects are implicitly passed by reference. Keep in mind that when you create a variable of a class type, you are creating a reference to an object. It is the reference, not the object itself, that is actually passed to the method. As a result, 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 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:

```java
// Objects are passed through their references.

class Test {
    int a, b;

    Test(int i, int j) {
        a = i;
        b = j;
    }

    /* Pass an object. Now, ob.a and ob.b in object used in the call will be changed. */
    void change(Test ob) {
        ob.a = ob.a + ob.b;
        ob.b = -ob.b;
    }
}

class PassObRef {
    public static void main(String args[]) {
        Test ob = new Test(15, 20);

        System.out.println("ob.a and ob.b before call: " + 
                            ob.a + " " + ob.b);

        ob.change(ob);

        System.out.println("ob.a and ob.b after call: " + 
                            ob.a + " " + ob.b);
    }
}

This program generates the following output:

ob.a and ob.b before call: 15 20
ob.a and ob.b after call: 35 -20

As you can see, in this case, the actions inside change( ) have affected the object used as an argument.
Ask the Expert

Q: Is there any way that I can pass a primitive type by reference?

A: Not directly. However, Java defines a set of classes that \textit{wrap} the primitive types in objects. These are \texttt{Double}, \texttt{Float}, \texttt{Byte}, \texttt{Short}, \texttt{Integer}, \texttt{Long}, and \texttt{Character}. In addition to allowing a primitive type to be passed by reference, these wrapper classes define several methods that enable you to manipulate their values. For example, the numeric type wrappers include methods that convert a numeric value from its binary form into its human-readable \texttt{String} form, and vice versa.

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 referred to by its corresponding argument.

Returning Objects

A method can return any type of data, including class types. For example, the class \texttt{ErrorMsg} shown here could be used to report errors. Its method, \texttt{getErrorMsg()}, returns a \texttt{String} object that contains a description of an error based upon the error code that it is passed.

```java
// Return a String object.
class ErrorMsg {
    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };

    // Return the error message.
    String getErrorMsg(int i) {
        if(i >= 0 & i < msgs.length)
            return msgs[i];
        else
            return "Invalid Error Code";
    }
}
```

```java
class ErrorMsg {
    public static void main(String args[]) {
        ErrorMsg err = new ErrorMsg();
        System.out.println(err.getErrorMsg(2));
        System.out.println(err.getErrorMsg(19));
    }
}
```
You can, of course, also return objects of classes that you create. For example, here is a reworked version of the preceding program that creates two error classes. One is called `Err`, and it encapsulates an error message along with a severity code. The second is called `ErrorInfo`. It defines a method called `getErrorInfo()`, which returns an `Err` object.

```java
// Return a programmer-defined object.
class Err {
    String msg; // error message
    int severity; // code indicating severity of error
    Err(String m, int s) {
        msg = m;
        severity = s;
    }
}

class ErrorInfo {
    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };
    int howbad[] = { 3, 3, 2, 4 };
    Err getErrorInfo(int i) {
        if(i >= 0 & i < msgs.length)
            return new Err(msgs[i], howbad[i]);
        else
            return new Err("Invalid Error Code", 0);
    }
}

class ErrInfo {
    public static void main(String args[]) {
        ErrorInfo err = new ErrorInfo();
        Err e;
        e = err.getErrorInfo(2);
        System.out.println(e.msg + " severity: " + e.severity);
        e = err.getErrorInfo(19);
        System.out.println(e.msg + " severity: " + e.severity);
    }
}
```
Each time `getErrorInfo()` is invoked, a new `Err` object is created, and a reference to it is returned to the calling routine. This object is then used within `main()` to display the error message and severity code.

When an object is returned by a method, it remains in existence until there are no more references to it. At that point, it is subject to garbage collection. Thus, an object won’t be destroyed just because the method that created it terminates.

**Method Overloading**

In this section, you will learn about one of Java’s most exciting features: method overloading. In Java, two or more methods within the same class can 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 implements polymorphism.

In general, to overload a method, simply declare different versions of it. The compiler takes care of the rest. You must observe one important restriction: the type and/or number of the parameters of each overloaded method must differ. It is not sufficient for two methods to differ only in their return types. (Return types do not provide sufficient information in all cases for Java to decide which method to use.) Of course, overloaded methods *may* differ in their return types, too. When an overloaded method is called, the version of the method whose parameters match the arguments is executed.

Here is a simple example that illustrates method overloading:

```java
// Demonstrate method overloading.
class Overload {

    void ovlDemo() {  // First version
        System.out.println("No parameters");
    }

    // Overload ovlDemo for one integer parameter.
    void ovlDemo(int a) {  // Second version
        System.out.println("One parameter: " + a);
    }
}
```
This program generates the following output:

No parameters

One parameter: 2

Two parameters: 4 6
Result of `ovlDemo(4, 6)`: 10

Two double parameters: 1.1 2.32
Result of `ovlDemo(1.1, 2.32)`: 3.42

As you can see, `ovlDemo()` 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 two `double` parameters. Notice that the first two versions of `ovlDemo()` return `void`, and the second two return a value. This is perfectly valid, but as explained, overloading is not affected one way or the
other by the return type of a method. Thus, attempting to use the following two versions of `ovlDemo()` will cause an error:

```java
// One ovlDemo(int) is OK.
void ovlDemo(int a) {
    System.out.println("One parameter: "+ a);
}
/* Error! Two ovlDemo(int)s are not OK even though
return types differ. */
int ovlDemo(int a) {
    System.out.println("One parameter: "+ a);
    return a * a;
}
```

As the comments suggest, the difference in their return types is insufficient for the purposes of overloading.

As you will recall from Chapter 2, Java provides certain automatic type conversions. These conversions also apply to parameters of overloaded methods. For example, consider the following:
The output from the program is shown here:

Inside f(int): 10
Inside f(double): 10.1
Inside f(int): 99
Inside f(int): 10
Inside f(double): 11.5

In this example, only two versions of f() are defined: one that has an int parameter and one that has a double parameter. However, it is possible to pass f() a byte, short, or float value. In the case of byte and short, Java automatically converts them to int. Thus, f(int) is invoked. In the case of float, the value is converted to double and f(double) is called.

It is important to understand, however, that the automatic conversions apply only if there is no direct match between a parameter and an argument. For example, here is the preceding program with the addition of a version of f() that specifies a byte parameter:
Now when the program is run, the following output is produced:

```
Inside f(int): 10
Inside f(double): 10.1
Inside f(byte): 99
Inside f(int): 10
Inside f(double): 11.5
```

In this version, since there is a version of f( ) that takes a byte argument, when f( ) is called with a byte argument, f(byte) is invoked and the automatic conversion to int does not occur.

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 to have 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 of the 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 correct 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 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 overload only closely related operations.

---

**Ask the Expert**

**Q:** I’ve heard the term *signature* used by Java programmers. What is it?

**A:** As it applies to Java, a signature is the name of a method plus its parameter list. Thus, for the purposes of overloading, no two methods within the same class can have the same signature. Notice that a signature does not include the return type, since it is not used by Java for overload resolution.

---

**Overloading Constructors**

Like methods, constructors can also be overloaded. Doing so allows you to construct objects in a variety of ways. For example, consider the following program:
The output from the program is shown here:

```
Inside MyClass().
Inside MyClass(int).
Inside MyClass(double).
Inside MyClass(int, int).
t1.x: 0
t2.x: 88
t3.x: 17
t4.x: 8
```

`MyClass()` is overloaded four ways, each constructing an object differently. The proper constructor is called based upon the parameters specified when `new` is executed. By overloading a class' constructor, you give the user of your class flexibility in the way objects are constructed.

One of the most common reasons that constructors are overloaded is to allow one object to initialize another. For example, consider this program that uses the `Summation` class to compute the summation of an integer value:
Often, as this example shows, an advantage of providing a constructor that uses one object to initialize another is efficiency. In this case, when `s2` is constructed, it is not necessary to recompute the summation. Of course, even in cases when efficiency is not an issue, it is often useful to provide a constructor that makes a copy of an object.

Try This 6-2 Overloading the Queue Constructor

In this project, you will enhance the `Queue` class by giving it two additional constructors. The first will construct a new queue from another queue. The second will construct a queue, giving it initial values. As you will see, adding these constructors enhances the usability of `Queue` substantially.

1. Create a file called `QDemo2.java` and copy the updated `Queue` class from Try This 6-1 into it.
2. First, add the following constructor, which constructs a queue from a queue.

```java
// Construct a Queue from a Queue.
Queue(Queue ob) {
    putloc = ob.putloc;
    getloc = ob.getloc;
    q = new char[ob.q.length];

    // copy elements
    for(int i=getloc; i < putloc; i++)
        q[i] = ob.q[i];
}
```

Look closely at this constructor. It initializes `putloc` and `getloc` to the values contained in the `ob` parameter. It then allocates a new array to hold the queue and copies the elements from `ob` into that array. Once constructed, the new queue will be an identical copy of the original, but both will be completely separate objects.

3. Now add the constructor that initializes the queue from a character array, as shown here:

```java
// Construct a Queue with initial values.
Queue(char a[]) {
    putloc = 0;
    getloc = 0;
    q = new char[a.length];

    for(int i = 0; i < a.length; i++) put(a[i]);
}
```

This constructor creates a queue large enough to hold the characters in `a` and then stores those characters in the queue.

4. Here is the complete updated `Queue` class along with the `QDemo2` class, which demonstrates it:
class Queue {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty Queue given its size.
    Queue(int size) {
        q = new char[size]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Construct a Queue from a Queue.
    Queue(Queue ob) {
        putloc = ob.putloc;
        getloc = ob.getloc;
        q = new char[ob.q.length];

        // copy elements
        for(int i=getloc; i < putloc; i++)
            q[i] = ob.q[i];
    }

    // Construct a Queue with initial values.
    Queue(char a[]) {
        putloc = 0;
        getloc = 0;
        q = new char[a.length];

        for(int i = 0; i < a.length; i++) put(a[i]);
    }
}
// Put a character into the queue.
void put(char ch) {
    if (putloc == q.length) {
        System.out.println("- Queue is full.");
        return;
    }

    q[putloc++] = ch;
}

// Get a character from the queue.
char get() {
    if (getloc == putloc) {
        System.out.println("- Queue is empty.");
        return (char) 0;
    }

    return q[getloc++];
}

// Demonstrate the Queue class.
class QDemo2 {
    public static void main(String args[]) {
        // construct 10-element empty queue
        Queue q1 = new Queue(10);

        char name[] = {'T', 'o', 'm'};
        // construct queue from array
        Queue q2 = new Queue(name);

        char ch;
        int i;

        // put some characters into q1
        for (i = 0; i < 10; i++)
            q1.put((char) ('A' + i));

        // construct queue from another queue
        Queue q3 = new Queue(q1);

        // Show the queues.
        System.out.print("Contents of q1: ");
        for (i = 0; i < 10; i++) {
            ch = q1.get();
            }
Recursion

In Java, a method can call itself. This process is called recursion, and a method that calls itself is said to be recursive. In general, recursion is the process of defining something in terms of itself and is somewhat similar to a circular definition. The key component of a recursive method is a statement that executes a call to itself. Recursion is a powerful control mechanism.

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 \( 1 \times 2 \times 3 \), or 6. The following program shows a recursive way to compute the factorial of a number. For comparison purposes, a nonrecursive equivalent is also included.
The output from this program is shown here:

Factorials using recursive method.
Factorial of 3 is 6
Factorial of 4 is 24
Factorial of 5 is 120

Factorials using iterative method.
Factorial of 3 is 6
Factorial of 4 is 24
Factorial of 5 is 120

The operation of the nonrecursive method factI( ) should be clear. It uses a loop starting at 1 and progressively multiplies each number by the moving product.
The operation of the recursive \texttt{factR()} is a bit more complex. When \texttt{factR()} is called with an argument of 1, the method returns 1; otherwise, it returns the product of \texttt{factR(n-1)*n}. To evaluate this expression, \texttt{factR()} is called with \texttt{n-1}. This process repeats until \texttt{n} equals 1 and the calls to the method begin returning. For example, when the factorial of 2 is calculated, the first call to \texttt{factR()} will cause a second call to be made with an argument of 1. This call will return 1, which is then multiplied by 2 (the original value of \texttt{n}). The answer is then 2. You might find it interesting to insert \texttt{println()} statements into \texttt{factR()} that show at what level each call is, and what the intermediate results 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. A recursive call does not make a new copy of the method. Only the arguments are new. 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 their iterative equivalents because of the added overhead of the additional method calls. Too 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 recursion is that some types of algorithms can be implemented more clearly and simply recursively than they can be iteratively. For example, the Quicksort sorting algorithm is quite difficult to implement in an iterative way. Also, some problems, especially AI-related ones, seem to lend themselves to recursive solutions. When writing recursive methods, you must have a conditional statement, such as an \texttt{if}, 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 type of error is very common when working with recursion. Use \texttt{println()} statements liberally so that you can watch what is going on and abort execution if you see that you have made a mistake.

**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 through an object of its class, but 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 \texttt{static}. When a member is declared \texttt{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 \texttt{static}. The most common example of a \texttt{static} member is \texttt{main()}. \texttt{main()} is declared as \texttt{static} because it must be called by the JVM when your program begins. Outside the class, to use a \texttt{static} member, you need only specify the name of its class followed by the dot operator. No object needs to be created. For example, if you want to assign the value 10 to a \texttt{static} variable called \texttt{count} that is part of the \texttt{Timer} class, use this line:

\begin{verbatim}
Timer.count = 10;
\end{verbatim}

This format is similar to that used to access normal instance variables through an object, except that the class name is used. A \texttt{static} method can be called in the same way—by use of the dot operator on the name of the class.
Variables declared as static are, essentially, global variables. When an object is declared, no copy of a static variable is made. Instead, all instances of the class share the same static variable. Here is an example that shows the differences between a static variable and an instance variable:

```java
// Use a static variable.
class StaticDemo {
    int x; // a normal instance variable
    static int y; // a static variable

    // Return the sum of the instance variable x
    // and the static variable y.
    int sum() {
        return x + y;
    }
}

class SDemo {
    public static void main(String args[]) {
        StaticDemo ob1 = new StaticDemo();
        StaticDemo ob2 = new StaticDemo();

        // Each object has its own copy of an instance variable.
        ob1.x = 10;
        ob2.x = 20;
        System.out.println("Of course, ob1.x and ob2.x " +
                           "are independent.");
        System.out.println("ob1.x: " + ob1.x +
                           "ob2.x: " + ob2.x);
        System.out.println();

        // Each object shares one copy of a static variable.
        System.out.println("The static variable y is shared.");
        StaticDemo.y = 19;
        System.out.println("Set StaticDemo.y to 19.");

        System.out.println("ob1.sum(): " + ob1.sum());
        System.out.println("ob2.sum(): " + ob2.sum());
        System.out.println();

        StaticDemo.y = 100;
        System.out.println("Change StaticDemo.y to 100");

        System.out.println("ob1.sum(): " + ob1.sum());
        System.out.println("ob2.sum(): " + ob2.sum());
        System.out.println();
    }
}
```

The output from the program is shown here:
As you can see, the static variable y is shared by both ob1 and ob2. Changing it affects the entire class, not just an instance.

The difference between a static method and a normal method is that the static method is called through its class name, without any object of that class being created. You have seen an example of this already: the sqrt( ) method, which is a static method within Java’s standard Math class. Here is an example that creates a static method:

```java
// Use a static method.
class StaticMeth {
    static int val = 1024; // a static variable

    // a static method
    static int valDiv2() {
        return val/2;
    }
}

class SDemo2 {
    public static void main(String args[]) {
        System.out.println("val is " + StaticMeth.val);
        System.out.println("StaticMeth.valDiv2(): " +
                          StaticMeth.valDiv2());

        StaticMeth.val = 4;
        System.out.println("val is " + StaticMeth.val);
        System.out.println("StaticMeth.valDiv2(): " +
                          StaticMeth.valDiv2());
    }
}
```

The output is shown here:
Methods declared as `static` have several restrictions:

- They can directly call only other `static` methods.
- They can directly access only `static` data.
- They do not have a `this` reference.

For example, in the following class, the `static` method `valDivDenom()` is illegal:

```java
class StaticError {
    int denom = 3; // a normal instance variable
    static int val = 1024; // a static variable

    /* Error! Can't access a non-static variable
     * from within a static method. */
    static int valDivDenom() {
        return val/denom; // won't compile!
    }
}
```

Here, `denom` is a normal instance variable that cannot be accessed within a `static` method.

**Static Blocks**

Sometimes a class will require some type of initialization before it is ready to create objects. For example, it might need to establish a connection to a remote site. It also might need to initialize certain `static` variables before any of the class’ `static` methods are used. To handle these types of situations, Java allows you to declare a `static` block. A `static` block is executed when the class is first loaded. Thus, it is executed before the class can be used for any other purpose. Here is an example of a `static` block:
As you can see, the static block is executed before any objects are constructed.

Try This 6-3 The Quicksort

In Chapter 5 you were shown a simple sorting method called the Bubble sort. It was mentioned at the time that substantially better sorts exist. Here you will develop a version of one of the best: the Quicksort. The Quicksort, invented and named by C.A.R. Hoare, is the best general-purpose sorting algorithm currently available. The reason it could not be shown in Chapter 5 is that the best implementations of the Quicksort rely on recursion. The version we will develop sorts a character array, but the logic can be adapted to sort any type of object you like.

The Quicksort is built on the idea of partitions. The general procedure is to select a value, called the comparand, and then to partition the array into two sections. All elements greater than or equal to the partition value are put on one side, and those less than the value are put on the other. This process is then repeated for each remaining section until the array is sorted. For example, given the array

```java
// Use a static block
class StaticBlock {
    static double rootOf2;
    static double rootOf3;

    static {
        System.out.println("Inside static block.");
        rootOf2 = Math.sqrt(2.0);
        rootOf3 = Math.sqrt(3.0);
    }

    StaticBlock(String msg) {
        System.out.println(msg);
    }
}

class SDemo3 {
    public static void main(String args[]) {
        StaticBlock ob = new StaticBlock("Inside Constructor");

        System.out.println("Square root of 2 is " +
                            StaticBlock.rootOf2);
        System.out.println("Square root of 3 is " +
                            StaticBlock.rootOf3);
    }
}

The output is shown here:

Inside static block.
Inside Constructor
Square root of 2 is 1.4142135623730951
Square root of 3 is 1.7320508075688772

As you can see, the static block is executed before any objects are constructed.

```
and using the value \(d\) as the comparand, the first pass of the Quicksort would rearrange the array as follows:

<table>
<thead>
<tr>
<th>Initial</th>
<th>f e d a c b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass1</td>
<td>b c a d e f</td>
</tr>
</tbody>
</table>

This process is then repeated for each section—that is, \(bca\) and \(def\). As you can see, the process is essentially recursive in nature, and indeed, the cleanest implementation of Quicksort is recursive.

You can select the comparand value in two ways. You can either choose it at random, or you can select it by averaging a small set of values taken from the array. For optimal sorting, you should select a value that is precisely in the middle of the range of values. However, this is not easy to do for most sets of data. In the worst case, the value chosen is at one extremity. Even in this case, however, Quicksort still performs correctly. The version of Quicksort that we will develop selects the middle element of the array as the comparand.

1. Create a file called `QSDemo.java`.
2. First, create the `Quicksort` class shown here:
To keep the interface to the Quicksort simple, the Quicksort class provides the qsort() method, which sets up a call to the actual Quicksort method, qs(). This enables the Quicksort to be called with just the name of the array to be sorted, without having to provide an initial partition. Since qs() is only used internally, it is specified as private.

3. To use the Quicksort, simply call Quicksort.qsort(). Since qsort() is specified as static, it can be called through its class rather than on an object. Thus, there is no need to create a Quicksort object. After the call returns, the array will be sorted. Remember, this version works only for character arrays, but you can adapt the logic to sort any type of arrays you want.

4. Here is a program that demonstrates Quicksort:
// Try This 6-3: A simple version of the Quicksort.
class Quicksort {

    // Set up a call to the actual Quicksort method.
    static void qsort(char items[]) {
        qs(items, 0, items.length-1);
    }

    // A recursive version of Quicksort for characters.
    private static void qs(char items[], int left, int right) {
        int i, j;
        char x, y;
        
        i = left; j = right;
        x = items[(left+right)/2];
        
        do {
            while((items[i] < x) && (i < right)) i++;
            while((x < items[j]) && (j > left)) j--;
            
            if(i <= j) {
                y = items[i];
                items[i] = items[j];
                items[j] = y;
                i++; j--;
            }
        } while(i <= j);
        
        if(left < j) qs(items, left, j);
        if(i < right) qs(items, i, right);
    }
}

class QSDemo {
Introducing Nested and Inner Classes

In Java, you can define a nested class. This is a class that is declared within another class. Frankly, the nested class is a somewhat advanced topic. In fact, nested classes were not even allowed in the first version of Java. It was not until Java 1.1 that they were added. However, it is important that you know what they are and the mechanics of how they are used because they play an important role in many real-world programs.

A nested class does not exist independently of its enclosing class. Thus, the scope of a nested class is bounded by its outer 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 general types of nested classes: those that are preceded by the static modifier and those that are not. The only type that we are concerned about in this book is the non-static variety. This type of nested class is also called an inner 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.

Sometimes an inner class is used to provide a set of services that is used only by its enclosing class. Here is an example that uses an inner class to compute various values for its enclosing class:

```java
public static void main(String args[]) {  
    char a[] = { 'd', 'x', 'a', 'r', 'p', 'j', 'i' };  
    int i;

    System.out.print("Original array: ");
    for(i=0; i < a.length; i++)
        System.out.print(a[i]);

    System.out.println();
    // now, sort the array
    Quicksort.qsort(a);

    System.out.print("Sorted array: ");
    for(i=0; i < a.length; i++)
        System.out.print(a[i]);
}
```

```java
// Use an inner class.
class Outer {
    int nums[];
```
The output from the program is shown here:

Minimum: 1
Maximum: 9
Average: 5

In this example, the inner class **Inner** computes various values from the array **nums**, which is a member of **Outer**. As explained, an inner class has access to the members of its enclosing class, so it is perfectly acceptable for **Inner** to access the **nums** array directly. Of course, the opposite is not true. For example, it would not be possible for **analyze()** to invoke the **min()** method directly, without...
As mentioned, it is possible to nest a class within a block scope. Doing so simply creates a localized class that is not known outside its block. The following example adapts the ShowBits class developed in Try This 5-3 for use as a local class.

```java
// Use ShowBits as a local class.
class LocalClassDemo {
    public static void main(String args[]) {

        // An inner class version of ShowBits.
        class ShowBits {
            int numbits;

            ShowBits(int n) {
                numbits = n;
            }

            void show(long val) {
                long mask = 1;

                // left-shift a 1 into the proper position
                mask <<= numbits-1;

                int spacer = 0;
                for(; mask != 0; mask >>= 1) {
                    if((val & mask) != 0) System.out.print("1");
                    else System.out.print("0");
                    spacer++;
                    if((spacer % 8) == 0) {
                        System.out.print(" ");
                        spacer = 0;
                    }
                }
                System.out.println();
            }
        }

        for(byte b = 0; b < 10; b++) {
            ShowBits byteval = new ShowBits(8);
            System.out.print(b + " in binary: ");
            byteval.show(b);
        }
    }
}
```

The output from this version of the program is shown here:
In this example, the ShowBits class is not known outside of main( ), and any attempt to access it by any method other than main( ) will result in an error.

One last point: You can create an inner class that does not have a name. This is called an anonymous inner class. An object of an anonymous inner class is instantiated when the class is declared, using new. Anonymous inner classes are discussed further in Chapter 16.

Varargs: Variable-Length Arguments
Sometimes you will want to create a method that takes a variable number of arguments, based on its precise usage. For example, a method that opens an Internet connection might take a user name, password, file name, 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. To create such a method implies that there must be some way to create a list of arguments that is variable in length, rather than fixed.

In the past, methods that required a variable-length argument list 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 situations, it applies to only a narrow class of situations. In cases where the maximum number of potential arguments is 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. Frankly, both of these approaches often resulted in clumsy solutions, and it was widely acknowledged that a better approach was needed.

Ask the Expert

Q: What makes a static nested class different from a non-static one?

A: A static nested class is one that has the static modifier applied. Because it is static, it can access only other static members of the enclosing class directly. It must access other members of its outer class through an object reference.

Beginning with JDK 5, this need was addressed by the inclusion of a feature that simplified the
creation of methods that require a variable number of arguments. This feature is called varargs, which 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. The parameter list for a varargs method is not fixed, but rather variable in length. Thus, a varargs method can take a variable number of arguments.

**Varargs Basics**

A variable-length argument is specified by three periods (…). For example, here is how to write a method called `vaTest()` that takes a variable number of arguments:

```java
// vaTest() uses a vararg.
static void vaTest(int ... v) {
    System.out.println("Number of args: " + v.length);
    System.out.println("Contents: ");

    for(int i=0; i < v.length; i++)
        System.out.println(" arg "+ i + ": "+ v[i]);

    System.out.println();
}
```

Notice that `v` is declared as shown here:

```java
int ... v
```

This syntax tells the compiler that `vaTest()` can be called with zero or more arguments. Furthermore, it causes `v` to be implicitly declared as an array of type `int[]`. Thus, inside `vaTest()`, `v` is accessed using the normal array syntax.

Here is a complete program that demonstrates `vaTest()`:
There are two important things to notice about this program. First, as explained, inside `vaTest()`, `v` is operated on as an array. This is because `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 `v`. Second, in `main()`, `vaTest()` is called with different numbers of arguments, including no arguments at all. The arguments are automatically put in an array and passed to `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:
int doIt(int a, int b, double c, int ... vals) {

In this case, the first three arguments used in a call to doIt() are matched to the first three parameters. Then, any remaining arguments are assumed to belong to vals.

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.println(msg + v.length);
        System.out.println("Contents: ");
        for(int i=0; i < v.length; i++)
            System.out.println(" arg " + i + " : " + v[i]);
        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:

One vararg: 1
Contents:
  arg 0: 10

Three varargs: 3
Contents:
  arg 0: 1
  arg 1: 2
  arg 2: 3

No varargs: 0
Contents:

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:
The attempt to declare the second varargs parameter is illegal.

**Overloading Varargs Methods**

You can overload a method that takes a variable-length argument. For example, the following program overloads `vaTest( )` three times:

```java
// Varargs and overloading.
class VarArgs3 {

  static void vaTest(int ... v) {
    System.out.println("vaTest(int ...): " +
                        "Number of args: " + v.length);
    System.out.println("Contents: ");

    for(int i=0; i < v.length; i++)
      System.out.println(" arg " + i + ": " + v[i]);
    System.out.println();
  }

  static void vaTest(boolean ... v) {
    System.out.println("vaTest(boolean ...): " +
                        "Number of args: " + v.length);
    System.out.println("Contents: ");

    for(int i=0; i < v.length; i++)
      System.out.println(" arg " + i + ": " + v[i]);
    System.out.println();
  }

  static void vaTest(String msg, int ... v) {
    System.out.println("vaTest(String, int ...): " +
                        msg + v.length);
    System.out.println("Contents: ");

    for(int i=0; i < v.length; i++)
      System.out.println(" arg " + i + ": " + v[i]);
    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:
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 varargs 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.

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:

```java
vaTest(); // Error: Ambiguous!
```

Because the vararg parameter can be empty, this call could be translated into a call to `vaTest(int ...)` or to `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
Chapter 6 Self Test

1. Given this fragment,
   
   ```java
   class X {
       private int count;
   }
   is the following fragment correct?
   
   class Y {
       public static void main(String args[]) {
           X ob = new X();
           ob.count = 10;
   ```

2. An access modifier must _________ a member’s declaration.

3. The complement of a queue is a stack. It uses first-in, last-out accessing and is often likened to a stack of plates. The first plate put on the table is the last plate used. Create a stack class called Stack that can hold characters. Call the methods that access the stack push( ) and pop( ). Allow the user to specify the size of the stack when it is created. Keep all other members of the Stack class private. (Hint: You can use the Queue class as a model; just change the way the data is accessed.)

4. Given this class,
   
   ```java
   class Test {
       int a;
       Test(int i) { a = i; }
   }
   ```
   write a method called swap() that exchanges the contents of the objects referred to by two Test object references.

5. Is the following fragment correct?
   
   ```java
   class X {
       int meth(int a, int b) { ... }
       String meth(int a, int b) { ... }
   }
   ```

6. Write a recursive method that displays the contents of a string backwards.

7. If all objects of a class need to share the same variable, how must you declare that variable?

8. Why might you need to use a static block?

9. What is an inner class?

10. To make a member accessible by only other members of its class, what access modifier must be used?

11. The name of a method plus its parameter list constitutes the method’s ________________.
12. An int argument is passed to a method by using call-by-_______________.

13. Create a varargs method called sum() that sums the int values passed to it. Have it return the result. Demonstrate its use.

14. Can a varargs method be overloaded?

15. Show an example of an overloaded varargs method that is ambiguous.
Chapter 7
Inheritance

Key Skills & Concepts

- Understand inheritance basics
- Call superclass constructors
- Use `super` to access superclass members
- Create a multilevel class hierarchy
- Know when constructors are called
- Understand superclass references to subclass objects
- Override methods
- Use overridden methods to achieve dynamic method dispatch
- Use abstract classes
- Use `final`
- Know the `Object` class

Inheritance is one of the three foundation principles 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 language 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 variables and methods defined by the superclass and adds its own, unique elements.

Inheritance Basics
Java supports inheritance by allowing one class to incorporate another class into its declaration. This is done by using the extends keyword. Thus, the subclass adds to (extends) the superclass.

Let’s begin with a short example that illustrates several of the key features of inheritance. The following program creates a superclass called TwoDShape, which stores the width and height of a two-dimensional object, and a subclass called Triangle. Notice how the keyword extends is used to create a subclass.

// A simple class hierarchy.

// A class for two-dimensional objects.
class TwoDShape {

double width;
double height;

void showDim() {
    System.out.println("Width and height are "+
                        width + " and " + height);
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    String style;               // Triangle inherits TwoDShape.
    double area() {
        return width * height / 2;  // Triangle can refer to the members of TwoDShape
                                     // as if they were part of Triangle.
    }

    void showStyle() {
        System.out.println("Triangle is "+ style);
    }
}

class Shapes {
    public static void main(String args[]) {
        Triangle t1 = new Triangle();
        Triangle t2 = new Triangle();

        t1.width = 4.0;
        t1.height = 4.0;                  // All members of Triangle are available to Triangle
        t1.style = "filled";              // objects, even those inherited from TwoDShape.

        t2.width = 8.0;
        t2.height = 12.0;
        t2.style = "outlined";

        System.out.println("Info for t1: ");
        t1.showStyle();
        t1.showDim();
        System.out.println("Area is "+ t1.area());

        System.out.println();

        System.out.println("Info for t2: ");
        t2.showStyle();
        t2.showDim();
        System.out.println("Area is "+ t2.area());
    }
}
Here, TwoDShape defines the attributes of a “generic” two-dimensional shape, such as a square, rectangle, triangle, and so on. The Triangle class creates a specific type of TwoDShape, in this case, a triangle. The Triangle class includes all of TwoDObject and adds the field style, the method area( ), and the method showStyle( ). The triangle’s style is stored in style. This can be any string that describes the triangle, such as "filled", "outlined", "transparent", or even something like "warning symbol", "isosceles", or "rounded". The area( ) method computes and returns the area of the triangle, and showStyle( ) displays the triangle style.

Because Triangle includes all of the members of its superclass, TwoDShape, it can access width and height inside area( ). Also, inside main( ), objects t1 and t2 can refer to width and height directly, as if they were part of Triangle. Figure 7-1 depicts conceptually how TwoDShape is incorporated into Triangle.

![Figure 7-1 A conceptual depiction of the Triangle class](image)

Even though TwoDShape is a superclass for Triangle, 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. For example, the following is perfectly valid:

```java
TwoDShape shape = new TwoDShape();
shape.width = 10;
shape.height = 20;
shape.showDim();
```
Of course, an object of TwoDShape has no knowledge of or access to any subclasses of TwoDShape.

The general form of a class declaration that inherits a superclass is shown here:

```java
class subclass-name extends superclass-name {
    // body of class
}
```

You can specify only one superclass for any subclass that you create. Java does not support the inheritance of multiple superclasses into a single subclass. (This differs from C++, in which you can inherit multiple base classes. Be aware of this when converting C++ code to Java.) You can, however, create a hierarchy of inheritance in which a subclass becomes a superclass of another subclass. Of course, no class can be a superclass of itself.

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, here is another subclass of TwoDShape that encapsulates rectangles:

```java
// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    boolean isSquare() {
        if(width == height) return true;
        return false;
    }

    double area() {
        return width * height;
    }
}
```

The Rectangle class includes TwoDShape and adds the methods isSquare(), which determines if the rectangle is square, and area(), which computes the area of a rectangle.

### Member Access and Inheritance

As you learned in Chapter 6, often an instance variable of a class will be declared private to prevent its unauthorized use or tampering. Inheriting a class does not overrule the private access restriction. Thus, even though a subclass includes all of the members of its superclass, it cannot access those members of the superclass that have been declared private. For example, if, as shown here, width and height are made private in TwoDShape, then Triangle will not be able to access them:
The Triangle class will not compile because the reference to width and height inside the area() method causes an access violation. Since width and height are declared private, they are accessible only by other members of their own class. Subclasses have no access to them.

Remember that a class member that has been declared private will remain private to its class. It is not accessible by any code outside its class, including subclasses.

At first, you might think that the fact that subclasses do not have access to the private members of superclasses is a serious restriction that would prevent the use of private members in many situations. However, this is not true. As explained in Chapter 6, Java programmers typically use accessor methods to provide access to the private members of a class. Here is a rewrite of the TwoDShape and Triangle classes that uses methods to access the private instance variables width and height:
// Use accessor methods to set and get private members.

// A class for two-dimensional objects.
class TwoDShape {
    private double width; // these are
    private double height; // now private

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }
}
Ask the Expert

Q: When should I make an instance variable private?

A: There are no hard and fast rules, but here are two general principles. If an instance variable is to be used only by methods defined within its class, then it should be made private. If an instance variable must be within certain bounds, then it should be private and made available only
Constructors and Inheritance

In a hierarchy, it is possible for both superclasses and subclasses to have their own constructors. This raises an important question: What constructor is responsible for building an object of the subclass—the one in the superclass, the one in the subclass, or both? The answer is this: The constructor for the superclass constructs the superclass portion of the object, and the constructor for the subclass constructs the subclass part. This makes sense because the superclass has no knowledge of or access to any element in a subclass. Thus, their construction must be separate. The preceding examples have relied upon the default constructors created automatically by Java, so this was not an issue. However, in practice, most classes will have explicit constructors. Here you will see how to handle this situation.

When only the subclass defines a constructor, the process is straightforward: simply construct the subclass object. The superclass portion of the object is constructed automatically using its default constructor. For example, here is a reworked version of Triangle that defines a constructor. It also makes style private, since it is now set by the constructor.

```java
// Add a constructor to Triangle.

// A class for two-dimensional objects.
class TwoDShape {
    private double width; // these are
    private double height; // now private

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+
                           width + " and " + height);
    }
}
```
Here, Triangle's constructor initializes the members of TwoDClass that it inherits along with its own style field.

When both the superclass and the subclass define constructors, the process is a bit more complicated because both the superclass and subclass constructors must be executed. In this case, you must use another of Java's keywords, super, which has two general forms. The first calls a superclass constructor. The second is used to access a member of the superclass that has been hidden by a member of a subclass. Here, we will look at its first use.

**Using super to Call Superclass Constructors**
A subclass can call a constructor defined by its superclass by use of the following form of `super`:

```
super(parameter-list);
```

Here, `parameter-list` specifies any parameters 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 the version of `TwoDShape` in the following program. It defines a constructor that initializes `width` and `height`.

```java
// Add constructors to TwoDShape.
class TwoDShape {
    private double width;
    private double height;

    // Parameterized constructor.
    TwoDShape(double w, double h) { // A constructor for TwoDShape
        width = w;
        height = h;
    }

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+
                         width + " and " + height);
    }
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    Triangle(String s, double w, double h) { // call superclass constructor
        super(w, h); // Use super() to execute the TwoDShape constructor.
        style = s;
    }

    double area() {
        return getWidth() * getHeight() / 2;
    }
}
```
Here, `Triangle()` calls `super()` with the parameters `w` and `h`. This causes the `TwoDShape()` constructor to be called, which initializes `width` and `height` using these values. `Triangle` no longer initializes these values itself. It need only initialize the value unique to it: `style`. This leaves `TwoDShape` free to construct its subobject in any manner that it so chooses. Furthermore, `TwoDShape` can add functionality about which existing subclasses have no knowledge, thus preventing existing code from breaking.

Any form of constructor defined by the superclass can be called by `super()`. The constructor executed will be the one that matches the arguments. For example, here are expanded versions of both `TwoDShape` and `Triangle` that include default constructors and constructors that take one argument:
class TwoDShape {
    private double width;
    private double height;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
    }

    // Parameterized constructor.
    TwoDShape(double w, double h) {
        width = w;
        height = h;
    }
}
// Construct object with equal width and height.
TwoDSShape(double x) {
    width = height = x;
}

// Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

void showDim() {
    System.out.println("Width and height are " +
    width + " and " + height);
}

// A subclass of TwoDSShape for triangles.
class Triangle extends TwoDSShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "none";
    }

    // Constructor
    Triangle(String s, double w, double h) {
        super(w, h); // call superclass constructor
        style = s;
    }

    // One argument constructor.
    Triangle(double x) {
        super(x); // call superclass constructor
        style = "filled";
    }

double area() {
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is " + style);
}
Here is the output from this version:

Info for t1:
Triangle is outlined
Width and height are 8.0 and 12.0
Area is 48.0

Info for t2:
Triangle is outlined
Width and height are 8.0 and 12.0
Area is 48.0

Info for t3:
Triangle is filled
Width and height are 4.0 and 4.0
Area is 8.0

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 multilevel hierarchy. Also, `super()` must always be the first statement executed inside a subclass constructor.

### Using super to Access Superclass Members

There is a second form of `super` that 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 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:

```java
// Using super to overcome name hiding.
class A {
    int i;
}
// Create a subclass by extending class A.
class B extends A {
    int i; // this i hides the i in A
    B(int a, int b) {
        super.i = a; // i in A ← Here, super.i refers to the i in A.
        i = b; // i in B
    }
    void show() {
        System.out.println("i in superclass: " + super.i);
        System.out.println("i in subclass: " + i);
    }
}
class UseSuper {
    public static void main(String args[]) {
        B subOb = new B(1, 2);
        subOb.show();
    }
}
```

This program displays the following:

```
i in superclass: 1
i in subclass: 2
```
Although the instance variable \( i \) in \( B \) hides the \( i \) in \( A \), \texttt{super} allows access to the \( i \) defined in the superclass. \texttt{super} can also be used to call methods that are hidden by a subclass.

### Try This 7–1 Extending the Vehicle Class

#### TruckDemo.java

To illustrate the power of inheritance, we will extend the \texttt{Vehicle} class first developed in \textit{Chapter 4}. As you should recall, \texttt{Vehicle} encapsulates information about vehicles, including the number of passengers they can carry, their fuel capacity, and their fuel consumption rate. We can use the \texttt{Vehicle} class as a starting point from which more specialized classes are developed. For example, one type of vehicle is a truck. An important attribute of a truck is its cargo capacity. Thus, to create a \texttt{Truck} class, you can extend \texttt{Vehicle}, adding an instance variable that stores the carrying capacity. Here is a version of \texttt{Truck} that does this. In the process, the instance variables in \texttt{Vehicle} will be made \texttt{private}, and accessor methods are provided to get and set their values.

1. Create a file called \texttt{TruckDemo.java} and copy the last implementation of \texttt{Vehicle} from \textit{Chapter 4} into the file:

2. Create the \texttt{Truck} class as shown here:

   ```java
   // Extend Vehicle to create a Truck specialization.
   class Truck extends Vehicle {
       private int cargocap; // cargo capacity in pounds

       // This is a constructor for Truck.
       Truck(int p, int f, int m, int c) {
           // Initialize Vehicle members using Vehicle's constructor. */
           super(p, f, m);

           cargocap = c;
       }

       // Accessor methods for cargocap.
       int getCargo() { return cargocap; }
       void putCargo(int c) { cargocap = c; }
   }
   ```

   Here, \texttt{Truck} inherits \texttt{Vehicle}, adding \texttt{cargocap}, \texttt{getCargo()}, and \texttt{putCargo()}. Thus, \texttt{Truck} includes all of the general vehicle attributes defined by \texttt{Vehicle}. It need add only those items that are unique to its own class.

3. Next, make the instance variables of \texttt{Vehicle} private, as shown here:
4. Here is an entire program that demonstrates the **Truck** class:

    // Try This 7-1
    //
    // Build a subclass of Vehicle for trucks.

    class Vehicle {
        private int passengers; // number of passengers
        private int fuelcap; // fuel capacity in gallons
        private int mpg; // fuel consumption in miles per gallon

        // This is a constructor for Vehicle.
        Vehicle(int p, int f, int m) {
            passengers = p;
            fuelcap = f;
            mpg = m;
        }

        // Return the range.
        int range() {
            return mpg * fuelcap;
        }

        // Compute fuel needed for a given distance.
        double fuelneeded(int miles) {
            return (double) miles / mpg;
        }

        // Accessor methods for instance variables.
        int getPassengers() { return passengers; }
        void setPassengers(int p) { passengers = p; }
        int getFuelcap() { return fuelcap; }
        void setFuelcap(int f) { fuelcap = f; }
        int getMpg() { return mpg; }
        void setMpg(int m) { mpg = m; }
    }

    // Extend Vehicle to create a Truck specialization.
    class Truck extends Vehicle {
        private int cargocap; // cargo capacity in pounds

        // This is a constructor for Truck.
        Truck(int p, int f, int m, int c) {
            /* Initialize Vehicle members using
               Vehicle's constructor. */
            super(p, f, m);
            cargocap = c;
        }

        // Accessor methods for cargocap.
        int getCargo() { return cargocap; }
        void putCargo(int c) { cargocap = c; }
    }
5. The output from this program is shown here:

Semi can carry 44000 pounds.
To go 252 miles semi needs 36.0 gallons of fuel.

Pickup can carry 2000 pounds.
To go 252 miles pickup needs 16.8 gallons of fuel.

6. Many other types of classes can be derived from Vehicle. For example, the following skeleton creates an off-road class that stores the ground clearance of the vehicle.

    // Create an off-road vehicle class
    class OffRoad extends Vehicle {
        private int ground Clearance; // ground clearance in inches

        // ...
    }

The key point is that 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.

---

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 Triangle is used as a superclass to create the subclass called ColorTriangle. ColorTriangle inherits all of the traits of Triangle and TwoDShape and adds a field called color, which holds the color of the triangle.

```java
// A multilevel hierarchy.
class TwoDShape {
    private double width;
    private double height;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
    }

    // Parameterized constructor.
    TwoDShape(double w, double h) {
        width = w;
        height = h;
    }

    // Construct object with equal width and height.
    TwoDShape(double x) {
        width = height = x;
    }

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are " + 
                         width + " and " + height);
    }
}

// Extend TwoDShape.
class Triangle extends TwoDShape {
    private String style;
```
// A default constructor.
Triangle() {
    super();
    style = "none";
}

Triangle(String s, double w, double h) {
    super(w, h); // call superclass constructor
    style = s;
}

// One argument constructor.
Triangle(double x) {
    super(x); // call superclass constructor
    style = "filled";
}

double area() {
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is "+ style);
}

// Extend Triangle.
class ColorTriangle extends Triangle {

    private String color;

    ColorTriangle(String c, String s, double w, double h) {
        super(s, w, h);
        color = c;
    }

    String getColor() { return color; }

    void showColor() {
        System.out.println("Color is "+ color);
    }
}

class Shapes6 {
    public static void main(String args[]) {
        ColorTriangle t1 =
            new ColorTriangle("Blue", "outlined", 8.0, 12.0);
The output of this program is shown here:

Info for t1:
Triangle is outlined
Width and height are 8.0 and 12.0
Color is Blue
Area is 48.0

Info for t2:
Triangle is filled
Width and height are 2.0 and 2.0
Color is Red
Area is 2.0

Because of inheritance, ColorTriangle can make use of the previously defined classes of Triangle and TwoDShape, 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 ColorTriangle calls the constructor in Triangle. The super( ) in Triangle calls the constructor in TwoDShape. 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.

When Are Constructors Executed?
In the foregoing discussion of inheritance and class hierarchies, an important question may have occurred to you: When a subclass object is created, whose constructor is executed first, the one in the subclass or the one defined by the superclass? 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
(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("Constructing A.");
    }
}

// Create a subclass by extending class A.
class B extends A {
    B() {
        System.out.println("Constructing B.");
    }
}

// Create another subclass by extending B.
class C extends B {
    C() {
        System.out.println("Constructing C.");
    }
}

class OrderOfConstruction {
    public static void main(String args[]) {
        C c = new C();
    }
}
```

The output from this program is shown here:

Constructing A.
Constructing B.
Constructing C.

As you can see, the constructors are executed in order of derivation.

If you think about it, it makes sense that constructors are executed 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 by the subclass. Therefore, it must complete its execution first.

Superclass References and Subclass Objects
As you know, Java is a strongly typed language. Aside from the standard conversions and automatic promotions that apply to its primitive types, type compatibility is strictly enforced. Therefore, a reference variable for one class type cannot normally refer to an object of another class type. For
example, consider the following program:

```java
// This will not compile.
class X {
    int a;
    X(int i) { a = i; }
}

class Y {
    int a;
    Y(int i) { a = i; }
}

class IncompatibleRef {
    public static void main(String args[]) {
        X x = new X(10);
        X x2;
        Y y = new Y(5);

        x2 = x; // OK, both of same type

        x2 = y; // Error, not of same type
    }
}
```

Here, even though class X and class Y are structurally the same, it is not possible to assign an X reference to a Y object because they have different types. In general, an object reference variable can refer only to objects of its type.

There is, however, an important exception to Java’s strict type enforcement. A reference variable of a superclass can be assigned a reference to an object of any subclass derived from that superclass. In other words, a superclass reference can refer to a subclass object. Here is an example:
Here, Y is now derived from X; thus, it is permissible for x2 to be assigned a reference to a Y 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 x2 can’t access b even when it refers to a Y 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 program is commented out.

Although the preceding discussion may seem a bit esoteric, it has some important practical applications. One is described here. The other is discussed later in this chapter, when method overriding is covered.

An important place where subclass references are assigned to superclass variables is when constructors are called in a class hierarchy. As you know, it is common for a class to define a constructor that takes an object of the class as a parameter. This allows the class to construct a copy of an object. Subclasses of such a class can take advantage of this feature. For example, consider the following versions of TwoDShape and Triangle. Both add constructors that take an object as a parameter.

```java
// A superclass reference can refer to a subclass object.
class X {
    int a;
    X(int i) { a = i; }
}

class Y extends X {
    int b;
    Y(int i, int j) {
        super(j);
        b = i;
    }
}

class SupSubRef {
    public static void main(String args[]) {
        X x = new X(10);
        X x2;
        Y y = new Y(5, 6);

        x2 = x; // OK, both of same type
        System.out.println("x2.a: " + x2.a); // OK because Y is a subclass of X;
        // thus x2 can refer to y.

        x2 = y; // still Ok because Y is derived from X
        System.out.println("x2.a: " + x2.a);

        // X references know only about X members
        x2.a = 19; // OK
        // x2.b = 27; // Error, X doesn't have a b member
    }
}
```
class TwoDShape {
    private double width;
    private double height;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
    }

    // Parameterized constructor.
    TwoDShape(double w, double h) {
        width = w;
        height = h;
    }

    // Construct an object with equal width and height.
    TwoDShape(double x) {
        width = height = x;
    }

    // Construct an object from an object.
    TwoDShape(TwoDShape ob) {
        width = ob.width;
        height = ob.height;
    }

    // Accessor methods for width and height.
    double getWidth() { return width; }
    double getHeight() { return height; }
    void setWidth(double w) { width = w; }
    void setHeight(double h) { height = h; }

    void showDim() {
        System.out.println("Width and height are "+
            width + " and " + height);
    }
}

// A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "none";
    }

    // Constructor for Triangle.
    Triangle(String s, double w, double h) {
        super(w, h); // call superclass constructor
        style = s;
    }
}
In this program, \texttt{t2} is constructed from \texttt{t1} and is, thus, identical. The output is shown here:

\begin{verbatim}
Info for t1:
Triangle is outlined
Width and height are 8.0 and 12.0
Area is 48.0
Info for t2:
Triangle is outlined
Width and height are 8.0 and 12.0
Area is 48.0
\end{verbatim}
Pay special attention to this **Triangle** constructor:

```java
// Construct an object from an object.
Triangle(Triangle ob) {
    super(ob); // pass object to TwoDShape constructor
    style = ob.style;
}
```

It receives an object of type **Triangle** and it passes that object (through `super`) to this **TwoDShape** constructor:

```java
// Construct an object from an object.
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
}
```

The key point is that **TwoDShape**() is expecting a **TwoDShape** object. However, **Triangle**() passes it a **Triangle** object. The reason this works is because, as explained, a superclass reference can refer to a subclass object. Thus, it is perfectly acceptable to pass **TwoDShape**() a reference to an object of a class derived from **TwoDShape**. Because the **TwoDShape**() constructor is initializing only those portions of the subclass object that are members of **TwoDShape**, it doesn’t matter that the object might also contain other members added by derived classes.

**Method Overriding**

In a class hierarchy, when a method in a subclass has the same return type and 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 a 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:
The output produced by this program is shown here:

k: 3

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 want 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.
If you substitute this version of `show()` into the previous program, you will see the following output:

```
i and j: 1 2
k: 3
```

Here, `super.show()` calls the superclass version of `show()`.

Method overriding occurs only when the 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:
The version of `show()` in `B` takes a string parameter. This makes its signature different from the one in `A`, which takes no parameters. Therefore, no overriding (or name hiding) takes place.

**Overridden Methods Support Polymorphism**
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 namespace 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’s 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:
The output from the program is shown here:

who() in Sup
who() in Sub1
who() in Sub2

This program creates a superclass called Sup and two subclasses of it, called Sub1 and Sub2. Sup declares a method called who(), and the subclasses override it. Inside the main() method, objects of type Sup, Sub1, and Sub2 are declared. Also, a reference of type Sup, called supRef, is declared. The program then assigns a reference to each type of object to supRef and uses that reference to call
who(). As the output shows, the version of who() executed is determined by the type of object being referred to at the time of the call, not by the class type of supRef.

---

**Ask the Expert**

**Q:** Overridden methods in Java look a lot like virtual functions in C++. Is there a similarity?

**A:** Yes. Readers familiar with C++ will recognize that overridden methods in Java are equivalent in purpose and similar in operation to virtual functions in C++.

---

**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 that 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.

---

**Applying Method Overriding to TwoDShape**

To better understand the power of method overriding, we will apply it to the TwoDShape class. In the preceding examples, each class derived from TwoDShape defines a method called area(). This suggests that it might be better to make area() part of the TwoDShape class, allowing each subclass to override it, defining how the area is calculated for the type of shape that the class encapsulates. The following program does this. For convenience, it also adds a name field to TwoDShape. (This makes it easier to write demonstration programs.)
// Use dynamic method dispatch.
class TwoDShape {
    private double width;
    private double height;
    private String name;

    // A default constructor.
    TwoDShape() {
        width = height = 0.0;
        name = "none";
    }

    // Parameterized constructor.
    TwoDShape(double w, double h, String n) {
        width = w;
        height = h;
        name = n;
    }

    // Construct object with equal width and height.
    TwoDShape(double x, String n) {
        width = height = x;
        name = n;
    }
}
Construct an object from an object.

```java
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
    name = ob.name;
}
```

Accessor methods for width and height.

```java
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }
```

String getName() { return name; }

```java
void showDim() {
    System.out.println("Width and height are " +
    width + " and " + height);
}
```

The area() method defined by TwoDShape

```java
double area() {
    System.out.println("area() must be overridden");
    return 0.0;
}
```

A subclass of TwoDShape for triangles.

```java
class Triangle extends TwoDShape {
    private String style;

    // A default constructor.
    Triangle() {
        super();
        style = "none";
    }

    // Constructor for Triangle.
    Triangle(String s, double w, double h) {
        super(w, h, "triangle");
        style = s;
    }

    // One argument constructor.
    Triangle(double x) {
        super(x, "triangle"); // call superclass constructor
        style = "filled";
    }
```
// Construct an object from an object.
Triangle(Triangle ob) {
    super(ob); // pass object to TwoDShape constructor
    style = ob.style;
}

// Override area() for Triangle.
double area() { // Override area() for Triangle
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is " + style);
}

// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    // A default constructor.
    Rectangle() {
        super();
    }

    // Constructor for Rectangle.
    Rectangle(double w, double h) {
        super(w, h, "rectangle"); // call superclass constructor
    }

    // Construct a square.
    Rectangle(double x) {
        super(x, "rectangle"); // call superclass constructor
    }

    // Construct an object from an object.
    Rectangle(Rectangle ob) {
        super(ob); // pass object to TwoDShape constructor
    }

    boolean isSquare() {
        if(getWidth() == getHeight()) return true;
        return false;
    }

    // Override area() for Rectangle.
    double area() { // Override area() for Rectangle
        return getWidth() * getHeight();
    }
}
The output from the program is shown here:

object is triangle
Area is 48.0

object is rectangle
Area is 100.0

object is rectangle
Area is 40.0

object is triangle
Area is 24.5

object is generic
area() must be overridden
Area is 0.0

Let's examine this program closely. First, as explained, area() is now part of the TwoDShape class and is overridden by Triangle and Rectangle. Inside TwoDShape, area() is given a placeholder implementation that simply informs the user that this method must be overridden by a subclass. Each override of area() supplies an implementation that is suitable for the type of object encapsulated by the subclass. Thus, if you were to implement an ellipse class, for example, then area() would need to compute the area() of an ellipse.

There is one other important feature in the preceding program. Notice in main() that shapes is declared as an array of TwoDShape objects. However, the elements of this array are assigned Triangle, Rectangle, and TwoDShape references. This is valid because, as explained, a superclass reference can refer to a subclass object. The program then cycles through the array, displaying information about each object. Although quite simple, this illustrates the power of both inheritance and method overriding. The type of object referred to by a superclass reference variable is determined at run time and acted on accordingly. If an object is derived from TwoDShape, then its area can be obtained by calling area(). The interface to this operation is the same no matter what
type of shape is being used.

Using Abstract Classes

Sometimes you will want to create a superclass that defines only 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 but does not, itself, provide an implementation of one or more of these methods. 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 version of `TwoDShape` 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 in 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 which must be overridden by the subclass in order for the subclass to have any meaning. Consider the class `Triangle`. It is incomplete 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.

An abstract method is created by specifying the `abstract` type modifier. An abstract method contains no body and is, therefore, not implemented by the superclass. Thus, a subclass must override it—it cannot simply use the version defined in the superclass. To declare an abstract method, use this general form:

```java
abstract type name(parameter-list);
```

As you can see, no method body is present. The `abstract` modifier can be used only on instance methods. It cannot be applied to static methods or to constructors.

A class that contains one or more abstract methods must also be declared as abstract by preceding its `class` declaration with the `abstract` modifier. Since an abstract class does not define a complete implementation, there can be no objects of an abstract class. Thus, attempting to create an object of an abstract class by using `new` will result in a compile-time error.

When a subclass inherits an abstract class, it must implement all of the abstract methods in the superclass. If it doesn’t, then the subclass must also be specified as `abstract`. Thus, the `abstract` attribute is inherited until such time as a complete implementation is achieved.

Using an abstract class, you can improve the `TwoDShape` class. Since there is no meaningful concept of area for an undefined two-dimensional figure, the following version of the preceding program declares `area()` as `abstract` inside `TwoDShape`, and `TwoDShape` as `abstract`. This, of course, means that all classes derived from `TwoDShape` must override `area()`.

```java
// Create an abstract class.
abstract class TwoDShape {
    private double width;
    private double height;
    private String name;
} // TwoDShape is now abstract.
```
A default constructor.
TwoDShape() {
    width = height = 0.0;
    name = "none";
}

Parameterized constructor.
TwoDShape(double w, double h, String n) {
    width = w;
    height = h;
    name = n;
}

Construct object with equal width and height.
TwoDShape(double x, String n) {
    width = height = x;
    name = n;
}

Construct an object from an object.
TwoDShape(TwoDShape ob) {
    width = ob.width;
    height = ob.height;
    name = ob.name;
}

Accessor methods for width and height.
double getWidth() { return width; }
double getHeight() { return height; }
void setWidth(double w) { width = w; }
void setHeight(double h) { height = h; }

String getName() { return name; }

void showDim() {
    System.out.println("Width and height are "+
                        width + " and " + height);
}

Now, area() is abstract.
abstract double area(); // Make area() into an
                        abstract method.

A subclass of TwoDShape for triangles.
class Triangle extends TwoDShape {
    private String style;
}
// A default constructor.
Triangle() {
    super();
    style = "none";
}

// Constructor for Triangle.
Triangle(String s, double w, double h) {
    super(w, h, "triangle");
    style = s;
}

// One argument constructor.
Triangle(double x) {
    super(x, "triangle"); // call superclass constructor
    style = "filled";
}

// Construct an object from an object.
Triangle(Triangle ob) {
    super(ob); // pass object to TwoDShape constructor
    style = ob.style;
}

double area() {
    return getWidth() * getHeight() / 2;
}

void showStyle() {
    System.out.println("Triangle is " + style);
}

// A subclass of TwoDShape for rectangles.
class Rectangle extends TwoDShape {
    // A default constructor.
    Rectangle() {
        super();
    }

    // Constructor for Rectangle.
    Rectangle(double w, double h) {
        super(w, h, "rectangle"); // call superclass constructor
    }
}
As the program illustrates, all subclasses of TwoDShape must override area(). To prove this to yourself, try creating a subclass that does not override area(). You will receive a compile-time error. Of course, it is still possible to create an object reference of type TwoDShape, which the program does. However, it is no longer possible to declare objects of type TwoDShape. Because of this, in main() the shapes array has been shortened to 4, and a TwoDShape object is no longer created.

One last point: Notice that TwoDShape still includes the showDim() and getName() methods and that these are not modified by abstract. It is perfectly acceptable—indeed, quite common—for an abstract class to contain concrete methods which a subclass is free to use as is. Only those methods
declared as **abstract** need be overridden by subclasses.

**Using final**

As powerful and useful as method overriding and inheritance are, sometimes you will want to prevent them. For example, you might have a class that encapsulates control of some hardware device. Further, this class might offer the user the ability to initialize the device, making use of private, proprietary information. In this case, you don’t want users of your class to be able to override the initialization method. Whatever the reason, in Java it is easy to prevent a method from being overridden or a class from being inherited by using the keyword **final**.

**final Prevents Overriding**

To prevent 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.

**final Prevents Inheritance**

You can prevent a class from being inherited by preceding its 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.
```java
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**.
Using final with Data Members

In addition to the uses of final just shown, final can also be applied to member variables to create what amounts to named constants. If you precede a class variable’s name with final, its value cannot be changed throughout the lifetime of your program. You can, of course, give that variable an initial value. For example, in Chapter 6 a simple error-management class called ErrorMsg was shown. That class mapped a human-readable string to an error code. Here, that original class is improved by the addition of final constants which stand for the errors. Now, instead of passing getErrorMsg( ) a number such as 2, you can pass the named integer constant DISKERR.

```java
class ErrorMsg {
    // Error codes.
    final int OUTERR = 0;
    final int INERR = 1;
    final int DISKERR = 2;
    final int INDEXERR = 3;

    String msgs[] = {
        "Output Error",
        "Input Error",
        "Disk Full",
        "Index Out-Of-Bounds"
    };

    // Return the error message.
    String getErrorMsg(int i) {
        if(i >=0 & i < msgs.length)
            return msgs[i];
        else
            return "Invalid Error Code";
    }
}
```

As a point of style, many Java programmers use uppercase identifiers for final constants, as does the preceding example. But this is not a hard and fast rule.
**The Object Class**

Java defines one special class called `Object` that is an implicit superclass of all other classes. In other words, all other classes are subclasses of `Object`. 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><code>Object clone( )</code></td>
<td>Creates a new object that is the same as the object being cloned.</td>
</tr>
<tr>
<td>boolean <code>equals(Object object)</code></td>
<td>Determines whether one object is equal to another.</td>
</tr>
<tr>
<td><code>void finalize( )</code></td>
<td>Called before an unused object is recycled.</td>
</tr>
<tr>
<td><code>Class&lt;?&gt; getClass( )</code></td>
<td>Obtains the class of an object at run time.</td>
</tr>
<tr>
<td><code>int hashCode( )</code></td>
<td>Returns the hash code associated with the invoking object.</td>
</tr>
<tr>
<td><code>void notify( )</code></td>
<td>Resumes execution of a thread waiting on the invoking object.</td>
</tr>
<tr>
<td><code>void notifyAll( )</code></td>
<td>Resumes execution of all threads waiting on the invoking object.</td>
</tr>
<tr>
<td><code>String toString( )</code></td>
<td>Returns a string that describes the object.</td>
</tr>
<tr>
<td><code>void wait( )</code></td>
<td>Waits on another thread of execution.</td>
</tr>
<tr>
<td><code>void wait(long milliseconds)</code></td>
<td></td>
</tr>
<tr>
<td><code>void wait(long milliseconds, int nanoseconds)</code></td>
<td></td>
</tr>
</tbody>
</table>
The methods `getClass()`, `notify()`, `notifyAll()`, and `wait()` are declared as `final`. You can override the others. Several of these methods are described later in this book. However, notice two methods now: `equals()` and `toString()`. The `equals()` method compares two objects. It returns `true` if the objects are equivalent, and `false` otherwise. 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. Generics allow the type of data used by a class or method to be specified as a parameter. Generics are discussed in Chapter 13.

**Chapter 7 Self Test**

1. Does a superclass have access to the members of a subclass? Does a subclass have access to the members of a superclass?

2. Create a subclass of `TwoDShape` called `Circle`. Include an `area()` method that computes the area of the circle and a constructor that uses `super` to initialize the `TwoDShape` portion.

3. How do you prevent a subclass from having access to a member of a superclass?

4. Describe the purpose and use of the two versions of `super` described in this chapter.

5. Given the following hierarchy:

   ```java
   class Alpha {
   ...}
   
class Beta extends Alpha {
   ...
   }
   
Class Gamma extends Beta {
   ...
   }
   ```
   In what order do the constructors for these classes complete their execution when a `Gamma` object is instantiated?

6. A superclass reference can refer to a subclass object. Explain why this is important as it relates to method overriding.

7. What is an abstract class?

8. How do you prevent a method from being overridden? How do you prevent a class from being inherited?

9. Explain how inheritance, method overriding, and abstract classes are used to support polymorphism.

10. What class is a superclass of every other class?

11. A class that contains at least one abstract method must, itself, be declared abstract. True or False?

12. What keyword is used to create a named constant?
Chapter 8
Packages and Interfaces

Key Skills & Concepts
- Use packages
- Understand how packages affect access
- Apply the protected access modifier
- Import packages
- Know Java’s standard packages
- Understand interface fundamentals
- Implement an interface
- Apply interface references
- Understand interface variables
- Extend interfaces
- Create default and static interface methods

This chapter examines two of Java’s most innovative features: packages and interfaces. Packages are groups of related classes. Packages help organize your code and provide another layer of encapsulation. An interface defines a set of methods that will be implemented by a class. Thus, an interface gives you a way to specify what a class will do, but not how it will do it. Packages and
interfaces give you greater control over the organization of your program.

**Packages**

In programming, it is often helpful to group related pieces of a program together. In Java, this is accomplished by using a package. A package serves two purposes. First, it provides a mechanism by which related pieces of a program can be organized as a unit. Classes defined within a package must be accessed through their package name. Thus, a package provides a way to name a collection of classes. Second, a package participates in Java’s access control mechanism. Classes defined within a package can be made private to that package and not accessible by code outside the package. Thus, the package provides a means by which classes can be encapsulated. Let’s examine each feature a bit more closely.

In general, when you name a class, you are allocating a name from the *namespace*. A namespace defines a declarative region. In Java, no two classes can use the same name from the same namespace. Thus, within a given namespace, each class name must be unique. The examples shown in the preceding chapters have all used the default (global) namespace. While this is fine for short sample programs, it becomes a problem as programs grow and the default namespace becomes crowded. In large programs, finding unique names for each class can be difficult. Furthermore, you must avoid name collisions with code created by other programmers working on the same project, and with Java’s library. The solution to these problems is the package because it gives you a way to partition the namespace. When a class is defined within a package, the name of that package is attached to each class, thus avoiding name collisions with other classes that have the same name, but are in other packages.

Since a package usually contains related classes, Java defines special access rights to code within a package. In a package, you can define code that is accessible by other code within the same package but not by code outside the package. This enables you to create self-contained groups of related classes that keep their operation private.

**Defining a Package**

All classes in Java belong to some package. When no `package` statement is specified, the default (global) package is used. Furthermore, the default package has no name, which makes the default package transparent. 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 one or more packages for your code.

To create a package, put a `package` command at the top of a Java source file. The classes declared within that file will then belong to the specified package. Since a package defines a namespace, the names of the classes that you put into the file become part of that package’s namespace.

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 `mypack`:

```java
package mypack;
```
Java uses the file system to manage packages, with each package stored in its own directory. For example, the `.class` files for any classes you declare to be part of `mypack` must be stored in a directory called `mypack`.

Like the rest of Java, package names are case sensitive. This means that the directory in which a package is stored must be precisely the same as the package name. If you have trouble trying the examples in this chapter, remember to check your package and directory names carefully. Lowercase is often used for package names.

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 pack1.pack2.pack3...packN;
```

Of course, you must create directories that support the package hierarchy that you create. For example,

```java
package alpha.beta.gamma;
```

must be stored in `.../alpha/beta/gamma`, where `...` specifies the path to the specified directories.

### 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, assuming the following package specification:

```java
package mypack
```

In order for a program to find `mypack`, one of three things must be true: The program can be executed from a directory immediately above `mypack`, or `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`.

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 by the following examples.

One last point: To avoid problems, it is best to keep all `.java` and `.class` files associated with a package in that package’s directory. Also, compile each file from the directory above the package directory.
A Short Package Example
Keeping the preceding discussion in mind, try this short package example. It creates a simple book database that is contained within a package called `bookpack`.

```java
// A short package demonstration.
package bookpack;

class Book {
    private String title;
    private String author;
    private int pubDate;

    Book(String t, String a, int d) {
        title = t;
        author = a;
        pubDate = d;
    }

    void show() {
        System.out.println(title);
        System.out.println(author);
        System.out.println(pubDate);
        System.out.println();
    }
}

class BookDemo {
    public static void main(String args[]) {
        Book books[] = new Book[5];

        books[0] = new Book("Java: A Beginner's Guide",
                             "Schildt", 2014);
                             "Schildt", 2014);
                             "Schildt and Holmes", 2003);
                             "Clancy", 1986);
                             "Kerouac", 1955);

        for(int i=0; i < books.length; i++) books[i].show();
    }
}
```

Call this file `BookDemo.java` and put it in a directory called `bookpack`.
Next, compile the file. You can do this by specifying

```
javac bookpack/BookDemo.java
```

from the directory directly above `bookpack`. Then try executing the class, using the following
command line:

```java
java bookpack.BookDemo
```

Remember, you will need to be in the directory above `bookpack` when you execute this command.
(Or, use one of the other two options described in the preceding section to specify the path to `bookpack`.)

As explained, `BookDemo` and `Book` are now part of the package `bookpack`. This means that `BookDemo` cannot be executed by itself. That is, you cannot use this command line:

```java
java BookDemo
```

Instead, `BookDemo` must be qualified with its package name.

### Packages and Member Access

The preceding chapters have introduced the fundamentals of access control, including the `private` and `public` modifiers, but they have not told the entire story. The reason for this is that packages also participate in Java’s access control mechanism, and a complete discussion had to wait until packages were covered.

The visibility of an element is determined by its access specification—`private`, `public`, `protected`, or default—and the package in which it resides. Thus, the visibility of an element is determined by its visibility within a class and its visibility within a package. This multilayered approach to access control supports a rich assortment of access privileges. Table 8-1 summarizes the various access levels. Let’s examine each access option individually.

<table>
<thead>
<tr>
<th>Visible within same class</th>
<th>Visible within same package by subclass</th>
<th>Visible within same package by non-subclass</th>
<th>Visible within different package by subclass</th>
<th>Visible within different package by non-subclass</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 8-1 Class Member Access

If a member of a class has no explicit access modifier, then it is visible within its package but not outside its package. Therefore, you will use the default access specification for elements that you want to keep private to a package but public within that package.

Members explicitly declared `public` are visible everywhere, including different classes and
different packages. There is no restriction on their use or access. A **private** member is accessible only to the other members of its class. A **private** member is unaffected by its membership in a package. A member specified as **protected** is accessible within its package and to all subclasses, including subclasses in other packages.

Table 8-1 applies only to members of classes. A top-level 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, it can be accessed only by other code within its same package. Also, a class that is declared **public** must reside in a file by the same name.

### A Package Access Example

In the **package** example shown earlier, both **Book** and **BookDemo** were in the same package, so there was no problem with **BookDemo** using **Book** because the default access privilege grants all members of the same package access. However, if **Book** were in one package and **BookDemo** were in another, the situation would be different. In this case, access to **Book** would be denied. To make **Book** available to other packages, you must make three changes. First, **Book** needs to be declared **public**. This makes **Book** visible outside of **bookpack**. Second, its constructor must be made **public**, and finally, its **show( )** method needs to be **public**. This allows them to be visible outside of **bookpack**, too. Thus, to make **Book** usable by other packages, it must be recoded as shown here:

```java
// Book recoded for public access.
package bookpack;

public class Book {  // **Book** and its members must be **public** in order to be used by other packages.
    private String title;
    private String author;
    private int pubDate;

    // Now public.
    public Book(String t, String a, int d) {
        title = t;
        author = a;
        pubDate = d;
    }

    // Now public.
    public void show() {
        System.out.println(title);
        System.out.println(author);
        System.out.println(pubDate);
        System.out.println();
    }
}
```

To use **Book** from another package, either you must use the **import** statement described in the next section, or you must fully qualify its name to include its full package specification. For example, here is a class called **UseBook**, which is contained in the **bookpackext** package. It fully qualifies **Book** in
To better understand the effects of protected, let’s work through an example. First, change the Book class so that its instance variables are protected, as shown here:

```java
class Book {
  protected String title;
  protected String author;
  protected int year;

  protected Book(String title, String author, int year) {
    this.title = title;
    this.author = author;
    this.year = year;
  }

  public String getTitle() {
    return title;
  }

  public String getAuthor() {
    return author;
  }

  public int getYear() {
    return year;
  }

  public void setTitle(String title) {
    this.title = title;
  }

  public void setAuthor(String author) {
    this.author = author;
  }

  public void setYear(int year) {
    this.year = year;
  }
}
```

Notice how every use of Book is preceded with the bookpack qualifier. Without this specification, Book would not be found when you tried to compile UseBook.

**Understanding Protected Members**

Newcomers to Java are sometimes confused by the meaning and use of protected. As explained, the protected modifier creates a member that is accessible within its package and to subclasses in other packages. Thus, a protected member is available for all subclasses to use but is still protected from arbitrary access by code outside its package.

To better understand the effects of protected, let’s work through an example. First, change the Book class so that its instance variables are protected, as shown here:
// Make the instance variables in Book protected.
package bookpack;

public class Book {
    // these are now protected
    protected String title; // These are now protected.
    protected String author;
    protected int pubDate;

    public Book(String t, String a, int d) {
        title = t;
        author = a;
        pubDate = d;
    }

    public void show() {
        System.out.println(title);
        System.out.println(author);
        System.out.println(pubDate);
        System.out.println();
    }
}

Next, create a subclass of Book, called ExtBook, and a class called ProtectDemo that uses ExtBook. ExtBook adds a field that stores the name of the publisher and several accessor methods. Both of these classes will be in their own package called bookpackext. They are shown here:
Look first at the code inside ExtBook. Because ExtBook extends Book, it has access to the protected members of Book, even though ExtBook is in a different package. Thus, it can access title, author, and pubDate directly, as it does in the accessor methods it creates for those variables. However, in ProtectDemo, access to these variables is denied because ProtectDemo is not a subclass of Book. For example, if you remove the comment symbol from the following line, the program will not compile.

```java
// books[0].title = "test title"; // Error - not accessible
```
Importing Packages

When you use a class from another package, you can fully qualify the name of the class with the name of its package, as the preceding examples have done. However, such an approach could easily become tiresome and awkward, especially if the classes you are qualifying are deeply nested in a package hierarchy. Since Java was invented by programmers for programmers—and programmers don’t like tedious constructs—it should come as no surprise that a more convenient method exists for using the contents of packages: the import statement. Using import you can bring one or more members of a package into view. This allows you to use those members directly, without explicit package qualification.

Ask the Expert

Q: I know that C++ also includes an access specifier called protected. Is it similar to Java’s?

A: Similar, but not the same. In C++, protected creates a member that can be accessed by subclasses but is otherwise private. In Java, protected creates a member that can be accessed by any code within its package but only by subclasses outside of its package. You need to be careful of this difference when porting code between C++ and Java.

Here is the general form of the import statement:

```java
import pkg.classname;
```

Here, `pkg` is the name of the package, which can include its full path, and `classname` is the name of the class being imported. If you want to import the entire contents of a package, use an asterisk (*) for the class name. Here are examples of both forms:

```java
import mypack.MyClass
import mypack.*;
```

In the first case, the MyClass class is imported from mypack. In the second, all of the classes in mypack are imported. In a Java source file, import statements occur immediately following the package statement (if it exists) and before any class definitions.

You can use import to bring the bookpack package into view so that the Book class can be used without qualification. To do so, simply add this import statement to the top of any file that uses Book.

```java
import bookpack.*;
```

For example, here is the UseBook class recoded to use import:
Java’s Class Library Is Contained in Packages

As explained earlier in this book, Java defines a large number of standard classes that are available to all programs. This class library is often referred to as the Java API (Application Programming Interface). The Java API is stored in packages. At the top of the package hierarchy is \texttt{java}.

Descending from \texttt{java} are several subpackages. Here are a few examples:

<table>
<thead>
<tr>
<th>Subpackage</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>java.lang</td>
<td>Contains a large number of general-purpose classes</td>
</tr>
<tr>
<td>java.io</td>
<td>Contains I/O classes</td>
</tr>
<tr>
<td>java.net</td>
<td>Contains classes that support networking</td>
</tr>
<tr>
<td>java.applet</td>
<td>Contains classes for creating applets</td>
</tr>
<tr>
<td>java.awt</td>
<td>Contains classes that support the Abstract Window Toolkit</td>
</tr>
</tbody>
</table>

Since the beginning of this book, you have been using \texttt{java.lang}. It contains, among several others, the \texttt{System} class, which you have been using when performing output using \texttt{println( )}. The \texttt{java.lang} package is unique because it is imported automatically into every Java program. This is why you did not have to import \texttt{java.lang} in the preceding sample programs. However, you must explicitly import the other packages. We will be examining several packages in subsequent chapters.

Interfaces

In object-oriented programming, it is sometimes helpful to define what a class must do but not how it will do it. You have already seen an example of this: the abstract method. An abstract method defines the signature for a method but provides no implementation. A subclass must provide its own
implementation of each abstract method defined by its superclass. Thus, an abstract method specifies the interface to the method but not the implementation. While abstract classes and methods are useful, it is possible to take this concept a step further. In Java, you can fully separate a class’ interface from its implementation by using the keyword interface.

An interface is syntactically similar to an abstract class, in that you can specify one or more methods that have no body. Those methods must be implemented by a class in order for their actions to be defined. Thus, an interface specifies what must be done, but not how to do it. Once an interface is defined, any number of classes can implement it. Also, one class can implement any number of interfaces.

To implement an interface, a class must provide bodies (implementations) for the methods described by the interface. Each class is free to determine the details of its own implementation. Two classes might implement the same interface in different ways, but each class still supports the same set of methods. Thus, code that has knowledge of the interface can use objects of either class since the interface to those objects is the same. By providing the interface keyword, Java allows you to fully utilize the “one interface, multiple methods” aspect of polymorphism.

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. Thus, prior to JDK 8, an interface could define only what, but not how, as just described. JDK 8 changes this. Today, 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.

Here is a simplified general form of a traditional interface:

```java
access interface name { 
    ret-type method-name1(param-list);
    ret-type method-name2(param-list);
    type var1 = value;
    type var2 = value;
    // ...
    ret-type method-nameN(param-list);
    type varN = value;
}
```

Here, access is either public or not used. When no access modifier is included, then default access results, and the interface is available only to other members of its package. When it is declared as public, the interface can be used by any other code. (When an interface is declared public, it must be in a file of the same name.) name is the name of the interface and can be any valid identifier.

In the traditional form of an interface, methods are declared using only their return type and signature. They are, essentially, abstract methods. Thus, each class that includes such an interface must implement all of its methods. In an interface, methods are implicitly public.

Variables declared in an interface are not instance variables. Instead, they are implicitly public, final, and static and must be initialized. Thus, they are essentially constants. Here is an example of an
interface definition. It specifies the interface to a class that generates a series of numbers.

```java
public interface Series {
    int getNext(); // return next number in series
    void reset();  // restart
    void setStart(int x); // set starting value
}
```

This interface is declared public so that it can be implemented by code in any package.

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 {
    // class-body
}
```

To implement more than one interface, the interfaces are separated with a comma. Of course, the extends clause is optional.

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 an example that implements the Series interface shown earlier. It creates a class called ByTwos, which generates a series of numbers, each two greater than the previous one.
Notice that the methods `getNext()`, `reset()`, and `setStart()` are declared using the `public` access specifier. This is necessary. Whenever you implement a method defined by an interface, it must be implemented as `public` because all members of an interface are implicitly `public`.

Here is a class that demonstrates `ByTwos`:
The output from this program is shown here:

Next value is 2
Next value is 4
Next value is 6
Next value is 8
Next value is 10

Resetting
Next value is 2
Next value is 4
Next value is 6
Next value is 8
Next value is 10

Starting at 100
Next value is 102
Next value is 104
Next value is 106
Next value is 108
Next value is 110

It is both permissible and common for classes that implement interfaces to define additional members of their own. For example, the following version of `ByTwos` adds the method `getPrevious()`, which returns the previous value:
Notice that the addition of `getPrevious()` required a change to the implementations of the methods defined by `Series`. However, since the interface to those methods stays the same, the change is seamless and does not break preexisting code. This is one of the advantages of interfaces.

As explained, any number of classes can implement an interface. For example, here is a class called `ByThrees` that generates a series that consists of multiples of three:
One more point: If a class includes an interface but does not fully implement the methods defined by that interface, then that class must be declared as **abstract**. No objects of such a class can be created, but it can be used as an abstract superclass, allowing subclasses to provide the complete implementation.

**Using Interface References**

You might be somewhat surprised to learn that you can declare a reference variable of an interface type. In other words, you can create an interface reference variable. Such a variable can refer to any object that implements its interface. When you call a method on an object through an interface reference, it is the version of the method implemented by the object that is executed. This process is similar to using a superclass reference to access a subclass object, as described in Chapter 7.

The following example illustrates this process. It uses the same interface reference variable to call methods on objects of both **ByTwos** and **ByThrees**.
// Demonstrate interface references.

class ByTwos implements Series {
    int start;
    int val;

    ByTwos() {
        start = 0;
        val = 0;
    }

    public int getNext() {
        val += 2;
        return val;
    }

    public void reset() {
        val = start;
    }

    public void setStart(int x) {
        start = x;
        val = x;
    }
}

class ByThrees implements Series {
    int start;
    int val;
In `main()`, `ob` is declared to be a reference to a `Series` interface. This means that it can be used to store references to any object that implements `Series`. In this case, it is used to refer to `twoOb` and `threeOb`, which are objects of type `ByTwos` and `ByThrees`, respectively, which both implement `Series`. An interface reference variable has knowledge only of the methods declared by its interface declaration. Thus, `ob` could not be used to access any other variables or methods that might be supported by the object.

### Try This 8-1 Creating a Queue Interface

```
ICharQ.java
IQDemo.java
```

To see the power of interfaces in action, we will look at a practical example. In earlier chapters, you developed a class called `Queue` that implemented a simple fixed-size queue for characters. However, there are many ways to implement a queue. For example, the queue can be of a fixed size...
or it can be “growable.” The queue can be linear, in which case it can be used up, or it can be circular, in which case elements can be put in as long as elements are being taken off. The queue can also be held in an array, a linked list, a binary tree, and so on. No matter how the queue is implemented, the interface to the queue remains the same, and the methods `put()` and `get()` define the interface to the queue independently of the details of the implementation. Because the interface to a queue is separate from its implementation, it is easy to define a queue interface, leaving it to each implementation to define the specifics.

In this project, you will create an interface for a character queue and three implementations. All three implementations will use an array to store the characters. One queue will be the fixed-size, linear queue developed earlier. Another will be a circular queue. In a circular queue, when the end of the underlying array is encountered, the get and put indices automatically loop back to the start. Thus, any number of items can be stored in a circular queue as long as items are also being taken out. The final implementation creates a dynamic queue, which grows as necessary when its size is exceeded.

1. Create a file called `ICharQ.java` and put into that file the following interface definition:

   ```java
   // A character queue interface.
   public interface ICharQ {
     // Put a character into the queue.
     void put(char ch);

     // Get a character from the queue.
     char get();
   }
   
   As you can see, this interface is very simple, consisting of only two methods. Each class that implements `ICharQ` will need to implement these methods.

2. Create a file called `IQDemo.java`.

3. Begin creating `IQDemo.java` by adding the `FixedQueue` class shown here:
This implementation of \texttt{ICharQ} is adapted from the \texttt{Queue} class shown in \texttt{Chapter 5} and should already be familiar to you.

4. To \texttt{IQDemo.java} add the \texttt{CircularQueue} class shown here. It implements a circular queue for characters.
The circular queue works by reusing space in the array that is freed when elements are retrieved. Thus, it can store an unlimited number of elements as long as elements are also being removed. While conceptually simple—just reset the appropriate index to zero when the end of the array is reached—the boundary conditions are a bit confusing at first. In a circular queue, the queue is full not when the end of the underlying array is reached, but rather when storing an item would cause an unretrieved item to be overwritten. Thus, \texttt{put()} must check several conditions in order to determine if the queue is full. As the comments suggest, the queue is full when either \texttt{putloc} is one less than \texttt{getloc}, or if \texttt{putloc} is at the end of the array and \texttt{getloc} is at the beginning. As before, the queue is empty when \texttt{getloc} and \texttt{putloc} are equal. To make these checks easier, the
5. Put into IQDemo.java the DynQueue class shown next. It implements a “growable” queue that expands its size when space is exhausted.

```java
// A dynamic queue.
class DynQueue implements ICharQ {
    private char q[]; // this array holds the queue
    private int putloc, getloc; // the put and get indices

    // Construct an empty queue given its size.
    public DynQueue(int size) {
        q = new char[size]; // allocate memory for queue
        putloc = getloc = 0;
    }

    // Put a character into the queue.
    public void put(char ch) {
        if(putloc==q.length) {
            // increase queue size
            char t[] = new char[q.length * 2];

            // copy elements into new queue
            for(int i=0; i < q.length; i++)
                t[i] = q[i];

            q = t;
        }

        q[putloc++] = ch;
    }

    // Get a character from the queue.
    public char get() {
        if(getloc == putloc) {
            System.out.println(" - Queue is empty.");
            return (char) 0;
        }

        return q[getloc++];
    }
}
```

In this queue implementation, when the queue is full, an attempt to store another element causes a new underlying array to be allocated that is twice as large as the original, the current contents of the queue are copied into this array, and a reference to the new array is stored in q.

6. To demonstrate the three ICharQ implementations, enter the following class into IQDemo.java. It uses an ICharQ reference to access all three queues.
// Demonstrate the ICharQ interface.
class IQDemo {
    public static void main(String args[]) {
        FixedQueue q1 = new FixedQueue(10);
        DynQueue q2 = new DynQueue(5);
        CircularQueue q3 = new CircularQueue(10);

        ICharQ iq;

        char ch;
        int i;
iQ = q1;
// Put some characters into fixed queue.
for(i=0; i < 10; i++)
    iQ.put((char) ('A' + i));

// Show the queue.
System.out.print("Contents of fixed queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}
System.out.println();

iQ = q2;
// Put some characters into dynamic queue.
for(i=0; i < 10; i++)
    iQ.put((char) ('Z' - i));

// Show the queue.
System.out.print("Contents of dynamic queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}
System.out.println();

iQ = q3;
// Put some characters into circular queue.
for(i=0; i < 10; i++)
    iQ.put((char) ('A' + i));

// Show the queue.
System.out.print("Contents of circular queue: ");
for(i=0; i < 10; i++) {
    ch = iQ.get();
    System.out.print(ch);
}
System.out.println();

// Put more characters into circular queue.
for(i=10; i < 20; i++)
    iQ.put((char) ('A' + i));

// Show the queue.
System.out.print("Contents of circular queue: ");
for(i=0; i < 10; i++) {
7. The output from this program is shown here:

```
ch = iQ.get();
System.out.print(ch);
```

```java
System.out.println("\nStore and consume from" +
    " circular queue.");

// Store in and consume from circular queue.
for(i=0; i < 20; i++) {
    iQ.put((char) ('A' + i));
    ch = iQ.get();
    System.out.print(ch);
}
```

7. The output from this program is shown here:

Contents of fixed queue: ABCDEFGHIJ
Contents of dynamic queue: ZYXWVUTSRQ
Contents of circular queue: ABCDEFGHIJ
Contents of circular queue: KLMNOPQRSTUVWXYZ
Store and consume from circular queue.
ABCDHJIKLMPQRST

8. Here are some things to try on your own. Create a circular version of DynQueue. Add a reset() method to ICharQ, which resets the queue. Create a static method that copies the contents of one type of queue into another.

Variables in Interfaces
As mentioned, variables can be declared in an interface, but they are implicitly public, static, and final. At first glance, you might think that there would be very limited use for such variables, but the opposite is true. Large programs typically make use of several constant values that describe such things as array size, various limits, special values, and the like. Since a large program is typically held in a number of separate source files, there needs to be a convenient way to make these constants available to each file. In Java, interface variables offer one solution.

To define a set of shared constants, create an interface that contains only these constants, without any methods. Each file that needs access to the constants simply “implements” the interface. This brings the constants into view. Here is an example:
NOTE
The technique of using an interface to define shared constants 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:

```java
// An interface that contains constants.
interface IConst {
    int MIN = 0;
    int MAX = 10;
    String ERRORMSG = "Boundary Error";
}

class IConstD implements IConst {
    public static void main(String args[]) {
        int nums[] = new int[MAX];

        for(int i=MIN; i < 11; i++) {
            if(i >= MAX) System.out.println(ERRORMSG);
            else {
                nums[i] = i;
                System.out.print(nums[i] + " ");
            }
        }
    }
}
```
As an experiment, you might 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 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 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 non-modifiable sequences, then remove() is essentially optional because it won’t be used by non-modifiable sequences. In the past, a class that implemented a non-modifiable 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 either does nothing or reports an error. Providing this default prevents a class used for non-modifiable 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: an interface still cannot have instance variables. 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:

```java
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getUserID();

    // This is a default method. Notice that it provides
    // a default implementation.
    default int getAdminID() { return 1; }
}
```
MyIF declares two methods. The first, `getUserID()`, is a standard interface method declaration. It defines no implementation whatsoever. The second method is `getAdminID()`, and it does include a default implementation. In this case, it simply returns 1. Pay special attention to the way `getAdminID()` 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 `getAdminID()` 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
// Implement MyIF.
class MyIFImp implements MyIF {
    // Only getUserID() defined by MyIF needs to be implemented.
    // getAdminID() can be allowed to default.
    public int getUserID() {
        return 100;
    }
}
```

The following code creates an instance of `MyIFImp` and uses it to call both `getUserID()` and `getAdminID()`.

```java
// Use the default method.
class DefaultMethodDemo {
    public static void main(String args[]) {
        MyIFImp obj = new MyIFImp();

        // Can call getUserID(), because it is explicitly
        // implemented by MyIFImp:
        System.out.println("User ID is " + obj.getUserID());

        // Can also call getAdminID(), because of default
        // implementation:
        System.out.println("Administrator ID is " + obj.getAdminID());
    }
}
```

The output is shown here:

User ID is 100
Administrator ID is 1

As you can see, the default implementation of `getAdminID()` was automatically used. It was not necessary for `MyIFImp` to define it. Thus, for `getAdminID()`, implementation by a class is optional. (Of course, its implementation by a class will be *required* if the class needs to return a different ID.)

It is both possible and common for an implementing class to define its own implementation of a default method. For example, `MyIFImp2` overrides `getAdminID()`, as shown here:
Now, when `getAdminID()` is called, a value other than its default is returned.

A More Practical Example of a Default Method
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 return to the `Series` interface shown earlier in this chapter. For the sake of discussion, assume that `Series` is widely used and many programs rely on it. Further assume that through an analysis of usage patterns, it was discovered that many implementations of `Series` were adding a method that returned an array that contained the next \( n \) elements in the series. Given this situation, you decide to enhance `Series` so that it includes such a method, calling the new method `getNextArray()` and declaring it as shown here:

```java
int[] getNextArray(int n)
```

Here, \( n \) specifies the number of elements to retrieve. Prior to default methods, adding this method to `Series` would have broken preexisting code because existing implementations would not have defined the method. However, by providing a default for this new method, it can be added to `Series` without causing harm. Let’s work through the process.

In some cases, when a default method is added to an existing interface, its implementation simply reports an error if an attempt is made to use the default. This approach is necessary in the case of default methods for which no implementation can be provided that will work in all cases. These types of default methods define what is, essentially, optional code. However, in some cases, you can define a default method that will work in all cases. This is the situation for `getNextArray()`. Because `Series` already requires that a class implement `getNext()`, the default version of `getNextArray()` can use it. Thus, here is one way to implement the new version of `Series` that includes the default `getNextArray()` method:

class MyIFImp2 implements MyIF {
    // Here, implementations for both getUserID() and getAdminID() are provided.
    public int getUserID() {
        return 100;
    }
    public int getAdminID() {
        return 42;
    }
}
Pay special attention to the way that the default method `getNextArray()` is implemented. Because `getNext()` was part of the original specification for `Series`, any class that implements `Series` will provide that method. Thus, it can be used inside `getNextArray()` to obtain the next \( n \) elements in the series. As a result, any class that implements the enhanced version of `Series` will be able to use `getNextArray()` as is, and no class is required to override it. Therefore, no preexisting code is broken. Of course, it is still possible for a class to provide its own implementation of `getNextArray()`, if you choose.

As the preceding example shows, the default method provides two major benefits:

- It gives you a way to gracefully evolve interfaces over time without breaking existing code.
- It provides optional functionality without requiring that a class provide a placeholder implementation when that functionality is not needed.

In the case of `getNextArray()`, the second point is especially important. If an implementation of `Series` does not require the capability offered by `getNextArray()`, it need not provide its own placeholder implementation. This allows cleaner code to be created.

### 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 (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 resolve 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’s version is used. This is the case even if MyClass implements both Alpha and Beta. In this case, both defaults are overridden by MyClass’s implementation.

Second, in cases in which a class inherits two interfaces that both have the same default method, if the class does not override that method, then an error will result. Continuing with the example, if MyClass inherits 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 refer explicitly to a default implementation by using a new form of super. Its general form is shown here:

```
InterfaceName.super.methodName()
```

For example, if Beta wants to refer to Alpha’s default for reset( ), it can use this statement:

```
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:

```
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 earlier. The static method is getUniversalID(). It returns zero.
The `getUniversalID( )` method can be called, as shown here:

```java
public interface MyIF {
    // This is a "normal" interface method declaration.
    // It does NOT define a default implementation.
    int getUserID();

    // This is a default method. Notice that it provides
    // a default implementation.
    default int getAdminID() {
        return 1;
    }

    // This is a static interface method.
    static int getUniversalID() {
        return 0;
    }
}
```

The `getUniversalID( )` method can be called, as shown here:

```java
int uID = MyIF.getUniversalID();
```

As mentioned, no implementation or instance of `MyIF` is required to call `getUniversalID( )` 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.

**Chapter 8 Self Test**

1. Using the code from Try This 8-1, put the `ICharQ` interface and its three implementations into a package called `qpack`. Keeping the queue demonstration class `IQDemo` in the default package, show how to import and use the classes in `qpack`.

2. What is a namespace? Why is it important that Java allows you to partition the namespace?

3. Packages are stored in ______________.

4. Explain the difference between `protected` and default access.

5. Explain the two ways that the members of a package can be used by other packages.

6. “One interface, multiple methods” is a key tenet of Java. What feature best exemplifies it?
7. How many classes can implement an interface? How many interfaces can a class implement?

8. Can interfaces be extended?

9. Create an interface for the Vehicle class from Chapter 7. Call the interface IVehicle.

10. Variables declared in an interface are implicitly static and final. Can they be shared with other parts of a program?

11. A package is, in essence, a container for classes. True or False?

12. What standard Java package is automatically imported into a program?

13. What keyword is used to declare a default interface method?

14. Beginning with JDK 8, is it possible to define a static method in an interface?

15. Assume that the ICharQ interface shown in Try This 8-1 has been in widespread use for several years. Now, you want to add a method to it called reset(), which will be used to reset the queue to its empty, starting condition. Assuming JDK 8 or later, how can this be accomplished without breaking preexisting code?

16. How is a static method in an interface called?
Chapter 9
Exception Handling

Key Skills & Concepts
- Know the exception hierarchy
- Use `try` and `catch`
- Understand the effects of an uncaught exception
- Use multiple `catch` statements
- Catch subclass exceptions
- Nest `try` blocks
- Throw an exception
- Know the members of `Throwable`
- Use `finally`
- Use `throws`
- Know Java’s built-in exceptions
- Create custom exception classes

This chapter discusses exception handling. An exception is an error that occurs at run time. Using Java’s exception handling subsystem you can, in a structured and controlled manner, handle run-time
errors. Although most modern programming languages offer some form of exception handling, Java’s support for it is both easy-to-use and flexible.

A principal advantage of exception handling is that it automates much of the error handling code that previously had to be entered “by hand” into any large program. For example, in some older computer languages, error codes are returned when a method fails, and these values must be checked manually, each time the method is called. This approach is both tedious and error-prone. Exception handling streamlines error handling by allowing your program to define a block of code, called an *exception handler*, that is executed automatically when an error occurs. It is not necessary to manually check the success or failure of each specific operation or method call. If an error occurs, it will be processed by the exception handler.

Another reason that exception handling is important is that Java defines standard exceptions for common program errors, such as divide-by-zero or file-not-found. To respond to these errors, your program must watch for and handle these exceptions. Also, Java’s API library makes extensive use of exceptions.

In the final analysis, to be a successful Java programmer means that you are fully capable of navigating Java’s exception handling subsystem.

### The Exception Hierarchy

In Java, all exceptions are represented by classes. All exception classes are derived from a class called **Throwable**. Thus, when an exception occurs in a program, an object of some type of exception class is generated. There are two direct subclasses of **Throwable**: **Exception** and **Error**. Exceptions of type **Error** are related to errors that occur in the Java virtual machine itself, and not in your program. These types of exceptions are beyond your control, and your program will not usually deal with them. Thus, these types of exceptions are not described here.

Errors that result from program activity are represented by subclasses of **Exception**. For example, divide-by-zero, array boundary, and file errors fall into this category. In general, your program should handle exceptions of these types. An important subclass of **Exception** is **RuntimeException**, which is used to represent various common types of run-time errors.

### Exception Handling Fundamentals

Java exception handling is managed via five keywords: **try**, **catch**, **throw**, **throws**, and **finally**. They form an interrelated subsystem in which the use of one implies the use of another. Throughout the course of this chapter, each keyword is examined in detail. However, it is useful at the outset to have a general understanding of the role each plays in exception handling. 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 run-time system. To manually throw an exception, use the keyword **throw**. In some cases, an exception that is thrown out of a method must be specified as such by a **throws** clause. Any code that absolutely must be executed upon exiting from a **try** block is put in a **finally** block.

### Ask the Expert
Q: Just to be sure, could you review the conditions that cause an exception to be generated?

A: Exceptions are generated in three different ways. First, the Java Virtual Machine can generate an exception in response to some internal error which is beyond your control. Normally, your program won’t handle these types of exceptions. Second, standard exceptions, such as those corresponding to divide-by-zero or array index out-of-bounds, are generated by errors in program code. You need to handle these exceptions. Third, you can manually generate an exception by using the `throw` statement. No matter how an exception is generated, it is handled in the same way.

Using try and catch

At the core of exception handling are `try` and `catch`. These keywords work together; you can’t have a `catch` without a `try`. Here is the general form of the `try/catch` exception handling blocks:

```java
try {
    // block of code to monitor for errors
}
catch (ExcepType1 exOb) {
    // handler for ExcepType1
}
catch (ExcepType2 exOb) {
    // handler for ExcepType2
}
```

Here, `ExcepType` is the type of exception that has occurred. When an exception is thrown, it is caught by its corresponding `catch` statement, which then processes the exception. As the general form shows, there can be more than one `catch` statement associated with a `try`. The type of the exception determines which `catch` statement is executed. That is, if the exception type specified by a `catch` statement matches that of the exception, then that `catch` statement is executed (and all others are bypassed). When an exception is caught, `exOb` will receive its value.

Here is an important point: If no exception is thrown, then a `try` block ends normally, and all of its `catch` statements are bypassed. Execution resumes with the first statement following the last `catch`. Thus, `catch` statements are executed only if an exception is thrown.

**NOTE**

Beginning with JDK 7, there is another form of the `try` statement that supports automatic resource management. This form of `try` is called `try-with-resources`. It is described in Chapter 10, in the context of managing I/O streams (such as those connected to a file) because streams are some of the
A Simple Exception Example
Here is a simple example that illustrates how to watch for and catch an exception. As you know, it is an error to attempt to index an array beyond its boundaries. When this occurs, the JVM throws an `ArrayIndexOutOfBoundsException`. The following program purposely generates such an exception and then catches it:

```java
// Demonstrate exception handling.
class ExcDemo1 {
    public static void main(String args[]) {
        int nums[] = new int[4];
        try {
            System.out.println("Before exception is generated.");
            // Generate an index out-of-bounds exception.
            nums[7] = 10;  // Attempt to index past nums boundary.
            System.out.println("this won't be displayed");
        } catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("Index out-of-bounds!");
        }
        System.out.println("After catch statement.");
    }
}
```

This program displays the following output:

```
Before exception is generated.
Index out-of-bounds!
After catch statement.
```

Although quite short, the preceding program illustrates several key points about exception handling. First, the code that you want to monitor for errors is contained within a `try` block. Second, when an exception occurs (in this case, because of the attempt to index `nums` beyond its bounds), the exception is thrown out of the `try` block and caught by the `catch` statement. At this point, control passes to the `catch`, and the `try` block is terminated. That is, `catch` is not called. Rather, program execution is transferred to it. Thus, the `println( )` statement following the out-of-bounds index will never execute. After the `catch` statement executes, program control continues with the statements following the `catch`. Thus, it is the job of your exception handler to remedy the problem that caused the exception so that program execution can continue normally.

Remember, if no exception is thrown by a `try` block, no `catch` statements will be executed and program control resumes after the `catch` statement. To confirm this, in the preceding program, change the line
Now, no exception is generated, and the catch block is not executed.

It is important to understand that all code within a try block is monitored for exceptions. This includes exceptions that might be generated by a method called from within the try block. An exception thrown by a method called from within a try block can be caught by the catch statements associated with that try block—assuming, of course, that the method did not catch the exception itself. For example, this is a valid program:

```java
/* An exception can be generated by one method and caught by another. */
class ExcTest {
    // Generate an exception.
    static void genException() {
        int nums[] = new int[4];
        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
        System.out.println("this won't be displayed");
    }
}

class ExcDemo2 {
    public static void main(String args[]) {
        try {
            ExcTest.genException();
        } catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("Index out-of-bounds!");
        }
        System.out.println("After catch statement.");
    }
}
```

This program produces the following output, which is the same as that produced by the first version of the program shown earlier:

Before exception is generated.
Index out-of-bounds!
After catch statement.

Since genException() is called from within a try block, the exception that it generates (and does not catch) is caught by the catch in main(). Understand, however, that if genException() had caught the exception itself, it never would have been passed back to main().

The Consequences of an Uncaught Exception
Catching one of Java's standard exceptions, as the preceding program does, has a side benefit: It prevents abnormal program termination. When an exception is thrown, it must be caught by some piece of code, somewhere. In general, if your program does not catch an exception, then it will be caught by the JVM. The trouble is that the JVM's default exception handler terminates execution and displays a stack trace and error message. For example, in this version of the preceding example, the index out-of-bounds exception is not caught by the program.

```java
// Let JVM handle the error.
class NotHandled {
    public static void main(String args[]) {
        int nums[] = new int[4];

        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
        nums[7] = 10;
    }
}
```

When the array index error occurs, execution is halted, and the following error message is displayed.

```
Exception in thread "main" java.lang.ArrayIndexOutOfBoundsException: 7
    at NotHandled.main(NotHandled.java:9)
```

While such a message is useful for you while debugging, it would not be something that you would want others to see, to say the least! This is why it is important for your program to handle exceptions itself, rather than rely upon the JVM.

As mentioned earlier, the type of the exception must match the type specified in a catch statement. If it doesn’t, the exception won’t be caught. For example, the following program tries to catch an array boundary error with a catch statement for an ArithmeticException (another of Java’s built-in exceptions). When the array boundary is overrun, an ArrayIndexOutOfBoundsException is generated, but it won’t be caught by the catch statement. This results in abnormal program termination.
As the output demonstrates, a catch for `ArithmeticException` won’t catch an `ArrayIndexOutOfBoundsException`.

**Exceptions Enable You to Handle Errors Gracefully**

One of the key benefits of exception handling is that it enables your program to respond to an error and then continue running. For example, consider the following example that divides the elements of one array by the elements of another. If a division by zero occurs, an `ArithmeticException` is generated. In the program, this exception is handled by reporting the error and then continuing with execution. Thus, attempting to divide by zero does not cause an abrupt run-time error resulting in the termination of the program. Instead, it is handled gracefully, allowing program execution to continue.
The output from the program is shown here:

4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16

This example makes another important point: Once an exception has been handled, it is removed from the system. Therefore, in the program, each pass through the loop enters the try block anew; any prior exceptions have been handled. This enables your program to handle repeated errors.

**Using Multiple catch Statements**

As stated earlier, you can associate more than one catch statement with a try. In fact, it is common to do so. However, each catch must catch a different type of exception. For example, the program shown here catches both array boundary and divide-by-zero errors:
This program produces the following output:

4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
No matching element found.

As the output confirms, each catch statement responds only to its own type of exception.

In general, catch expressions are checked in the order in which they occur in a program. Only a matching statement is executed. All other catch blocks are ignored.

Catching Subclass Exceptions

There is one important point about multiple catch statements that relates to subclasses. A catch clause for a superclass will also match any of its subclasses. For example, since the superclass of all exceptions is Throwable, to catch all possible exceptions, catch Throwable. If you want to catch exceptions of both a superclass type and a subclass type, put the subclass first in the catch sequence. If you don’t, then the superclass catch will also catch all derived classes. This rule is self-enforcing because putting the superclass first causes unreachable code to be created, since the subclass catch clause can never execute. In Java, unreachable code is an error.

For example, consider the following program:
Ask the Expert

Q: Why would I want to catch superclass exceptions?

A: There are, of course, a variety of reasons. Here are a couple. First, if you add a catch clause that catches exceptions of type Exception, then you have effectively added a “catch all” clause to your exception handler that deals with all program-related exceptions. Such a “catch all” clause might be useful in a situation in which abnormal program termination must be avoided no matter what occurs. Second, in some situations, an entire category of exceptions can be handled by the same clause. Catching the superclass of these exceptions allows you to handle all without duplicated code.

In this case, catch(Throwable) catches all exceptions except for
ArrayIndexOutOfBoundsException. The issue of catching subclass exceptions becomes more important when you create exceptions of your own.

Try Blocks Can Be Nested

One `try` block can be nested within another. An exception generated within the inner `try` block that is not caught by a `catch` associated with that `try` is propagated to the outer `try` block. For example, here the `ArrayIndexOutOfBoundsException` is not caught by the inner `catch`, but by the outer `catch`:

```java
// Use a nested try block.
class NestTrys {
    public static void main(String args[]) {
        // Here, numer is longer than denom.
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };
        int denom[] = { 2, 0, 4, 4, 0, 8 };

        try { // outer try
            for(int i=0; i<numer.length; i++) {
                try { // nested try
                    System.out.println(numer[i] + " / " +
                                      denom[i] + " is " +
                                      numer[i]/denom[i]);
                } catch (ArithmeticException exc) {
                    // catch the exception
                    System.out.println("Can't divide by Zero!");
                }
            }
            catch (ArrayIndexOutOfBoundsException exc) {
                // catch the exception
                System.out.println("No matching element found.");
                System.out.println("Fatal error - program terminated.");
            }
        }
    }
}
```

The output from the program is shown here:

```
4 / 2 is 2
Can't divide by Zero!
16 / 4 is 4
32 / 4 is 8
Can't divide by Zero!
128 / 8 is 16
No matching element found.
Fatal error - program terminated.
```

In this example, an exception that can be handled by the inner `try`—in this case, a divide-by-zero error—allows the program to continue. However, an array boundary error is caught by the outer `try`, which causes the program to terminate.
Although certainly not the only reason for nested \texttt{try} statements, the preceding program makes an important point that can be generalized. Often nested \texttt{try} blocks are used to allow different categories of errors to be handled in different ways. Some types of errors are catastrophic and cannot be fixed. Some are minor and can be handled immediately. You might use an outer \texttt{try} block to catch the most severe errors, allowing inner \texttt{try} blocks to handle less serious ones.

**Throwing an Exception**

The preceding examples have been catching exceptions generated automatically by the JVM. However, it is possible to manually throw an exception by using the \texttt{throw} statement. Its general form is shown here:

\begin{verbatim}
throw exceptOb;
\end{verbatim}

Here, \texttt{exceptOb} must be an object of an exception class derived from \texttt{Throwable}.

Here is an example that illustrates the \texttt{throw} statement by manually throwing an \texttt{ArithmeticException}:

\begin{verbatim}
// Manually throw an exception.
class ThrowDemo {
    public static void main(String args[]) {
        try {
            System.out.println("Before throw.");
            throw new ArithmeticException();  // Throw an exception.
        }
        catch (ArithmeticException exc) {
            // catch the exception
            System.out.println("Exception caught.");
        }
        System.out.println("After try/catch block.");
    }
}
\end{verbatim}

The output from the program is shown here:

Before throw.
Exception caught.
After try/catch block.

Notice how the \texttt{ArithmeticException} was created using \texttt{new} in the \texttt{throw} statement. Remember, \texttt{throw} throws an object. Thus, you must create an object for it to throw. That is, you can’t just throw a type.

**Rethrowing an Exception**

An exception caught by one \texttt{catch} statement can be rethrown so that it can be caught by an outer \texttt{catch}. The most likely reason for rethrowing this way is to allow multiple handlers access to the exception. For example, perhaps one exception handler manages one aspect of an exception, and a second handler copes with another aspect. Remember, when you rethrow an exception, it will not be
recaught by the same `catch` statement. It will propagate to the next `catch` statement. The following program illustrates rethrowing an exception:

```java
// Rethrow an exception.
class Rethrow {
    public static void genException() {
        // here, numer is longer than denom
        int numer[] = { 4, 8, 16, 32, 64, 128, 256, 512 };
        int denom[] = { 2, 0, 4, 4, 0, 8 };
    }
}

Ask the Expert

Q: Why would I want to manually throw an exception?

A: Most often, the exceptions that you will throw will be instances of exception classes that you created. As you will see later in this chapter, creating your own exception classes allows you to handle errors in your code as part of your program’s overall exception handling strategy.

```java
for(int i=0; i<numer.length; i++) {
    try {
        System.out.println(numer[i] + " / " +
                denom[i] + " is " +
                numer[i]/denom[i]);
    }
    catch (ArithmeticException exc) {
        // catch the exception
        System.out.println("Can't divide by Zero!");
    }
    catch (ArrayIndexOutOfBoundsException exc) {
        // catch the exception
        System.out.println("No matching element found.");
        throw exc; // rethrow the exception
    }
}
```
In this program, divide-by-zero errors are handled locally, by `genException()`, but an array boundary error is rethrown. In this case, it is caught by `main()`.

**A Closer Look at Throwable**

Up to this point, we have been catching exceptions, but we haven’t been doing anything with the exception object itself. As the preceding examples all show, a `catch` clause specifies an exception type and a parameter. The parameter receives the exception object. Since all exceptions are subclasses of `Throwable`, all exceptions support the methods defined by `Throwable`. Several commonly used ones are shown in Table 9-1.

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>fillInStackTrace()</code></td>
<td>Returns a <code>Throwable</code> object that contains a completed stack trace. This object can be rethrown.</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>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>toString()</code></td>
<td>Returns a <code>String</code> object containing a complete description of the exception. This method is called by <code>println()</code> when outputting a <code>Throwable</code> object.</td>
</tr>
</tbody>
</table>

**Table 9-1  Commonly Used Methods Defined by Throwable**

Of the methods defined by `Throwable`, two of the most interesting are `printStackTrace()` and `toString()`. You can display the standard error message plus a record of the method calls that lead up to the exception by calling `printStackTrace()`. You can use `toString()` to retrieve the standard error message. The `toString()` method is also called when an exception is used as an argument to `println()`. The following program demonstrates these methods:
class ExcTest {
    static void genException() {
        int nums[] = new int[4];

        System.out.println("Before exception is generated.");

        // generate an index out-of-bounds exception
        nums[7] = 10;
        System.out.println("this won't be displayed");
    }
}

class UseThrowableMethods {  
    public static void main(String args[]) {  
        try { 
            ExcTest.genException();  
        }
        catch (ArrayIndexOutOfBoundsException exc) { 
            // catch the exception  
            System.out.println("Standard message is: ");
            System.out.println(exc);
            System.out.println("\nStack trace: ");
            exc.printStackTrace();
        }
        System.out.println("After catch statement.");
    }
}

The output from this program is shown here:

Before exception is generated.
Standard message is:
java.lang.ArrayIndexOutOfBoundsException: 7

Stack trace:
java.lang.ArrayIndexOutOfBoundsException: 7
    at ExcTest.genException(UseThrowableMethods.java:10)
    at UseThrowableMethods.main(UseThrowableMethods.java:19)
After catch statement.

Using finally
Sometimes you will want to define a block of code that will execute when a try/catch block is left. For example, an exception might cause an error that terminates the current method, causing its premature return. However, that method may have opened a file or a network connection that needs to be closed. Such types of circumstances are common in programming, and Java provides a convenient
way to handle them: **finally**.

To specify a block of code to execute when a **try/catch** block is exited, include a **finally** block at the end of a **try/catch** sequence. The general form of a **try/catch** that includes **finally** is shown here.

```java
try {
    // block of code to monitor for errors
}
catch (Exception ex) {
    // handler for Exception
}
catch (Exception ex) {
    // handler for Exception
}
//...
finally {
    // finally code
}
```

The **finally** block will be executed whenever execution leaves a **try/catch** block, no matter what conditions cause it. That is, whether the **try** block ends normally, or because of an exception, the last code executed is that defined by **finally**. The **finally** block is also executed if any code within the **try** block or any of its **catch** statements return from the method.

Here is an example of **finally**:
// Use finally.
class UseFinally {
    public static void genException(int what) {
        int t;
        int nums[] = new int[2];

        System.out.println("Receiving "+ what);
        try {
            switch (what) {
                case 0:
                    t = 10 / what; // generate div-by-zero error
                    break;
                case 1:
                    break;
                case 2:
                    return; // return from try block
            }
        } catch (ArithmeticException exc) {
            // catch the exception
            System.out.println("Can't divide by Zero!");
            return; // return from catch
        } catch (ArrayIndexOutOfBoundsException exc) {
            // catch the exception
            System.out.println("No matching element found.");
        }
        finally { // This is executed on the way out of try/catch blocks.
            System.out.println("Leaving try.");
        }
    }
}

class FinallyDemo {
    public static void main(String args[]) {
        for(int i=0; i < 3; i++) {
            UseFinally.genException(i);
            System.out.println();
        }
    }
}

Here is the output produced by the program:

Receiving 0
Can't divide by Zero!
Leaving try.

Receiving 1
No matching element found.
Leaving try.

Receiving 2
Leaving try.
As the output shows, no matter how the try block is exited, the finally block is executed.

**Using throws**

In some cases, if a method generates an exception that it does not handle, it must declare that exception in a throws clause. Here is the general form of a method that includes a throws clause:

```
ret-type methName(param-list) throws except-list {
    // body
}
```

Here, except-list is a comma-separated list of exceptions that the method might throw outside of itself.

You might be wondering why you did not need to specify a throws clause for some of the preceding examples, which threw exceptions outside of methods. The answer is that exceptions that are subclasses of Error or RuntimeException don’t need to be specified in a throws list. Java simply assumes that a method may throw one. All other types of exceptions do need to be declared. Failure to do so causes a compile-time error.

Actually, you saw an example of a throws clause earlier in this book. As you will recall, when performing keyboard input, you needed to add the clause

```java
throws java.io.IOException
```

to main( ). Now you can understand why. An input statement might generate an IOException, and at that time, we weren’t able to handle that exception. Thus, such an exception would be thrown out of main( ) and needed to be specified as such. Now that you know about exceptions, you can easily handle IOException.

Let’s look at an example that handles IOException. It creates a method called prompt( ), which displays a prompting message and then reads a character from the keyboard. Since input is being performed, an IOException might occur. However, the prompt( ) method does not handle IOException itself. Instead, it uses a throws clause, which means that the calling method must handle it. In this example, the calling method is main( ), and it deals with the error.
On a related point, notice that IOException is fully qualified by its package name java.io. As you will learn in Chapter 10, Java’s I/O system is contained in the java.io package. Thus, the IOException is also contained there. It would also have been possible to import java.io and then refer to IOException directly.

Three Recently Added Exception Features
Beginning with JDK 7, Java's exception handling mechanism has been expanded with the addition of three features. The first supports automatic resource management, which 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 try, called the try-with-resources statement, and it is described in Chapter 10, when files are discussed. The second new feature is called multi-catch, and the third is sometimes called final rethrow or more precise rethrow. These two features are described here.

Multi-catch allows two or more exceptions to be caught by the same catch clause. As you learned earlier, it is possible (indeed, common) for a try to be followed by two or more catch clauses. Although each catch clause often supplies its own unique code sequence, it is not uncommon to have situations in which two or more catch clauses execute the same code sequence even though they catch different exceptions. Instead of having to catch each exception type individually, you can now use a single catch clause to handle the exceptions without code duplication.

To create a multi-catch, specify a list of exceptions within a single catch clause. You do this by separating each exception type in the list 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 how you can use the multi-catch feature to catch both ArithmeticException and ArrayIndexOutOfBoundsException with a single catch clause:
Here is a simple program that demonstrates the use of this multi-catch:

```java
// Use the multi-catch feature. Note: This code requires JDK 7 or later to compile.
class MultiCatch {
    public static void main(String args[]) {
        int a=88, b=0;
        int result;
        char chrs[] = { 'A', 'B', 'C' };

        for(int i=0; i < 2; i++) {
            try {
                if(i == 0)
                    result = a / b; // generate an ArithmeticException
                else
                    chrs[5] = 'X'; // generate an ArrayIndexOutOfBoundsException
            }
            catch(ArithmeticException | ArrayIndexOutOfBoundsException e) {
                System.out.println("Exception caught: "+ e);
            }
        }
        System.out.println("After multi-catch.");
    }
}
```

The program will generate an `ArithmeticException` when the division by zero is attempted. It will generate an `ArrayIndexOutOfBoundsException` when the attempt is made to access outside the bounds of `chrs`. 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. While this capability might not be needed often, it is now available for use. For the final rethrow feature to be in force, the `catch` parameter must be effectively `final`. This means that it must not be assigned a new value inside the `catch` block. It can also be explicitly specified as `final`, but this is not necessary.

**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`. Since `java.lang` is implicitly imported into all Java programs, most exceptions derived from `RuntimeException` are automatically available. Furthermore, they 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 9-2. Table 9-3 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 other types of exceptions that relate to other packages, such as `IOException` mentioned earlier.
Table 9-2  The Unchecked Exceptions 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 integer 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 9-3  The Checked Exceptions Defined in java.lang

<table>
<thead>
<tr>
<th>Exception</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>ClassNotFoundException</td>
<td>Class not found.</td>
</tr>
<tr>
<td>CloneNotSupportedException</td>
<td>Attempt to clone an object that does not implement the Cloneable 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>Superclass of reflection-related exceptions.</td>
</tr>
</tbody>
</table>

Ask the Expert

Q: I have heard that Java supports something called *chained exceptions*. What are they?

A: Chained exceptions were added to Java by JDK 1.4. The chained exception feature allows you to specify one exception as the underlying cause of another. 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 added to `Throwable` are `getCause()` and `initCause()`. These methods are shown here:

```
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. In general, `initCause()` is used to set a cause for legacy exception classes that don’t support the two additional constructors described earlier.

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.

---

### Creating Exception Subclasses

Although Java’s built-in exceptions handle most common errors, Java’s exception handling mechanism is not limited to these errors. In fact, part of the power of Java’s approach to exceptions is its ability to handle exception types that you create. Through the use of custom exceptions, you can manage errors that relate specifically to your application. Creating an exception class is easy. 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 create, have the methods defined by `Throwable` available to them. Of course, you can override one or more of these methods in exception subclasses that you create.

Here is an example that creates an exception called `NonIntResultException`, which is generated
when the result of dividing two integer values produces a result with a fractional component. 

NonIntResultException has two fields which hold the integer values; a constructor; and an override 
of the toString() method, allowing the description of the exception to be displayed using println() 

The output from the program is shown here:

```java
// Use a custom exception.

// Create an exception.
class NonIntResultException extends Exception {
    int n;
    int d;

    NonIntResultException(int i, int j) {
        n = i;
        d = j;
    }

    public String toString() {
        return "Result of " + n + " / " + d + " is non-integer.";
    }
}

class CustomExceptDemo {
    public static void main(String args[]) {
        // Here, numer contains some odd values.
        int numer[] = {4, 8, 15, 32, 64, 127, 256, 512};
        int denom[] = {2, 0, 4, 4, 0, 0, 0};

        for(int i=0; i<numer.length; i++) {
            try {
                if((numer[i]%2) != 0)
                    throw new NonIntResultException(numer[i], denom[i]);

                System.out.println(numer[i] + " / " +
                                   denom[i] + " is " +
                                   numer[i]/denom[i]);
            }
            catch (ArithmeticException exc) {
                // catch the exception
                System.out.println("Can't divide by Zero!");
            }
            catch (ArrayIndexOutOfBoundsException exc) {
                // catch the exception
                System.out.println("No matching element found.");
            }
            catch (NonIntResultException exc) {
                System.out.println(exc);
            }
        }
    }
}
```
Ask the Expert

Q: When should I use exception handling in a program? When should I create my own custom exception classes?

A: Since the Java API makes extensive use of exceptions to report errors, nearly all real-world programs will make use of exception handling. This is the part of exception handling that most new Java programmers find easy. It is harder to decide when and how to use your own custom-made exceptions. In general, errors can be reported in two ways: return values and exceptions. When is one approach better than the other? Simply put, in Java, exception handling should be the norm. Certainly, returning an error code is a valid alternative in some cases, but exceptions provide a more powerful, structured way to handle errors. They are the way professional Java programmers handle errors in their code.

Try This 9-1 Adding Exceptions to the Queue Class

In this project, you will create two exception classes that can be used by the queue classes developed by Project 8-1. They will indicate the queue-full and queue-empty error conditions. These exceptions can be thrown by the put() and get() methods, respectively. For the sake of simplicity, this project will add these exceptions to the FixedQueue class, but you can easily incorporate them into the other queue classes from Project 8-1.

1. You will create two files that will hold the queue exception classes. Call the first file QueueFullException.java and enter into it the following:
A `QueueFullException` will be generated when an attempt is made to store an item in an already full queue.

2. Create the second file `QueueEmptyException.java` and enter into it the following:

```java
public class QueueEmptyException extends Exception {

    public String toString() {
        return "\nQueue is empty."
    }
}
```

A `QueueEmptyException` will be generated when an attempt is made to remove an element from an empty queue.

3. Modify the `FixedQueue` class so that it throws exceptions when an error occurs, as shown here. Put it in a file called `FixedQueue.java`. 

```java
// An exception for queue-full errors.
public class QueueFullException extends Exception {
    int size;

    QueueFullException(int s) { size = s; }

    public String toString() {
        return "\nQueue is full. Maximum size is " + size;
    }
}
```
Notice that two steps are required to add exceptions to `FixedQueue`. First, `get()` and `put()` must have a `throws` clause added to their declarations. Second, when an error occurs, these methods throw an exception. Using exceptions allows the calling code to handle the error in a rational fashion. You might recall that the previous versions simply reported the error. Throwing an exception is a much better approach.

4. To try the updated `FixedQueue` class, use the `QExcDemo` class shown here. Put it into a file called `QExcDemo.java`:
5. Since `FixedQueue` implements the `ICharQ` interface, which defines the two queue methods `get()` and `put()`, `ICharQ` will need to be changed to reflect the `throws` clause. Here is the updated `ICharQ` interface. Remember, this must be in a file by itself called `ICharQ.java`.

```java
// A character queue interface that throws exceptions.
public interface ICharQ {

    // Put a character into the queue.
    void put(char ch) throws QueueFullException;

    // Get a character from the queue.
    char get() throws QueueEmptyException;
}
```
6. Now, compile the updated ICharQ.java file. Then, compile FixedQueue.java, QueueFullException.java, QueueEmptyException.java, and QExcDemo.java. Finally, run QExcDemo. You will see the following output:

```
Attempting to store : A - OK
Attempting to store : B - OK
Attempting to store : C - OK
Attempting to store : D - OK
Attempting to store : E - OK
Attempting to store : F - OK
Attempting to store : G - OK
Attempting to store : H - OK
Attempting to store : I - OK
Attempting to store : J - OK
Attempting to store : K
Queue is full. Maximum size is 10

Getting next char: A
Getting next char: B
Getting next char: C
Getting next char: D
Getting next char: E
Getting next char: F
Getting next char: G
Getting next char: H
Getting next char: I
Getting next char: J
Getting next char:
Queue is empty.
```

---

**Chapter 9 Self Test**

1. What class is at the top of the exception hierarchy?
2. Briefly explain how to use `try` and `catch`.
3. What is wrong with this fragment?
   ```java
   // ...
   vals[18] = 10;
   catch (ArrayIndexOutOfBoundsException exc) {
     // handle error
   }
   4. What happens if an exception is not caught?
5. What is wrong with this fragment?
   
   class A extends Exception { ...
   
   class B extends A { ...
   
   // ...

   try {
       // ...
   }
catch (A exc) { ... }
catch (B exc) { ... }

6. Can an inner catch rethrow an exception to an outer catch?

7. The finally block is the last bit of code executed before your program ends. True or False? Explain your answer.

8. What type of exceptions must be explicitly declared in a throws clause of a method?

9. What is wrong with this fragment?
   
   class MyClass { // ...
   // ...
   throw new MyClass();

10. In question 3 of the Chapter 6 Self Test, you created a Stack class. Add custom exceptions to your class that report stack full and stack empty conditions.

11. What are the three ways that an exception can be generated?

12. What are the two direct subclasses of Throwable?

13. What is the multi-catch feature?

14. Should your code typically catch exceptions of type Error?
Chapter 10  
Using I/O

Key Skills & Concepts

- Understand the stream
- Know the difference between byte and character streams
- Know Java’s byte stream classes
- Know Java’s character stream classes
- Know the predefined streams
- Use byte streams
- Use byte streams for file I/O
- Automatically close a file by using `try-with-resources`
- Read and write binary data
- Use random-access files
- Use character streams
- Use character streams for file I/O
- Apply Java’s type wrappers to convert numeric strings

Since the beginning of this book, you have been using parts of the Java I/O system, such as `println( )`. 
However, you have been doing so without much formal explanation. Because the Java I/O system is based upon a hierarchy of classes, it was not possible to present its theory and details without first discussing classes, inheritance, and exceptions. Now it is time to examine Java’s approach to I/O in detail.

Be forewarned, Java’s I/O system is quite large, containing many classes, interfaces, and methods. Part of the reason for its size is that Java defines two complete I/O systems: one for byte I/O and the other for character I/O. It won’t be possible to discuss every aspect of Java’s I/O here. (An entire book could easily be dedicated to Java’s I/O system!) This chapter will, however, introduce you to the most important and commonly used features. Fortunately, Java’s I/O system is cohesive and consistent; once you understand its fundamentals, the rest of the I/O system is easy to master.

Before we begin, an important point needs to be made. The I/O classes described in this chapter support text-based console I/O and file I/O. They are not used to create graphical user interfaces (GUIs). Thus, you will not use them to create windowed applications, for example. However, Java does include substantial support for building graphical user interfaces. The basics of GUI programming are found in Chapter 15, where applets are introduced; Chapter 16, which offers an introduction to Swing; and Chapter 17, which presents an overview of JavaFX. (Swing and JavaFX are two of Java’s GUI toolkits.)

Java’s I/O Is Built upon Streams
Java programs perform I/O through streams. An I/O 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 they are linked to differ. Thus, the same I/O classes and methods can be applied to different types of devices. For example, the same methods that you use to write to the console can also be used to write to a disk file. Java implements I/O streams within class hierarchies defined in the java.io package.

Byte Streams and Character Streams
Modern versions of Java define two types of I/O streams: byte and character. (The original version of Java defined only the byte stream, but character streams were quickly added.) Byte streams provide a convenient means for handling input and output of bytes. They are used, for example, when reading or writing binary data. They are especially helpful when working with files. Character streams are designed for handling the 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 fact that Java defines two different types of streams makes the I/O system quite large because two separate sets of class hierarchies (one for bytes, one for characters) are needed. The sheer number of I/O classes can make the I/O system appear more intimidating than it actually is. Just remember, for the most part, the functionality of byte streams is paralleled by that of the character streams.

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.

The Byte Stream Classes
Byte streams are defined by using two class hierarchies. At the top of these are two abstract classes: InputStream and OutputStream. InputStream defines the characteristics common to byte input
streams and **OutputStream** describes the behavior of byte output streams.

From **InputStream** and **OutputStream** are created several concrete subclasses that offer varying functionality and handle the details of reading and writing to various devices, such as disk files. The byte stream classes are shown in **Table 10-1**. Don’t be overwhelmed by the number of different classes. Once you can use one byte stream, the others are easy to master.

<table>
<thead>
<tr>
<th>Byte Stream Class</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>BufferedInputStream</td>
<td>Buffered input stream</td>
</tr>
<tr>
<td>BufferedOutputStream</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 <strong>InputStream</strong></td>
</tr>
<tr>
<td>FilterOutputStream</td>
<td>Implements <strong>OutputStream</strong></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>Output stream that contains <strong>println</strong></td>
</tr>
<tr>
<td>PushbackInputStream</td>
<td>Input stream that allows bytes to be returned to the stream</td>
</tr>
<tr>
<td>SequencelInputStream</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 10-1** The Byte Stream Classes

The **Character Stream Classes**

Character streams are defined by using two class hierarchies topped by these two abstract classes: **Reader** and **Writer**. **Reader** is used for input, and **Writer** is used for output. Concrete classes derived from **Reader** and **Writer** operate on Unicode character streams.

From **Reader** and **Writer** are derived several concrete subclasses that handle various I/O situations. In general, the character-based classes parallel the byte-based classes. The character stream classes are shown in **Table 10-2**.
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. Among other things, it contains three predefined stream variables, called in, out, and err. These fields are declared as public, final, and static 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 by default the keyboard. System.err refers to the standard error stream, which is also the console by default. However, these streams can 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. The reason they are byte and not character streams is that the predefined streams were part of the original specification for Java, which did not include the character streams. As you will see, it is possible to wrap these within character-based streams if desired.

Using the Byte Streams

We will begin our examination of Java’s I/O with the byte streams. As explained, at the top of the byte stream hierarchy are the InputStream and OutputStream classes. Table 10-3 shows the methods in InputStream, and Table 10-4 shows the methods in OutputStream. In general, the
methods in `InputStream` and `OutputStream` can throw an `IOException` on error. The methods defined by these two abstract classes are available to all of their subclasses. Thus, they form a minimal set of I/O functions that all byte streams will have.

<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 of input currently available for reading.</td>
</tr>
<tr>
<td><code>void close( )</code></td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td><code>void mark(int numBytes)</code></td>
<td>Places a mark at the current point in the input stream that will remain valid until <code>numBytes</code> bytes are read.</td>
</tr>
<tr>
<td><code>boolean markSupported( )</code></td>
<td>Returns true if <code>mark()</code>/<code>reset()</code> are supported by the invoking stream.</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 stream is encountered.</td>
</tr>
<tr>
<td><code>int read(byte buffer[])</code></td>
<td>Attempts to read up to <code>buffer.length</code> bytes into <code>buffer</code> and returns the actual number of bytes that were successfully read. –1 is returned when the end of the stream is encountered.</td>
</tr>
<tr>
<td><code>int read(byte buffer[], int offset, int numBytes)</code></td>
<td>Attempts to read up to <code>numBytes</code> bytes into <code>buffer</code> starting at <code>buffer[offset]</code>, returning the number of bytes successfully read. –1 is returned when the end of the stream is encountered.</td>
</tr>
<tr>
<td><code>void reset( )</code></td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td><code>long skip(long numBytes)</code></td>
<td>Ignores (that is, skips) <code>numBytes</code> bytes of input, returning the number of bytes actually ignored.</td>
</tr>
</tbody>
</table>

**Table 10-3  The Methods Defined by **`**InputStream**`**

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>void close( )</code></td>
<td>Closes the output stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td><code>void flush( )</code></td>
<td>Causes any output that has been buffered to be sent to its destination. That is, it flushes the output buffer.</td>
</tr>
<tr>
<td><code>void write(int b)</code></td>
<td>Writes a single byte to an output stream. Note that the parameter is an int, which allows you to call <code>write()</code> with expressions without having to cast them back to <code>byte</code>.</td>
</tr>
<tr>
<td><code>void write(byte buffer[])</code></td>
<td>Writes a complete array of bytes to an output stream.</td>
</tr>
<tr>
<td><code>void write(byte buffer[], int offset, int numBytes)</code></td>
<td>Writes a subrange of <code>numBytes</code> bytes from the array <code>buffer</code>, beginning at <code>buffer[offset]</code>.</td>
</tr>
</tbody>
</table>

**Table 10-4  The Methods Defined by **`**OutputStream**`**

### Reading Console Input

Originally, the only way to perform console input was to use a byte stream, and much Java code still uses the byte streams exclusively. Today, you can use byte or character streams. For commercial code, the preferred method of reading console input is to use a character-oriented stream. Doing so makes your program easier to internationalize and easier to maintain. It is also more convenient to operate directly on characters rather than converting back and forth
between characters and bytes. However, for sample programs, simple utility programs for your own use, and applications that deal with raw keyboard input, using the byte streams is acceptable. For this reason, console I/O using byte streams is examined here.

Because **System.in** is an instance of **InputStream**, you automatically have access to the methods defined by **InputStream**. Unfortunately, **InputStream** defines only one input method, **read()**, which reads bytes. There are three versions of **read()**, which are shown here:

```java
int read() throws IOException
int read(byte data[]) throws IOException
int read(byte data[], int start, int max) throws IOException
```

In **Chapter 3**, you saw how to use the first version of **read()** to read a single character from the keyboard (from **System.in**). It returns –1 when the end of the stream is encountered. The second version reads bytes from the input stream and puts them into **data** until either the array is full, the end of stream is reached, or an error occurs. It returns the number of bytes read, or –1 when the end of the stream is encountered. The third version reads input into **data** beginning at the location specified by **start**. Up to **max** bytes are stored. It returns the number of bytes read, or –1 when the end of the stream is reached. All throw an **IOException** when an error occurs. When reading from **System.in**, pressing **ENTER** generates an end-of-stream condition.

Here is a program that demonstrates reading an array of bytes from **System.in**. 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, but you can handle these types of errors yourself, if you choose.

```java
// Read an array of bytes from the keyboard.

import java.io.*;

class ReadBytes {
    public static void main(String args[])
        throws IOException {
        byte data[] = new byte[10];

        System.out.println("Enter some characters.");
        System.in.read(data); // Read an array of bytes
        System.out.print("You entered: ");
        for(int i=0; i < data.length; i++)
            System.out.print((char) data[i]);
    }
}
```

Here is a sample run:

Enter some characters.
Read Bytes
You entered: Read Bytes
Writing Console Output

As is the case with console input, Java originally provided only byte streams for console output. Java 1.1 added character streams. For the most portable code, character streams are recommended. Because `System.out` is a byte stream, however, byte-based console output is still widely used. In fact, all of the programs in this book up to this point have used it! Thus, it is examined here.

Console output is most easily accomplished with `print( )` and `println( )`, with which you are already familiar. These methods are defined by the class `PrintStream` (which is the type of the object referenced by `System.out`). Even though `System.out` is a byte stream, it is still acceptable to use this stream for simple console output.

Since `PrintStream` is an output stream derived from `OutputStream`, it also implements the low-level method `write( )`. Thus, it is possible to write to the console by using `write( )`. The simplest form of `write( )` defined by `PrintStream` is shown here:

```java
void write(int byteval)
```

This method writes the byte specified by `byteval` to the file. Although `byteval` is declared as an integer, only the low-order 8 bits are written. Here is a short example that uses `write( )` to output the character X followed by a new line:

```java
// Demonstrate System.out.write().
class WriteDemo {
    public static void main(String args[]) {
        int b;

        b = 'X';
        System.out.write(b);  // Write a byte to the screen.
        System.out.write('
');
    }
}
```

You will not often use `write( )` to perform console output (although it might be useful in some situations), since `print( )` and `println( )` are substantially easier to use.

`PrintStream` supplies two additional output methods: `printf( )` and `format( )`. Both give you detailed control over the precise format of data that you output. For example, you can specify the number of decimal places displayed, a minimum field width, or the format of a negative value. Although we won’t be using these methods in the examples in this book, they are features that you will want to look into as you advance in your knowledge of Java.

Reading and Writing Files Using Byte Streams

Java provides a number of classes and methods that allow you to read and write files. Of course, the most common types of files are disk files. In Java, all files are byte-oriented, and Java provides methods to read and write bytes from and to a file. Thus, reading and writing files using byte streams is very common. However, Java allows you to wrap a byte-oriented file stream within a character-based object, which is shown later in this chapter.

To create a byte stream linked to a file, use `FileInputStream` or `FileOutputStream`. To open a
Inputting from a File
A file is opened for input by creating a FileInputStream object. Here is a commonly used constructor:

FileInputStream(String fileName) throws FileNotFoundException

Here, fileName specifies the name of the file you want to open. If the file does not exist, then FileNotFoundException is thrown. FileNotFoundException is a subclass of IOException.

To read from a file, you can use read(). The version that we will use is shown here:

int read() throws IOException

Each time it is called, read() reads a single byte from the file and returns it as an integer value. It returns -1 when the end of the file is encountered. It throws an IOException when an error occurs. Thus, this version of read() is the same as the one used to read from the console.

When you are done with a file, you must close it by calling close(). Its general form 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.

The following program uses read() to input and display the contents of a text file, the name of which is specified as a command-line argument. Notice how the try/catch blocks handle I/O errors that might occur.
Notice that the preceding example closes the file stream after the try block that reads the file has completed. Although this approach is occasionally useful, Java supports a variation that is often a better choice. 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:
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. Although not an issue in this example (or most other example programs) because the program simply ends if an unexpected exception occurs, this can be a major source of trouble in larger programs. Using `finally` avoids this trouble.

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 was successfully opened. Thus, `close()` will not be 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, this `catch` clause could be used to catch both exceptions, eliminating the need to catch `FileNotFoundException` separately. In this case, the standard exception message, which describes the error, is displayed.
Q: I noticed that `read()` returns −1 when the end of the file has been reached, but that it does not have a special return value for a file error. Why not?

A: In Java, errors are handled by exceptions. Thus, if `read()`, or any other I/O method, returns a value, it means that no error has occurred. This is a much cleaner way than handling I/O errors by using special error codes.

In this approach, any error, including an error opening the file, will simply be handled by the single `catch` statement. Because of its compactness, this approach is used by most of the I/O examples in this book. Be aware, however, that it will not be 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 file name. In such a situation, you might want to prompt for the correct name, for example, before entering a `try` block that accesses the file.

**Writing to a File**

To open a file for output, create a `FileOutputStream` object. Here are two commonly used constructors:

```java
FileOutputStream(String fileName) throws FileNotFoundException
FileOutputStream(String fileName, boolean append) throws FileNotFoundException
```

If the file cannot be created, then `FileNotFoundException` is thrown. In the first form, when an output file is opened, any preexisting file by the same name is destroyed. In the second form, if `append` is `true`, then output is appended to the end of the file. Otherwise, the file is overwritten.

To write to a file, you will use the `write()` method. 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 8 bits are written to the file. If an error occurs during writing, an `IOException` is thrown.

Once you are done with an output file, you must close it using `close()`, shown here:

```java
void close() throws IOException
```
Closing a file releases the system resources allocated to the file, allowing them to be used by another file. It also ensures that any output remaining in an output buffer is actually written to the physical device.

The following example copies a text file. The names of the source and destination files are specified on the command line.

```java
/* Copy a text file.
   To use this program, specify the name
   of the source file and the destination file.
   For example, to copy a file called FIRST.TXT
to a file called SECOND.TXT, use the following
command line.

    java CopyFile FIRST.TXT SECOND.TXT
*/

import java.io.*;

class CopyFile {
    public static void main(String args[]) throws IOException {
        int i;
        FileInputStream fin = null;
        FileOutputStream fout = null;

        // First, make sure that both files has been specified.
        if (args.length != 2) {
            System.out.println("Usage: CopyFile from to");
            return;
        }

        // Copy a File.
        try {
            // Attempt to open the files.
            fin = new FileInputStream(args[0]);
            fout = new FileOutputStream(args[1]);

            do {
                i = fin.read();
                if (i != -1) fout.write(i);
            } while (i != -1);

            catch (IOException exc) {
                System.out.println("I/O Error: " + exc);
            }
        } finally {
            try {
                if (fin != null) fin.close();
            } catch (IOException exc) {
                System.out.println("Error Closing Input File");
            }
            try {
                if (fout != null) fout.close();
            } catch (IOException exc) {
                System.out.println("Error Closing Output File");
            }
        }
    }
}
```

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. This is the way files have been closed since Java was first created. As a result, this approach is widespread in existing code. Furthermore, this approach is still valid and useful. However, beginning with JDK 7, Java has included a feature that offers another, more streamlined way to manage resources, such as file streams, by automating the closing process. It is based on another version of the try statement called try-with-resources, and is sometimes referred to as automatic resource management. The principal advantage of try-with-resources 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.

The try-with-resources statement has this general form:

```java
try (resource-specification) {
    // use the resource
}
```

Here, resource-specification is a statement that declares and initializes a resource, such as a file. 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.) A try-with-resources statement can also include catch and finally clauses.

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 defined in java.io. Both interfaces are implemented by the stream classes, including FileInputStream and FileOutputStream. 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-with-resources` statement:

```java
try(FileInputStream fin = new FileInputStream(args[0])) {
    do {
        i = fin.read();
        if(i != -1) System.out.print((char) i);
    while(i != -1);
} catch(IOException exc) {
    System.out.println("I/O Error: " + exc);
}
```

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 exited, the file 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 automatic resource management.

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`. 
In this program, notice how the input and output files are opened within the try:

```java
try (FileInputStream fin = new FileInputStream(args[0]);
     FileOutputStream fout = new FileOutputStream(args[1])) {
    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.
    do {
        i = fin.read();
        if (i != -1) fout.write(i);
    } while (i != -1);
} catch (IOException exc) {
    System.out.println("I/O Error: " + exc);
}
```

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 try-with-resources.

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, with a try-with-resources statement, 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 use of the getSuppressed() method defined by Throwable.

Because of its advantages, try-with-resources will be used by the remaining examples in this chapter. However, it is still very important that you are familiar with the traditional approach shown earlier in which close() is called explicitly. 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 or updating this older code. Second, for a period of time, you might need to work in an environment that predates JDK 7. In such a situation, the try-with-resources statement will not be available and the traditional approach must be employed. Finally, there may be cases in which explicitly closing a resource is more appropriate than the automated approach. The foregoing notwithstanding, if you are using JDK 7, JDK 8, or later, then you will usually want to use the new, automated approach to resource management. It offers a streamlined, robust alternative to the traditional approach.

Reading and Writing Binary Data
So far, we have just been reading and writing bytes containing ASCII characters, but it is possible—indeed, common—to read and write other types of data. For example, you might want to create a file that contains ints, doubles, or shorts. To read and write binary values of the Java primitive types, you will use DataInputStream and DataOutputStream.

DataOutputStream implements the DataOutput interface. This interface defines methods that write all of Java’s primitive types to a file. It is important to understand that this data is written using its internal, binary format, not its human-readable text form. Several commonly used output methods for Java’s primitive types are shown in Table 10-5. Each throws an IOException on failure.

Table 10-5 Commonly Used Output Methods Defined by DataOutputStream

<table>
<thead>
<tr>
<th>Output Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>void writeBoolean</td>
<td>Writes the boolean specified by val.</td>
</tr>
<tr>
<td>boolean val)</td>
<td></td>
</tr>
<tr>
<td>void writeByte</td>
<td>Writes the low-order byte specified by val.</td>
</tr>
<tr>
<td>int val)</td>
<td></td>
</tr>
<tr>
<td>void writeChar</td>
<td>Writes the value specified by val as a char.</td>
</tr>
<tr>
<td>int val)</td>
<td></td>
</tr>
<tr>
<td>void writeDouble</td>
<td>Writes the double specified by val.</td>
</tr>
<tr>
<td>double val)</td>
<td></td>
</tr>
<tr>
<td>void writeFloat</td>
<td>Writes the float specified by val.</td>
</tr>
<tr>
<td>float val)</td>
<td></td>
</tr>
<tr>
<td>void writeInt</td>
<td>Writes the int specified by val.</td>
</tr>
<tr>
<td>int val)</td>
<td></td>
</tr>
<tr>
<td>void writeLong</td>
<td>Writes the long specified by val.</td>
</tr>
<tr>
<td>long val)</td>
<td></td>
</tr>
<tr>
<td>void writeShort</td>
<td>Writes the value specified by val as a short.</td>
</tr>
<tr>
<td>short val)</td>
<td></td>
</tr>
</tbody>
</table>

Here is the constructor for DataOutputStream. Notice that it is built upon an instance of OutputStream.

DataOutputStream(OutputStream outputStream)

Here, outputStream is the stream to which data is written. To write output to a file, you can use the object created by FileOutputStream for this parameter.

DataInputStream implements the DataInput interface, which provides methods for reading all of Java’s primitive types. These methods are shown in Table 10-6, and each can throw an IOException. DataInputStream uses an InputStream instance as its foundation, overlaying it with methods that read the various Java data types. Remember that DataInputStream reads data in its binary format, not its human-readable form. The constructor for DataInputStream is shown here:
Table 10-6  Commonly Used Input Methods Defined by DataInputStream

<table>
<thead>
<tr>
<th>Input Method</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>boolean readBoolean()</td>
<td>Reads a boolean.</td>
</tr>
<tr>
<td>byte readByte()</td>
<td>Reads a byte.</td>
</tr>
<tr>
<td>char readChar()</td>
<td>Reads a char.</td>
</tr>
<tr>
<td>double readDouble()</td>
<td>Reads a double.</td>
</tr>
<tr>
<td>float readFloat()</td>
<td>Reads a float.</td>
</tr>
<tr>
<td>int readInt()</td>
<td>Reads an int.</td>
</tr>
<tr>
<td>long readLong()</td>
<td>Reads a long.</td>
</tr>
<tr>
<td>short readShort()</td>
<td>Reads a short.</td>
</tr>
</tbody>
</table>

DataInputStream(InputStream inputStream)

Here, inputStream is the stream that is linked to the instance of DataInputStream being created. To read input from a file, you can use the object created by FileInputStream for this parameter.

Here is a program that demonstrates DataOutputStream and DataInputStream. It writes and then reads back various types of data to and from a file.

```java
// Write and then read back binary data.

import java.io.*;

class RWData {
    public static void main(String args[])
    {
        int i = 10;
        double d = 1023.56;
        boolean b = true;

        // Write some values.
        try (DataOutputStream dataOut =
             new DataOutputStream(new FileOutputStream("testdata"))
```
System.out.println("Writing " + i);
    dataOut.writeInt(i);

    System.out.println("Writing " + d);
    dataOut.writeDouble(d);

    System.out.println("Writing " + b);
    dataOut.writeBoolean(b);

    System.out.println("Writing " + 12.2 * 7.4);
    dataOut.writeDouble(12.2 * 7.4);
}

try (DataInputStream dataIn =
    new DataInputStream(new FileInputStream("testdata")))
{
    i = dataIn.readInt();
    System.out.println("Reading " + i);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);

    b = dataIn.readBoolean();
    System.out.println("Reading " + b);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);
}

catch (IOException exc) {
    System.out.println("Read error.");
}

System.out.println();

// Now, read them back.
try (DataInputStream dataIn =
    new DataInputStream(new FileInputStream("testdata")))
{
    i = dataIn.readInt();
    System.out.println("Reading " + i);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);

    b = dataIn.readBoolean();
    System.out.println("Reading " + b);

    d = dataIn.readDouble();
    System.out.println("Reading " + d);
}

catch (IOException exc) {
    System.out.println("Read error.");
}

The output from the program is shown here.

Writing 10
Writing 1023.56
Writing true
Writing 90.28

Reading 10
Reading 1023.56
Reading true
Reading 90.28
This project develops a simple, yet useful file comparison utility. It works by opening both files to be compared and then reading and comparing each corresponding set of bytes. If a mismatch is found, the files differ. If the end of each file is reached at the same time and if no mismatches have been found, then the files are the same. Notice that it uses a `try-with-resources` statement to automatically close the files.

1. Create a file called `CompFiles.java`.

2. Into `CompFiles.java`, add the following program:
3. To try **CompFiles**, first copy **CompFiles.java** to a file called **temp**. Then, try this command line:

```
java CompFiles CompFiles.java temp
```

The program will report that the files are the same. Next, compare **CompFiles.java** to **CopyFile.java** (shown earlier) using this command line:

```
java CompFiles CompFiles.java CopyFile.java
```

These files differ and **CompFiles** will report this fact.

4. On your own, try enhancing **CompFiles** with various options. For example, add an option that ignores the case of letters. Another idea is to have **CompFiles** display the position within the file...
Random-Access Files
Up to this point, we have been using sequential files, which are files that are accessed in a strictly linear fashion, one byte after another. However, Java also allows you to access the contents of a file in random order. To do this, you will use RandomAccessFile, which encapsulates a random-access file. RandomAccessFile is not derived from InputStream or OutputStream. Instead, it implements the interfaces DataInput and DataOutput, which define the basic I/O methods. It also supports positioning requests—that is, you can position the file pointer within the file. The constructor that we will be using is shown here:

RandomAccessFile(String fileName, String access)
    throws FileNotFoundException

Here, the name of the file is passed in fileName and access determines what type of file access is permitted. If it is "r", the file can be read but not written. If it is "rw", the file is opened in read-write mode.

The method seek( ), shown here, is used to set the current position of the file pointer within the file:

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 read( ) and write( ) methods. It also implements the DataInput and DataOutput interfaces, which means that methods to read and write the primitive types, such as readInt( ) and writeDouble( ), are available.

Here is an example that demonstrates random-access I/O. It writes six doubles to a file and then reads them back in nonsequential order.
The output from the program is shown here.

First value is 19.4
Second value is 10.1
Fourth value is 33.0

Here is every other value:
19.4 123.54 87.9

Notice how each value is located. Since each double value is 8 bytes long, each value starts on an 8-byte boundary. Thus, the first value is located at zero, the second begins at byte 8, the third starts at byte 16, and so on. Thus, to read the fourth value, the program seeks to location 24.
Ask the Expert

Q: In looking through the documentation provided by the JDK, I noticed a class called Console. Is this a class that I can use to perform console-based I/O?

A: The short answer is Yes. The Console class was added by JDK 6, and it is used to read from and write to the console. 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(). It is shown here.

```
static Console console()
```

If a console is available, then a reference to it is returned. Otherwise, null is returned. A console may not be available in all cases, such as when a program runs as a background task. Therefore, if null is returned, no console I/O is possible.

Console defines several methods that perform I/O, such as readLine() and printf(). It also defines a method called readPassword(), which can be used to obtain a password. It lets your application read a password without echoing what is typed. You can also obtain a reference to the Reader and the Writer that are attached to the console. In general, Console is a class that you may find useful for some types of applications.

Using Java’s Character-Based Streams

As the preceding sections have shown, Java’s byte streams are both powerful and flexible. However, they are not the ideal way to handle character-based I/O. For this purpose, Java defines the character stream classes. At the top of the character stream hierarchy are the abstract classes Reader and Writer. Table 10-7 shows the methods in Reader, and Table 10-8 shows the methods in Writer. Most of the methods can throw an IOException on error. The methods defined by these two abstract classes are available to all of their subclasses. Thus, they form a minimal set of I/O functions that all character streams will have.
<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>abstract void close( )</td>
<td>Closes the input source. Further read attempts will generate an IOException.</td>
</tr>
<tr>
<td>void 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>boolean markSupported( )</td>
<td>Returns true if mark() / reset() are supported on this stream.</td>
</tr>
<tr>
<td>int 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 stream is encountered.</td>
</tr>
<tr>
<td>int read(char[] buffer)</td>
<td>Attempts to read up to buffer.length characters into buffer and returns the actual number of characters that were successfully read. -1 is returned when the end of the stream is encountered.</td>
</tr>
<tr>
<td>abstract int read(char[] buffer, int offset, int numChars)</td>
<td>Attempts to read up to numChars characters into buffer starting at buffer[offset], returning the number of characters successfully read. -1 is returned when the end of the stream is encountered.</td>
</tr>
<tr>
<td>int read(CharBuffer buffer)</td>
<td>Attempts to fill the buffer specified by buffer, returning the number of characters successfully read. -1 is returned when the end of the stream is encountered. CharBuffer is a class that encapsulates a sequence of characters, such as a string.</td>
</tr>
<tr>
<td>boolean ready( )</td>
<td>Returns true if the next input request will not wait. Otherwise, it returns false.</td>
</tr>
<tr>
<td>void reset( )</td>
<td>Resets the input pointer to the previously set mark.</td>
</tr>
<tr>
<td>long skip(long numChars)</td>
<td>Skips over numChars characters of input, returning the number of characters actually skipped.</td>
</tr>
</tbody>
</table>

**Table 10-7** The Methods Defined by Reader
Console Input Using Character Streams

For code that will be internationalized, inputting from the console using Java’s character-based streams is a better, more convenient way to read characters from the keyboard than is using the byte streams. However, since System.in is a byte stream, you will need to wrap System.in inside some type of Reader. The best class for reading console input is BufferedReader, which supports a buffered input stream. However, you cannot construct a BufferedReader directly from System.in. Instead, you must first convert it into a character stream. To do this, you will use InputStreamReader, which converts bytes to characters. To obtain an InputStreamReader object that is linked to System.in, use the constructor shown next:

InputStreamReader(InputStream inputStream)

Since System.in refers to an object of type InputStream, it can be used for inputStream.

Next, using the object produced by InputStreamReader, construct a BufferedReader using the constructor shown here:

BufferedReader(Reader inputReader)

Here, inputReader is the stream that is linked to the instance of BufferedReader being created. Putting it all together, the following line of code creates a BufferedReader that is connected to the

<table>
<thead>
<tr>
<th>Method</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Writer append(char ch)</td>
<td>Appends ch to the end of the invoking output stream. Returns a reference to the invoking stream.</td>
</tr>
<tr>
<td>Writer append(CharSequence chars)</td>
<td>Appends chars to the end of the invoking output stream. Returns a reference to the invoking stream. CharSequence is an interface that defines read-only operations on a sequence of characters.</td>
</tr>
<tr>
<td>Writer append(CharSequence chars, int begin, int end)</td>
<td>Appends the sequence of chars starting at begin and stopping with end to the end of the invoking output stream. Returns a reference to the invoking stream. CharSequence is an interface that defines read-only operations on a sequence of characters.</td>
</tr>
<tr>
<td>abstract void close()</td>
<td>Closes the output stream. Further write attempts will generate an IOException.</td>
</tr>
<tr>
<td>abstract void flush()</td>
<td>Causes any output that has been buffered to be sent to its destination. That is, it flushes the output buffer.</td>
</tr>
<tr>
<td>void write(int ch)</td>
<td>Writes a single character to the invoking output stream. Note that the parameter is an int, which allows you to call write() with expressions without having to cast them back to char.</td>
</tr>
<tr>
<td>void write(char buffer[], int offset, int numChars)</td>
<td>Writes a complete array of characters to the invoking output stream.</td>
</tr>
<tr>
<td>abstract void write(char buffer[], int offset, int numChars)</td>
<td>Writes a subrange of numChars characters from the array buffer, beginning at buffer[offset] to the invoking output stream.</td>
</tr>
<tr>
<td>void write(String str)</td>
<td>Writes str to the invoking output stream.</td>
</tr>
<tr>
<td>void write(String str, int offset, int numChars)</td>
<td>Writes a subrange of numChars characters from the array str, beginning at the specified offset.</td>
</tr>
</tbody>
</table>
Keyboard.

BufferedReader br = new BufferedReader(new
    InputStreamReader(System.in));

After this statement executes, br will be a character-based stream that is linked to the console through System.in.

Reading Characters
Characters can be read from System.in using the read() method defined by BufferedReader in much the same way as they were read using byte streams. Here are three versions of read() supported by BufferedReader.

int read( ) throws IOException
int read(char data[ ]) throws IOException
int read(char data[ ], int start, int max) throws IOException

The first version of read( ) reads a single Unicode character. It returns -1 when the end of the stream is reached. The second version reads characters from the input stream and puts them into data until either the array is full, the end of stream is reached, or an error occurs. It returns the number of characters read or -1 at the end of the stream. The third version reads input into data beginning at the location specified by start. Up to max characters are stored. It returns the number of characters read or -1 when the end of the stream is encountered. All throw an IOException on error. When reading from System.in, pressing ENTER generates an end-of-stream condition.

The following program demonstrates read( ) by reading characters from the console until the user types a period. Notice that any I/O exceptions that might be generated are simply thrown out of main( ). As mentioned earlier in this chapter, such an approach is common when reading from the console. Of course, you can handle these types of errors under program control, if you choose.
Here is a sample run:
Enter characters, period to quit.
One Two.

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:

String readLine( ) throws IOException
It returns a String object that contains the characters read. It returns null if an attempt is made to read when at the end of the stream.

The following program demonstrates BufferedReader and the readLine( ) method. The program reads and displays lines of text until you enter the word “stop”.

// Use a BufferedReader to read characters from the console.
import java.io.*;

class ReadChars {
    public static void main(String args[])
        throws IOException
    {
        char c;
        BufferedReader br = new BufferedReader(new InputStreamReader(System.in));

        System.out.println("Enter characters, period to quit.");

        // read characters
        do {
            c = (char) br.read();
            System.out.println(c);
        } while(c != '.');
    }
}

Here is a sample run:
Enter characters, period to quit.
One Two.

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:

String readLine( ) throws IOException
It returns a String object that contains the characters read. It returns null if an attempt is made to read when at the end of the stream.

The following program demonstrates BufferedReader and the readLine( ) method. The program reads and displays lines of text until you enter the word “stop”.

// Use a BufferedReader to read characters from the console.
import java.io.*;

class ReadChars {
    public static void main(String args[])
        throws IOException
    {
        char c;
        BufferedReader br = new BufferedReader(new BufferedReader(new InputStreamReader(System.in)));

        System.out.println("Enter characters, period to quit.");

        // read characters
        do {
            c = (char) br.read();
            System.out.println(c);
        } while(c != '.');
    }
}
Console Output Using Character Streams

While it is still permissible to use `System.out` to write to the console under Java, its use is recommended mostly for debugging purposes or for sample programs such as those found in this book. For real-world programs, the preferred method of writing to the console when using Java is through a `PrintWriter` stream. `PrintWriter` is one of the character-based classes. As explained, using a character-based class for console output makes it easier to internationalize your program.

`PrintWriter` defines several constructors. The one we will use is shown here:

```
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 `println()` and `println()` methods for all types including `Object`. Thus, you can use these methods in just the same way as they have been used with `System.out`. If an argument is not a primitive type, the `PrintWriter` methods will call the object’s `toString()` method and then print out the result.

To write to the console using a `PrintWriter`, specify `System.out` for the output stream and flush the stream after each call to `println()`. For example, this line of code creates a `PrintWriter` that is connected to console output.

```
PrintWriter pw = new PrintWriter(System.out, true);
```

The following application illustrates using a `PrintWriter` to handle console output.
To demonstrate PrintWriter:

```java
import java.io.*;

public class PrintWriterDemo {
    public static void main(String args[]) {
        PrintWriter pw = new PrintWriter(System.out, true);
        int i = 10;
        double d = 123.65;

        pw.println("Using a PrintWriter.");
        pw.println(i);
        pw.println(d);

        pw.println(i + " + " + d + " is " + (i+d));
    }
}
```

The output from this program is:

```
Using a PrintWriter.
10
123.65
10 + 123.65 is 133.65
```

Remember that 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` will make your real-world applications easier to internationalize. Since no advantage is to be gained by using a `PrintWriter` in the sample programs shown in this book, for convenience we will continue to use `System.out` to write to the console.

**File I/O Using Character Streams**

Although byte-oriented file handling is the most common, it is possible to use character-based streams for this purpose. The advantage to the character streams is that they operate directly on Unicode characters. Thus, if you want to store Unicode text, the character streams are certainly your best option. In general, to perform character-based file I/O, you will use the `FileReader` and `FileWriter` classes.

**Using a FileWriter**

`FileWriter` creates a `Writer` that you can use to write to a file. Two commonly used constructors are shown here:

- `FileWriter(String fileName) throws IOException`
- `FileWriter(String fileName, boolean append) throws IOException`

Here, `fileName` is the full path name of a file. If `append` is `true`, then output is appended to the end of the file. Otherwise, the file is overwritten. Either throws an `IOException` on failure. `FileWriter` is derived from `OutputStreamWriter` and `Writer`. Thus, it has access to the methods defined by these
Here is a simple key-to-disk utility that reads lines of text entered at the keyboard and writes them to a file called "test.txt". Text is read until the user enters the word "stop". It uses a FileWriter to output to the file.

```java
// A simple key-to-disk utility that demonstrates a FileWriter.
import java.io.*;

class KtoD {
    public static void main(String args[])
    {
        String str;
        BufferedReader br =
            new BufferedReader(new InputStreamReader(System.in));
        System.out.println("Enter text ('stop' to quit). ");
        try (FileWriter fw = new FileWriter("test.txt")) { ← Create a FileWriter.
            do {
                System.out.println(":\ ");
                str = br.readLine();
                if(str.compareTo("stop") == 0) break;
                str = str + "\r\n"; // add newline
                fw.write(str); ← Write strings to the file.
            } while(str.compareTo("stop") != 0);
        } catch(IOException exc) {
            System.out.println("I/O Error: " + exc);
        }
    }
}
```

**Using a FileReader**

The FileReader class creates a Reader that you can use to read the contents of a file. A commonly used constructor is shown here:

FileReader(String `fileName`) throws FileNotFoundException

Here, `fileName` is the full path name of a file. It throws a FileNotFoundException if the file does not exist. FileReader is derived from InputStreamReader and Reader. Thus, it has access to the methods defined by these classes.

The following program creates a simple disk-to-screen utility that reads a text file called "test.txt" and displays its contents on the screen. Thus, it is the complement of the key-to-disk utility shown in the previous section.
In this example, notice that the `FileReader` is wrapped in a `BufferedReader`. This gives it access to `readLine()` . Also, closing the `BufferedReader`, `br` in this case, automatically closes the file.

**Ask the Expert**

**Q:** I have heard about another I/O package called NIO. Can you tell me about it?

**A:** Originally called *New I/O*, NIO was added to Java by JDK 1.4. It supports a channel-based approach to I/O operations. The NIO classes are contained in `java.nio` and its subordinate packages, such as `java.nio.channels` and `java.nio.charset`.

NIO 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 new I/O 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.

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. 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 most applicable to socket-backed channels.

Beginning with JDK 7, NIO was substantially enhanced, so much so that the term *NIO.2* is often used. 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 greatly expanded the ways in which NIO can be used, especially with files.

It is important to understand that NIO does not replace the I/O classes found in `java.io`, which are discussed in this chapter. Instead, the NIO classes are designed to supplement the standard I/O system, offering an alternative approach, which can be beneficial in some circumstances.
Using Java’s Type Wrappers to Convert Numeric Strings

Before leaving the topic of I/O, we will examine a technique useful when reading numeric strings. As you know, Java’s `println( )` method provides a convenient way to output various types of data to the console, including numeric values of the built-in types, such as `int` and `double`. Thus, `println( )` automatically converts numeric values into their human-readable form. However, methods like `read( )` do not provide a parallel functionality that reads and converts a string containing a numeric value into its internal, binary format. For example, there is no version of `read( )` that reads a string such as "100" and then automatically converts it into its corresponding binary value that is able to be stored in an `int` variable. Instead, Java provides various other ways to accomplish this task. Perhaps the easiest is to use one of Java’s type wrappers.

Java’s type wrappers are classes that encapsulate, or `wrap`, the primitive types. Type wrappers are needed because the primitive types are not objects. This limits their use to some extent. For example, a primitive type cannot be passed by reference. To address this kind of need, Java provides classes that correspond to each of the primitive types.

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. As a side benefit, the numeric wrappers also define methods that convert a numeric string into its corresponding binary equivalent. Several of these conversion methods are shown here. Each returns a binary value that corresponds to the string.

<table>
<thead>
<tr>
<th>Wrapper</th>
<th>Conversion Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double</td>
<td>static double parseDouble(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Float</td>
<td>static float parseFloat(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Long</td>
<td>static long parseLong(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Integer</td>
<td>static int parseInt(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Short</td>
<td>static short parseShort(String str) throws NumberFormatException</td>
</tr>
<tr>
<td>Byte</td>
<td>static byte parseByte(String str) throws NumberFormatException</td>
</tr>
</tbody>
</table>

The integer wrappers also offer a second parsing method that allows you to specify the radix.

The parsing methods give us an easy way to convert a numeric value, read as a string from the keyboard or a text file, into its proper internal format. For example, the following program demonstrates `parseInt( )` and `parseDouble( )`. It averages a list of numbers entered by the user. It first asks the user for the number of values to be averaged. It then reads that number using `readLine( )` and uses `parseInt( )` to convert the string into an integer. Next, it inputs the values, using `parseDouble( )` to convert the strings into their `double` equivalents.
Here is a sample run:

How many numbers will you enter: 5
Enter 5 values.
    : 1.1
    : 2.2
    : 3.3
    : 4.4
    : 5.5
Average is 3.3
**Ask the Expert**

**Q:** What else can the primitive type wrapper classes do?

**A:** The primitive type wrappers provide a number of methods that help integrate the primitive types into the object hierarchy. For example, various storage mechanisms provided by the Java library, including maps, lists, and sets, work only with objects. Thus, to store an `int`, for example, in a list, it must be wrapped in an object. Also, all type wrappers have a method called `compareTo()`, which compares the value contained within the wrapper; `equals()`, which tests two values for equality; and methods that return the value of the object in various forms. The topic of type wrappers is taken up again in Chapter 12, when autoboxing is discussed.

---

**Try This 10-2 Creating a Disk-Based Help System**

In **Try This 4-1**, you created a `Help` class that displayed information about Java’s control statements. In that implementation, the help information was stored within the class itself, and the user selected help from a menu of numbered options.

Although this approach was fully functional, it is certainly not the ideal way of creating a Help system. For example, to add to or change the help information, the source code of the program needed to be modified. Also, the selection of the topic by number rather than by name is tedious, and is not suitable for long lists of topics. Here, we will remedy these shortcomings by creating a disk-based Help system.

The disk-based Help system stores help information in a help file. The help file is a standard text file that can be changed or expanded at will, without changing the Help program. The user obtains help about a topic by typing in its name. The Help system searches the help file for the topic. If it is found, information about the topic is displayed.

1. Create the help file that will be used by the Help system. The help file is a standard text file that is organized like this:
The name of each topic must be preceded by a #, and the topic name must be on a line of its own. Preceding each topic name with a # allows the program to quickly find the start of each topic. After the topic name are any number of information lines about the topic. However, there must be a blank line between the end of one topic’s information and the start of the next topic. Also, there must be no trailing spaces at the end of any help-topic lines.

Here is a simple help file that you can use to try the disk-based Help system. It stores information about Java’s control statements.
2. Create a file called FileHelp.java.

3. Begin creating the new Help class with these lines of code.

```java
class Help {
    String helpfile; // name of help file

    Help(String fname) {
        helpfile = fname;
    }
}
```

The name of the help file is passed to the Help constructor and stored in the instance variable helpfile. Since each instance of Help will have its own copy of helpfile, each instance can use a different file. Thus, you can create different sets of help files for different sets of topics.

4. Add the helpOn() method shown here to the Help class. This method retrieves help on the specified topic.
The first thing to notice is that `helpOn()` handles all possible I/O exceptions itself and does not include a `throws` clause. By handling its own exceptions, it prevents this burden from being passed on to all code that uses it. Thus, other code can simply call `helpOn()` without having to wrap that call in a `try/catch` block.

The help file is opened using a `FileReader` that is wrapped in a `BufferedReader`. Since the help file contains text, using a character stream allows the Help system to be more efficiently internationalized.

The `helpOn()` method works like this. A string containing the name of the topic is passed in the `what` parameter. The help file is then opened. Then, the file is searched, looking for a match between `what` and a topic in the file. Remember, in the file, each topic is preceded by a #, so the search loop scans the file for #s. When it finds one, it then checks to see if the topic following that # matches the one passed in `what`. If it does, the information associated with that topic is
displayed. If a match is found, `helpOn()` returns `true`. Otherwise, it returns `false`.

5. The **Help** class also provides a method called `getSelection()`. It prompts the user for a topic and returns the topic string entered by the user.

```java
// Get a Help topic.
String getSelection() {
    String topic = "";

    BufferedReader br = new BufferedReader(
        new InputStreamReader(System.in));

    System.out.print("Enter topic: ");
    try {
        topic = br.readLine();
    } catch (IOException exc) {
        System.out.println("Error reading console.");
    }
    return topic;
}
```

This method creates a `BufferedReader` attached to `System.in`. It then prompts for the name of a topic, reads the topic, and returns it to the caller.

6. The entire disk-based Help system is shown here:

```java
/*
   Try This 10-2

   A help program that uses a disk file
to store help information.
*/

import java.io.*;

/* The Help class opens a help file,
searches for a topic, and then displays
the information associated with that topic.
Notice that it handles all I/O exceptions
itself, avoiding the need for calling
code to do so. */
class Help {
    String helpfile; // name of help file
```
Help(String fname) {
    helpfile = fname;
}

// Display help on a topic.
boolean helpOn(String what) {
    int ch;
    String topic, info;

    // Open the help file.
    try (BufferedReader helpRdr =
         new BufferedReader(new FileReader(helpfile)))
    {
        do {
            // read characters until a # is found
            ch = helpRdr.read();

            // now, see if topics match
            if(ch == '#') {
                topic = helpRdr.readLine();
                if(what.compareTo(topic) == 0) { // found topic
                    do {
                        info = helpRdr.readLine();
                        if(info != null) System.out.println(info);
                    } while((info != null) &&
                            (info.compareTo("") != 0));
                    return true;
                }
            }
        } while(ch != -1);
    }
    catch(IOException exc) {
        System.out.println("Error accessing help file.");
        return false;
    }
    return false; // topic not found
}

// Get a Help topic.
String getSelection() {
    String topic = "");
    BufferedReader br = new BufferedReader(
        new InputStreamReader(System.in));

    System.out.print("Enter topic: ");
    try {
        topic = br.readLine();
    }
    catch (IOException exc) {
        System.out.println("Error reading input.");
    }
    return topic;
}
Ask the Expert

Q: In addition to the parse methods defined by the primitive type wrappers, is there another easy way to convert a numeric string entered at the keyboard into its equivalent binary format?

A: Yes! Another way to convert a numeric string into its internal, binary format is to use one of the methods defined by the `Scanner` class, packaged in `java.util`. `Scanner` reads formatted (that is, human-readable) input and converts it into its binary form. `Scanner` can be used to read input from a variety of sources, including the console and files. Therefore, you can use `Scanner` to read a numeric string entered at the keyboard and assign its value to a variable. Although `Scanner` contains far too many features to describe in detail, the following illustrates its basic usage.

To use `Scanner` to read from the keyboard, you must first create a `Scanner` linked to console input. To do this, you will use the following constructor:
Scanner(InputStream from)

This creates a Scanner that uses the stream specified by from as a source for input. You can use this constructor to create a Scanner linked to console input, as shown here:

Scanner conin = new Scanner(System.in);

This works because System.in is an object of type InputStream. After this line executes, conin can be used to read input from the keyboard.

Once you have created a Scanner, it is a simple matter to use it to read numeric input. Here is the general 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.

As the preceding indicates, Scanner defines two sets of methods that enable you to read input. The first are the hasNext methods. These include methods such as hasNextInt() and hasNextDouble(), for example. Each of the hasNext methods returns true if the desired data type is the next available item in the data stream, and false otherwise. For example, calling hasNextInt() returns true only if the next item in the stream is the human-readable form of an integer. If the desired data is available, you can read it by calling one of Scanner’s next methods, such as nextInt() or nextDouble(). These methods convert the human-readable form of the data into its internal, binary representation and return the result. For example, to read an integer, call nextInt().

The following sequence shows how to read an integer from the keyboard.

Scanner conin = new Scanner(System.in);
int i;

if (conin.hasNextInt()) i = conin.nextInt();

Using this code, if you enter the number 123 on the keyboard, then i will contain the value 123.

Technically, you can call a next method without first calling a hasNext method. However, doing so is not usually a good idea. If a next method cannot find the type of data it is looking for, it throws an InputMismatchException. 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.

---

**Chapter 10 Self Test**

1. Why does Java define both byte and character streams?
2. Even though console input and output is text-based, why does Java still use byte streams for this purpose?
3. Show how to open a file for reading bytes.
4. Show how to open a file for reading characters.
5. Show how to open a file for random-access I/O.
6. How can you convert a numeric string such as "123.23" into its binary equivalent?
7. Write a program that copies a text file. In the process, have it convert all spaces into hyphens. Use the byte stream file classes. Use the traditional approach to closing a file by explicitly calling `close()`.
8. Rewrite the program described in question 7 so that it uses the character stream classes. This time, use the `try-with-resources` statement to automatically close the file.
9. What type of stream is `System.in`?
10. What does the `read()` method of `InputStream` return when the end of the stream is reached?
11. What type of stream is used to read binary data?
12. `Reader` and `Writer` are at the top of the ____________ class hierarchies.
13. The `try-with-resources` statement is used for ____________ ____________ ____________.
14. If you are using the traditional method of closing a file, then closing a file within a `finally` block is generally a good approach. True or False?
Chapter 11
Multithreaded Programming

Key Skills & Concepts
- Understand multithreading fundamentals
- Know the Thread class and the Runnable interface
- Create a thread
- Create multiple threads
- Determine when a thread ends
- Use thread priorities
- Understand thread synchronization
- Use synchronized methods
- Use synchronized blocks
- Communicate between threads
- Suspend, resume, and stop threads

Although Java contains many innovative features, one of its most exciting is its 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.
Multithreading Fundamentals

There are two distinct types of multitasking: process-based and thread-based. It is important to understand the difference between the two. 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, it is process-based multitasking that allows you to run the Java compiler at the same time you are using a text editor or browsing the Internet. 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 at once. For instance, a text editor can be formatting text at the same time that it is printing, as long as these two actions are being performed by two separate threads. Although Java programs make use of process-based multitasking environments, process-based multitasking is not under the control of Java. Multithreaded multitasking is.

A principal advantage of multithreading is that it enables you to write very efficient programs because it lets you utilize the idle time that is present in most programs. As you probably know, most I/O devices, whether they be network ports, disk drives, or the keyboard, are much slower than the CPU. Thus, a program will often spend a majority of its execution time waiting to send or receive information to or from a device. By using multithreading, your program can execute another task during this idle time. For example, while one part of your program is sending a file over the Internet, another part can be reading keyboard input, and still another can be buffering the next block of data to send.

As you probably know, over the past few years, multiprocessor and multicore systems have become commonplace. Of course, single-processor 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 multiprocessor/m multicore 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.

A thread can be in one of several states. It can be running. It can be ready to run as soon as it gets CPU time. A running thread can be suspended, which is a temporary halt to its execution. It can later be resumed. A thread can be blocked when waiting for a resource. A thread can be terminated, in which case its execution ends and cannot be resumed.

Along with thread-based multitasking comes the need for a special type of feature called synchronization, which allows the execution of threads to be coordinated in certain well-defined ways. Java has a complete subsystem devoted to synchronization, and its key features are also described here.

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 through language elements makes multithreading especially convenient. Many of the details are handled for you.

The Thread Class and Runnable Interface

Java’s multithreading system is built upon the Thread class and its companion interface, Runnable. Both are packaged in java.lang. Thread encapsulates a thread of execution. 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. Here are some of the more commonly used ones (we will be looking at these more closely as they are used):

<table>
<thead>
<tr>
<th>Method</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>final String getName( )</td>
<td>Obtains a thread’s name.</td>
</tr>
<tr>
<td>final int getPriority( )</td>
<td>Obtains a thread’s priority.</td>
</tr>
<tr>
<td>final boolean isAlive( )</td>
<td>Determines whether a thread is still running.</td>
</tr>
<tr>
<td>final void join( )</td>
<td>Waits for a thread to terminate.</td>
</tr>
<tr>
<td>void run( )</td>
<td>Entry point for the thread.</td>
</tr>
<tr>
<td>static void sleep(long milliseconds)</td>
<td>Suspends a thread for a specified period of milliseconds.</td>
</tr>
<tr>
<td>void start( )</td>
<td>Starts a thread by calling its run( ) method.</td>
</tr>
</tbody>
</table>

All processes have at least one thread of execution, which is usually called the **main thread**, because it is the one that is executed when your program begins. Thus, the main thread is the thread that all of the preceding example programs in the book have been using. From the main thread, you can create other threads.

**Creating a Thread**

You create a thread by instantiating an object of type **Thread**. The **Thread** class encapsulates an object that is runnable. As mentioned, Java defines two ways in which you can create a runnable object:

- You can implement the **Runnable** interface.
- You can extend the **Thread** class.

Most of the examples in this chapter will use the approach that implements **Runnable**. However, **Try This 11-1** shows how to implement a thread by extending **Thread**. Remember: Both approaches still use the **Thread** class to instantiate, access, and control the thread. The only difference is how a thread-enabled class is created.

The **Runnable** interface abstracts a unit of executable code. You can construct a thread on any object that implements the **Runnable** interface. **Runnable** defines only one method called **run( )**, which is declared like this:

```java
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. 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 have created a class that implements **Runnable**, you will instantiate an object of type **Thread** on an object of that class. **Thread** defines several constructors. The one that we will use first is shown here:
Thread(Runnable threadOb)

In this constructor, `threadOb` is an instance of a class that implements the `Runnable` interface. This defines where execution of the thread will begin.

Once created, the new thread 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:

```java
void start()
```

Here is an example that creates a new thread and starts it running:

```java
// Create a thread by implementing Runnable.

class MyThread implements Runnable {
    String thrdName;
    // Objects of MyThread can be run in their own threads because MyThread implements Runnable.
```
Let's look closely at this program. First, `MyThread` implements `Runnable`. This means that an object of type `MyThread` is suitable for use as a thread and can be passed to the `Thread` constructor.

Inside `run()`, a loop is established that counts from 0 to 9. Notice the call to `sleep()`. 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 can throw an `InterruptedException`. Thus, calls to it must be wrapped in a `try` block. The `sleep()` method also

```java
MyThread(String name) {
    thrdName = name;
}

// Entry point of thread.
public void run() {
    System.out.println(thrdName + " starting.");
    try {
        for(int count=0; count < 10; count++) {
            Thread.sleep(400);
            System.out.println("In " + thrdName + ", count is " + count);
        }
    } catch(InterruptedException exc) {
        System.out.println(thrdName + " interrupted.");
    }
    System.out.println(thrdName + " terminating.");
}

class UseThreads {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");

        // First, construct a MyThread object.
        MyThread mt = new MyThread("Child #1"); // Create a runnable object.

        // Next, construct a thread from that object.
        Thread newThrd = new Thread(mt); // Construct a thread on that object.

        // Finally, start execution of the thread.
        newThrd.start(); // Start running the thread.

        for(int i=0; i<50; i++) {
            System.out.print(\n            try {
                Thread.sleep(100);
            } catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        }

        System.out.println("Main thread ending.");
    }
}
```
has a second form, which allows you to specify the period in terms of milliseconds and nanoseconds if you need that level of precision. In \texttt{run()}, \texttt{sleep()} pauses the thread for 400 milliseconds each time through the loop. This lets the thread run slow enough for you to watch it execute.

Inside \texttt{main()}, a new \texttt{Thread} object is created by the following sequence of statements:

```java
// First, construct a MyThread object.
MyThread mt = new MyThread("Child #1");

// Next, construct a thread from that object.
Thread newThrd = new Thread(mt);

// Finally, start execution of the thread.
newThrd.start();
```

As the comments suggest, first an object of \texttt{MyThread} is created. This object is then used to construct a \texttt{Thread} object. This is possible because \texttt{MyThread} implements \texttt{Runnable}. Finally, execution of the new thread is started by calling \texttt{start()}. This causes the child thread's \texttt{run()} method to begin. After calling \texttt{start()}, execution returns to \texttt{main()}, and it enters \texttt{main()}'s \texttt{for} loop. Notice that this loop iterates 50 times, pausing 100 milliseconds each time through the loop. Both threads continue running, sharing the CPU in single-CPU systems, until their loops finish. The output produced by this program is as follows. Because of differences between computing environments, the precise output that you see may differ slightly from that shown here:

Main thread starting.
.Child #1 starting.
....In Child #1, count is 0
....In Child #1, count is 1
....In Child #1, count is 2
....In Child #1, count is 3
....In Child #1, count is 4
....In Child #1, count is 5
....In Child #1, count is 6
....In Child #1, count is 7
....In Child #1, count is 8
....In Child #1, count is 9
Child #1 terminating.
............Main thread ending.

There is another point of interest to notice in this first threading example. To illustrate the fact that the main thread and \texttt{mt} execute concurrently, it is necessary to keep \texttt{main()} from terminating until \texttt{mt} is finished. Here, this is done through the timing differences between the two threads. Because the calls to \texttt{sleep()} inside \texttt{main()}'s \texttt{for} loop cause a total delay of 5 seconds (50 iterations times 100 milliseconds), but the total delay within \texttt{run()}'s loop is only 4 seconds (10 iterations times 400 milliseconds), \texttt{run()} will finish approximately 1 second before \texttt{main()}. As a result, both the main thread and \texttt{mt} will execute concurrently until \texttt{mt} ends. Then, about 1 second later \texttt{main()} ends.

Although this use of timing differences to ensure that \texttt{main()} finishes last is sufficient for this simple example, it is not something that you would normally use in practice. Java provides much
better ways of waiting for a thread to end. It is, however, sufficient for the next few programs. Later in this chapter, you will see a better way for one thread to wait until another completes.

One other point: In a multithreaded program, you often will want the main thread to be the last thread to finish running. As a general rule, a program continues to run until all of its threads have ended. Thus, having the main thread finish last is not a requirement. It is, however, often a good practice to follow—especially when you are first learning about threads.

**Some Simple Improvements**

While the preceding program is perfectly valid, some simple improvements will make it more efficient and easier to use. First, it is possible to have a thread begin execution as soon as it is created. In the case of `MyThread`, this is done by instantiating a `Thread` object inside `MyThread`'s constructor. Second, there is no need for `MyThread` to store the name of the thread since it is possible to give a name to a thread when it is created. To do so, use this version of `Thread`'s constructor:

```
Thread(Runnable threadOb, String name)
```

Here, `name` becomes the name of the thread.

**Ask the Expert**

**Q:** You state that in a multithreaded program, one will often want the main thread to finish last. Can you explain?

**A:** The main thread is a convenient place to perform the orderly shutdown of your program, such as the closing of files. It also provides a well-defined exit point for your program. Therefore, it often makes sense for it to finish last. Fortunately, as you will soon see, it is trivially easy for the main thread to wait until the child threads have completed.

You can obtain the name of a thread by calling `getName()` defined by `Thread`. Its general form is shown here:

```
final String getName()
```

Although not needed by the following program, you can set the name of a thread after it is created by using `setName()`, which is shown here:

```
final void setName(String threadName)
```

Here, `threadName` specifies the name of the thread.

Here is the improved version of the preceding program:
This version produces the same output as before. Notice that the thread is stored in `thrd` inside `MyThread`.

Try This 11-1 Extending Thread

```java
// Improved MyThread.

class MyThread implements Runnable {
    Thread thrd; \- A reference to the thread is stored in thrd.

    // Construct a new thread.
    MyThread(String name) {
        thrd = new Thread(this, name); \- The thread is named when it is created.
        thrd.start(); \- start the thread \- Begin executing the thread.
    }

    // Begin execution of new thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            for(int count=0; count<10; count++) {
                Thread.sleep(400);
                System.out.println("In " + thrd.getName() + ", count is " + count);
            }
        }
        catch(InterruptedException exc) {
            System.out.println(thrd.getName() + " interrupted.");
        }
        System.out.println(thrd.getName() + " terminating.");
    }
}

class UseThreadsImproved {
    public static void main(String args[]) {
        System.out.println("Main thread starting.");
        MyThread mt = new MyThread("Child #1");

        for(int i=0; i < 50; i++) { \- Now the thread starts when it is created.
            System.out.print("");
            try {
                Thread.sleep(100);
            }
            catch(InterruptedException exc) {
                System.out.println("Main thread interrupted.");
            }
        }
        System.out.println("Main thread ending.");
    }
}
```
Implementing `Runnable` is one way to create a class that can instantiate thread objects. Extending `Thread` is the other. In this project, you will see how to extend `Thread` by creating a program functionally identical to the `UseThreadsImproved` program.

When a class extends `Thread`, it 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. It is possible to override other `Thread` methods, but doing so is not required.

1. Create a file called `ExtendThread.java`. Into this file, copy the code from the second threading example (`UseThreadsImproved.java`).

2. Change the declaration of `MyThread` so that it extends `Thread` rather than implementing `Runnable`, as shown here:
   ```java
   class MyThread extends Thread {
   ```

3. Remove this line:
   ```java
   Thread thrd;
   ```
   The `thrd` variable is no longer needed, since `MyThread` includes an instance of `Thread` and can refer to itself.

4. Change the `MyThread` constructor so that it looks like this:
   ```java
   // Construct a new thread.
   MyThread(String name) {
       super(name); // name thread
       start(); // start the thread
   }
   ```
   As you can see, first `super` is used to call this version of `Thread`’s constructor:
   ```java
   Thread(String name);
   ```
   Here, `name` is the name of the thread.

5. Change `run()` so it calls `getName()` directly, without qualifying it with the `thrd` variable. It should look like this:
6. Here is the completed program that now extends **Thread** rather than implementing **Runnable**. The output is the same as before.
Creating Multiple Threads
The preceding examples have created only one child thread. However, your program can spawn as many threads as it needs. For example, the following program creates three child threads:

```java
/*
   Try This 11-1

   Extend Thread.
*/
class MyThread extends Thread {

   // Construct a new thread.
   MyThread(String name) {
      super(name); // name thread
      start(); // start the thread
   }

   // Begin execution of new thread.
   public void run() {
      System.out.println(getName() + " starting.");
      try {
         for(int count=0; count < 10; count++) {
            Thread.sleep(400);
            System.out.println("In " + getName() + ", count is " + count);
         }
      } catch(InterruptedException exc) {
         System.out.println(getName() + " interrupted.");
      }

      System.out.println(getName() + " terminating.");
   }
}

class ExtendThread {
   public static void main(String args[]) {
      System.out.println("Main thread starting.");

      MyThread mt = new MyThread("Child #1");

      for(int i=0; i < 50; i++) {
         System.out.print(“.”);
         try {
            Thread.sleep(100);
         } catch(InterruptedException exc) {
            System.out.println("Main thread interrupted.");
         }
      }

      System.out.println("Main thread ending.");
   }
}
```
Sample output from this program follows:
Q: Why does Java have two ways to create child threads (by extending Thread or implementing Runnable) and which approach is better?

A: 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. Some 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 to simply implement Runnable. Also, by implementing Runnable, you enable your thread to inherit a class other than Thread.
As you can see, once started, all three child threads share the CPU. Notice that the threads are started in the order in which they are created. However, this may not always be the case. Java is free to schedule the execution of threads in its own way. Of course, because of differences in timing or environment, the precise output from the program may differ, so don’t be surprised if you see slightly different results when you try the program.

Determining When a Thread Ends

It is often useful to know when a thread has ended. For example, in the preceding examples, for the sake of illustration it was helpful to keep the main thread alive until the other threads ended. In those examples, this was accomplished by having the main thread sleep longer than the child threads that it spawned. This is, of course, hardly a satisfactory or generalizable solution!

Fortunately, Thread provides two means by which you can determine if a thread has ended. First, you can call isAlive( ) on the thread. Its general form is shown here:

```java
final boolean isAlive()
```

The isAlive( ) method returns true if the thread upon which it is called is still running. It returns false otherwise. To try isAlive( ), substitute this version of MoreThreads for the one shown in the preceding program:
This version produces output that is similar to the previous version, except that `main( )` ends as soon as the other threads finish. The difference is that it uses `isAlive( )` to wait for the child threads to terminate. Another way to wait for a thread to finish is to call `join( )`, shown here:

```java
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 a program that uses `join( )` to ensure that the main thread is the last to stop:
Sample output from this program is shown here. Remember that when you try the program, your precise output may vary slightly.
As you can see, after the calls to `join()` return, the threads have stopped executing.

**Thread Priorities**
Each thread has associated with it a priority setting. A thread’s priority determines, in part, how much CPU time a thread receives relative to the other active threads. In general, over a given period of time, low-priority threads receive little. High-priority threads receive a lot. As you might expect, how much CPU time a thread receives has profound impact on its execution characteristics and its interaction with other threads currently executing in the system.

It is important to understand that factors other than a thread’s priority also affect how much CPU
time a thread receives. For example, if a high-priority thread is waiting on some resource, perhaps for keyboard input, then it will be blocked, and a lower priority thread will run. However, when that high-priority thread gains access to the resource, it can preempt the low-priority thread and resume execution. Another factor that affects the scheduling of threads is the way the operating system implements multitasking. (See “Ask the Expert” at the end of this section.) Thus, just because you give one thread a high priority and another a low priority does not necessarily mean that one thread will run faster or more often than the other. It’s just that the high-priority thread has greater potential access to the CPU.

When a child thread is started, its priority setting is equal to that of its parent thread. You can change a thread’s priority by calling `setPriority()` , 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()
```

The following example demonstrates two threads at different priorities. The threads are created as instances of `Priority`. The `run()` method contains a loop that counts the number of iterations. The loop stops when either the count reaches 10,000,000 or the static variable `stop` is `true`. Initially, `stop` is set to `false`, but the first thread to finish counting sets `stop` to `true`. This causes the second thread to terminate with its next time slice. Each time through the loop the string in `currentName` is checked against the name of the executing thread. If they don’t match, it means that a task-switch occurred. Each time a task-switch happens, the name of the new thread is displayed, and `currentName` is given the name of the new thread. Displaying each thread switch allows you to watch (in a very imprecise way) when the threads gain access to the CPU. After both threads stop, the number of iterations for each loop is displayed.

```java
// Demonstrate thread priorities.

class Priority implements Runnable {
    int count;
    Thread thrd;
```
static boolean stop = false;
static String currentName;

/* Construct a new thread. Notice that this
   constructor does not actually start the
   threads running. */

Priority(String name) {
    thrd = new Thread(this, name);
    count = 0;
    currentName = name;
}

// Begin execution of new thread.
public void run() {
    System.out.println(thrd.getName() + " starting.");
    do {
        count++;
        if(currentName.compareTo(thrd.getName()) != 0) {
            currentName = thrd.getName();
            System.out.println("In " + currentName);
        }
    } while(stop == false && count < 10000000); ▶️ The first thread to
    stop = true;
    System.out.println("\n" + thrd.getName() +
    " terminating.");
}

class PriorityDemo {
    public static void main(String args[]) {
        Priority mt1 = new Priority("High Priority");
        Priority mt2 = new Priority("Low Priority");

        // set the priorities
        mt1.thrd.setPriority(Thread.NORM_PRIORITY+2); ▶️ Give mt1 a higher priority
        mt2.thrd.setPriority(Thread.NORM_PRIORITY-2);

        // start the threads
        mt1.thrd.start();
        mt2.thrd.start();

        try {
            mt1.thrd.join();
            mt2.thrd.join();
        }
        catch(InterruptedException exc) {
            System.out.println("Main thread interrupted.");
        }
        System.out.println("\nHigh priority thread counted to " +
        mt1.count);
        System.out.println("Low priority thread counted to " +
        mt2.count);
    }
}
Here is a sample run on a single-core system:

High Priority starting.
In High Priority
Low Priority starting.
In Low Priority
In High Priority

High Priority terminating.

Low Priority terminating.

High priority thread counted to 10000000
Low priority thread counted to 8183

In this run, the high-priority thread got a vast majority of the CPU time. Of course, the exact output produced by this program will depend upon the speed of your CPU, the number of CPUs in your system, the operating system you are using, and the number of other tasks running in the system.

Ask the Expert

Q: Does the operating system’s implementation of multitasking affect how much CPU time a thread receives?

A: Aside from a thread’s priority setting, the most important factor affecting thread execution is the way the operating system implements multitasking and scheduling. Some operating systems use preemptive multitasking in which each thread receives a time slice, at least occasionally. Other systems use nonpreemptive scheduling in which one thread must yield execution before another thread will execute. In nonpreemptive systems, it is easy for one thread to dominate, preventing others from running.

Synchronization

When using multiple threads, it is sometimes necessary to coordinate the activities of two or more. The process by which this is achieved is called synchronization. The most common reason for synchronization is when two or more threads need access to a shared resource that can be used by only one thread at a time. For example, when one thread is writing to a file, a second thread must be prevented from doing so at the same time. Another reason for synchronization is when one thread is waiting for an event that is caused by another thread. In this case, there must be some means by which the first thread is held in a suspended state until the event has occurred. Then, the waiting thread must resume execution.

Key to synchronization in Java is the concept of the monitor, which controls access to an object. A
monitor works by implementing the concept of a lock. When an object is locked by one thread, no other thread can gain access to the object. When the thread exits, the object is unlocked and is available for use by another thread.

All objects in Java have a monitor. This feature is built into the Java language, itself. Thus, all objects can be synchronized. Synchronization is supported by the keyword `synchronized` and a few well-defined methods that all objects have. Since synchronization was designed into Java from the start, it is much easier to use than you might first expect. In fact, for many programs, the synchronization of objects is almost transparent.

There are two ways that you can synchronize your code. Both involve the use of the `synchronized` keyword, and both are examined here.

### Using Synchronized Methods

You can synchronize access to a method by modifying it with the `synchronized` keyword. When that method is called, the calling thread enters the object’s monitor, which then locks the object. While locked, no other thread can enter the method, or enter any other synchronized method defined by the object’s class. When the thread returns from the method, the monitor unlocks the object, allowing it to be used by the next thread. Thus, synchronization is achieved with virtually no programming effort on your part.

The following program demonstrates synchronization by controlling access to a method called `sumArray()`, which sums the elements of an integer array.

```java
// Use synchronize to control access.

class SumArray {
    private int sum;

    synchronized int sumArray(int nums[]) {
        sum = 0; // reset sum
        for(int i=0; i<nums.length; i++) {
            sum += nums[i];
            System.out.println("Running total for " +
                Thread.currentThread().getName() +
                " is " + sum);
        }
        return sum;
    }
}
```
try {
    Thread.sleep(10); // allow task-switch
} catch (InterruptedException exc) {
    System.out.println("Thread interrupted.");
}
return sum;
}

class MyThread implements Runnable {
    Thread thrd;
    static SumArray sa = new SumArray();
    int a[];
    int answer;

    // Construct a new thread.
    MyThread(String name, int nums[]) {
        thrd = new Thread(this, name);
        a = nums;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        int sum;

        System.out.println(thrd.getName() + " starting.");

        answer = sa.sumArray(a);
        System.out.println("Sum for " + thrd.getName() + " is " + answer);

        System.out.println(thrd.getName() + " terminating.");
    }
}

class Sync {
    public static void main(String args[]) {
        int a[] = {1, 2, 3, 4, 5};

        MyThread mt1 = new MyThread("Child #1", a);
        MyThread mt2 = new MyThread("Child #2", a);
The output from the program is shown here. (The precise output may differ on your computer.)

Child #1 starting.
Running total for Child #1 is 1
Child #2 starting.
Running total for Child #1 is 3
Running total for Child #1 is 6
Running total for Child #1 is 10
Running total for Child #1 is 15
Sum for Child #1 is 15
Child #1 terminating.
Running total for Child #2 is 1
Running total for Child #2 is 3
Running total for Child #2 is 6
Running total for Child #2 is 10
Running total for Child #2 is 15
Sum for Child #2 is 15
Child #2 terminating.

Let’s examine this program in detail. The program creates three classes. The first is `SumArray`. It contains the method `sumArray()`, which sums an integer array. The second class is `MyThread`, which uses a `static` object of type `SumArray` to obtain the sum of an integer array. This object is called `sa` and because it is `static`, there is only one copy of it that is shared by all instances of `MyThread`. Finally, the class `Sync` creates two threads and has each compute the sum of an integer array.

Inside `sumArray()`, `sleep()` is called to purposely allow a task switch to occur, if one can—but it can’t. Because `sumArray()` is synchronized, it can be used by only one thread at a time. Thus, when the second child thread begins execution, it does not enter `sumArray()` until after the first child thread is done with it. This ensures that the correct result is produced.

To fully understand the effects of `synchronized`, try removing it from the declaration of `sumArray()`. After doing this, `sumArray()` is no longer synchronized, and any number of threads may use it concurrently. The problem with this is that the running total is stored in `sum`, which will be changed by each thread that calls `sumArray()` through the `static` object `sa`. Thus, when two threads call `sa.sumArray()` at the same time, incorrect results are produced because `sum` reflects the summation of both threads, mixed together. For example, here is sample output from the program after `synchronized` has been removed from `sumArray()`’s declaration. (The precise output may differ on
As the output shows, both child threads are calling `sa.sumArray()` concurrently, and the value of `sum` is corrupted. Before moving on, let’s review the key points of a synchronized method:

- A synchronized method is created by preceding its declaration with `synchronized`.
- For any given object, once a synchronized method has been called, the object is locked and no synchronized methods on the same object can be used by another thread of execution.
- Other threads trying to call an in-use synchronized object will enter a wait state until the object is unlocked.
- When a thread leaves the synchronized method, the object is unlocked.

**The synchronized Statement**

Although creating `synchronized` methods within classes that you create is an easy and effective means of achieving synchronization, it will not work in all cases. For example, you might want to synchronize access to some method that is not modified by `synchronized`. This can occur because you want to use a class that was not created by you but by a third party, and you do not have access to the source code. Thus, it is not possible for you to 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 a `synchronized` block:

```java
synchronized(objref) {
    // statements to be synchronized
}
```

Here, `objref` is a reference to the object being synchronized. Once a synchronized block has been
entered, no other thread can call a synchronized method on the object referred to by \texttt{objref} until the block has been exited.

For example, another way to synchronize calls to \texttt{sumArray()} is to call it from within a synchronized block, as shown in this version of the program:

```java
// Use a synchronized block to control access to SumArray.
class SumArray {
    private int sum;

    int sumArray(int nums[]) {
        sum = 0; // reset sum
        for(int i=0; i<nums.length; i++) {
            sum += nums[i];
            System.out.println("Running total for "+
                             Thread.currentThread().getName()+
                             " is "+sum);
            try {
                Thread.sleep(10); // allow task-switch
            } catch(InterruptedException exc) {
                System.out.println("Thread interrupted.");
            }
        }
        return sum;
    }
}

class MyThread implements Runnable {
    Thread thrd;
    static SumArray sa = new SumArray();
    int a[];
    int answer;
    
    // Construct a new thread.
    MyThread(String name, int nums[]) {
        thrd = new Thread(this, name);
        a = nums;
        thrd.start(); // start the thread
    }
    
    // Begin execution of new thread.
    public void run() {
        int sum;
        System.out.println(thrd.getName() + " starting.");
    }
```
This version produces the same, correct output as the one shown earlier that uses a synchronized method.

Ask the Expert

Q: I have heard of something called the “concurrency utilities.” What are these? Also, what is the Fork/Join Framework?

A: The concurrency utilities, which are packaged in `java.util.concurrent` (and its subpackages), support concurrent programming. Among several other items, they offer synchronizers, thread pools, execution managers, and locks that expand your control over thread execution. One of the most exciting features of the concurrent API is the Fork/Join Framework.

The Fork/Join Framework supports what is often termed parallel programming. This is the name commonly given to the techniques that take advantage of computers that contain two or more processors (including multicore systems) by subdividing a task into subtasks, with each subtask executing on its own processor. As you can imagine, such an approach can lead to significantly higher throughput and performance. The key advantage of the Fork/Join Framework is ease of use; it streamlines the development of multithreaded code that automatically scales to utilize the number of processors in a system. Thus, it facilitates the creation of concurrent solutions to some common...
programming tasks, such as performing operations on the elements of an array. The concurrency utilities in general, and the Fork/Join Framework specifically, are features that you will want to explore after you have become more experienced with multithreading.

Thread Communication Using notify( ), wait( ), and notifyAll( )
Consider the following situation. A thread called T is executing inside a synchronized method and needs access to a resource called R that is temporarily unavailable. What should T do? If T enters some form of polling loop that waits for R, T ties up the object, preventing other threads’ access to it. This is a less than optimal solution because it partially defeats the advantages of programming for a multithreaded environment. A better solution is to have T temporarily relinquish control of the object, allowing another thread to run. When R becomes available, T can be notified and resume execution. Such an approach relies upon some form of interthread communication in which one thread can notify another that it is blocked and be notified that it can resume execution. Java supports interthread communication with the `wait()`, `notify()`, and `notifyAll()` methods.

The `wait()`, `notify()`, and `notifyAll()` methods are part of all objects because they are implemented by the `Object` class. These methods should be called only from within a `synchronized` context. Here is how they are used. When a thread is temporarily blocked from running, it calls `wait()`. This causes the thread to go to sleep and the monitor for that object to be released, allowing another thread to use the object. At a later point, the sleeping thread is awakened when some other thread enters the same monitor and calls `notify()`, or `notifyAll()`.

Following are the various forms of `wait()` defined by `Object`:

```java
final void wait( ) throws InterruptedException
final void wait(long millis) throws InterruptedException
final void wait(long millis, int nanos) throws InterruptedException
```

The first form waits until notified. The second form waits until notified or until the specified period of milliseconds has expired. The third form allows you to specify the wait period in terms of nanoseconds.

Here are the general forms for `notify()` and `notifyAll()`:

```java
final void notify()
final void notifyAll()
```

A call to `notify()` resumes one waiting thread. A call to `notifyAll()` notifies all threads, with the highest priority thread gaining access to the object.

Before looking at an example that uses `wait()`, 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*. The conditions that lead to a spurious wakeup are complex and beyond the scope of this book. However, Oracle recommends that because of the remote possibility of a spurious wakeup, 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.

An Example That Uses \texttt{wait( )} and \texttt{notify( )}

To understand the need for and the application of \texttt{wait( )} and \texttt{notify( )}, we will create a program that simulates the ticking of a clock by displaying the words Tick and Tock on the screen. To accomplish this, we will create a class called \texttt{TickTock} that contains two methods: \texttt{tick( )} and \texttt{tock( )}. The \texttt{tick( )} method displays the word "Tick", and \texttt{tock( )} displays "Tock". To run the clock, two threads are created, one that calls \texttt{tick( )} and one that calls \texttt{tock( )}. The goal is to make the two threads execute in a way that the output from the program displays a consistent "Tick Tock"—that is, a repeated pattern of one tick followed by one tock.

```java
// Use \texttt{wait( )} and \texttt{notify( )} to create a ticking clock.

class TickTock {
    String state; // contains the state of the clock

    synchronized void tick(boolean running) {
        if(!running) { // stop the clock
            state = "ticked";
            notify(); // notify any waiting threads
            return;
        }
        System.out.print("Tick ");
        state = "ticked"; // set the current state to ticked
        notify(); // let tock() run
        try {
            while(!state.equals("tocked"))
                wait(); // wait for tock() to complete
        } catch(InterruptedException exc) {
            System.out.println("Thread interrupted.");
        }
    }

    synchronized void tock(boolean running) {
        if(!running) { // stop the clock
```
state = "ticked";
notify(); // notify any waiting threads
return;
}

System.out.println("Tock");

state = "ticked"; // set the current state to ticked
notify(); // let tick() run ← tock() notifies tick().
try {
    while(!state.equals("ticked"))
        wait(); // wait for tick to complete ← tock() waits for tick().
}
catch(InterruptedException exc) {
    System.out.println("Thread interrupted.");
}

}

class MyThread implements Runnable {
    Thread thrd;
    TickTock ttOb;

    // Construct a new thread.
    MyThread(String name, TickTock tt) {
        thrd = new Thread(this, name);
        ttOb = tt;
        thrd.start(); // start the thread
    }

    // Begin execution of new thread.
    public void run() {
        if(thrd.getName().compareTo("Tick") == 0) {
            for(int i=0; i<5; i++) ttOb.tick(true);
            ttOb.tick(false);
        } else {
            for(int i=0; i<5; i++) ttOb.tock(true);
            ttOb.tock(false);
        }
    }
}

class ThreadCom {
public static void main(String args[]) {
    TickTock tt = new TickTock();
    MyThread mt1 = new MyThread("Tick", tt);
    MyThread mt2 = new MyThread("Tock", tt);

    try {
        mt1.thrd.join();
        mt2.thrd.join();
    } catch(InterruptedException exc) {
        System.out.println("Main thread interrupted.");
    }
}
Here is the output produced by the program:

```
Tick Tock
Tick Tock
Tick Tock
Tick Tock
Tick Tock
```

Let's take a close look at this program. The heart of the clock is the **TickTock** class. It contains two methods, **tick()** and **tock()**, which communicate with each other to ensure that a Tick is always followed by a Tock, which is always followed by a Tick, and so on. Notice the **state** field. When the clock is running, **state** will hold either the string "ticked" or "tocked", which indicates the current state of the clock. In **main()**, a **TickTock** object called **tt** is created, and this object is used to start two threads of execution.

The threads are based on objects of type **MyThread**. The **MyThread** constructor is passed two arguments. The first becomes the name of the thread. This will be either "Tick" or "Tock". The second is a reference to the **TickTock** object, which is **tt** in this case. Inside the **run()** method of **MyThread**, if the name of the thread is "Tick", then calls to **tick()** are made. If the name of the thread is "Tock", then the **tock()** method is called. Five calls that pass **true** as an argument are made to each method. The clock runs as long as **true** is passed. A final call that passes **false** to each method stops the clock.

The most important part of the program is found in the **tick()** and **tock()** methods of **TickTock**. We will begin with the **tick()** method, which, for convenience, is shown here:

```java
synchronized void tick(boolean running) {
    if(!running) { // stop the clock
        state = "ticked";
        notify(); // notify any waiting threads
        return;
    }

    System.out.print("Tick ");
    state = "ticked"; // set the current state to ticked
    notify(); // let tock() run
    try {
        while(!state.equals("tocked"))
            wait(); // wait for tock() to complete
    }
    catch(InterruptedException exc) {
        System.out.println("Thread interrupted.");
    }
}
```

First, notice that **tick()** is modified by **synchronized**. Remember, **wait()** and **notify()** apply only to synchronized methods. The method begins by checking the value of the **running** parameter. This
parameter is used to provide a clean shutdown of the clock. If it is `false`, then the clock has been stopped. If this is the case, `state` is set to "ticked" and a call to `notify()` is made to enable any waiting thread to run. We will return to this point in a moment.

Assuming that the clock is running when `tick()` executes, the word "Tick" is displayed, `state` is set to "ticked", and then a call to `notify()` takes place. The call to `notify()` allows a thread waiting on the same object to run. Next, `wait()` is called within a `while` loop. The call to `wait()` causes `tick()` to suspend until another thread calls `notify()`. Therefore, the loop will not iterate until another thread calls `notify()` on the same object. As a result, when `tick()` is called, it displays one "Tick", lets another thread run, and then suspends.

The `while` loop that calls `wait()` checks the value of `state`, waiting for it to equal "tocked", which will be the case only after the `tock()` method executes. As explained, using a `while` loop to check this condition prevents a spurious wakeup from incorrectly restarting the thread. If `state` does not equal "tocked" when `wait()` returns, it means that a spurious wakeup occurred, and `wait()` is simply called again.

The `tock()` method is an exact copy of `tick()` except that it displays "Tock" and sets `state` to "tocked". Thus, when entered, it displays "Tock", calls `notify()`, and then waits. When viewed as a pair, a call to `tick()` can only be followed by a call to `tock()`, which can only be followed by a call to `tick()`, and so on. Therefore, the two methods are mutually synchronized.

The reason for the call to `notify()` when the clock is stopped is to allow a final call to `wait()` to succeed. Remember, both `tick()` and `tock()` execute a call to `wait()` after displaying their message. The problem is that when the clock is stopped, one of the methods will still be waiting. Thus, a final call to `notify()` is required in order for the waiting method to run. As an experiment, try removing this call to `notify()` and watch what happens. As you will see, the program will "hang," and you will need to press CTRL-C to exit. The reason for this is that when the final call to `tock()` calls `wait()`, there is no corresponding call to `notify()` that lets `tock()` conclude. Thus, `tock()` just sits there, waiting forever.

Before moving on, if you have any doubt that the calls to `wait()` and `notify()` are actually needed to make the "clock" run right, substitute this version of `TickTock` into the preceding program. It has all calls to `wait()` and `notify()` removed.
After the substitution, the output produced by the program will look like this:

```
Tick Tick Tick Tick Tick Tock
Tock
Tock
Tock
Tock
```

Clearly, the `tick()` and `tock()` methods are no longer working together!

---

**Ask the Expert**

**Q:** I have heard the term *deadlock* applied to misbehaving multithreaded programs. What is it, and how can I avoid it? Also, what is a *race condition*, and how can I avoid that, too?

**A:** Deadlock is, as the name implies, a situation in which one thread is waiting for another thread to do something, but that other thread is waiting on the first. Thus, both threads are suspended, waiting on each other, and neither executes. This situation is analogous to two overly polite
people, both insisting that the other step through a door first!

Avoiding deadlock seems easy, but it’s not. For example, deadlock can occur in roundabout ways. The cause of the deadlock often is not readily understood just by looking at the source code to the program because concurrently executing threads can interact in complex ways at run time. To avoid deadlock, careful programming and thorough testing is required. Remember, if a multithreaded program occasionally “hangs,” deadlock is the likely cause.

A race condition occurs when two (or more) threads attempt to access a shared resource at the same time, without proper synchronization. For example, one thread may be writing a new value to a variable while another thread is incrementing the variable’s current value. Without synchronization, the new value of the variable will depend upon the order in which the threads execute. (Does the second thread increment the original value or the new value written by the first thread?) In situations like this, the two threads are said to be “racing each other,” with the final outcome determined by which thread finishes first. Like deadlock, a race condition can occur in difficult-to-discover ways. The solution is prevention: careful programming that properly synchronizes access to shared resources.

Suspending, Resuming, and Stopping Threads

It is sometimes useful to suspend execution of a thread. For example, a separate thread can be used to display the time of day. If the user does not desire a clock, then its thread can be suspended. Whatever the case, it is a simple matter to suspend a thread. Once suspended, it is also a simple matter to restart the thread.

The mechanisms to suspend, stop, and resume threads differ between early versions of Java and more 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. They have the following forms:

final void resume()

final void suspend()

final void stop()

While these methods seem to be a perfectly reasonable and convenient approach to managing the execution of threads, they must no longer be used. Here’s why. The suspend() method of the Thread class was deprecated by Java 2. This was done because suspend() can sometimes cause serious problems that involve deadlock. 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 was also deprecated by Java 2. This was done because this method too can sometimes cause serious problems.

Since you cannot now use the suspend(), resume(), or stop() methods to control a thread, you might at first be thinking that there is no way 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 if that thread should suspend, resume, or stop its own execution. Typically, this is
accomplished by establishing two flag variables: one for suspend and resume, and one for stop. For suspend and resume, as long as the 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. For the stop flag, if it is set to "stop," the thread must terminate.

The following example shows one way to implement your own versions of suspend(), resume(), and stop():

```java
// Suspending, resuming, and stopping a thread.

class MyThread implements Runnable {
    Thread thrd;

    boolean suspended; // Suspends thread when true.
    boolean stopped; // Stops thread when true.

    MyThread(String name) {
        thrd = new Thread(this, name);
        suspended = false;
        stopped = false;
        thrd.start();
    }

    // This is the entry point for thread.
    public void run() {
        System.out.println(thrd.getName() + " starting.");
        try {
            for(int i = 1; i < 1000; i++) {
                System.out.print(i + " ");
                if((i%10)==0) {
                    System.out.println();
                    Thread.sleep(250);
                }
            }

            // Use synchronized block to check suspended and stopped.
            synchronized(this) {
                while(suspended) {
                    wait();
                }
                if(stopped) break;
            }
        } catch (InterruptedException exc) {
            System.out.println(thrd.getName() + " interrupted.");
        }
        System.out.println(thrd.getName() + " exiting.");
    }

    // Stop the thread.
    synchronized void mystop() {
        stopped = true;
    }
```
// The following ensures that a suspended thread can be stopped.
// suspended = false;
// notify();

// Suspend the thread.
synchronized void mysuspend() {
    suspended = true;
}

// Resume the thread.
synchronized void myresume() {
    suspended = false;
    notify();
}

class Suspend {
    public static void main(String args[]) {
        MyThread ob1 = new MyThread("My Thread");

        try {
            Thread.sleep(1000); // let ob1 thread start executing

            ob1.mysuspend();
            System.out.println("Suspending thread.");
            Thread.sleep(1000);

            ob1.myresume();
            System.out.println("Resuming thread.");
            Thread.sleep(1000);

            ob1.mysuspend();
            System.out.println("Suspending thread.");
            Thread.sleep(1000);

            ob1.myresume();
            System.out.println("Resuming thread.");
            Thread.sleep(1000);

            ob1.mysuspend();
            System.out.println("Suspending thread.");

            try {
                Thread.sleep(1000);
            } catch (InterruptedException e) {
                ob1.mystop();
            }
        }
    }
}

class MyThread {
    String threadName;

    public MyThread(String threadName) {
        this.threadName = threadName;
    }

    public synchronized void mythread() {
        while (suspended) {
            try {
                Thread.sleep(1000);
            } catch (InterruptedException e) {
                Thread.currentThread().interrupt();
            }
        }
        System.out.println("Exiting thread ");
        suspended = true;
    }

    public synchronized void myresume() {
        suspended = true;
        notify();
    }

    public synchronized void mysuspend() {
        suspended = false;
    }
}

class InterruptedThread {
    public static void main(String args[]) {
        MyThread ob1 = new MyThread("Interrupted Thread");

        ob1.mysuspend();
        System.out.println("Suspending thread.");
        ob1.myresume();
        System.out.println("Resuming thread.");
        ob1.mysuspend();
        System.out.println("Suspending thread.");
        ob1.myresume();
        System.out.println("Resuming thread.");

        ob1.mysuspend();
        System.out.println("Suspending thread.");
        Thread.sleep(1000);
        System.out.println("Main thread Interrupted");
    }
}
Sample output from this program is shown here. (Your output may differ slightly.)

My Thread starting.
1 2 3 4 5 6 7 8 9 10
11 12 13 14 15 16 17 18 19 20
21 22 23 24 25 26 27 28 29 30
31 32 33 34 35 36 37 38 39 40
Suspending thread.
Resuming thread.
41 42 43 44 45 46 47 48 49 50
51 52 53 54 55 56 57 58 59 60
61 62 63 64 65 66 67 68 69 70
71 72 73 74 75 76 77 78 79 80
Suspending thread.
Resuming thread.
81 82 83 84 85 86 87 88 89 90
91 92 93 94 95 96 97 98 99 100
101 102 103 104 105 106 107 108 109 110
111 112 113 114 115 116 117 118 119 120
Stopping thread.
My Thread exiting.
Main thread exiting.

Here is how the program works. The thread class MyThread defines two Boolean variables, suspended and stopped, which govern the suspension and termination of a thread. Both are initialized to false by the constructor. The run( ) method contains a synchronized statement block that checks suspended. If that variable is true, the wait( ) method is invoked to suspend the execution of the thread. To suspend execution of the thread, call mysuspend( ), which sets suspended to true. To resume execution, call myresume( ), which sets suspended to false and invokes notify( ) to restart the thread.

To stop the thread, call mystop( ), which sets stopped to true. In addition, mystop( ) sets suspended to false and then calls notify( ). These steps are necessary to stop a suspended thread.

Ask the Expert
Q: Multithreading seems like a great way to improve the efficiency of my programs. Can you give me any tips on effectively using it?

A: The key to effectively utilizing multithreading is to think concurrently rather than serially. For example, when you have two subsystems within a program that are fully independent of each other, consider making them into individual threads. 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, overhead is associated with context switching. If you create too many threads, more CPU time will be spent changing contexts than in executing your program!

Try This 11-2 Using the Main Thread

UseMain.java

All Java programs have at least one thread of execution, called the main thread, which is given to the program automatically when it begins running. So far, we have been taking the main thread for granted. In this project, you will see that the main thread can be handled just like all other threads.

1. Create a file called UseMain.java.

2. To access the main thread, you must obtain a Thread object that refers to it. You do this by calling the currentThread() method, which is a static member of Thread. Its general form is shown here:

   static Thread currentThread()

   This method returns a reference to the thread in which it is called. Therefore, if you call currentThread() while execution is inside the main thread, you will obtain a reference to the main thread. Once you have this reference, you can control the main thread just like any other thread.

3. Enter the following program into the file. It obtains a reference to the main thread, and then gets and sets the main thread’s name and priority.
/*
Try This 11-2

Controlling the main thread.
*/

class UseMain {
    public static void main(String args[]) {
        Thread thrd;

        // Get the main thread.
        thrd = Thread.currentThread();

        // Display main thread's name.
        System.out.println("Main thread is called: " +
                            thrd.getName());

        // Display main thread's priority.
        System.out.println("Priority: " +
                            thrd.getPriority());

        System.out.println();

        // Set the name and priority.
        System.out.println("Setting name and priority.\n");
        thrd.setName("Thread #1");
        thrd.setPriority(Thread.NORM_PRIORITY+3);

        System.out.println("Main thread is now called: " +
                            thrd.getName());

        System.out.println("Priority is now: " +
                            thrd.getPriority());
    }
}

4. The output from the program is shown here:

Main thread is called: main
Priority: 5

Setting name and priority.

Main thread is now called: Thread #1
Priority is now: 8

5. You need to be careful about what operations you perform on the main thread. For example, if you add the following code to the end of main(), the program will never terminate because it will be waiting for the main thread to end!
try {
    thrd.join();
} catch (InterruptedException exc) {
    System.out.println("Interrupted");
}


**Chapter 11 Self Test**

1. How does Java’s multithreading capability enable you to write more efficient programs?
2. Multithreading is supported by the _________ class and the ________ interface.
3. When creating a runnable object, why might you want to extend **Thread** rather than implement **Runnable**?
4. Show how to use **join()** to wait for a thread object called **MyThrd** to end.
5. Show how to set a thread called **MyThrd** to three levels above normal priority.
6. What is the effect of adding the **synchronized** keyword to a method?
7. The **wait()** and **notify()** methods are used to perform _____________________.
8. Change the **TickTock** class so that it actually keeps time. That is, have each tick take one half second, and each tock take one half second. Thus, each tick-tock will take one second. (Don’t worry about the time it takes to switch tasks, etc.)
9. Why can’t you use **suspend()**, **resume()**, and **stop()** for new programs?
10. What method defined by **Thread** obtains the name of a thread?
11. What does **isAlive()** return?
12. On your own, try adding synchronization to the **Queue** class developed in previous chapters so that it is safe for multithreaded use.
Chapter 12
Enumerations, Autoboxing, Static Import, and Annotations

Key Skills & Concepts
- Understand enumeration fundamentals
- Use the class-based features of enumerations
- Apply the `values()` and `valueOf()` methods to enumerations
- Create enumerations that have constructors, instance variables, and methods
- Employ the `ordinal()` and `compareTo()` methods that enumerations inherit from `Enum`
- Use Java’s type wrappers
- Know the basics of autoboxing and auto-unboxing
- Use autoboxing with methods
- Understand how autoboxing works with expressions
- Apply static import
- Gain an overview of annotations

This chapter discusses enumerations, autoboxing, static import, and annotations. Although none of these were part of the original definition of Java, each having been added by JDK 5, they significantly enhanced the power and usability of the language. In the case of enumerations and autoboxing, both addressed what was, at the time, long-standing needs. Static import streamlined the use of static
Enumerations

In its simplest form, an enumeration is a list of named constants that define a new data type. An object of an enumeration type can hold only the values that are defined by the list. Thus, an enumeration gives you a way to precisely define a new type of data that has a fixed number of valid values.

Enumerations are common in everyday life. For example, an enumeration of the coins used in the United States is penny, nickel, dime, quarter, half-dollar, and dollar. An enumeration of the months in the year consists of the names January through December. An enumeration of the days of the week is Sunday, Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday.

From a programming perspective, enumerations are useful whenever you need to define a set of values that represent a collection of items. For example, you might use an enumeration to represent a set of status codes, such as success, waiting, failed, and retrying, which indicate the progress of some action. In the past, such values were defined as final variables, but enumerations offer a more structured approach.

Enumeration Fundamentals

An enumeration is created using the enum keyword. For example, here is a simple enumeration that lists various forms of transportation:

```java
// An enumeration of transportation.
enum Transport {
    CAR, TRUCK, AIRPLANE, TRAIN, BOAT
}
```

The identifiers CAR, TRUCK, and so on, are called enumeration constants. Each is implicitly declared as a public, static member of Transport. Furthermore, the enumeration constants’ type is the type of the enumeration in which the constants are declared, which is Transport in this case. Thus, in the language of Java, these constants are called self-typed, where “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 that you do one of the primitive types. For example, this declares tp as a variable of enumeration type Transport:

```java
Transport tp;
```

Because tp is of type Transport, the only values that it can be assigned are those defined by the enumeration. For example, this assigns tp the value AIRPLANE:

```java
tp = Transport.AIRPLANE;
```
Notice that the symbol \texttt{AIRPLANE} is qualified by \texttt{Transport}.

Two enumeration constants can be compared for equality by using the \texttt{==} relational operator. For example, this statement compares the value in \texttt{tp} with the \texttt{TRAIN} constant:

\begin{verbatim}
if (tp == Transport.TRAIN) // ...
\end{verbatim}

An enumeration value can also be used to control a \texttt{switch} statement. Of course, all of the \texttt{case} statements must use constants from the same \texttt{enum} as that used by the \texttt{switch} expression. For example, this \texttt{switch} is perfectly valid:

\begin{verbatim}
// Use an enum to control a switch statement.
switch(tp) {
    case CAR:
        // ...
    case TRUCK:
        // ...
}
\end{verbatim}

Notice that in the \texttt{case} statements, the names of the enumeration constants are used without being qualified by their enumeration type name. That is, \texttt{TRUCK}, not \texttt{Transport.TRUCK}, is used. This is because the type of the enumeration in the \texttt{switch} expression has already implicitly specified the \texttt{enum} type of the \texttt{case} constants. There is no need to qualify the constants in the \texttt{case} statements with their \texttt{enum} type name. In fact, attempting to do so will cause a compilation error.

When an enumeration constant is displayed, such as in a \texttt{println()} statement, its name is output. For example, given this statement:

\begin{verbatim}
System.out.println(Transport.BOAT);
\end{verbatim}

the name \texttt{BOAT} is displayed.

The following program puts together all of the pieces and demonstrates the \texttt{Transport} enumeration:
The output from the program is shown here:

Value of \(tp\): AIRPLANE

\(tp\) contains TRAIN.

A train runs on rails.

Before moving on, it’s necessary to make one stylistic point. The constants in `Transport` use uppercase. (Thus, `CAR`, not `car`, is used.) However, the use of uppercase is not required. In other words, there is no rule that requires enumeration constants to be in uppercase. Because enumerations often replace `final` variables, which have traditionally used uppercase, some programmers believe that uppercasing enumeration constants is also appropriate. There are, of course, other viewpoints and styles. The examples in this book will use uppercase for enumeration constants, for consistency.
Java Enumerations Are Class Types

Although the preceding examples show the mechanics of creating and using an enumeration, they don’t show all of its capabilities. Unlike the way enumerations are implemented in some other languages, Java implements enumerations as class types. Although you don’t instantiate an enum using new, it otherwise acts much like other classes. The fact that enum defines a class enables the Java enumeration to have powers that enumerations in some other languages do not. For example, you can give it constructors, add instance variables and methods, and even implement interfaces.

The values() and valueOf() Methods

All enumerations automatically have 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 Transport enumeration shown earlier, the return type of Transport.valueOf("TRAIN") is Transport. The value returned is TRAIN. The following program demonstrates the values() and valueOf() methods:

```java
// Use the built-in enumeration methods.

// An enumeration of Transport varieties.
enum Transport {
    CAR, TRUCK, AIRPLANE, TRAIN, BOAT
}

class EnumDemo2 {
    public static void main(String args[])
    {
        Transport tp;

        System.out.println("Here are all Transport constants");

        // use values()
        Transport allTransports[] = Transport.values(); // Obtain an array of Transport constants.
        for(Transport t : allTransports)
            System.out.println(t);
        System.out.println();

        // use valueOf()
        tp = Transport.valueOf("AIRPLANE"); // Obtain the constant with the name AIRPLANE.
        System.out.println("tp contains " + tp);
    }
}
```

The output from the program is shown here:
Here are all Transport constants

CAR
TRUCK
AIRPLANE
TRAIN
BOAT

tp contains AIRPLANE

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 allTransports was created and assigned a reference to the enumeration array. However, this step is not necessary because the for loop could have been written as shown here, eliminating the need for the allTransports variable:

```java
for (Transport t : Transport.values())
    System.out.println(t);
```

Now, notice how the value corresponding to the name AIRPLANE was obtained by calling valueOf():

```java
tp = Transport.valueOf("AIRPLANE");
```

As explained, valueOf() returns the enumeration value associated with the name of the constant represented as a string.

Constructors, Methods, Instance Variables, and Enumerations
It is important to understand that each enumeration constant is an object of its enumeration type. Thus, an enumeration can define constructors, add methods, and have instance variables. When you define a constructor for an enum, the constructor is called when each enumeration constant is created. Each enumeration constant can call any method defined by the enumeration. Each enumeration constant has its own copy of any instance variables defined by the enumeration. The following version of Transport illustrates the use of a constructor, an instance variable, and a method. It gives each type of transportation a typical speed.
This version of Transport adds three things. The first is the instance variable speed, which is used to hold the speed of each kind of transport. The second is the Transport constructor, which is passed the speed of a transport. The third is the method getSpeed(), which returns the value of speed.

When the variable tp is declared in main(), the constructor for Transport 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:

```java
enum Transport {
    CAR(65), TRUCK(55), AIRPLANE(600), TRAIN(70), BOAT(22);
}
```

These values are passed to the s parameter of Transport(), which then assigns this value to speed. There is something else to notice about the list of enumeration constants: it is terminated by a semicolon. That is, the last constant, BOAT, is followed by a semicolon. When an enumeration
contains other members, the enumeration list must end in a semicolon.

Because each enumeration constant has its own copy of **speed**, you can obtain the speed of a specified type of transport by calling **getSpeed()**. For example, in **main()** the speed of an airplane is obtained by the following call:

```java
Transport.AIRPLANE.getSpeed()
```

The speed of each transport is obtained by cycling through the enumeration using a **for** loop. Because there is a copy of **speed** 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 available only when enumerations are implemented as classes, as Java does.

Although the preceding example contains only one constructor, an **enum** can offer two or more overloaded forms, just as can any other class.

---

**Ask the Expert**

**Q:** Since enumerations have been added to Java, should I avoid the use of **final** variables? In other words, have enumerations rendered **final** variables obsolete?

**A:** No. Enumerations are appropriate when you are working with lists of items that must be represented by identifiers. A **final** variable is appropriate when you have a constant value, such as an array size, that will be used in many places. Thus, each has its own use. The advantage of enumerations is that **final** variables don’t have to be pressed into service for a job for which they are not ideally suited.

---

**Two Important Restrictions**

There are two restrictions that apply to enumerations. First, an enumeration can’t inherit another class. Second, an **enum** cannot be a superclass. This means that an **enum** can’t be extended. Otherwise, **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.

**Enumerations Inherit Enum**

Although you can’t inherit a superclass when declaring an **enum**, all enumerations automatically inherit one: **java.lang.Enum**. This class defines several methods that are available for use by all enumerations. Most often, you won’t need to use these methods, but there are two that you may occasionally employ: **ordinal()** and **compareTo()**.

The **ordinal()** method obtains a value that indicates an enumeration constant’s position in the list of constants. This is called its **ordinal value**. The **ordinal()** method is shown here:

```java
final int ordinal()
```
It returns the ordinal value of the invoking constant. Ordinal values begin at zero. Thus, in the `Transport` enumeration, `CAR` has an ordinal value of zero, `TRUCK` has an ordinal value of 1, `AIRPLANE` 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.

The following program demonstrates `ordinal()` and `compareTo()`:

```java
// Demonstrate ordinal() and compareTo().

// An enumeration of Transport varieties.
enum Transport {
    CAR, TRUCK, AIRPLANE, TRAIN, BOAT
}

class EnumDemo4 {
    public static void main(String args[])
    {
        Transport tp, tp2, tp3;

        // Obtain all ordinal values using ordinal().
        System.out.println("Here are all Transport constants + " + " and their ordinal values: ");
        for(Transport t : Transport.values())
            System.out.println(t + " " + t.ordinal()); // Obtain ordinal values.

        tp = Transport.AIRPLANE;
        tp2 = Transport.TRAIN;
        tp3 = Transport.AIRPLANE;

        System.out.println();

        // Demonstrate compareTo()
        if(tp.compareTo(tp2) < 0) System.out.println(tp + " comes before " + tp2);
        if(tp.compareTo(tp2) > 0) System.out.println(tp2 + " comes before " + tp);
        if(tp.compareTo(tp3) == 0) System.out.println(tp + " equals " + tp3);
    }
}
```

The output from the program is shown here:
Enumerations are particularly useful when your program needs a set of constants, but the actual values of the constants are arbitrary, as long as all differ. This type of situation comes up quite often when programming. One common instance involves handling the states in which some device can exist. For example, imagine that you are writing a program that controls a traffic light. Your traffic light code must automatically cycle through the light’s three states: green, yellow, and red. It also must enable other code to know the current color of the light and let the color of the light be set to a known initial value. This means that the three states must be represented in some way. Although it would be possible to represent these three states by integer values (for example, the values 1, 2, and 3) or by strings (such as "red", "green", and "yellow"), an enumeration offers a much better approach. Using an enumeration results in code that is more efficient than if strings represented the states and more structured than if integers represented the states.

In this project, you will create a simulation of an automated traffic light, as just described. This project not only demonstrates an enumeration in action, it also shows another example of multithreading and synchronization.

1. Create a file called `TrafficLightDemo.java`.
2. Begin by defining an enumeration called `TrafficLightColor` that represents the three states of the light, as shown here:
   ```java
   // An enumeration of the colors of a traffic light.
   enum TrafficLightColor {
       RED, GREEN, YELLOW
   }
   ```
   Whenever the color of the light is needed, its enumeration value is used.
3. Next, begin defining `TrafficLightSimulator`, as shown next. `TrafficLightSimulator` is the class that encapsulates the traffic light simulation.
Notice that TrafficLightSimulator implements Runnable. This is necessary because a separate thread is used to run each traffic light. This thread will cycle through the colors. Two constructors are created. The first lets you specify the initial light color. The second defaults to red. Both start a new thread to run the light.

Now look at the instance variables. A reference to the traffic light thread is stored in thrd. The current traffic light color is stored in tlc. The stop variable is used to stop the simulation. It is initially set to false. The light will run until this variable is set to true. The changed variable is true when the light has changed.

4. Next, add the run() method, shown here, which begins running the traffic light:
This method cycles the light through the colors. First, it sleeps an appropriate amount of time, based on the current color. Then, it calls \texttt{changeColor()} to change to the next color in the sequence.

5. Now, add the \texttt{changeColor()} method, as shown here:

```java
// Change color.
synchronized void changeColor() {
    switch(tlc) {
        case RED:
            tlc = TrafficLightColor.GREEN;
            break;
        case YELLOW:
            tlc = TrafficLightColor.RED;
            break;
        case GREEN:
            tlc = TrafficLightColor.YELLOW;
    }

    changed = true;
    notify(); // signal that the light has changed
}
```

The \texttt{switch} statement examines the color currently stored in \texttt{tlc} and then assigns the next color in the sequence. Notice that this method is synchronized. This is necessary because it calls \texttt{notify()} to signal that a color change has taken place. (Recall that \texttt{notify()} can be called only from a synchronized context.)
6. The next method is `waitForChange( )`, which waits until the color of the light is changed.

```java
// Wait until a light change occurs. 
 synchronized void waitForChange() {
    try {
        while(!changed)
            wait(); // wait for light to change
        changed = false;
    } catch(InterruptedException exc) {
        System.out.println(exc);
    }
}
```

This method simply calls `wait( )`. This call won’t return until `changeColor( )` executes a call to `notify( )`. Thus, `waitForChange( )` won’t return until the color has changed.

7. Finally, add the methods `getColor( )`, which returns the current light color, and `cancel( )`, which stops the traffic light thread by setting `stop` to `true`. These methods are shown here:

```java
// Return current color. 
 synchronized TrafficLightColor getColor() {
    return tlc;
}

// Stop the traffic light. 
 synchronized void cancel() {
    stop = true;
}
```

8. Here is all the code assembled into a complete program that demonstrates the traffic light:

```java
// Try This 12-1

// A simulation of a traffic light that uses
// an enumeration to describe the light’s color.
```
// An enumeration of the colors of a traffic light.
enum TrafficLightColor {
    RED, GREEN, YELLOW
}

// A computerized traffic light.
class TrafficLightSimulator implements Runnable {
    private Thread thrd; // holds the thread that runs the simulation
    private TrafficLightColor tlc; // holds the traffic light color
    boolean stop = false; // set to true to stop the simulation
    boolean changed = false; // true when the light has changed

    TrafficLightSimulator(TrafficLightColor init) {
        tlc = init;

        thrd = new Thread(this);
        thrd.start();
    }

    TrafficLightSimulator() {
        tlc = TrafficLightColor.RED;

        thrd = new Thread(this);
        thrd.start();
    }

    // Start up the light.
    public void run() {
        while(!stop) {
            try {
                switch(tlc) {
                    case GREEN:
                        Thread.sleep(10000); // green for 10 seconds
                        break;
                    case YELLOW:
                        Thread.sleep(2000); // yellow for 2 seconds
                        break;
                    case RED:
                        Thread.sleep(12000); // red for 12 seconds
                        break;
                }
            } catch(InterruptedException exc) {
                System.out.println(exc);
            }
            changeColor();
        }
    }
}
The following output is produced. As you can see, the traffic light cycles through the colors in order of green, yellow, and red:
In the program, notice how the use of the enumeration simplifies and adds structure to the code that needs to know the state of the traffic light. Because the light can have only three states (red, green, or yellow), the use of an enumeration ensures that only these values are valid, thus preventing accidental misuse.

9. It is possible to improve the preceding program by taking advantage of the class capabilities of an enumeration. For example, by adding a constructor, instance variable, and method to `TrafficLightColor`, you can substantially improve the preceding programming. This improvement is left as an exercise. See Self Test, question 4.

---

**Autoboxing**

Beginning with JDK 5, Java has included two very helpful features: *autoboxing* and *auto-unboxing*. Autoboxing/unboxing greatly simplifies and streamlines code that must convert primitive types into objects, and vice versa. Because such situations are found frequently in Java code, the benefits of autoboxing/unboxing affect nearly all Java programmers. As you will see in Chapter 13, autoboxing/unboxing also contributes greatly to the usability of generics.

Autoboxing/unboxing is directly related to Java’s type wrappers, and to the way that values are moved into and out of an instance of a wrapper. For this reason, we will begin with an overview of the type wrappers and the process of manually boxing and unboxing values.

**Type Wrappers**

As you know, Java uses primitive 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 basic types 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 were introduced briefly in Chapter 10. Here, we will look at them more closely.

The type wrappers are `Double`, `Float`, `Long`, `Integer`, `Short`, `Byte`, `Character`, and `Boolean`. 
which are packaged in `java.lang`. These classes offer a wide array of methods that allow you to fully integrate the primitive types into Java’s object hierarchy.

Probably 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 numeric types. 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` and `Double`:

```java
Integer(int num)
Integer(String str) throws NumberFormatException
Double(double num)
Double(String str) throws NumberFormatException
```

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 process of encapsulating a value within an object is called `
boxing`
. Prior to JDK 5, all boxing took place manually, with the programmer explicitly constructing an instance of a wrapper with the desired value. For example, this line manually boxes the value 100 into an `Integer`:

```java
Integer iOb = new Integer(100);
```

In this example, a new `Integer` object with the value 100 is explicitly created and a reference to this object is assigned to `iOb`.

The process of extracting a value from a type wrapper is called `
unboxing`
. Again, prior to JDK 5,
all unboxing also took place manually, with the programmer explicitly calling a method on the wrapper to obtain its value. For example, this manually unboxes the value in `iOb` into an `int`.

```java
int i = iOb.intValue();
```

Here, `intValue()` returns the value encapsulated within `iOb` as an `int`. The following program demonstrates the preceding concepts:

```java
// Demonstrate manual boxing and unboxing with a type wrapper.
class Wrap {
    public static void main(String args[]) {
        Integer iOb = new Integer(100); // Manually box the value 100.
        int i = iOb.intValue(); // Manually unbox the value in iOb.
        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`. Finally, it displays the values of `i` and `iOb`, both of which are 100.

The same general procedure used by the preceding example to manually box and unbox values was required by all versions of Java prior to JDK 5 and may still be found in legacy code. The problem is that it is both tedious and error-prone because it requires the programmer to manually create the appropriate object to wrap a value and to explicitly obtain the proper primitive type when its value is needed. Fortunately, autoboxing/unboxing fundamentally improves on these essential procedures.

**Autoboxing Fundamentals**

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. With autoboxing it is not 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:

```java
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:
Java handles the details for you.

The following program demonstrates the preceding statements:

```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, and 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 the following:
This program displays the following result:

m() received 199
Return value from m2() is 10
Return value from m3() is 99
Square root of iOb is 10.0

In the program, notice that m() specifies an Integer parameter. Inside main(), m() is passed the int value 199. Because m() is expecting an Integer, this value is automatically boxed. Next, m2() is called. It returns the int value 10. This int value is assigned to iOb in main(). Because iOb is an Integer, the value returned by m2() is autoboxed. Next, m3() is called. It returns an Integer that is
Auto-unboxed into an `int`. Finally, `Math.sqrt()` is called with `iOb` as an argument. In this case, `iOb` is auto-unboxed and its value promoted to `double`, since that is the type expected by `Math.sqrt()`.

**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:

```java
class AutoBox3 {
    public static void main(String args[]) {
        Integer iOb, iOb2;
        int i;
        
        iOb = 99;
        System.out.println("Original value of iOb: "+iOb);
        
        // The following automatically unboxes iOb,
        // performs the increment, and then reboxes
        // the result back into iOb.
        ++iOb;
        System.out.println("After ++iOb: "+iOb);
        
        // Here, iOb is unboxed, its value is increased by 10,
        // and the result is boxed and stored back in iOb.
        iOb += 10;
        System.out.println("After iOb += 10: "+iOb);
        
        // Here, iOb is unboxed, the expression is
        // evaluated, and the result is reboxed and
        // assigned to iOb2.
        iOb2 = iOb + (iOb / 3);
        System.out.println("iOb2 after expression: "+iOb2);
        
        // The same expression is evaluated, but the
        // result is not reboxed.
        i = iOb + (iOb / 3);
        System.out.println("i after expression: "+i);
    }
}
```

The output is shown here:

```
Original value of iOb: 99
After ++iOb: 100
After iOb += 10: 110
iOb2 after expression: 146
i after expression: 146
```

In the program, pay special attention to this line:

```
++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.

Because of auto-unboxing, you can use integer numeric objects, such as an Integer, 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. With early versions of Java, such code would have involved casts and calls to methods such as intValue( ).

**A Word of Warning**

Because of autoboxing and auto-unboxing, one might be tempted to use objects such as Integer or 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 = 10.2;
b = 11.4;
c = 9.8;
Double avg = (a + b + c) / 3;
```

In this example, objects of type Double hold values, which are then averaged and the result assigned to another Double object. 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 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.

**Static Import**

Java supports an expanded use 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. This is called
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 solutions to a quadratic equation, which has this form:

\[ ax^2 + bx + c = 0 \]

The program 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.

```java
// Find the solutions to a quadratic equation.
class Quadratic {
    public static void main(String args[]) {
        // a, b, and c represent the coefficients in the
        // quadratic equation: ax^2 + bx + c = 0
        double a, b, c, x;

        // Solve 4x^2 + x - 3 = 0 for x.
        a = 4;
        b = 1;
        c = -3;

        // Find first solution.
        x = (-b + Math.sqrt(Math.pow(b, 2) - 4 * a * c)) / (2 * a);
        System.out.println("First solution: " + x);

        // Find second solution.
        x = (-b - Math.sqrt(Math.pow(b, 2) - 4 * a * c)) / (2 * a);
        System.out.println("Second solution: " + x);
    }
}
```

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 expression:

\[ x = (-b + \text{Math.sqrt(} \text{Math.pow(b, 2) - 4 \times a \times c)\text{)} / (2 \times a); \]

Furthermore, 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()) are used can become 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:
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 its class name. Therefore, the expression can more conveniently be specified, as shown here:

```
x = (-b + sqrt(pow(b, 2) - 4 * a * c)) / (2 * a);
```

As you can see, this form is considerably shorter and easier to read.

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. Its general form is shown here:

```
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:
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.Math.*;
```

After this statement, you can output to the console without having to qualify `out` with `System`, as shown here:

```java
System.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`.

As convenient as static import can be, it is important not to abuse it. Remember, one 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 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.

---

**Ask the Expert**

**Q**: Using static import, can I import the static members of classes that I create?

**A**: Yes, you can use static import to import the static members of classes and interfaces you create. Doing so is especially convenient when you define several static members that are used frequently throughout a large program. For example, if a class defines a number of `static final` constants that define various limits, then using static import to bring them into view will save you a lot of tedious typing.

---

**Annotations (Metadata)**

Java provides 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. 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, by the compiler, or by a deployment tool. The term *metadata* is also used to refer to this feature, but the term annotation is the most descriptive, and more commonly used.

Annotation is a large and sophisticated topic, and it is far beyond the scope of this book to cover it...
in detail. However, an overview is given here so that you will be familiar with the concept.

**NOTE**


An annotation is created through a mechanism based on the `interface`. Here is a simple example:

```java
// A simple annotation type.
@interface MyAnno {
    String str();
    int val();
}
```

This declares an annotation called `MyAnno`. 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.

All annotation types automatically extend the `Annotation` interface. Thus, `Annotation` is a superinterface of all annotations. It is declared within the `java.lang.annotation` package.

Originally, annotations were used to annotate only declarations. In this usage, 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 such cases, the annotation precedes the rest of the declaration. Beginning with JDK 8, you can also annotate a `type use`, such as a cast or a method return type.

When you apply an annotation, you give values to its members. For example, here is an example of `MyAnno` being applied to a method:

```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.

Annotations that don’t have parameters are called *marker annotations*. These are specified without passing any arguments and without using parentheses. Their sole purpose is to mark an item with some attribute.

Java defines many built-in annotations. Most are specialized, but nine are general purpose. Four are imported from `java.lang.annotation`: `@Retention`, `@Documented`, `@Target`, and `@Inherited`. Five, `@Override`, `@Deprecated`, `@SafeVarargs`, `@FunctionalInterface`, and `@SuppressWarnings`, are included in `java.lang`. These are shown in Table 12-1.
Table 12-1  The General Purpose Built-in Annotations

<table>
<thead>
<tr>
<th>Annotation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>@Retention</td>
<td>Specifies the retention policy that will be associated with the annotation. The retention policy determines how long an annotation is present during the compilation and deployment process.</td>
</tr>
<tr>
<td>@Documented</td>
<td>A marker annotation 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.</td>
</tr>
<tr>
<td>@Target</td>
<td>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. <strong>@Target</strong> takes one argument, which must be a constant or array of constants from the <strong>ElementType</strong> enumeration, which defines various constants, such as <strong>CONSTRUCTOR, FIELD, and METHOD</strong>. The argument determines the types of items to which the annotation can be applied. If <strong>@Target</strong> is not specified, the annotation can be used on any declaration.</td>
</tr>
<tr>
<td>@Inherited</td>
<td>A marker annotation that causes the annotation for a superclass to be inherited by a subclass.</td>
</tr>
<tr>
<td>@Override</td>
<td>A method annotated with <strong>@Override</strong> 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. This is a marker annotation.</td>
</tr>
<tr>
<td>@Deprecated</td>
<td>A marker annotation that indicates that a declaration is obsolete and has been replaced by a newer form.</td>
</tr>
<tr>
<td>@SafeVarargs</td>
<td>A marker annotation that indicates that no unsafe actions related to a varargs parameter in a method or constructor occur. Can be applied only to static or final methods or constructors.</td>
</tr>
<tr>
<td>@SuppressWarnings</td>
<td>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.</td>
</tr>
<tr>
<td>@FunctionalInterface</td>
<td>A marker annotation that is used to annotate an interface declaration. It indicates that the annotated interface is a <strong>functional interface</strong>, which is an interface that contains one and only one abstract method. Functional interfaces are used by lambda expressions. (See Chapter 14 for details on functional interfaces.) It is important to understand that <strong>@FunctionalInterface</strong> is purely informational. Any interface with exactly one abstract method is, by definition, a functional interface.</td>
</tr>
</tbody>
</table>

**NOTE**

To **java.lang.annotation**, JDK 8 adds the annotations **@Repeatable** and **@Native**. **@Repeatable** supports repeatable annotations, which are annotations that can be applied more than once to a single item. **@Native** is used to annotate a constant field accessed by executable (i.e., native) code. Both are special-use annotations that are beyond the scope of this book.

Here is an example that uses **@Deprecated** to mark the **MyClass** class and the **getMsg()** method. When you try to compile this program, warnings will report the use of these deprecated elements.
Chapter 12 Self Test

1. Enumeration constants are said to be *self-typed*. What does this mean?

2. What class do all enumerations automatically inherit?

3. Given the following enumeration, write a program that uses `values()` to show a list of the constants and their ordinal values.

```java
enum Tools {
    SCREWDRIVER, WRENCH, HAMMER, PLIERS
}
```

4. The traffic light simulation developed in *Try This 12-1* can be improved with a few simple changes that take advantage of an enumeration’s class features. In the version shown, the duration of each color was controlled by the `TrafficLightSimulator` class by hard-coding these values into the `run()` method. Change this so that the duration of each color is stored by the constants in the `TrafficLightColor` enumeration. To do this, you will need to add a constructor, a private instance variable, and a method called `getDelay()`.

After making these changes, what
improvements do you see? On your own, can you think of other improvements? (Hint: Try using ordinal values to switch light colors rather than relying on a switch statement.)

5. Define boxing and unboxing. How does autoboxing/unboxing affect these actions?

6. Change the following fragment so that it uses autoboxing.
   ```java
   Short val = new Short(123);
   ```

7. In your own words, what does static import do?

8. What does this statement do?
   ```java
   import static java.lang.Integer.parseInt;
   ```

9. Is static import designed for special-case situations, or is it good practice to bring all static members of all classes into view?

10. An annotation is syntactically based on a/an ________________.

11. What is a marker annotation?

12. An annotation can be applied only to methods. True or False?
Chapter 13
Generics

Key Skills & Concepts
- Understand the benefits of generics
- Create a generic class
- Apply bounded type parameters
- Use wildcard arguments
- Apply bounded wildcards
- Create a generic method
- Create a generic constructor
- Create a generic interface
- Utilize raw types
- Apply type inference with the diamond operator
- Understand erasure
- Avoid ambiguity errors
- Know generics restrictions

Since its original 1.0 version, many new features have been added to Java. All have enhanced and
expanded the scope of the language, but one that has had an especially profound and far-reaching impact is generics because its effects were felt throughout the entire Java language. For example, generics added a completely new syntax element and caused changes to many of the classes and methods in the core API. It is not an overstatement to say that the inclusion of generics fundamentally reshaped the character of Java.

The topic of generics is quite large, and some of it is sufficiently advanced to be beyond the scope of this book. However, a basic understanding of generics is necessary for all Java programmers. At first glance, the generics syntax may look a bit intimidating, but don’t worry. Generics are surprisingly simple to use. By the time you finish this chapter, you will have a grasp of the key concepts that underlie generics and sufficient knowledge to use generics effectively in your own programs.

Generics Fundamentals

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. A class, interface, or method that operates on a type parameter is called generic, as in generic class or generic method.

Ask the Expert

Q: I have heard that Java’s generics are similar to templates in C++. Is this the case?

A: Java generics are similar to templates in C++. What Java calls a parameterized type, C++ calls a template. However, Java generics and C++ templates are not the same, and there are some fundamental differences between the two approaches to generic types. For the most part, Java’s approach is simpler to use.

A word of warning: If you have a background in C++, it is important not to jump to conclusions about how generics work in Java. The two approaches to generic code differ in subtle but fundamental ways.

A principal advantage of generic code is that it will automatically work with the type of data passed to its type parameter. Many algorithms are logically the same no matter what type of data they are being applied to. For example, a Quicksort is the same whether it is sorting 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.

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 of object. Thus, in pre-generics code, generalized classes, interfaces, and methods used Object references to operate on various types of data. The problem was that they could not do so with type safety because casts were
needed to explicitly convert from **Object** to the actual type of data being operated upon. Thus, it was possible to accidentally create type mismatches. Generics add the type safety that was lacking because they make these casts automatic and implicit. In short, generics expand your ability to reuse code and let you do so safely and reliably.

**A Simple Generics Example**

Before discussing any more theory, it’s best to look at a simple generics example. 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
```

Declare a generic class. T is the
generic type parameter.
The output produced by the program is shown here:
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.

In the declaration of `Gen`, there is no special significance to the name `T`. Any valid identifier could have been used, but `T` is traditional. Furthermore, it is recommended that type parameter names be single-character, capital letters. Other commonly used type parameter names are `V` and `E`.

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 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`. It does this by calling `getName()` on the `Class` object returned by the call to `getClass()` on `ob`. We haven't used this feature before, so let's examine it closely. As you should recall from Chapter 7, the `Object` class defines the method `getClass()`. Thus, `getClass()` is a member of all class types. It returns a `Class` object that corresponds to the class type of the object on which it is called. `Class` is a class defined within `java.lang` that

```java
Type of T is java.lang.Integer
value: 88

Type of T is java.lang.String
value: Generics Test
```
encapsulates information about a class. **Class** defines several methods that can be used to obtain information about a class at run time. Among these is 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:

```java
Gen<Integer> iOb;
```

Look carefully 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** was 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*, which is discussed later in this chapter.

The next line assigns to **iOb** a reference to an instance of an **Integer** version of the **Gen** class.

```java
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:

```java
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 of checking is one of the main benefits of generics because it ensures type safety.

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 auto-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`.

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 `T`. 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 arguments differ. This is part of the way that generics add type safety and prevent errors.

### 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:
The output from this program is shown here:

Type of T is java.lang.Integer
Type of V is java.lang.String
value: 88
value: Generics

Notice how TwoGen is declared:

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:

```
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:

```
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 creating a generic instance:

```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 stores a numeric value and is capable of performing various mathematical functions, such as computing the reciprocal or obtaining the fractional component. Furthermore, you want to use the class to compute these quantities for 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:
Unfortunately, **NumericFns** will not compile as written because both methods will generate compile-time errors. First, examine the **reciprocal( )** method, which attempts to return the reciprocal of **num**. To do this, it must divide 1 by the value of **num**. The value of **num** is obtained by calling **doubleValue( )**, which obtains the **double** version of the numeric object stored in **num**. 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 **NumericFns** objects using only numeric types. Thus, when you try to compile **NumericFns**, an error is reported that indicates that the **doubleValue( )** method is unknown. The same type of error occurs twice in **fraction( )**, which needs to call both **doubleValue( )** and **intValue( )**. Both calls result in error messages stating that these methods are 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:

```
<T extends superclass>
```
This specifies that \( T \) can be replaced only by \textit{superclass}, or subclasses of \textit{superclass}. Thus, \textit{superclass} defines an inclusive, upper limit.

You can use an upper bound to fix the \textbf{NumericFns} class shown earlier by specifying \textbf{Number} as an upper bound, as shown here:

```java
// In this version of NumericFns, the type argument // for T must be either Number, or a class derived // from Number.
class NumericFns<T extends Number> {  
    T num;

    // Pass the constructor a reference to // a numeric object.
    NumericFns(T n) {
        num = n;
    }

    // Return the reciprocal.
    double reciprocal() {
        return 1 / num.doubleValue();
    }

    // Return the fractional component.
    double fraction() {
        return num.doubleValue() - num.intValue();
    }

    // ...
}

// Demonstrate NumericFns.
class BoundsDemo {
    public static void main(String args[]) {
        NumericFns<Integer> iOb = new NumericFns<Integer>(5);  
        Integer is OK because it is a subclass of Number.
    }
}
Notice how `NumericFns` is now declared by this line:

```java
class NumericFns<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 `NumericFns` objects from being created. For example, if you remove the comments from the lines at the end of the program, and then try re-compiling, you will receive compile-time errors because `String` is not a subclass of `Number`.

Bounded types are especially useful when you need to ensure that one type parameter is compatible with another. For example, consider the following class called `Pair`, which stores two objects that must be compatible with each other:
Notice that `Pair` uses two type parameters, `T` and `V`, and that `V` extends `T`. This means that `V` will either be the same as `T` or a subclass of `T`. This ensures that the two arguments to `Pair`’s constructor will be objects of the same type or of related types. For example, the following constructions are valid:

```java
// This is OK because both T and V are Integer.
Pair<Integer, Integer> x = new Pair<Integer, Integer>(1, 2);

// This is OK because Integer is a subclass of Number.
Pair<Number, Integer> y = new Pair<Number, Integer>(10.4, 12);
```

However, the following is invalid:

```java
// This causes an error because String is not a subclass of Number
Pair<Number, String> z = new Pair<Number, String>(10.4, "12");
```

In this case, `String` is not a subclass of `Number`, which violates the bound specified by `Pair`.

### Using Wildcard Arguments

As useful as type safety is, sometimes it can get in the way of perfectly acceptable constructs. For example, given the `NumericFns` class shown at the end of the preceding section, assume that you want to add a method called `absEqual( )` that returns true if two `NumericFns` objects contain numbers whose absolute values are the same. Furthermore, you want this method to be able to work properly no matter what type of number each object holds. For example, if one object contains the `Double` value 1.25 and the other object contains the `Float` value –1.25, then `absEqual( )` would return true. One way to implement `absEqual( )` is to pass it a `NumericFns` argument, and then compare the absolute value of that argument against the absolute value of the invoking object, returning true only if the values are the same. For example, you want to be able to call `absEqual( )`, as shown here:

```java
NumericFns<Double> dOb = new NumericFns<Double>(1.25);
NumericFns<Float> fOb = new NumericFns<Float>(-1.25);

if(dOb.absEqual(fOb))
    System.out.println("Absolute values are the same.");
else
    System.out.println("Absolute values differ.");
```
At first, creating `absEqual()` seems like an easy task. Unfortunately, trouble starts as soon as you try to declare a parameter of type `NumericFns`. What type do you specify for `NumericFns`’ type parameter? At first, you might think of a solution like this, in which `T` is used as the type parameter:

```java
// This won't work!
// Determine if the absolute values of two objects are the same.
boolean absEqual(NumericFns<T> ob) {
    if(Math.abs(num.doubleValue()) ==
        Math.abs(ob.num.doubleValue())) return true;

    return false;
}
```

Here, the standard method `Math.abs()` is used to obtain the absolute value of each number, and then the values are compared. The trouble with this attempt is that it will work only with other `NumericFns` objects whose type is the same as the invoking object. For example, if the invoking object is of type `NumericFns<Integer>`, then the parameter `ob` must also be of type `NumericFns<Integer>`. It can’t be used to compare an object of type `NumericFns<Double>`, for example. Therefore, this approach does not yield a general (i.e., generic) solution.

To create a generic `absEqual()` 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 `absEqual()` method:

```java
// Determine if the absolute values of two objects are the same.
// objects are the same.
boolean absEqual(NumericFns<?> ob) {
    if(Math.abs(num.doubleValue()) ==
        Math.abs(ob.num.doubleValue())) return true;

    return false;
}
```

Here, `NumericFns<?>` matches any type of `NumericFns` object, allowing any two `NumericFns` objects to have their absolute values compared. The following program demonstrates this:

```java
// Use a wildcard.
class NumericFns<T extends Number> {
    T num;

    // Pass the constructor a reference to
    // a numeric object.
    NumericFns(T n) {
        num = n;
    }

    // Return the reciprocal.
    double reciprocal() {
```
In the program, notice these two calls to `absEqual()`:

```java
// Return the fractional component.
double fraction() {
    return num.doubleValue() - num.intValue();
}

// Determine if the absolute values of two
// objects are the same.
boolean absEqual(NumericFns<? super Number> ob) {
    if (Math.abs(num.doubleValue()) ==
        Math.abs(ob.num.doubleValue())) return true;
    return false;
}

// Demonstrate a wildcard.
class WildcardDemo {
    public static void main(String args[]) {
        NumericFns<Integer> iOb =
            new NumericFns<Integer>(6);
        NumericFns<Double> dOb =
            new NumericFns<Double>(-6.0);
        NumericFns<Long> lOb =
            new NumericFns<Long>(5L);
        System.out.println("Testing iOb and dOb.");
        if(iOb.absEqual(dOb))
            System.out.println("Absolute values are equal.");
        else
            System.out.println("Absolute values differ.");
        System.out.println();
        System.out.println("Testing iOb and lOb.");
        if(iOb.absEqual(lOb))
            System.out.println("Absolute values are equal.");
        else
            System.out.println("Absolute values differ.");
    }
}
```

The output is shown here:

Testing iOb and dOb.
Absolute values are equal.

Testing iOb and lOb.
Absolute values differ.

In the program, notice these two calls to `absEqual()`:
In the first call, \texttt{iOb} is an object of type \texttt{NumericFns<Integer>} and \texttt{dOb} is an object of type \texttt{NumericFns<Double>}. However, through the use of a wildcard, it is possible for \texttt{iOb} to pass \texttt{dOb} in the call to \texttt{absEqual()}. The same applies to the second call, in which an object of type \texttt{NumericFns<Long>} is passed.

One last point: It is important to understand that the wildcard does not affect what type of \texttt{NumericFns} objects can be created. This is governed by the \texttt{extends} clause in the \texttt{NumericFns} declaration. The wildcard simply matches any \textit{valid} \texttt{NumericFns} object.

**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 method that is designed to operate only on objects that are subclasses of a specific superclass. To understand why, let's work through a simple example. Consider the following set of classes:

```java
class A {
    // ...  
}

class B extends A {
    // ...  
}

class C extends A {
    // ...  
}

// Note that D does NOT extend A.
class D {
    // ...  
}
```

Here, class \texttt{A} is extended by classes \texttt{B} and \texttt{C}, but not by \texttt{D}.

Next, consider the following very simple generic class:

```java
// A simple generic class.
class Gen<T> {
    T ob;

    Gen(T o) {
        ob = o;
    }
}
```
Gen takes one type parameter, which specifies the type of object stored in \( \text{ob} \). Because \( T \) is unbounded, the type of \( T \) is unrestricted. That is, \( T \) can be of any class type.

Now, suppose that you want to create a method that takes as an argument any type of Gen object so long as its type parameter is \( A \) or a subclass of \( A \). In other words, you want to create a method that operates only on objects of Gen<type>, where type is either \( A \) or a subclass of \( A \). To accomplish this, you must use a bounded wildcard. For example, here is a method called test() that accepts as an argument only Gen objects whose type parameter is \( A \) or a subclass of \( A \):

```java
// Here, the ? will match A or any class type
// that extends A.
static void test(Gen<? extends A> o) {
    // ...
}
```

The following class demonstrates the types of Gen objects that can be passed to test( ).

```java
class UseBoundedWildcard {
    // Here, the ? will match A or any class type
    // that extends A.
    static void test(Gen<? extends A> o) {
        // ...
    }

    public static void main(String args[]) {
        A a = new A();
        B b = new B();
        C c = new C();
        D d = new D();

        Gen<A> w = new Gen<A>(a);
        Gen<B> w2 = new Gen<B>(b);
        Gen<C> w3 = new Gen<C>(c);
        Gen<D> w4 = new Gen<D>(d);

        // These calls to test() are OK.
        test(w);
        test(w2);
        test(w3);  // These are legal because w, w2, and w3 are subclasses of A.

        // Can't call test() with w4 because
        // it is not an object of a class that
        // inherits A.
        test(w4);  // Error! This is illegal because w4 is not a subclass of A.
    }
}
```

In main( ), objects of type \( A, B, C, \) and \( D \) are created. These are then used to create four Gen objects, one for each type. Finally, four calls to test( ) are made, with the last call commented out. The first three calls are valid because \( w, w2, \) and \( w3 \) are Gen objects whose type is either \( A \) or a subclass of \( A \). However, the last call to test( ) is illegal because \( w4 \) is an object of type \( D \), which is not derived from \( A \). Thus, the bounded wildcard in test( ) will not accept \( w4 \) as an argument.

In general, to establish an upper bound for a wildcard, use the following type of wildcard expression:
Ask the Expert

Q: Can I cast one instance of a generic class into another?

A: Yes, you can cast one instance of a generic class into another, but only if the two are otherwise compatible and their type arguments are the same. For example, assume a generic class called `Gen` that is declared like this:

```java
class Gen<T> { // ... 
Next, assume that `x` is declared as shown here:
```
```java
Gen<Integer> x = new Gen<Integer> ();
```
Then, this cast is legal
```java
(Gen<Integer>) x // legal
```
because `x` is an instance of `Gen<Integer>`. But, this cast
```java
(Gen<Long>) x // illegal
```
is not legal because `x` is not an instance of `Gen<Long>`.

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 (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:

```java
<? super subclass>
```
In this case, only classes that are superclasses of `subclass` are acceptable arguments. This is an inclusive clause.

Generic Methods

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 nongeneric class.

The following program declares a nongeneric class called `GenericMethodDemo` and a static
generic method within that class called **arraysEqual()**. This method determines if two arrays contain the same elements, in the same order. It can be used to compare any two arrays as long as the arrays are of the same or compatible types and the array elements are, themselves, comparable.

```java
// Demonstrate a simple generic method.
class GenericMethodDemo {

    // Determine if the contents of two arrays are the same.
    static <T extends Comparable<T>, V extends T> boolean arraysEqual(T[] x, V[] y) {
        // If array lengths differ, then the arrays differ.
        if(x.length != y.length) return false;

        for(int i=0; i < x.length; i++)
            if(!x[i].equals(y[i])) return false; // arrays differ

        return true; // contents of arrays are equivalent
    }

    public static void main(String args[]) {
        Integer nums[] = { 1, 2, 3, 4, 5 };           
        Integer nums2[] = { 1, 2, 3, 4, 5 };          
        Integer nums3[] = { 1, 2, 7, 4, 5 };          
        Integer nums4[] = { 1, 2, 7, 4, 5, 6 };       

        if(arraysEqual(nums, nums))
            System.out.println("nums equals nums");

        if(arraysEqual(nums, nums2))
            System.out.println("nums equals nums2");

        if(arraysEqual(nums, nums3))
            System.out.println("nums equals nums3");

        if(arraysEqual(nums, nums4))
            System.out.println("nums equals nums4");

        // Create an array of Doubles
        Double dvals[] = { 1.1, 2.2, 3.3, 4.4, 5.5 };  

        // This won't compile because nums and dvals are not of the same type.
        // if(arraysEqual(nums, dvals))
        // System.out.println("nums equals dvals");
    }
}
```

The output from the program is shown here:

```
nums equals nums
nums equals nums2
```

Let’s examine **arraysEqual()** closely. First, notice how it is declared by this line:

```java
static <T extends Comparable<T>, V extends T> boolean arraysEqual(T[] x, V[] y) {
```

The type parameters are declared before the return type of the method. Also note that **T** extends
Comparable<T> 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 arraysEqual() 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 be either the same as type T or a subclass of T. This relationship enforces that arraysEqual() can be called only with arguments that are comparable with each other. Also notice that arraysEqual() is static, enabling it to be called independently of any object. Understand, though, that generic methods can be either static or nonstatic. There is no restriction in this regard.

Now, notice how arraysEqual() 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(arraysEqual(nums, nums))
```

the element type of the first argument is Integer, which causes Integer to be substituted for T. The element type of the second argument is also Integer, which makes Integer a substitute for V, too. Thus, the call to arraysEqual() is legal, and the two arrays can be compared.

Now, notice the commented-out code, shown here:

```java
//    if(arraysEqual(nums, dvals))
//      System.out.println("nums equals dvals");
```

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 Integer, making T into Integer, but the second argument is of type Double, which is not a subclass of Integer. This makes the call to arraysEqual() illegal, and results in a compile-time type-mismatch error.

The syntax used to create arraysEqual() can be generalized. Here is the syntax for a generic method:

```java
<type-param-list> ret-type meth-name(param-list) { // …
```

In all cases, 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.

**Generic Constructors**

A constructor can be generic, even if its class is not. For example, in the following program, the class Summation is not generic, but its constructor is.
The **Summation** class computes and encapsulates the summation of the numeric value passed to its constructor. Recall that the summation of $N$ is the sum of all the whole numbers between 0 and $N$. Because **Summation**() specifies a type parameter that is bounded by **Number**, a **Summation** object can be constructed using any numeric type, including **Integer**, **Float**, or **Double**. No matter what numeric type is used, its value is converted to **Integer** by calling `intValue()` , and the summation is computed. Therefore, it is not necessary for the class **Summation** to be generic; only a generic constructor is needed.

### Generic Interfaces

As you saw in the **GenericMethodDemo** program presented earlier, an interface can be generic. In that example, the standard interface **Comparable<T>** was used to ensure that elements of two arrays could be compared. Of course, you can also define your own generic interface. Generic interfaces are specified just like generic classes. Here is an example. It creates an interface called **Containment**, which can be implemented by classes that store one or more values. It declares a method called `contains()` that determines if a specified value is contained by the invoking object.
Although most aspects of this program should be easy to understand, a couple of key points need to be made. First, notice that `Containment` is declared like this:

```
interface Containment<T> {

    // The contains() method tests if a specific item is contained within an object that implements Containment.
    boolean contains(T o);
}
```

Any class that implements a generic interface must itself be generic.
In general, a generic interface is declared in the same way as a generic class. In this case, the type parameter \( T \) specifies the type of objects that are contained.

Next, \textbf{Containment} is implemented by \textbf{MyClass}. Notice the declaration of \textbf{MyClass}, shown here:

```java
class MyClass\<T\> implements Containment\<T\> { }
```

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 \textbf{MyClass} is in error:

```java
class MyClass implements Containment\<T\> { // Wrong!
```

This declaration is wrong because \textbf{MyClass} does not declare a type parameter, which means that there is no way to pass one to \textbf{Containment}. In this case, the identifier \( T \) is simply unknown and the compiler reports an error. Of course, if a class implements a \textit{specific type} of generic interface, such as shown here:

```java
class MyClass implements Containment\<Double\> { // OK
```

then the implementing class does not need to be generic.

As you might expect, the type parameter(s) specified by a generic interface can be bounded. This lets you limit the type of data for which the interface can be implemented. For example, if you wanted to limit \textbf{Containment} to numeric types, then you could declare it like this:

```java
interface Containment\<T extends Number\> { }
```

Now, any implementing class must pass to \textbf{Containment} a type argument also having the same bound. For example, now \textbf{MyClass} must be declared as shown here:

```java
class MyClass\<T extends Number\> implements Containment\<T\> { }
```

Pay special attention to the way the type parameter \( T \) is declared by \textbf{MyClass} and then passed to \textbf{Containment}. Because \textbf{Containment} now requires a type that extends \textbf{Number}, the implementing class (\textbf{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 \textit{implements} clause. In fact, it would be wrong to do so. For example, this declaration is incorrect and won’t compile:

```java
// This is wrong!
class MyClass\<T extends Number\>
    implements Containment\<T extends Number\> { // Wrong!
```

Once the type parameter has been established, it is simply passed to the interface without further modification.

Here is the generalized syntax for a generic interface:

```java
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:

```java
class class-name<type-param-list>
    implements interface-name<type-param-list> {
```

**Try This 13-1 Create a Generic Queue**

One of the most powerful advantages that generics bring to programming is the ability to construct reliable, reusable code. As mentioned at the start of this chapter, many algorithms are the same no matter what type of data they are used on. For example, a queue works the same way whether that queue is for integers, strings, or *File* objects. Instead of creating a separate queue class for each type of object, you can craft a single, generic solution that can be used with any type of object. Thus, the development cycle of design, code, test, and debug occurs only once when you create a generic solution—not repeatedly, each time a queue is needed for a new data type.

In this project, you will adapt the queue example that has been evolving since Try This 5-2, making it generic. This project represents the final evolution of the queue. It includes a generic interface that defines the queue operations, two exception classes, and one queue implementation: a fixed-size queue. Of course, you can experiment with other types of generic queues, such as a generic dynamic queue or a generic circular queue. Just follow the lead of the example shown here.

Like the previous version of the queue shown in Try This 9-1, this project organizes the queue code into a set of separate files: one for the interface, one for each queue exception, one for the fixed-queue implementation, and one for the program that demonstrates it. This organization reflects the way that this project would normally be organized in the real world.

1. The first step in creating a generic queue is to create a generic interface that describes the queue’s two operations: put and get. The generic version of the queue interface is called *IGenQ* and it is shown here. Put this interface into a file called *IGenQ.java*.

   ```java
   // A generic queue interface.
   public interface IGenQ<T> {
       // Put an item into the queue.
       void put(T ch) throws QueueFullException;

       // Get an item from the queue.
       T get() throws QueueEmptyException;
   }
   ```

   Notice that the type of data stored by the queue is specified by the generic type parameter *T*. 

2. Next, create the files QueueFullException.java and QueueEmptyException.java. Put in each file its corresponding class, shown here:

```java
// An exception for queue-full errors.
public class QueueFullException extends Exception {
    int size;

    QueueFullException(int s) { size = s; }

    public String toString() {
        return "\nQueue is full. Maximum size is " +
        size;
    }
}

// An exception for queue-empty errors.
public class QueueEmptyException extends Exception {

    public String toString() {
        return "\nQueue is empty.";
    }
}
```

These classes encapsulate the two queue errors: full or empty. They are not generic classes because they are the same no matter what type of data is stored in a queue. Thus, these two files will be the same as those you used with Try This 9-1.

3. Now, create a file called GenQueue.java. Into that file, put the following code, which implements a fixed-size queue:
GenQueue is a generic class with type parameter T, which specifies the type of data stored in the queue. Notice that T is also passed to the IGenQ interface.

Notice that the GenQueue constructor is passed a reference to an array that will be used to hold the queue. Thus, to construct a GenQueue, you will first create an array whose type is compatible with the objects that you will be storing in the queue and whose size is long enough to store the number of objects that will be placed in the queue.

For example, the following sequence shows how to create a queue that holds strings:

```java
String strArray[] = new String[10];
GenQueue<String> strQ = new GenQueue<String>(strArray);
```

4. Create a file called GenQDemo.java and put the following code into it. This program demonstrates the generic queue.
Try This 13-1

Demonstrate a generic queue class.

*/
class GenQDemo {
    public static void main(String args[]) {
        // Create an integer queue.
        Integer iStore[] = new Integer[10];
        GenQueue<Integer> q = new GenQueue<Integer>(iStore);

        Integer iVal;

        System.out.println("Demonstrate a queue of Integers.");
        try {
            for(int i=0; i < 5; i++) {
                System.out.println("Adding " + i + " to q.");
                q.put(i); // add integer value to q
            }
        }
        catch (QueueFullException exc) {
            System.out.println(exc);
        }
        System.out.println();

        try {
            for(int i=0; i < 5; i++) {
                System.out.println("Getting next Integer from q: ");
                iVal = q.get();
                System.out.println(iVal);
            }
        }
        catch (QueueEmptyException exc) {
            System.out.println(exc);
        }
        System.out.println();

        // Create a Double queue.
        Double dStore[] = new Double[10];
        GenQueue<Double> q2 = new GenQueue<Double>(dStore);
Double dVal;

System.out.println("Demonstrate a queue of Doubles.");
try {
    for(int i=0; i < 5; i++) {
        System.out.println("Adding " + (double)i/2 + " to q2.");
        q2.put((double)i/2); // add double value to q2
    }
} 
catch (QueueFullException exc) {
    System.out.println(exc);
}
System.out.println();

try {
    for(int i=0; i < 5; i++) {
        System.out.print("Getting next Double from q2: ");
        dVal = q2.get();
        System.out.println(dVal);
    }
} 
catch (QueueEmptyException exc) {
    System.out.println(exc);
}
}

5. Compile the program and run it. You will see the output shown here:
6. On your own, try converting the `CircularQueue` and `DynQueue` classes from Try This 8-1 into generic classes.

**Raw Types and Legacy Code**

Because support for generics did not exist prior to JDK 5, it was necessary for Java to provide some transition path from old, pre-generics code. Simply put, pre-generics legacy code had to remain both functional and compatible with generics. This meant that 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:
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, in which 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:

```
//      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 `strOb` (a reference of type `Gen<String>`) a reference to a raw `Gen` object:

```
    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:

```
    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:

```
Gen raw = new Gen(new Double(98.6));
strOb = raw; // OK, but potentially wrong
```

In the first line, it is the use of `Gen` 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:

```
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
**Type Inference with the Diamond Operator**

Beginning with JDK 7, it is possible to shorten the syntax used to create an instance of a generic type. To begin, think back to the `TwoGen` class shown earlier in this chapter. A portion is shown here for convenience. Notice that it uses two generic types.

```java
class TwoGen<T, V> {
    T ob1;
    V ob2;

    // Pass the constructor a reference to
    // an object of type T.
    TwoGen(T o1, V o2) {
        ob1 = o1;
        ob2 = o2;
    }
    // ...
}
```

For versions of Java prior to JDK 7, to create an instance of `TwoGen`, you must use a statement similar to the following:

```java
TwoGen<Integer, String> tgOb =
    new TwoGen<Integer, String>(42, "testing");
```

Here, the type arguments (which are `Integer` and `String`) are specified twice: first, when `tgOb` is declared, and second, when a `TwoGen` 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. While there is nothing wrong, per se, with this form, it is a bit more verbose than it needs to be. Since, in the `new` clause, the type of the type arguments can be readily inferred, 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.

Beginning with JDK 7, the preceding declaration can be rewritten as shown here:

```java
TwoGen<Integer, String> tgOb =
    new TwoGen<>(42, "testing");
```

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. This is especially helpful for generic types that specify bounds.

The preceding example can be generalized. When type inference is used, the declaration syntax for a generic reference and instance creation has this general form:

```java
class-name?type-arg-list> var-name = new class-name<?>(cons-arg-list);
```
Here, the type argument list of the `new` clause is empty.

Although mostly for use in declaration statements, type inference can also be applied to parameter passing. For example, if the following method is added to `TwoGen`:

```java
boolean isSame(TwoGen<T, V> o) {
    if (oobl == o.obl && ob2 == o.ob2) return true;
    else return false;
}
```

then the following call is legal:

```java
if(tgOb.isSame(new TwoGen>(42, "testing"))) System.out.println("Same");
```

In this case, the type arguments for the arguments passed to `isSame( )` can be inferred from the parameters’ types. They don’t need to be specified again.

Because the diamond operator was added by JDK 7 and won’t work with older compilers, the remaining examples of generics 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 helpful when example code is shown. Of course, in your own code, the use of the type inference syntax will streamline your declarations.

**Erasure**

Usually, it is not necessary for the programmer 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 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, nongeneric 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 *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 `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.

**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:
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:

```java
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.

Second, and more fundamental, is that the type erasure of set() effectively reduces both versions to the following:

```java
void set(Object o) { // ...
}
```

Thus, the overloading of set() as attempted in MyGenClass is inherently ambiguous. The solution in this case is to use two separate method names rather than trying to overload set().

**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
// 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;
    }
}
```
Here, it is illegal to attempt to create an instance of \texttt{T}. The reason should be easy to understand: the compiler has no way to know what type of object to create. \texttt{T} is simply a placeholder.

**Restrictions on Static Members**

No \texttt{static} member can use a type parameter declared by the enclosing class. For example, both of the \texttt{static} members of this class are illegal:

```csharp
class Wrong\texttt{<T>} { 
    // Wrong, no static variables of type \texttt{T}.
    static \texttt{T} ob;

    // Wrong, no static method can use \texttt{T}.
    static \texttt{T} getob() {
        return ob;
    }
}
```

Although you can’t declare \texttt{static} members that use a type parameter declared by the enclosing class, you \texttt{can} declare \texttt{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:
As the program shows, it’s valid to declare a reference to an array of type \text{T}, as this line does:

\begin{verbatim}
T vals[]; // OK
\end{verbatim}

But, you cannot instantiate an array of \text{T}, as this commented-out line attempts:

\begin{verbatim}
// vals = new T[10]; // can't create an array of T
\end{verbatim}

The reason you can’t create an array of \text{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 \texttt{Gen( )} when an object is created and assign that reference to \texttt{vals}, as the program does in this line:

\begin{verbatim}
vals = nums; // OK to assign reference to existent array
\end{verbatim}

This works because the array passed to \texttt{Gen()} has a known type, which will be the same type as \text{T} at the time of object creation. Inside \texttt{main( )}, notice that you can’t declare an array of references to a specific generic type. That is, this line

\begin{verbatim}
// Gen<Integer> gens[] = new Gen<Integer>[10]; // Wrong!
\end{verbatim}

won’t compile.
Generic Exception Restriction
A generic class cannot extend Throwable. This means that you cannot create generic exception classes.

Continuing Your Study of Generics
As mentioned at the start, this chapter gives you sufficient knowledge to use generics effectively in your own programs. However, there are many side issues and special cases that are not covered here. Readers especially interested in generics will want to learn about how generics affect class hierarchies, run-time type comparisons, and overriding, for example. Discussions of these and other topics are found in my book Java: The Complete Reference, Ninth Edition (Oracle Press/McGraw-Hill Professional, 2014).

Chapter 13 Self Test

1. Generics are important to Java because they enable the creation of code that is
   A. Type-safe
   B. Reusable
   C. Reliable
   D. All of the above

2. Can a primitive type be used as a type argument?

3. Show how to declare a class called FlightSched that takes two generic parameters.

4. Beginning with your answer to question 3, change FlightSched’s second type parameter so that it must extend Thread.

5. Now, change FlightSched so that its second type parameter must be a subclass of its first type parameter.

6. As it relates to generics, what is the ? and what does it do?

7. Can the wildcard argument be bounded?

8. A generic method called MyGen() has one type parameter. Furthermore, MyGen() has one parameter whose type is that of the type parameter. It also returns an object of that type parameter. Show how to declare MyGen().

9. Given this generic interface
   ```java
   interface IGenIF<T, V extends T> { // ...
   show the declaration of a class called MyClass that implements IGenIF.
   ```

10. Given a generic class called Counter<T>, show how to create an object of its raw type.

11. Do type parameters exist at run time?

12. Convert your solution to question 10 of the Self Test for Chapter 9 so that it is generic. In the process, create a stack interface called IGenStack that generically defines the operations push(
13. What is `<>`?

14. How can the following be simplified?

```java
MyClass<Double, String> obj = new MyClass<Double, String>(1.1, "Hi");
```
Chapter 14
Lambda Expressions and Method References

Key Skills & Concepts
- Know the general form of a lambda expression
- Understand the definition of a functional interface
- Use expression lambdas
- Use block lambdas
- Use generic functional interfaces
- Understand variable capture in a lambda expression
- Throw an exception from a lambda expression
- Understand the method reference
- Understand the constructor reference
- Know about the predefined functional interfaces in \texttt{java.util.function}

With the release of JDK 8, a new feature has been added to Java that profoundly enhances the expressive power of the language. This feature is the \textit{lambda expression}. Not only do lambda expressions add new syntax elements to the language, they also streamline the way that certain common constructs are implemented. In much the same way that the addition of generics reshaped Java years ago, lambda expressions are reshaping Java today. They truly are that important.
The addition of lambda expressions have also provided the catalyst for other new Java features. You have already seen one of them—the default method—which was described in Chapter 8. It lets you define default behavior for an interface method. Another example is the method reference, described later in this chapter, which lets you refer to a method without executing it. Furthermore, the inclusion of lambda expressions resulted in new capabilities being incorporated into the API library.

Beyond the benefits that lambda expressions bring to the language, there is another reason why they constitute such 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 Java helps it remain the vibrant, innovative language that programmers have come to expect. This chapter presents an introduction to this exciting new feature.

Introducing Lambda Expressions
Key to understanding the lambda expression 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 a 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.

Let’s now look more closely at both lambda expressions and functional interfaces.

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.

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. On the right side is the lambda body, which specifies the actions of the lambda expression. Java defines two types of lambda bodies. One type 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.
At this point, it will be helpful to look at 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:

\[
() \rightarrow 98.6
\]

This lambda expression takes no parameters, thus the parameter list is empty. It returns the constant value 98.6. The return type is inferred to be `double`. Therefore, it is similar to the following method:

```java
double myMeth() { return 98.6; }
```

Of course, the method defined by a lambda expression does not have a name.

A slightly more interesting lambda expression is shown here:

\[
() \rightarrow Math.random() * 100
\]

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:

\[
(n) \rightarrow 1.0 / n
\]

This lambda expression returns the reciprocal of the value of parameter \(n\). Thus, if \(n\) is 4.0, the reciprocal is 0.25. Although it is possible to explicitly specify the type of a parameter, such as \(n\) in this case, often you won’t need to because, in many cases, its type can be inferred. Like a named method, a lambda expression can specify as many parameters as needed.

Any valid type can be used as the return type of a lambda expression. For example, this lambda expression returns `true` if the value of parameter \(n\) is even and `false` otherwise.

\[
(n) \rightarrow (n \% 2)==0
\]

Thus, the return type of this lambda expression is `boolean`.

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 just shown:

\[
n \rightarrow (n \% 2)==0
\]

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.

### Functional Interfaces

As stated, a functional interface is an interface that specifies only one abstract method. Before continuing, recall from Chapter 8 that not all interface methods are abstract. Beginning with JDK 8, it is possible for an interface to have one or more default methods. Default methods are not abstract. Neither are static interface methods. Thus, an interface method is abstract only if it is does not specify an implementation. This means that a functional interface can include default and/or static
methods, but in all cases it must have one and only one abstract method. Because non-default, non-static 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 MyValue {
    double getValue();
}
```

In this case, the method `getValue()` is implicitly abstract, and it is the only method defined by `MyValue`. Thus, `MyValue` 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 a simple example. First, a reference to the functional interface `MyValue` is declared:

```java
// Create a reference to a MyValue instance.
MyValue myVal;
```

Next, a lambda expression is assigned to that interface reference:

```java
// Use a lambda in an assignment context.
myVal = () -> 98.6;
```

This lambda expression is compatible with `getValue()` because, like `getValue()`, it has no parameters and returns a double result. In general, the type of the abstract method defined by the functional interface and the type of the lambda expression must be compatible. If they aren't, a compile-time error will result.

As you can probably guess, the two steps just shown can be combined into a single statement, if desired:

```java
MyValue myVal = () -> 98.6;
```

Here, `myVal` is initialized with the lambda expression.

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 98.6:
Because the lambda expression assigned to myVal returns the value 98.6, that is the value obtained when getValue() is called.

If the lambda expression takes one or more parameters, then the abstract method in the functional interface must also take the same number of parameters. For example, here is a functional interface called MyParamValue, which lets you pass a value to getValue():

```
interface MyParamValue {
    double getValue(double v);
}
```

You can use this interface to implement the reciprocal lambda shown in the previous section. For example:

```
MyParamValue myPval = (n) -> 1.0 / n;
```

You can then use myPval like this:

```
System.out.println("Reciprocal of 4 is " + myPval.getValue(4.0));
```

Here, getValue() is implemented by the lambda expression referred to by myPval, which returns the reciprocal of the argument. In this case, 4.0 is passed to getValue(), which returns 0.25.

There is something else of interest in the preceding example. 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 getValue() as defined by the MyParamValue interface, which is double. 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:

```
(double n) -> 1.0 / n;
```

Here, n is explicitly specified as double. Usually it is not necessary to explicitly specify the type.

Before moving on, it is important to emphasize a key point: 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 and its return type.

**Lambda Expressions in Action**

With the preceding discussion in mind, let’s look at some simple examples that put the basic lambda expression concepts into action. The first example assembles the pieces shown in the foregoing section into a complete program that you can run and experiment with.
Sample output from the program is shown here:

A constant value: 98.6
Reciprocal of 4 is 0.25
Reciprocal of 8 is 0.125

As mentioned, the lambda expression must be compatible with the abstract method that it is intended to implement. For this reason, the commented-out lines at the end of the preceding program are illegal. The first, because a value of type `String` is not compatible with `double`, which is the return type required by `getValue()`. The second, because `getValue(int)` in `MyParamValue` requires a parameter, and one is not provided.

A key aspect of a functional interface is that it can be used with any lambda expression that is compatible with it. For example, consider the following program. It defines a functional interface called `NumericTest` that declares the abstract method `test()`. This method has two `int` parameters and returns a `boolean` result. Its purpose is to determine if the two arguments passed to `test()` satisfy some condition. It returns the result of the test. In `main()`, three different tests are created through the
use of lambda expressions. One tests if the first argument can be evenly divided by the second; the second determines if the first argument is less than the second; and the third returns true if the absolute values of the arguments are equal. Notice that the lambda expressions that implement these tests have two parameters and return a boolean result. This is, of course, necessary since test( ) has two parameters and returns a boolean result.

```java
// Use the same functional interface with three different lambda expressions.

// A functional interface that takes two int parameters and returns
// a boolean result.
interface NumericTest {
    boolean test(int n, int m);
}

class LambdaDemo2 {
    public static void main(String args[])
    {
        // This lambda expression determines if one number is
        // a factor of another.
        NumericTest 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");
        System.out.println();

        // This lambda expression returns true if the first
        // argument is less than the second.
        NumericTest lessThan = (n, m) -> (n < m);
        if(lessThan.test(2, 10))
            System.out.println("2 is less than 10");
        if(!lessThan.test(10, 2))
            System.out.println("10 is not less than 2");
        System.out.println();

        // This lambda expression returns true if the absolute
        // values of the arguments are equal.
        NumericTest absEqual = (n, m) -> (n < 0 ? -n : n) == (m < 0 ? -m : m);
        if(absEqual.test(4, -4))
            System.out.println("Absolute values of 4 and -4 are equal.");
        if(!absEqual.test(4, -5))
            System.out.println("Absolute values of 4 and -5 are not equal.");
        System.out.println();
    }
}
```

The output is shown here:

2 is a factor of 10
3 is not a factor of 10

2 is less than 10
10 is not less than 2

Absolute values of 4 and -4 are equal.
Absolute values of 4 and -5 are not equal.
As the program illustrates, because all three lambda expressions are compatible with `test()`, all can be executed through a `NumericTest` reference. In fact, there is no need to use three separate `NumericTest` reference variables because the same one could have been used for all three tests. For example, you could create the variable `myTest` and then use it to refer to each test, in turn, as shown here:

```java
NumericTest myTest;

myTest = (n, d) -> (n % d) == 0;
if(myTest.test(10, 2))
    System.out.println("2 is a factor of 10");
// ... 
myTest = (n, m) -> (n < m);
if(myTest.test(2, 10))
    System.out.println("2 is less than 10");
// ... 
myTest = (n, m) -> (n < 0 ? -n : n) == (m < 0 ? -m : m);
if(myTest.test(4, -4))
    System.out.println("Absolute values of 4 and -4 are equal.");
// ...
```

Of course, using different reference variables called `isFactor`, `lessThan`, and `absEqual`, as the original program does, makes it very clear to which lambda expression each variable refers.

There is one other point of interest in the preceding program. Notice how the two parameters are specified for the lambda expressions. For example, here is the one that determines if one number is a factor of another:

```java
(n, d) -> (n % d) == 0
```

Notice that `n` and `d` are separated by commas. In general, 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.

Although the preceding examples used primitive values as the parameter types and return type of the abstract method defined by a functional interface, there is no restriction in this regard. For example, the following program declares a functional interface called `StringTest`. It has a method called `test()` that takes two `String` parameters and returns a `boolean` result. Thus, it can be used to test some condition related to strings. Here, a lambda expression is created that determines if one string is contained within another:

```java
StringTest myStringTest;

myStringTest = (s, t) -> t.contains(s);
if(myStringTest.test("Hello", "Hello World"))
    System.out.println("Hello contained in Hello World");
// ...
```
Notice that the lambda expression uses the `indexOf()` method defined by the `String` class to determine if one string is part of another. This works because the parameters `a` and `b` are determined by type inference to be of type `String`. Thus, it is permissible to call a `String` method on `a`.

**Ask the Expert**

**Q:** Earlier you mentioned that I can explicitly declare the type of a parameter in a lambda expression if needed. In cases in which a lambda expression requires two or more parameters, must I specify the types of all parameters, or can I let one or more use type inference?

**A:** In cases in which you need to explicitly declare the type of a parameter, then all of the...
parameters in the list must have declared types. For example, this is legal:

```java
(int n, int d) -> (n % d) == 0
```

But this is not legal:

```java
(int n, d) -> (n % d) == 0
```

Nor is this legal:

```java
(n, int 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, which becomes the lambda’s value. Although 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 find the smallest positive factor of an `int` value. It uses an interface called `NumericFunc` that has a method called `func()`, which takes one `int` argument and returns an `int` result. Thus, `NumericFunc` supports a numeric function on values of type `int`. 
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.

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. Earlier in this chapter, two different functional interfaces were created, one called NumericTest and the other called StringTest. They were used to determine if two values satisfied some condition. To do this, both defined a method called test() that took two parameters and returned a boolean result. In the case of NumericTest, the values being tested were integers. For StringTest, the values were of type String.
Thus, the only difference between the two methods was the type of data they operated on. Such a situation is perfect for generics. 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.

// A generic functional interface with two parameters
// that returns a boolean result.
interface SomeTest<T> { // A generic functional interface
    boolean test(T n, T m);
}

class GenericFunctionalInterfaceDemo {
    public static void main(String args[])
    {
        // This lambda expression determines if one integer is
        // a factor of another.
        SomeTest<Integer> isFactor = (n, d) -> (n % d) == 0;

        if(isFactor.test(10, 2))
            System.out.println("2 is a factor of 10");
        System.out.println();

        // The next lambda expression determines if one Double is
        // a factor of another.
        SomeTest<Double> isFactorD = (n, d) -> (n % d) == 0;

        if(isFactorD.test(212.0, 4.0))
            System.out.println("4.0 is a factor of 212.0");
        System.out.println();

        // This lambda expression determines if one string is
        // part of another.
        SomeTest<String> isIn = (a, b) -> a.indexOf(b) != -1;

        String str = "Generic Functional Interface";

        System.out.println("Testing string: " + str);
        if(isIn.test(str, "face"))
            System.out.println("'face' is found.");
        else
            System.out.println("'face' not found.");
    }
}
```

The output is shown here:
In the program, the generic functional interface `SomeTest` is declared as shown here:

```java
interface SomeTest<T> {
    boolean test(T n, T m);
}
```

Here, `T` specifies the type of both parameters for `test()`. This means that it is compatible with any lambda expression that takes two parameters of the same type and returns a `boolean` result.

The `SomeTest` interface is used to provide a reference to three different types of lambdas. The first uses type `Integer`, the second uses type `Double`, and the third uses type `String`. Thus, the same functional interface can be used to refer to the `isFactor`, `isFactorD`, and `isIn` lambdas. Only the type argument passed to `SomeTest` differs.

As a point of interest, the `NumericFunc` interface shown in the previous section can also be rewritten as a generic interface. This is an exercise in “Chapter 14 Self Test,” at the end of this chapter.

Try This 14-1  Pass a Lambda Expression as an Argument

```java
LambdaArgumentDemo.java
```

A lambda expression can be used in any context that provides a target type. The target contexts used by the preceding examples are assignment and initialization. Another one 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 illustrate the process, this project creates three string functions that perform the following operations: reverse a string, reverse the case of letters within a string, and replace spaces with hyphens. These functions are implemented as lambda expressions of the functional interface `StringFunc`. They are then passed as the first argument to a method called `changeStr()`. This method applies the string function to the string passed as the second argument to `changeStr()` and returns the result. Thus, `changeStr()` can be used to apply a variety of different string functions.

1. Create a file called `LambdaArgumentDemo.java`.
2. To the file, add the functional interface `StringFunc`, as shown here:
interface StringFunc {
    String func(String str);
}

This interface defines the method `func()`, which takes a `String` argument and returns a `String`. Thus, `func()` can act on a string and return the result.

3. Begin the `LambdaArgumentDemo` class, as shown here, by defining the `changeStr()` method:

```java
class LambdaArgumentDemo {
    // 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 an instance created
    // by a lambda expression. The second parameter specifies the
    // string to operate on.
    static String changeStr(StringFunc sf, String s) {
        return sf.func(s);
    }
}
```

As the comment indicates, `changeStr()` has two parameters. The type of the first is `StringFunc`. This means it can be passed a reference to any `StringFunc` instance. Thus, it can be passed a reference to an instance created by a lambda expression that is compatible with `StringFunc`. The string to be acted on is passed to `s`. The resulting string is returned.

4. Begin the `main()` method, as shown here:

```java
public static void main(String args[]) {
    String inStr = "Lambda Expressions Expand Java";
    String outStr;

    System.out.println("Here is input string: "+ inStr);
    // Here, inStr refers to the string that will be acted on, and outStr will receive the modified string.
}
```

5. Define a lambda expression that reverses the characters in a string and assign it to a `StringFunc` reference. Notice that this is another example of a block lambda.

```java
// Define a lambda expression that reverses the contents
// of a string and assign it to a StringFunc reference variable.
StringFunc reverse = (str) -> {
    String result = "";
    for(int i = str.length()-1; i >= 0; i--)
        result += str.charAt(i);
    return result;
};
```

6. Call `changeStr()`, passing in the `reverse` lambda and `inStr`. Assign the result to `outStr`, and display the result.
Because the first parameter to `changeStr()` is of type `StringFunc`, the `reverse` lambda can be passed to it. Recall that a lambda expression causes an instance of its target type to be created, which in this case is `StringFunc`. Thus, a lambda expression gives you a way to effectively pass a code sequence to a method.

7. Finish the program by adding lambdas that replace spaces with hyphens and invert the case of the letters, as shown next. Notice that both of these lambdas are embedded in the call to `changeStr()`, itself, rather than using a separate `StringFunc` variable.

```java
// This lambda expression replaces spaces with hyphens.
// It is embedded directly in the call to changeStr().
outStr = changeStr((str) -> str.replace(' ', '-'), inStr);
System.out.println("The string with spaces replaced: " + outStr);

// This block lambda inverts the case of the characters in the
// string. It is also embedded directly in the call to changeStr().
outStr = changeStr((str) -> {
    String result = "";
    char ch;

    for(int i = 0; i < str.length(); i++) {
        ch = str.charAt(i);
        if(Character.isUpperCase(ch))
            result += Character.toLowerCase(ch);
        else
            result += Character.toUpperCase(ch);
    }
    return result;
}, inStr);
System.out.println("The string in reversed case: " + outStr);
}
```

As you can see by looking at this code, embedding the lambda that replaces spaces with hyphens in the call to `changeStr()` is both convenient and easy to understand. This is because it is a short, expression lambda that simply calls `replace()` to replace spaces with hyphens. The `replace()` method is another method defined by the `String` class. The version used here takes as arguments the character to be replaced and its replacement. It returns a modified string.

For the sake of illustration, the lambda that inverts the case of the letters in a string is also embedded in the call to `changeStr()`. However, in this case, rather unwieldy code is produced that is somewhat hard to follow. Usually, it is better to assign such a lambda to a separate reference variable (as was done for the string-reversing lambda), and then pass that variable to the method. Of course, it is technically correct to pass a block lambda as an argument, as the example shows.

One other point: notice that the invert-case lambda uses the `static` methods `isUpperCase()`. 
toUpperCase(), and toLowerCase() defined by Character. Recall that Character is a wrapper class for char. The isUpperCase() method returns true if its argument is an uppercase letter and false otherwise. The toUpperCase() and toLowerCase() perform the indicated action and return the result. In addition to these methods, Character defines several others that manipulate or test characters. You will want to explore them on your own.

8. Here is all the code assembled into a complete program.

```java
// Use a lambda expression as an argument to a method.

interface StringFunc {
    String func(String str);
}

class LambdaArgumentDemo {

    // 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 an instance created
    // by a lambda expression. The second parameter specifies the
    // string to operate on.
    static String changeStr(StringFunc sf, String s) {
        return sf.func(s);
    }

    public static void main(String args[]) {
        String inStr = "Lambda Expressions Expand Java";
        String outStr;

        System.out.println("Here is input string: " + inStr);

        // Define a lambda expression that reverses the contents
        // of a string and assign it to a StringFunc reference variable.
```
StringFunc reverse = (str) -> {
    String result = "";

    for(int i = str.length()-1; i >= 0; i--)
        result += str.charAt(i);

    return result;
};

// Pass reverse to the first argument to changeStr().
// Pass the input string as the second argument.
outStr = changeStr(reverse, inStr);
System.out.println("The string reversed: " + outStr);

// This lambda expression replaces spaces with hyphens.
// It is embedded directly in the call to changeStr().
outStr = changeStr((str) -> str.replace( ' ', '-' ), inStr);
System.out.println("The string with spaces replaced: " + outStr);

// This block lambda inverts the case of the characters in the
// string. It is also embedded directly in the call to changeStr().
outStr = changeStr((str) -> {
    String result = "";
    char ch;

    for(int i = 0; i < str.length(); i++) {
        ch = str.charAt(i);
        if(Character.isUpperCase(ch))
            result += Character.toLowerCase(ch);
        else
            result += Character.toUpperCase(ch);
    }
    return result;
}, inStr);

System.out.println("The string in reversed case: " + outStr);
}

The following output is produced:

Here is input string: Lambda Expressions Expand Java
The string reversed: avaJ dnapxE snoonserpxE adbmaL
The string with spaces replaced: Lambda-Expressions-Expand-Java
The string in reversed case: 1AMBDA eXPRESSIONS eXPAND jAVA

Ask the Expert
Q: In addition to variable initialization, assignment, and argument passing, what other places constitute a target type context for a lambda expression?

A: Casts, the `?` operator, array initializers, `return` statements, and lambda expressions, themselves, can also serve as target type contexts.

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 variable 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 variable 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**. This is why the `println()` statement outputs the number 18. When `func()` is called with the argument 8, the value of `v` inside the lambda is set by adding **num** (which is 10) to the value passed to `n` (which is 8). Thus, `func()` returns 18. This works because **num** is not modified after it is initialized. 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.

**Throw an Exception from Within a Lambda Expression**

A lambda expression can throw an exception. If it throws a checked exception, however, then that exception must be compatible with the exception(s) listed in the `throws` clause of the abstract method in the functional interface. For example, if a lambda expression throws an `IOException`, then the abstract method in the functional interface must list `IOException` in a `throws` clause. This situation is demonstrated by the following program:

```java
// An example of capturing a local variable from the enclosing scope.
interface MyFunc {
    int func(int n);
}

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

        // A local variable that can be captured.
        int num = 10;

        MyFunc myLambda = (n) -> {
            // This use of num is OK. It does not modify num.
            int v = num + n;
            // However, the following is illegal because it attempts
            // to modify the value of num.
            // num++;

            return v;
        };

        // Use the lambda. This will display 18.
        System.out.println(myLambda.func(8));

        // The following line would also cause an error, because
        // it would remove the effectively final status from num.
        // num = 9;
    }
}
```
Because a call to read() could result in an IOException, the ioAction() method of the functional interface MyIOAction must include IOException in a throws clause. Without it, the program will not compile because the lambda expression will no longer be compatible with ioAction(). To prove this, simply remove the throws clause and try compiling the program. As you will see, an error will result.

### Ask the Expert

**Q:** Can a lambda expression use a parameter that is an array?

**A:** Yes. However, when the type of the parameter is inferred, the parameter to the lambda expression is *not* specified using the normal array syntax. Rather, the parameter is specified as a simple name, such as n, not as n[]. Remember, the type of a lambda expression parameter will be inferred from the target context. Thus, if the target context requires an array, then the parameter’s type will automatically be inferred as an array. To better understand this, let’s work through a short example.

Here is a generic functional interface called MyTransform, which can be used to apply some transform to the elements of an array:

```java
// A functional interface.
interface MyTransform<T> {
    void transform(T[] a);
}
```

Notice that the parameter to the transform() method is an array of type T. Now, consider the following lambda expression that uses MyTransform to convert the elements of an array of Double:

```java
MyIOAction myIO = (rdr) -> {
    int ch = rdr.read(); // could throw IOException
    // ...
    return true;
};
```
Here, the type of a in `transform()` is `Double[]`, because `Double` is specified as the type parameter for `MyTransform` when `sqrts` is declared. Therefore, the type of v in the lambda expression is inferred as `Double[]`. It is not necessary (or legal) to specify it as `v[]`.

One last point: It is legal to declare the lambda parameter as `Double[] v`, because doing so explicitly declares the type of the parameter. However, doing so gains nothing in this case.

---

**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 a functional interface. There are different types of method references. We will begin with method references to static methods.

**Method References to static Methods**

A method reference to a static method is created by specifying the method name preceded by its class name, using 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 the static method reference. It does so by first declaring a functional interface called `IntPredicate` that has a method called `test()`. This method has an `int` parameter and returns a `boolean` result. Thus, it can be used to test an integer value against some condition. The program then creates a class called `MyIntPredicates`, which defines three static methods, with each one checking if a value satisfies some condition. The methods are called `isPrime()`, `isEven()`, and `isPositive()`, and each method performs the test indicated by its name. Inside `MethodRefDemo`, a method called `numTest()` is created that has as its first parameter, a reference to `IntPredicate`. Its second parameter specifies the integer being tested. Inside `main()`, three different tests are performed by calling `numTest()`, passing in a method reference to the test to perform.
// Demonstrate a method reference for a static method.

// A functional interface for numeric predicates that operate
// on integer values.
interface IntPredicate {
    boolean test(int n);
}

// This class defines three static methods that check an integer
// against some condition.
class MyIntPredicates {
    // A static method that returns true if a number is prime.
    static boolean isPrime(int n) {
        if(n < 2) return false;
In the program, pay special attention to this line:

result = numTest(MyIntPredicates::isPrime, 17);

Here, a reference to the static method isPrime() is passed as the first argument to numTest(). This works because isPrime is compatible with the IntPredicate functional interface. Thus, the expression
MyIntPredicates::isPrime evaluates to a reference to an object in which isPrime( ) provides the implementation of test( ) in IntPredicate. The other two calls to numTest( ) work in the same way.

Method References to Instance Methods
A reference to an instance method on a specific object is create by this basic syntax:

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. Thus, the method referred to by the method reference operates relative to objRef. The following program illustrates this point. It uses the same IntPredicate interface and test( ) method as the previous program. However, it creates a class called MyIntNum, which stores an int value and defines the method isFactor( ), which determines if the value passed is a factor of the value stored by the MyIntNum instance. The main( ) method then creates two MyIntNum instances. It then calls numTest( ), passing in a method reference to the isFactor( ) method and the value to be checked. In each case, the method reference operates relative to the specific object.
This program produces the following output:

3 is a factor of 12
3 is not a factor of 16

In the program, pay special attention to the line:

IntPredicate ip = myNum::isFactor;

Here, the method reference assigned to ip refers to an instance method isFactor() on myNum. Thus, when test() is called through that reference, as shown here:

result = ip.test(3);
the method will call `isFactor()` on `myNum`, which is the object specified when the method reference was created. The same situation occurs with the method reference `myNum2::isFactor`, except that `isFactor()` will be called on `myNum2`. This is confirmed by the output.

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 (if any) specified by the method. Here is an example. It reworks the previous example. First, it replaces `IntPredicate` with the interface `MyIntNumPredicate`. In this case, the first parameter to `test()` is of type `MyIntNum`. It will be used to receive the object being operated upon. This allows the program to create a method reference to the instance method `isFactor()` that can be used with any `MyIntNum` object.
Ask the Expert

**Q:** How do I specify a method reference to a generic method?

**A:** Often, because of type inference, you won't need to explicitly specify a type argument to a generic method when obtaining its method reference, but Java does include a syntax to handle those cases in which you do. For example, assuming the following:

```java
// Use an instance method reference to refer to any instance.

// A functional interface for numeric predicates that operate
// on an object of type MyIntNum and an integer value.
interface MyIntNumPredicate {
    boolean test(MyIntNum mv, int n);
}

// This class stores an int value and defines the instance
// method isFactor(), which returns true if its argument
// is a factor of the stored value.
class MyIntNum {
    private int v;

    MyIntNum(int x) { v = x; }
    int getNum() { return v; }

    // Return true if n is a factor of v.
    boolean isFactor(int n) {
        return (v % n) == 0;
    }
}

class MethodRefDemo3 {
    public static void main(String args[])
    {
        boolean result;

        MyIntNum myNum = new MyIntNum(12);
        MyIntNum myNum2 = new MyIntNum(16);

        // This makes inp refer to the instance method isFactor().
        MyIntNumPredicate inp = MyIntNum::isFactor;

        // The following calls isFactor() on myNum.
        result = inp.test(myNum, 3);
        if(result)
            System.out.println("3 is a factor of " + myNum.getNum());

        // The following calls isFactor() on myNum2.
        result = inp.test(myNum2, 3);
        if(!result)
            System.out.println("3 is a not a factor of " + myNum2.getNum());
    }
}
```
the following statement is valid:

```java
SomeTest<Integer> mRef = MyClass::<Integer>myGenMeth;
```

Here, the type argument for the generic method `myGenMeth` is explicitly specified. Notice that the type argument 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. In cases in which a generic class is specified, the type argument follows the class name and precedes the `::`.

The output is shown here:

```
3 is a factor of 12
3 is a not a factor of 16
```

In the program, pay special attention to this line:

```java
MyIntNumPredicate inp = MyIntNum::isFactor;
```

It creates a method reference to the instance method `isFactor()` that will work with any object of type `MyIntNum`. For example, when `test()` is called through the `inp`, as shown here:

```java
result = inp.test(myNum, 3);
```

it results in a call to `myNum.isFactor(3)`. In other words, `myNum` becomes the object on which `isFactor(3)` is called.

### Constructor References

Similar to the way that you can create references to methods, you can also create references to constructors. Here is the general form of the syntax that you will use:

```java
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:
In the program, notice that the `func()` method of `MyFunc` returns a reference of type `MyClass` and has a `String` parameter. Next, notice that `MyClass` defines two constructors. The first specifies a parameter of type `String`. The second is the default, parameterless constructor. Now, examine the following line:

```java
MyFunc myClassCons = MyClass::new;                                // A constructor reference
```

Here, the expression `MyClass::new` creates a constructor reference to a `MyClass` constructor. In this case, because `MyFunc`'s `func()` method takes a `String` parameter, the constructor being referred to is `MyClass(String s)` 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:

```java
MyClass mc = myClassCons.func("Testing");
```

The output is shown here:

```
str in mc is Testing
```
In essence, `myClassCons` has become another way to call `MyClass(String s)`.

If you wanted `MyClass::new` to use `MyClass`’s default constructor, then you would need to use a functional interface that defines a method that has no parameter. For example, if you define `MyFunc2`, as shown here:

```java
interface MyFunc2 {
    MyClass func();
}
```

then the following line will assign to `MyClassCons` a reference to `MyClass`’s default (i.e., parameterless) constructor:

```java
MyFunc2 myClassCons = MyClass::new;
```

In general, the constructor that will be used when `::new` is specified is the one whose parameters match those specified by the functional interface.

---

**Ask the Expert**

**Q:** Can I declare a constructor reference that creates an array?

**A:** Yes. To create a constructor reference for an array, use this construct:

```java
type[]::new
```

Here, `type` specifies the type of object being created. For example, assuming the form of `MyClass` shown in the preceding example and given the `MyClassArrayCreator` interface shown here:

```java
interface MyClassArrayCreator {
    MyClass[] func(int n);
}
```

the following creates an array of `MyClass` objects and gives each element an initial value:

```java
MyClassArrayCreator mcArrayCons = MyClass[]::new;
MyClass[] a = mcArrayCons.func(3);
for(int i=0; i < 3; i++)
    a[i] = new MyClass(i);
```

Here, the call to `func(3)` causes a three-element array to be created. This example can be generalized. Any functional interface that will be used to create an array must contain a method that takes a single `int` parameter and returns a reference to the array of the specified size.

As a point of interest, you can create a generic functional interface that can be used with other types of classes, as shown here:
interface MyArrayCreator<T> {
    T[] func(int n);
}

For example, you could create an array of five Thread objects like this:

MyArrayCreator<Thread> mcArrayCons = Thread[] :: new;
Thread[] thrs = mcArrayCons.func(5);

One last point: In the case of creating a constructor reference for a generic class, you can specify
the type parameter in the normal way, after the class name. For example, if MyGenClass is declared
like this:

MyGenClass<T> { // ...

then the following creates a constructor reference with a type argument of Integer:

MyGenClass<Integer>:: new;

Because of type inference, you won’t always need to specify the type argument, but you can when
necessary.

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. In many cases, however, 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. Here is a
sampling:

<table>
<thead>
<tr>
<th>Interface</th>
<th>Purpose</th>
</tr>
</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. Returns a boolean value that indicates the outcome. Its method is called test().</td>
</tr>
</tbody>
</table>

The following program shows the Predicate interface in action. It uses Predicate as the functional
interface for a lambda expression that determines if a number is even. **Predicate**’s abstract method is called `test()`, and it is shown here:

```java
boolean test(T val)
```

It must return `true` if `val` satisfies some constraint or condition. As it is used here, it will return `true` if `val` is even.

```java
// Use the Predicate built-in functional interface.

// Import the Predicate interface.
import java.util.function.Predicate;

class UsePredicateInterface {
    public static void main(String args[]) {
        // This lambda uses Predicate<Integer> to determine
        // if a number is even.
        Predicate<Integer> isEven = (n) -> (n % 2) == 0; // Use the built-in
        // Predicate interface.
        
        if(isEven.test(4)) System.out.println("4 is even");
        if(!isEven.test(5)) System.out.println("5 is odd");
    }
}
```

---

**Ask the Expert**

**Q:** At the start of this chapter, you mentioned that the inclusion of lambda expressions resulted in new capabilities being incorporated into the API library. Can you give me an example?

**Q:** One of the most important enhancements to the Java API library added by JDK 8 is the new stream package `java.util.stream`. This package defines several stream classes, the most general of which is `Stream`. As it relates to `java.util.stream`, a `stream` is a conduit for data. Thus, a stream represents a sequence of objects. Furthermore, a stream supports many types of operations that let you create a **pipeline** that performs a series of actions on the data. Often, these actions are represented by lambda expressions. 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. One last point: although the streams supported by the new stream API have some similarities with the I/O streams described in Chapter 10, they are not the same.
Chapter 14 Self Test

1. What is the lambda operator?
2. What is a functional interface?
3. How do functional interfaces and lambda expressions relate?
4. What are the two general types of lambda expressions?
5. Show a lambda expression that returns true if a number is between 10 and 20, inclusive.
6. Create a functional interface that can support the lambda expression you created in question 5. Call the interface MyTest and its abstract method testing().
7. Create a block lambda that computes the factorial of an integer value. Demonstrate its use. Use NumericFunc, shown in this chapter, for the functional interface.
8. Create a generic functional interface called MyFunc<T>. Call its abstract method func(). Have func() return a reference of type T. Have it take a parameter of type T. (Thus, MyFunc will be a generic version of NumericFunc shown in the chapter.) Demonstrate its use by rewriting your answer to question 7 so it uses MyFunc<T> rather than NumericFunc.
9. Using the program shown in Try This 14-1, create a lambda expression that removes all spaces from a string and returns the result. Demonstrate this method by passing it to changeStr().
10. Can a lambda expression use a local variable? If so, what constraint must be met?
11. If a lambda expression throws a checked exception, the abstract method in the functional interface must have a throws clause that includes that exception. True or False?
12. What is a method reference?
13. When evaluated, a method reference creates an instance of the ____________ __________ supplied by its target context.
14. Given a class called MyClass that contains a static method called myStaticMethod(), show how to specify a method reference to myStaticMethod().
15. Given a class called MyClass that contains an instance method called myInstMethod() and assuming an object of MyClass called mcObj, show how to create a method reference to myInstMethod() on mcObj.
16. To the MethodRefDemo2 program, add a new method to MyIntNum called hasCommonFactor(). Have it return true if its int argument and the value stored in the invoking MyIntNum object have at least one factor in common. For example, 9 and 12 have a common
factor, which is 3, but 9 and 16 have no common factor. Demonstrate `hasCommonFactor()` via a method reference.

17. How is a constructor reference specified?

18. Java defines several predefined functional interfaces in what package?
Chapter 15
Applets, Events, and Miscellaneous Topics

Key Skills & Concepts
- Understand applet basics
- Know the applet architecture
- Create an applet skeleton
- Initialize and terminate applets
- Repaint applets
- Output to the status window
- Pass parameters to an applet
- Know the `Applet` class
- Understand the delegation event model
- Use the delegation event model
- Know the remaining Java keywords

Teaching the elements of the Java language is the primary goal of this book, and in this regard, we are nearly finished. The preceding 14 chapters have focused on the features of Java defined by the language, such as its keywords, syntax, block structure, type conversion rules, and so on. At this point, you have enough knowledge to write sophisticated, useful Java programs. However, there are
two fundamental parts of Java programming that are not defined by keywords, but by API classes and specialized techniques. These are applets and events.

Be forewarned: The topics of applets and event handling are very large. Full and detailed coverage of either is well beyond the scope of this book. Here, you will learn their fundamentals and see several examples, but we will only scratch the surface. After finishing this chapter, however, you will have a foundation upon which to build your knowledge.

This chapter ends with a description of the remaining Java keywords, such as `instanceof` and `native`, that have not been described elsewhere in this book. These keywords are used for more advanced programming, but they are summarized here for completeness.

**Applet Basics**

Applets differ from the type of programs shown in the preceding chapters. As mentioned in Chapter 1, applets are small programs that are designed for transmission over the Internet and run within a browser. Because Java’s virtual machine is in charge of executing all Java programs, including applets, applets offer a reasonably secure way to dynamically download and execute programs over the Web.

Before we begin, it is necessary to explain two general varieties of applets: those based on the Abstract Window Toolkit (AWT) and those based on Swing. Both the AWT and Swing support the creation of a graphical user interface (GUI). The AWT is the original GUI toolkit and Swing is a lightweight alternative. This chapter describes AWT-based applets. (Swing is introduced in Chapter 16.) It is important to understand, however, that Swing-based applets are built upon the same basic architecture as AWT-based applets. Furthermore, Swing is built on top of the AWT. Therefore, the information and techniques presented here describe the foundation of applet programming and most of it applies to both types of applets.

Prior to discussing any theory or details, let's begin by examining a simple applet. It performs one function: It displays the string "Java makes applets easy." inside a window.

```java
// A minimal AWT-based applet.
import java.awt.*;  // Notice these import statements.
import java.applet.*;

public class SimpleApplet extends Applet {
    public void paint(Graphics g) {
        g.drawString("Java makes applets easy.", 20, 20);  // This outputs to the applet's window.
    }
}
```

This applet begins with two `import` statements. The first imports the Abstract Window Toolkit classes. AWT-based applets interact with the user through the AWT, not through the console-based I/O classes. The AWT contains support for a limited window-based, graphical user interface. As you might expect, it is quite large and sophisticated. A complete discussion of it would require a book of its own. Fortunately, since we will be creating only very simple applets, we will make only limited use of the AWT. The next `import` statement imports the `applet` package. This package contains the class `Applet`. Every AWT-based applet that you create must be a subclass 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 outside code.

Inside SimpleApplet, paint() is declared. This method is defined by the AWT Component class (which is a superclass of Applet) and is overridden by the applet. paint() is called each time the applet must redisplay its output. This 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 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.

Inside paint(), there 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 the message to be displayed beginning at location 20,20.

Notice that the applet does not have a main() method. Unlike the programs shown earlier in this book, 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 a browser or other applet-enabled program.

After you have entered the source code for SimpleApplet, you compile in the same way that you have been compiling programs. However, running SimpleApplet involves a different process. There are two ways in which you can run an applet: inside a browser or with a special development tool that displays applets. The tool provided with the standard Java JDK is called appletviewer, and we will use it to run the applets developed in this chapter. Of course, you can also run them in your browser, but the appletviewer is much easier to use during development.

**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, unsigned local applets may be (probably 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.
One way to execute an applet (in either a Web browser or the `appletviewer`) 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, and other deployment strategies are available. Consult the Java documentation for the latest information.) Using the APPLET tag, here is the HTML file that will execute `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.

To execute `SimpleApplet` with an applet viewer, you will execute this HTML file. For example, if the preceding HTML file is called `StartApp.html`, then the following command line will run `SimpleApplet`:

```
C:\>appletviewer StartApp.html
```

Although there is nothing wrong with using a stand-alone HTML file to execute an applet, there is an easier way. Simply include a comment near the top of your applet’s source code file that contains the APPLET tag. 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("Java makes applets easy.", 20, 20);
    }
}
```

Now you can execute the applet by passing the name of its source file to `appletviewer`. For example, this command line will now display `SimpleApplet`:

```
C:\>appletviewer SimpleApplet.java
```

The window produced by `SimpleApplet`, as displayed by `appletviewer`, is shown in the following illustration:
When using **appletviewer**, keep in mind that it provides the window frame. Applets run in a browser will not have a visible frame.

Let’s review an applet’s key points:

- All AWT-based applets are subclasses of **Applet**.
- 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.

**Applet Organization and Essential Elements**

Although the preceding applet is completely valid, such a simple applet is of little value. Before you can create useful applets, you need to know more about how applets are organized, what methods they use, and how they interact with the run-time system.

**The 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 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, and 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 control to the system. 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.

Second, it is the user who initiates interaction with an applet—not the other way around. In a console-based program, when the program needs input, it will prompt the user and then call some input method. 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 a 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. 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 another GUI-based operating system), you know how intimidating that environment can be. Fortunately, Java provides a much cleaner approach that is more quickly mastered.

**A Complete Applet Skeleton**
Although *SimpleApplet* shown earlier is a real applet, it does not contain all of the elements required by most applets. Actually, all but the most trivial applets override a set of methods that provide the basic mechanism by which the browser or applet viewer interfaces to the applet and controls its execution. These life-cycle methods are `init()`, `start()`, `stop()`, and `destroy()`, and they are defined by *Applet*. A fifth method, `paint()`, is commonly overridden by AWT-based applets even though it is not a life-cycle method. It is inherited from the AWT *Component* class. Since default implementations for all of these methods are provided, applets do not need to override those methods they do not use. These four life-cycle methods plus `paint()` can be assembled into the skeleton shown here:

```java
// An AWT-based 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 AWT-based applet's window must be restored.
    public void paint(Graphics g) {
        // redisplay contents of window
    }
}
```

Although this skeleton does not do anything, it can be compiled and run. Thus, it can be used as a starting point for applets that you create.
NOTE

Overriding `paint()` applies mostly to AWT-based applets. Swing applets use a different painting mechanism.

Applet Initialization and Termination

It is important to understand the order in which the various methods shown in the skeleton are executed. 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.

The `init()` method is the first method to be called. In `init()` your applet will initialize variables and perform any other startup activities.

The `start()` method is called after `init()`. It is also called to restart an applet after it has been stopped, such as when the user returns to a previously displayed web page that contains an applet. Thus, `start()` might be called more than once during the life cycle of an applet.

The `paint()` method is called each time an AWT-based applet’s output must be redrawn and was described earlier.

When the page containing your applet is left, the `stop()` method is called. You will use `stop()` to suspend any child threads created by the applet and to perform any other activities required to put the applet in a safe, idle state. Remember, a call to `stop()` does not mean that the applet should be terminated because it might be restarted with a call to `start()` if the user returns to the page.

The `destroy()` method is called when the applet is no longer needed. It is used to perform any shutdown operations required of the applet.

Requesting Repainting

As a general rule, an AWT-based applet writes to its window only when its `paint()` method is called by the run-time system. 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 that one of the fundamental architectural constraints imposed on an applet is that it must quickly return control to the Java 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 run-time system. 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
The repaint() method is defined by the AWT’s Component class. It causes the run-time system to execute a call to your applet’s paint() method. Thus, for another part of your applet to output to its window, simply store the output and then call repaint(). This causes 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 simplest version of repaint() is shown here:

```java
void repaint()
```

This version causes the entire window to be repainted.

Another version of repaint() specifies a region that will be repainted:

```java
void repaint(int left, int top, int width, int height)
```

---

**Ask the Expert**

**Q:** Is it possible for a method other than paint() or update() to output to an applet’s window?

**A:** Yes. To do so, you must obtain a graphics context by calling getGraphics() (defined by Component) and then use this context to output to the window. However, for most AWT-based applications, it is better and easier to route window output through paint() and to call repaint() when the contents of the window change.

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 because window updates are costly in terms of time. If you only need to update a small portion of the window, it is more efficient to repaint only that region.

An example that demonstrates repaint() is found in Try This 15-1.

**The update() Method**

There is another method that relates to repainting called update() that your applet may want to override. This method is defined by the Component class, and it 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, but this is an advanced technique that is beyond the scope of this book. Also, overriding update() applies only to AWT-based applets.
Try This 15-1 A Simple Banner Applet

Banner.java

To demonstrate repaint( ), a simple banner applet is presented. 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. Banners are popular Web features, and this project shows how to use a Java applet to create one.

1. Create a file called Banner.java.
2. Begin creating the banner applet with the following lines:

```java
/*
* Try This 15-1
* 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="Banner" width=300 height=50>
</applet>
*/

public class Banner extends Applet implements Runnable {
    String msg = "Java Rules the Web ";
    Thread t;
    boolean stopFlag;

    // Initialize t to null.
    public void init() {
        t = null;
    }
}
```

Notice that Banner 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. The message that will be scrolled in the banner is contained in the String variable msg. A reference to the thread that runs the applet is stored in t. The Boolean variable stopFlag is used to stop the applet. Inside init( ), the thread reference variable t is set to null.

3. Add the start( ) method shown next:
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, `stopFlag` 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.

4. Add the `run()` method, as shown here:

```java
// 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 exc) {} 
    }
}
```

In `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 of `run()` 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.

5. Add the code for `stop()` and `paint()`, as shown here:
// 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);
}

If a browser is displaying the applet when a new page is viewed, the \texttt{stop()} method is called, which sets \texttt{stopFlag} to \texttt{true}, causing \texttt{run()} to terminate. It also sets \texttt{t} to \texttt{null}. Thus, there is no longer a reference to the \texttt{Thread} object, and it can be recycled the next time the garbage collector runs. 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, \texttt{start()} is once again called, which starts a new thread to execute the banner. Inside \texttt{paint()}, the message is rotated and then displayed.

6. The entire banner applet is shown here:

\texttt{/*
   *
   * Try This 15-1
   *
   * A simple banner applet.
   *
   * This applet creates a thread that scrolls the message contained in msg right to left}
import java.awt.*;
import java.applet.*;
/
APPLET code="Banner" width=300 height=50
*/

public class Banner extends Applet implements Runnable {
  String msg = "Java Rules the Web ";
  Thread t;
  boolean stopFlag;

  // Initialize t to null.
  public void init() {
    t = null;
  }

  // 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 exc) {}
    }
  }

  // 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);
  }
}
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()` , which is defined by `Applet` , with the string that you want displayed. The general form of `showStatus()` is shown here:

```java
void showStatus(String msg)
```

Here, `msg` is the string to be 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()`:

```java
// Using the Status Window.
import java.awt.*;
import java.applet.*;
/*
 <applet code="StatusWindow" width=300 height=50>
 </applet>
 */
public class StatusWindow extends Applet{
    // 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.");
    }
}
```

Sample output from this program is shown here:
Passing Parameters to Applets
You can pass parameters to your applet. To do so, use the PARAM attribute of the APPLET tag, specifying the parameter’s name and value. To retrieve a parameter, use the `getParameter()` method, defined by `Applet`. Its general form is shown here:

```java
String getParameter(String paramName)
```

Here, `paramName` is the name of the parameter. 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. If the specified parameter cannot be found, `null` is returned. Therefore, be sure to confirm that the value returned by `getParameter()` is valid. Also, check any parameter that is converted into a numeric value, confirming that a valid conversion took place.

Here is an example that demonstrates passing parameters:
The Applet Class
As mentioned, all AWT-based applets are subclasses of the Applet class. Applet inherits the
following superclasses defined by the AWT: Component, Container, and Panel. Thus, an applet has access to the full functionality of the AWT.

In addition to the methods described in the preceding sections, Applet contains several others that give you detailed control over the execution of your applet. All of the methods defined by Applet are shown in Table 15-1.

<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>AppState getAppleContext()</td>
<td>Returns the context associated with the applet.</td>
</tr>
<tr>
<td>String getAppleInfo()</td>
<td>Returns 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 param)</td>
<td>Returns the parameter associated with param. null is returned if the specified parameter is not found.</td>
</tr>
<tr>
<td>String[][] getParameterInfo()</td>
<td>Overides of this method should return a String table that describes the parameters recognized by the applet. Each entry in the table must consist of three strings that contain the name of the parameter, a description of its type and/or range, and an explanation of its purpose. The default implementation returns null.</td>
</tr>
<tr>
<td>void init()</td>
<td>This method is called when an applet begins execution. It is the first method called for any applet.</td>
</tr>
<tr>
<td>boolean isActive()</td>
<td>Returns true if the applet has been started. It returns false if the applet has been stopped.</td>
</tr>
<tr>
<td>boolean isValidateRoot()</td>
<td>Returns true, which indicates that an applet is a validate root.</td>
</tr>
</tbody>
</table>
In Java, GUI programs, such as applets, are event driven. Thus, event handling is at the core of successful GUI programming. Most events to which your program will respond are generated by the user. These events are passed to your program in a variety of ways, with the specific method depending upon the actual event. There are several types of events, including those generated by the mouse, the keyboard, and various controls, such as a push button. AWT-based events are supported by the `java.awt.event` package.

Before we start, it must be mentioned that it is not possible to fully discuss Java’s event handling mechanism. Event handling is a large topic with many special features and attributes, and a complete discussion is well beyond the scope of this book. However, the overview presented here will help you get started.

### The Delegation Event Model

The modern approach to handling events is based on the *delegation event model*. The delegation event model 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 received, the listener processes the event and then returns. The advantage of this design is that the 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.

**Events**
In the delegation model, an event is an object that describes a state change in a source. Among other reasons, an event can be generated as a consequence of a person interacting with the elements in a graphical user interface, such as pressing a button, entering a character via the keyboard, selecting an item in a list, and clicking the mouse.

**Event Sources**
An event source is an object that generates an event. A source must register listeners in order for the listener to receive notifications about a specific type of event. Each type of event has its own registration method. Here is the general form:

```java
public void addTypeListener(EventListener 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.

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:

```java
public void removeTypeListener(EventListener 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 AWT events are defined in a set of interfaces, such as those found in `java.awt.event`. For example, the `MouseMotionListener` interface defines methods that 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.

**Event Classes**
The classes that represent events are at the core of Java’s event handling mechanism. At the root of the Java event class hierarchy is `EventObject`, which is in `java.util`. It is the superclass for all events. The class `AWTEvent`, defined within the `java.awt` package, is a subclass of `EventObject`. It is the superclass (either directly or indirectly) for all AWT-based events used by the delegation event
The package `java.awt.event` defines several types of events that are generated by various user interface elements. Table 15-2 enumerates several commonly used ones and provides a brief description of when they are generated.

<table>
<thead>
<tr>
<th>Event Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ActionEvent</td>
<td>Generated when a button is pressed, a list item is double-clicked, or a menu item is selected.</td>
</tr>
<tr>
<td>AdjustmentEvent</td>
<td>Generated when a scroll bar is manipulated.</td>
</tr>
<tr>
<td>ComponentEvent</td>
<td>Generated when a component is hidden, moved, resized, or becomes visible.</td>
</tr>
<tr>
<td>ContainerEvent</td>
<td>Generated when a component is added to or removed from a container.</td>
</tr>
<tr>
<td>FocusEvent</td>
<td>Generated when a component gains or loses keyboard focus.</td>
</tr>
<tr>
<td>InputEvent</td>
<td>Abstract superclass for all component input event classes.</td>
</tr>
<tr>
<td>ItemEvent</td>
<td>Generated when a check box or list item is clicked; also occurs when a choice selection is made or a checkable menu item is selected or deselected.</td>
</tr>
<tr>
<td>KeyEvent</td>
<td>Generated when input is received from the keyboard.</td>
</tr>
<tr>
<td>MouseEvent</td>
<td>Generated when the mouse is dragged or moved, clicked, pressed, or released; also generated when the mouse enters or exits a component.</td>
</tr>
<tr>
<td>MouseWheelEvent</td>
<td>Generated when the mouse wheel is moved.</td>
</tr>
<tr>
<td>TextEvent</td>
<td>Generated when the value of a text area or text field is changed.</td>
</tr>
<tr>
<td>WindowEvent</td>
<td>Generated when a window is activated, closed, deactivated, deiconified, iconified, opened, or quit.</td>
</tr>
</tbody>
</table>

Table 15-2  Commonly Used Event Classes in `java.awt.event`

**Event Listener Interfaces**

Event listeners receive event notifications. Listeners for AWT-based events 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 15-3 lists several commonly used listener interfaces and provides a brief description of the methods they define.
Using the Delegation Event Model

Now that you have had an overview of the delegation event model and its various components, it is time to see it in practice. Applet programming 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 will 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 an example that handles one of the most commonly used event generators: the mouse. The example will show how to handle the basic mouse and mouse motion events. (Note that it is also possible to handle mouse wheel events, but this is left to you as an exercise.)

Handling Mouse and Mouse Motion Events

To handle mouse and mouse motion events, you must implement the `MouseListener` and the `MouseMotionListener` interfaces. The `MouseListener` interface defines five methods. If a mouse button is clicked, `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 a mouse button is pressed and released, respectively. The general forms of these methods are shown here:

```java
void mouseClicked(MouseEvent me)
void mouseEntered(MouseEvent me)
void mouseExited(MouseEvent me)
void mousePressed(MouseEvent me)
void mouseReleased(MouseEvent me)
```

The MouseMotionListener 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 MouseEvent object passed in me describes the event. MouseEvent defines a number of methods that you can use to get information about what happened. Possibly the most commonly used methods in MouseEvent are getX( ) and getY( ). These return the X and Y coordinates of the mouse (relative to the window) when the event occurred. Their forms are shown here:

```java
int getX()
int getY()
```

The next example will use these methods to display the current location of the mouse.

### A Simple Mouse Event Applet

The following applet demonstrates handling the basic mouse events. 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.
Q: You state that the `getX()` and `getY()` methods defined by `MouseEvent` return the window-relative coordinates of the mouse. Are there methods that return its screen-relative (that is, absolute) location?

A: Yes. `MouseEvent` defines methods that obtain the X and Y coordinates of the mouse relative to the screen. They are shown here:

```java
int getXOnScreen()

int getYOnScreen()
```

You might find it interesting to experiment with these methods by substituting them for `getX()` and `getY()` in the `MouseEvents` applet shown next.
public void mouseEntered(MouseEvent me) {
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse entered.";
    repaint();
}

public void mouseExited(MouseEvent me) {
    mouseX = 0;
    mouseY = 10;
    msg = "Mouse exited.";
    repaint();
}

public void mousePressed(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Down";
    repaint();
}

public void mouseReleased(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "Up";
    repaint();
}

public void mouseDragged(MouseEvent me) {
    // save coordinates
    mouseX = me.getX();
    mouseY = me.getY();
    msg = "*";
    showStatus("Dragging mouse at " + mouseX + ", " + mouseY);
    repaint();
}

public void mouseMoved(MouseEvent me) {
    // show status
    showStatus("Moving mouse at " + me.getX() + ", " + me.getY());
}

public void paint(Graphics g) {
    g.drawString(msg, mouseX, mouseY);
}
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 `Component`, 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 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.

**More Java Keywords**

Before concluding this chapter, a few more Java keywords need to be briefly discussed:

- `transient`
- `volatile`
- `instanceof`
- `native`
- `strictfp`
- `assert`

These keywords are most often used in programs more advanced than those found in this book. However, an overview of each is presented so that you will know their purpose.

**The transient and volatile Modifiers**
The `transient` and `volatile` keywords are type modifiers that handle somewhat specialized situations. When an instance variable is declared as `transient`, then its value need not persist when an object is stored. Thus, a `transient` field is one that does not affect the persisted state of an object.

The `volatile` modifier tells the compiler that a variable 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 will share the same variable. For efficiency considerations, each thread can keep its own, private copy of such a shared variable, possibly in a register of the CPU. 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, there may be times when it is inappropriate. In some cases, all that really matters is that the master copy of a variable always reflects the current state, and that this current state is used by all threads. To ensure this, declare the variable as `volatile`.

`instanceof`

Sometimes it is useful to know the type of an object during run time. 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 only be detected at run time. Because a superclass reference can refer to subclass objects, it is not always possible to know at compile time whether or not a cast involving a superclass reference is valid. The `instanceof` keyword addresses these types of situations. 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 or interface type. If the object referred to by `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.

`strictfp`

One of the more esoteric keywords is `strictfp`. When Java 2 was released several years ago, 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, 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 of the methods in the class are also `strictfp` automatically.

`assert`

The `assert` keyword is used during program development to create an `assertion`, which is a condition that is expected to 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 actually 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:

```java
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. For example,

```java
assert n > 0;
```

If `n` is less than or equal to zero, then an `AssertionError` is thrown. Otherwise, no action takes place.

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.

To enable assertion checking at run time, you must specify the `-ea` option. For example, to enable assertions for `Sample`, execute it using this line:

```
java -ea Sample
```

Assertions are quite useful during development because they streamline the type of error checking that is common during testing. But be careful—you must not rely on an assertion to perform any action actually required by the program. The reason is that normally, released code will be run with assertions disabled and the expression in an assertion will not be evaluated.

**Native Methods**

Although rare, there may occasionally be times when you will want to call a subroutine that is written in a language other than Java. Typically, such a subroutine will exist as executable code for the CPU and environment in which you are working—that is, native code. For example, you may wish to call a native code subroutine in order to achieve faster execution time. Or you may want to use a specialized, third-party library, such as a statistical package. However, since 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:
Once you have declared a native method, you must provide the native method and follow a rather complex series of steps in order to link it with your Java code.

Ask the Expert

Q: While we are on the subject of keywords, I have a question about this. I have occasionally noticed a form of this that takes parentheses. For example,

this(x);

Can you tell me what this does?

A: The form of this that you refer to enables one constructor to invoke another constructor within the same class. The general form of this use of this is shown here:

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. Here is a simple example:

class MyClass {
    int a;
    int b;
    // Initialize a and b individually.
    MyClass(int i, int j) {
        a = i;
        b = j;
    }
    // Use this() to initialize a and b to the same value.
    MyClass(int i) {
        this(i, i); // invokes MyClass(i, i)
    }
}

In MyClass, only the first constructor actually assigns a value to a and b. The second constructor simply invokes the first. Therefore, when this statement executes:

MyClass mc = new MyClass(8);

the call to MyClass(8) causes this(8, 8) to be executed, which translates into a call to MyClass(8, 8).
Invoking overloaded constructors through `this()` can be useful because it can prevent the unnecessary duplication of code. However, you need to be careful. Constructors that call `this()` will execute a bit slower than those that contain all of their initialization code in-line. This is because the call and return mechanism used when the second constructor is invoked adds overhead. Remember that object creation affects all users of your class. If your class will be used to create large numbers of objects, then you must carefully balance the benefits of smaller code against the increased time it takes to create an object. As you gain more experience with Java, you will find these types of decisions easier to make.

There are two restrictions you need to keep in mind when using `this()`. First, you cannot use any instance variable of the constructor’s class in a call to `this()`. Second, you cannot use `super()` and `this()` in the same constructor because each must be the first statement in the constructor.

---

**Chapter 15 Self Test**

1. What method is called when an applet first begins running? What method is called when an applet is removed from the system?

2. Explain why an applet must use multithreading if it needs to run continually.

3. Enhance Try This 15-1 so that it displays the string passed to it as a parameter. Add a second parameter that specifies the time delay (in milliseconds) between each rotation.

4. Extra challenge: Create an applet that displays the current time, updated once per second. To accomplish this, you will need to do a little research. Here is a hint to help you get started: One way to obtain the current time is to use a `Calendar` object, which is part of the `java.util` package. (Remember, Oracle provides online documentation for all of Java’s standard classes.) You should now be at the point where you can examine the `Calendar` class on your own and use its methods to solve this problem.

5. Briefly explain Java’s delegation event model.

6. Must an event listener register itself with a source?

7. Extra challenge: Another of Java’s display methods is `drawLine()`. It draws a line in the currently selected color between two points. It is part of the `Graphics` class. Using `drawLine()`, write a program that tracks mouse movement. If the button is pressed, have the program draw a continuous line until the mouse button is released.

8. Briefly describe the `assert` keyword.

9. Give one reason why a native method might be useful to some types of programs.

10. Extra challenge: Try adding support for `MouseWheelEvent` to the `MouseEvents` applet shown in the section “Using the Delegation Event Model.” To do this, implement the `MouseWheelListener` interface and add the applet as listener for this event by using `addMouseWheelListener()`. You will need to use Java’s API documentation to find the details.
about these items. No answer is given for this question. You must use your skills to provide your own solution.
Chapter 16
Introducing Swing

Key Skills & Concepts
- Know the origins and design philosophy of Swing
- Understand Swing components and containers
- Know layout manager basics
- Create, compile, and run a simple Swing application
- Use JButton
- Work with JTextField
- Create a JCheckBox
- Work with JList
- Use anonymous inner classes or lambda expressions to handle events
- Create a Swing applet

With the exception of the applet examples shown in Chapter 15, all of the programs in this book have been console-based. This means that they do not make use of a graphical user interface (GUI). Although console-based programs are excellent for teaching the basics of Java and for some types of programs, such as server-side code, most real-world applications will be GUI-based. At the time of this writing, the most widely used Java GUI is Swing.
Swing defines a collection of classes and interfaces that support a rich set of visual components, such as buttons, text fields, scroll panes, check boxes, trees, and tables, to name a few. Collectively, these controls can be used to construct powerful, yet easy-to-use graphical interfaces. Because of its widespread use, Swing is something with which all Java programmers should be familiar. Therefore, this chapter provides an introduction to this important GUI framework.

It is important to state at the outset that Swing is a very large topic that requires an entire book of its own. This chapter can only scratch its surface. However, the material presented here will give you a general understanding of Swing, including its history, basic concepts, and design philosophy. It then introduces five commonly used Swing components: the label, push button, text field, check box, and list. The chapter ends by showing how to create a Swing-based applet. Although this chapter describes only a small part of Swing’s features, after completing it, you will be able to begin writing simple GUI-based programs. You will also have a foundation upon which to continue your study of Swing.

Before moving on, it is necessary to mention that a new GUI framework called JavaFX has recently been created for Java. JavaFX provides a powerful, streamlined, flexible approach that simplifies the creation of visually exciting GUIs. As such, JavaFX has clearly been positioned as the platform of the future. Because of its importance, an introduction to JavaFX is provided in Chapter 17. Of course, Swing will continue to be in use for a long time, in part because of the large amount of legacy code that exists for it. Therefore, both Swing and JavaFX are likely to be part of any Java programmer’s job going forward.

NOTE

The Origins and Design Philosophy 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 (AWT). The AWT defines a basic set of components 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 an AWT 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 differences 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 JFC) was fully integrated into Java.

Swing addresses the limitations associated with the AWT’s components through the use of two key features: lightweight components and a pluggable look and feel. Although they are largely transparent to the programmer, these two features are at the foundation of Swing’s design philosophy and the reason for much of its power and flexibility. Let’s look at each.

With very few exceptions, Swing components are lightweight. This means that a component is written entirely in Java. They do not rely on platform-specific peers. Lightweight components have some important advantages, including efficiency and flexibility. Furthermore, because lightweight components do not translate into platform-specific peers, the look and feel of each component is determined by Swing, not by the underlying operating system. This means that each component can work in a consistent manner across all platforms.

Because each Swing component is rendered by Java code rather than by platform-specific peers, 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.

Java 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 a platform-independent look and feel that is available in all Java execution environments. It is also the default look and feel. For this reason, the default Java look and feel (metal) is used by the examples in this chapter.

Swing’s pluggable look and feel is made possible because Swing uses a modified version of the classic model-view-controller (MVC) architecture. 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 was 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. Although you won’t work directly with models or UI delegates in this chapter, they are, nevertheless, present behind the scene.

As you work through this chapter, you will see that even though Swing embodies very sophisticated design concepts, it is easy to use. In fact, one could argue that Swing’s ease of use is its most important advantage. Simply stated, Swing makes manageable the often difficult task of developing your program’s user interface. This lets you concentrate on the GUI itself, rather than on implementation details.
Q: You say that Swing defines a GUI that is superior to the AWT. Does this mean that Swing replaces the AWT?

A: No, Swing does not replace the AWT. Rather, Swing builds upon the foundation provided by the AWT. Thus, the AWT is still a crucial part of Java. Swing also uses the same event handling mechanism as the AWT (which was described in Chapter 15). Although knowledge of the AWT is not required by this chapter, you need a solid understanding of its structure and features if you seek full Swing mastery.

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 text field. 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.

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 javax.swing. The following table shows the class names for Swing components (including those used as containers):
Notice that all component classes begin with the letter J. For example, the class for a label is \texttt{JLabel}, the class for a push button is \texttt{JButton}, and the class for a check box is \texttt{JCheckBox}. This chapter introduces five commonly used components: \texttt{JLabel}, \texttt{JButton}, \texttt{JTextField}, \texttt{JCheckBox}, and \texttt{JList}. Once you understand their basic operation, it will be easy for you to learn to use the others.

\textbf{Containers}

Swing defines two types of containers. The first are top-level containers: \texttt{JFrame}, \texttt{JApplet}, \texttt{JWindow}, and \texttt{JDialog}. These containers do not inherit \texttt{JComponent}. They do, however, inherit the AWT classes \texttt{Component} and \texttt{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 \texttt{JFrame}. The one used for applets is \texttt{JApplet}.

The second type of container supported by Swing is the lightweight container. Lightweight containers do inherit \texttt{JComponent}. Examples of lightweight containers are \texttt{JPanel}, \texttt{JScrollPane}, and \texttt{JRootPane}. Lightweight containers are often used to collectively organize and manage groups of related components because a lightweight container can be contained within another container. Thus, you can use lightweight containers to create subgroups of related controls that are contained within an outer container.

\textbf{The Top-Level Container Panes}

Each top-level container defines a set of \textit{panes}. At the top of the hierarchy is an instance of \texttt{JRootPane}. \texttt{JRootPane} is a lightweight container whose purpose is to manage the other panes. It also helps manage the optional menu bar. The panes that compose the root pane are called the \textit{glass pane}, the \textit{content pane}, and the \textit{layered pane}.

The glass pane is the top-level pane. It sits above and completely covers all other panes. 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. 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. Therefore, the content pane holds
the components that the user interacts with.

## Layout Managers
Before you begin writing a Swing program, there is one more thing that you need to be aware of: the
layout manager. The layout manager controls the position of components within a container. Java
offers several layout managers. Most are provided by the AWT (within `java.awt`), but Swing adds a
few of its own. All layout managers are instances of a class that implements the `LayoutManager`
interface. (Some will also implement the `LayoutManager2` interface.) Here is a list of a few of the
layout managers available to the Swing programmer:

<table>
<thead>
<tr>
<th>LayoutManager</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>FlowLayout</td>
<td>A simple layout that positions components left-to-right, top-to-bottom. (Positions components right-to-left for some cultural settings.)</td>
</tr>
<tr>
<td>BorderLayout</td>
<td>Positions components within the center or the borders of the container. This is the default layout for a content pane.</td>
</tr>
<tr>
<td>GridLayout</td>
<td>Lays out components within a grid.</td>
</tr>
<tr>
<td>GridBagLayout</td>
<td>Lays out different size components within a flexible grid.</td>
</tr>
<tr>
<td>BoxLayout</td>
<td>Lays out components vertically or horizontally within a box.</td>
</tr>
<tr>
<td>SpringLayout</td>
<td>Lays out components subject to a set of constraints.</td>
</tr>
</tbody>
</table>

Frankly, the topic of layout managers is quite large, and it is not possible to examine it in detail in
this book. Fortunately, this chapter uses only two layout managers—`BorderLayout` and
`FlowLayout`—and both are very easy to use.

**BorderLayout** is the default layout manager for the content pane. It implements a layout style that
defines five locations to which a component can be added. The first is the center. The other four are
the sides (i.e., borders), which are called north, south, east, and west. By default, when you add a
component to the content pane, you are adding the component to the center. To add a component to
one of the other regions, specify its name.

Although a border layout is useful in some situations, often another, more flexible layout manager
is needed. One of the simplest is **FlowLayout**. A flow layout lays out components one row at a time,
top to bottom. When one row is full, layout advances to the next row. Although this scheme gives you
little control over the placement of components, it is quite simple to use. However, be aware that if
you resize the frame, the position of the components will change.
A First Simple Swing Program

Swing programs differ from the console-based programs shown earlier in this book. They also differ from the AWT-based applets shown in Chapter 15. Not only do Swing programs use the Swing component set to handle user interaction, but they 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 program.
import javax.swing.*;  // Swing programs must 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);  // Set the dimensions of the frame.

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);  // Terminate on close.

        // Create a text-based label.
        JLabel jlab = new JLabel(" Swing defines the modern Java GUI.");

        // Add the label to the content pane.
        jfrm.add(jlab);  // Add the label to the content pane.

        // Display the frame.
        jfrm.setVisible(true);  // Make the frame visible.
    }

    public static void main(String args[]) {
        // Create the frame on the event dispatching thread.
        SwingUtilities.invokeLater(new Runnable() {
            public void run() {
                new SwingDemo();  // SwingDemo must be created on the event dispatching thread.
            }
        });
    }
}
```

Swing programs are compiled and run in the same way as other Java applications. Thus, to
To compile this program, you can use this command line:

```
javac SwingDemo.java
```

To run the program, use this command line:

```
java SwingDemo
```

When the program is run, it will produce the window shown in Figure 16-1.

![A Simple Swing Application](image)

**Figure 16-1** The window produced by the **SwingDemo** program

The First Swing Example Line by Line

Because the **SwingDemo** program illustrates several key Swing concepts, we will examine it carefully, line by line. The program begins by importing the following package:

```java
import javax.swing.*;
```

This `javax.swing` package contains the components and models defined by Swing. For example, it defines classes that implement labels, buttons, edit controls, and menus. This package will be included in all programs that use Swing.

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:

```java
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:

```java
jfrm.setSize(275, 100);
```

The `setSize()` method sets the dimensions of the window, which are specified in pixels. Its general form is shown here:

```java
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:

```java
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);
```

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:

- `JFrame.DISPOSE_ON_CLOSE`
- `JFrame.HIDE_ON_CLOSE`
- `JFrame.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 `JLabel` component:

```java
JLabel jlab = new JLabel(" Swing defines the modern Java GUI.");
```

`JLabel` is the easiest-to-use Swing 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 `add()` method has several versions. The general form of the one used by the program is shown here:

```java
Component add(Component comp)
```

By default, the content pane associated with a `JFrame` uses a border layout. This version of `add()` adds the component (in this case, a 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 automatically adjusted to fit the size of the center.

The last statement in the `SwingDemo` constructor causes the window to become visible.

```java
jfrm.setVisible(true);
```
Q: I have seen Swing programs that use a method called `getContentPane( )` when adding a component to the content pane. What is this method and do I need to use it?

A: This question brings up an important historical point. 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 explicitly 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 the 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 automatically operate on the content pane.

The `setVisible( )` method has this general form:

```java
void setVisible(boolean flag)
```

If `flag` 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 (such as two different threads trying to update the same component at the same time), 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, it 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
```

---

### Ask the Expert

**Q:** You state that it is possible to add a component to the other regions of a border layout by using an overloaded version of add( ). Can you explain?

**A:** As explained, BorderLayout implements a layout style that defines five locations to which a component can be added. The first is the center. The other four are the sides (i.e., borders), which are called north, south, east, and west. By default, when you add a component to the content pane, you are adding the component to the center. To specify one of the other locations, use this form of add( ):

```java
void add(Component comp, Object loc)
```

Here, `comp` is the component to add and `loc` specifies the location to which it is added. The `loc` value is typically one of the following:

<table>
<thead>
<tr>
<th>BorderLayout.CENTER</th>
<th>BorderLayout.EAST</th>
<th>BorderLayout.NORTH</th>
</tr>
</thead>
<tbody>
<tr>
<td>BorderLayout.SOUTH</td>
<td>BorderLayout.WEST</td>
<td></td>
</tr>
</tbody>
</table>

In general, BorderLayout is most useful when you are creating a JFrame that contains a centered component (which might be a group of components held within one of Swing’s lightweight containers) that has a header and/or footer component associated with it. In other situations, one of
Java’s other layout managers will be more appropriate.

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 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 want to use invokeAndWait( ). (Creating Swing applets is described later in this chapter.)

One more point: The preceding program does not respond to any events, because JLabel is a passive component. In other words, a JLabel does not generate any events. Therefore, the preceding program does not include any event handlers. However, all other components generate events to which your program must respond, as the subsequent examples in this chapter show.

Use JButton
One of the most commonly used Swing controls is the push button. A push button is an instance of JButton. JButton inherits the abstract class AbstractButton, which defines the functionality common to all buttons. Swing push buttons can contain text, an image, or both, but this book uses only text-based buttons.

JButton supplies several constructors. The one used here is

JButton(String msg)

Here, msg specifies the string that will be displayed inside the button.

When a push button is pressed, it generates an ActionEvent. ActionEvent is defined by the AWT and also used by Swing. JButton provides the following methods, which are used to add or remove an action listener:

void addActionListener( ActionListener al )

void removeActionListener( ActionListener al )

Here, al specifies an object that will receive event notifications. This object must be an instance of a class that implements the ActionListener interface.

The ActionListener interface defines only one method: actionPerformed( ). It is shown here:

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. Your implementation of actionPerformed( ) must quickly respond to that event and return. As a general rule, event handlers must not engage in long operations, because doing so will slow down the entire application. If a time-consuming procedure must be performed, then a separate thread should be created for that purpose.
Using the `ActionEvent` object passed to `actionPerformed()`, you can obtain several useful pieces of information relating to the button-press event. The one used by this chapter is the `action command` string associated with the button. By default, this is the string displayed inside the button. The action command is obtained 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.

The following program demonstrates how to create a push button and respond to button-press events. **Figure 16-2** shows how the example appears on the screen.

```java
// Demonstrate a push button and handle action events.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class ButtonDemo implements ActionListener {

    JLabel jlab;

    ButtonDemo() {

        // Create a new JFrame container.
        JFrame jfrm = new JFrame("A Button 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 btnUp = new JButton("Up");
        JButton btnDown = new JButton("Down");

        // Add action listeners.
        btnUp.addActionListener(this);
        btnDown.addActionListener(this);
    }

    public static void main(String[] args) {
        new ButtonDemo();
    }
}
```

**Figure 16-2** Output from the `ButtonDemo` program
Let's take a close look at the new things in this program. 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 flow layout manager. The `java.awt.event` package is needed because it defines the `ActionListener` interface and the `ActionEvent` class.

Next, the class `ButtonDemo` is declared. Notice that it implements `ActionListener`. This means that `ButtonDemo` objects can be used to receive action events. Next, a `JLabel` reference is declared. This reference will be used within the `actionPerformed()` method to display which button has been pressed.

The `ButtonDemo` constructor begins by creating a `JFrame` called `jfrm`. It then sets the layout manager for the content pane of `jfrm` to `FlowLayout`, as shown here:

```java
jfrm.setLayout(new FlowLayout());
```

As explained earlier, by default, the content pane uses `BorderLayout` as its layout manager, but for many applications, `FlowLayout` is more convenient. Recall that a flow layout lays out components one row at a time, top to bottom. When one row is full, layout advances to the next row. Although this scheme gives you little control over the placement of components, it is quite simple to use. However, be aware that if you resize the frame, the position of the components will change.

After setting the size and the default close operation, `ButtonDemo()` creates two buttons, as shown here:
The first button will contain the text "Up", and the second will contain "Down".

Next, the instance of ButtonDemo referred to via this is added as an action listener for the buttons by these two lines:

```java
jbtnUp.addActionListener(this);
jbtnDown.addActionListener(this);
```

This approach means that the object that creates the buttons will also receive notifications when a button is pressed.

Each time a button is pressed, it generates an action event and all registered listeners are notified by calling the `actionPerformed()` method. The `ActionEvent` object representing the button event is passed as a parameter. In the case of ButtonDemo, this event is passed to this implementation of `actionPerformed()`:

```java
// Handle button events.
public void actionPerformed(ActionEvent ae) {
    if (ae.getActionCommand().equals("Up"))
        jlab.setText("You pressed Up.");
    else
        jlab.setText("You pressed down. ");
}
```

The event that occurred is passed via `ae`. Inside the method, the action command associated with the button that generated the event is obtained by calling `getActionCommand()`. (Recall that, by default, the action command is the same as the text displayed by the button.) Based on the contents of that string, the text in the label is set to show which button was pressed.

One last point: Remember that `actionPerformed()` is called on the event-dispatching thread as explained earlier. It must return quickly in order to avoid slowing down the application.

**Work with JTextField**

Another commonly used control is JTextField. It enables the user to enter a line of text. JTextField inherits the abstract class JTextComponent, which is the superclass of all text components. JTextField defines several constructors. The one we will use is shown here:

```java
JTextField(int cols)
```

Here, `cols` specifies the width of the text field in columns. It is important to understand that you can enter a string that is longer than the number of columns. It’s just that the physical size of the text field on the screen will be `cols` columns wide.

When you press **Enter** when inputting into a text field, an `ActionEvent` is generated. Therefore, JTextField provides the `addActionListener()` and `removeActionListener()` methods. To handle action events, you must implement the `actionPerformed()` method defined by the ActionListener interface. The process is similar to handling action events generated by a button, as described earlier.
Like a JButton, a JTextField has an action command string associated with it. By default, the action command is the current content of the text field. However, this default is seldom used. Instead, you will usually set the action command to a fixed value of your own choosing by calling the setActionCommand( ) method, shown here:

```java
void setActionCommand(String cmd)
```

The string passed in `cmd` becomes the new action command. The text in the text field is unaffected. Once you set the action command string, it remains the same no matter what is entered into the text field. One reason that you might want to explicitly set the action command is to provide a way to recognize the text field as the source of an action event. This is especially important when another control in the same frame also generates action events and you want to use the same event handler to process both events. Setting the action command gives you a way to tell them apart. Also, if you don’t set the action command associated with a text field, then by happenstance the contents of the text field might match the action command of another component.

**Ask the Expert**

**Q:** You explained that the action command associated with a text field can be set by calling setActionCommand( ). Can I use this method to set the action command associated with a push button?

**A:** Yes. As explained, by default the action command associated with a push button is the name of the button. To set the action command to a different value, you can use the setActionCommand( ) method. It works the same for JButton as it does for JTextField.

To obtain the string that is currently displayed in the text field, call getText( ) on the JTextField instance. It is declared as shown here:

```java
String getText( )
```

You can set the text in a JTextField by calling setText( ), shown next:

```java
void setText(String text)
```

Here, `text` is the string that will be put into the text field.

The following program demonstrates JTextField. It contains one text field, one push button, and two labels. One label prompts the user to enter text into the text field. When the user presses ENTER while focus is within the text field, the contents of the text field are obtained and displayed within a second label. The push button is called Reverse. When pressed, it reverses the contents of the text field. Sample output is shown in Figure 16-3.
Figure 16-3 Sample output from the **TFDemo** program

```java
// Use a text field.

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class TFDemo implements ActionListener {
    JTextField jtf;
    JButton jbtnRev;
    JLabel jlabPrompt, jlabContents;

    TFDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Use a Text Field");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());

        // Give the frame an initial size.
        jfrm.setSize(240, 120);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create a text field.
        jtf = new JTextField(10); // Create a text field that is 10 columns wide.

        // Set the action commands for the text field.
        jtf.setActionCommand("myTF"); // Set the action command for the text field.

        // Create the Reverse button.
        JButton jbtnRev = new JButton("Reverse");
    }
```
Much of the program will be familiar, but a few parts warrant special attention. First, notice that the action command associated with the text field is set to "myTF" by the following line:

```java
jtf.setActionCommand("myTF");
```

After this line executes, the action command string will always be "myTF" no matter what text is currently held in the text field. Therefore, the action command generated by `jtf` will not accidentally conflict with the action command associated with the Reverse push button. The `actionPerformed()` method makes use of this fact to determine what event has occurred. If the action command string is "Reverse", it can mean only one thing: that the Reverse push button has been pressed. Otherwise, the
action command was generated by the user pressing ENTER while the text field had input focus.

Finally, notice this line from within the `actionPerformed( )` method:

```java
jlabContents.setText("You pressed ENTER. Text is: " +
    jtf.getText());
```

As explained, when the user presses ENTER while focus is inside the text field, an `ActionEvent` is generated and sent to all registered action listeners, through the `actionPerformed( )` method. For `TFDemo`, this method simply obtains the text currently held in the text field by calling `getText( )` on `jtf`. It then displays the text through the label referred to by `jlabContents`.

### Create a JCheckBox

After the push button, perhaps the next most widely used control is the check box. In Swing, a check box is an object of type `JCheckBox`. `JCheckBox` inherits `AbstractButton` and `JToggleButton`. Thus, a check box is, essentially, a special type of button.

`JCheckBox` defines several constructors. The one used here is

```java
JCheckBox(String str)
```

It creates a check box that has the text specified by `str` as a label.

When a check box is selected or deselected (that is, checked or unchecked), an item event is generated. Item events are represented by the `ItemEvent` class. Item events are handled by classes that implement the `ItemListener` interface. This interface specifies only one method: `itemStateChanged( )`, which is shown here:

```java
void itemStateChanged(ItemEvent ie)
```

The item event is received in `ie`.

To obtain a reference to the item that changed, call `getItem( )` on the `ItemEvent` object. This method is shown here:

```java
Object getItem( )
```

The reference returned must be cast to the component class being handled, which in this case is `JCheckBox`.

You can obtain the text associated with a check box by calling `getText( )`. You can set the text after a check box is created by calling `setText( )`. These methods work the same as they do for `JButton`, described earlier.

The easiest way to determine the state of a check box is to call the `isSelected( )` method. It is shown here:

```java
boolean isSelected( )
```

It returns true if the check box is selected and false otherwise.

The following program demonstrates check boxes. It creates three check boxes called Alpha, Beta, and Gamma. Each time the state of a box is changed, the current action is displayed. Also, the list of
all currently selected check boxes is displayed. Sample output is shown in Figure 16-4.

![Demonstrate Check Boxes](Image)

Gamma was just selected.
Selected check boxes: Alpha Gamma

**Figure 16-4** Sample output from the **CBDemo** program

```java
// Demonstrate check boxes.
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;

class CBDemo implements ItemListener {

    JLabel jlabSelected;
    JLabel jlabChanged;
    JCheckBox jcbAlpha;
    JCheckBox jcbBeta;
    JCheckBox jcbGamma;

    CBDemo() {
        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Demonstrate Check Boxes");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());
    }
}
```
Give the frame an initial size.
jfrm.setSize(280, 120);

Terminate the program when the user closes the application.
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

Create empty labels.
jlabSelected = new JLabel("");  
jlabChanged = new JLabel("");  

Make check boxes.
jcbAlpha = new JCheckBox("Alpha");  
jcbBeta = new JCheckBox("Beta");  
jcbGamma = new JCheckBox("Gamma");  

Events generated by the check boxes  
are handled in common by the itemStateChanged()  
method implemented by CBDemo.
jcbAlpha.addItemListener(this);  
jcbBeta.addItemListener(this);  
jcbGamma.addItemListener(this);  

Add check boxes and labels to the content pane.
jfrm.add(jcbAlpha);  
jfrm.add(jcbBeta);  
jfrm.add(jcbGamma);  
jfrm.add(jlabChanged);  
jfrm.add(jlabSelected);

Display the frame.
jfrm.setVisible(true);

This is the handler for the check boxes.
public void itemStateChanged(ItemEvent ie) {  
  String str = ";

  Obtain a reference to the check box that  
  caused the event.
  JCheckBox cb = (JCheckBox) ie.getItem();  

  Report what check box changed.
  if (cb.isSelected())  
    jlabChanged.setText(cb.getText() + " was just selected.");  
  else
    jlabChanged.setText(cb.getText() + " was just cleared.");
The main point of interest in this program is the item event handler, `itemStateChanged( )`. It performs two functions. First, it reports whether the check box has been selected or cleared. Second, it displays all selected check boxes. It begins by obtaining a reference to the check box that generated the `ItemEvent`, as shown here:

```java
JCheckBox cb = (JCheckBox) ie.getItem();
```

The cast to `JCheckBox` is necessary because `getItem( )` returns a reference of type `Object`. Next, `itemStateChanged( )` calls `isSelected( )` on `cb` to determine the current state of the check box. If `isSelected( )` returns true, it means that the user selected the check box. Otherwise, the check box was cleared. It then sets the `jlabChanged` label to reflect what happened.

Finally, `itemStateChanged( )` checks the selected state of each check box, building a string that contains the names of those that are selected. It displays this string in the `jlabSelected` label.

### Work with JList

The last component that we will examine is `JList`. This is Swing’s basic list class. It supports the selection of one or more items from a list. Although often the list 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 it is now declared like this:

```java
class JList<E>
```
Here, \( E \) represents the type of the items in the list. As a result, JList is now type-safe. JList provides several constructors. The one used here is

\[
\text{JList}(E[\ ] \text{items})
\]

This creates a JList that contains the items in the array specified by items.

Although a JList will work properly by itself, most of the time you will wrap a JList inside a JScrollPane, which is a container that automatically provides scrolling for its contents. Here is the constructor that we will use:

\[
\text{JScrollPane}(\text{Component comp})
\]

Here, \( \text{comp} \) specifies the component to be scrolled, which in this case will be a JList. When you wrap a JList in a JScrollPane, long lists will automatically be scrollable. This 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, which is packaged in javax.swing.event. This listener specifies only one method, called valueChanged( ), which is shown here:

\[
\text{void valueChanged(ListSelectionEvent le)}
\]

Here, \( \text{le} \) is a reference to the object that generated the event. Although ListSelectionEvent does provide some methods of its own, often you will interrogate the JList object itself to determine what has occurred. ListSelectionEvent is also 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:

\[
\text{void setSelectionMode(int mode)}
\]

Here, \( \text{mode} \) specifies the selection mode. It must be one of these values defined by the ListSelectionModel interface (which is packaged in javax.swing):

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:
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.

You can obtain an array containing all selected items by calling `getSelectedIndices()`, shown next:

```java
int[ ] getSelectedIndices()
```

In the returned array, the indices are ordered from smallest to largest. If a zero-length array is returned, it means that no items are selected.

The following program demonstrates a simple `JList`, which holds a list of names. Each time a name 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 corresponding name. Sample output is shown in Figure 16-5.

```java
// Demonstrate a simple JList.

import javax.swing.*;
import javax.swing.event.*;
import java.awt.*;
import java.awt.event.*;

class ListDemo implements ListSelectionListener {

    JList<String> jlst;
    JLabel jlab;
    JScrollPane jscrlp;
```

ListDemo() { 
    // Create a new JFrame container.
    JFrame jfrm = new JFrame("JList Demo");

    // Specify a flow Layout.
    jfrm.setLayout(new FlowLayout());

    // Give the frame an initial size.
    jfrm.setSize(200, 160);

    // Terminate the program when the user closes the application.
    jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

    // Create a JList.
    jlst = new JList<String>(names); // Create the list.

    // Set the list selection mode to single-selection.
    jlst.setSelectionMode(ListSelectionModel.SINGLE_SELECTION); // Switch to single-selection mode.

    // Add list to a scroll pane.
    jscrlp = new JScrollPane(jlst); // Wrap the list in a scroll pane.

    // Set the preferred size of the scroll pane.
    jscrlp.setPreferredSize(new Dimension(120, 90));

    // Make a label that displays the selection.
    jlab = new JLabel("Please choose a name");

    // Add list selection handler.
    jlst.addListSelectionListener(this); // Listen for list selection events.

    // Add the list and label to the content pane.
    jfrm.add(jscrlp);
    jfrm.add(jlab);

    // Display the frame.
    jfrm.setVisible(true);
}

// Handle list selection events.
public void valueChanged(ListSelectionEvent le) { 
    // Get the index of the changed item.
    int idx = jlst.getSelectedIndex(); // Get the index of the selected/deselected item.
    }
Let's look closely at this program. First, notice the names array near the top of the program. It is initialized to a list of strings that contain various names. Inside ListDemo(), a JList called jlst is constructed using the names array. As mentioned, when the array constructor is used (as it is in this case), a JList instance is automatically created that contains the contents of the array. Thus, the list will contain the names in names.

Next, the selection mode is set to single selection. This means that only one item in this list can be selected at any one time. Then, jlst is wrapped inside a JScrollPane, and the preferred size of the scroll pane is set to 120 by 90. This makes for a compact, but easy-to-use scroll pane. In Swing, the setPreferredSize() method sets the ideal size of a component. Be aware that some layout managers are free to ignore this request, but most often the preferred size determines the size of the component.

A list selection event occurs whenever the user selects an item or changes the item selected. Inside the valueChanged() event handler, the index of the item selected is obtained by calling getSelectedIndex(). Because the list has been set to single-selection mode, this is also the index of the only item selected. This index is then used to index the names array to obtain the selected name. Notice that this index value is tested against –1. Recall that this is the value returned if no item has been selected. This will be the case when the selection event handler is called if the user has deselected an item. Remember: A selection event is generated when the user selects or deselects an item.

Try This 16-1  A Swing-Based File Comparison Utility

Although you know only a small amount about Swing, you can still put it to use to create a practical application. In Try This 10-1, you created a console-based file comparison utility. This project creates a Swing-based version of the program. As you will see, giving this application a Swing-based user interface substantially improves its appearance and makes it easier to use. Here is how the
Swing version looks:

Because Swing streamlines the creation of GUI-based programs, you might be surprised by how easy it is to create this program.

1. Begin by creating a file called SwingFC.java and then enter the following comment and import statements:

```java
/*
   Try This 16-1

   A Swing-based file comparison utility.

*/

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import java.io.*;
```

2. Next, begin the SwingFC class, as shown here:

```java
class SwingFC implements ActionListener {

    JTextField jtfFirst; // holds the first file name
    JTextField jtfSecond; // holds the second file name
    JButton jbtnComp; // button to compare the files
    JLabel jlabFirst, jlabSecond; // displays prompts
    JLabel jlabResult; // displays results and error messages

    The names of the files to compare are entered into the text fields defined by jtfFirst and jtfSecond. To compare the files, the user presses the jbtnComp button. Prompting messages are displayed in jlabFirst and jlabSecond. The results of the comparison, or any error messages, are displayed in jlabResult.

3. Code the SwingFC constructor like this:
Most of the code in this constructor should be familiar to you. However, notice one thing: an action listener is added only to the push button `jbtnCompare`. Action listeners are not added to the text fields. Here’s why: the contents of the text fields are needed only when the Compare button is pushed. At no other time are their contents required. Thus, there is no reason to respond to any text field events. As you begin to write more Swing programs, you will find that this is often the case when using a text field.

4. Begin creating the `actionPerformed()` event handler, as shown next. This method is called when the Compare button is pressed.
The method begins by confirming that the user has entered a file name into each of the text fields. If this is not the case, the missing file name is reported and the handler returns.

5. Now, finish `actionPerformed()` by adding the code that actually opens the files and then compares them.

```java
try (FileInputStream f1 = new FileInputStream(jtfFirst.getText());
     FileInputStream f2 = new FileInputStream(jtfSecond.getText()))

    // Check the contents of each file.
    do {
        i = f1.read();
        j = f2.read();
        if(i != j) break;
    } while(i != -1 && j != -1);

    if(i != j)
        jlabResult.setText("Files are not the same.");
    else
        jlabResult.setText("Files compare equal.");

    } catch (IOException exc) {
        jlabResult.setText("File Error");
    }
```

6. Finish `SwingFC` by adding the following `main()` method.

```java
public static void main(String args[]) {
    // Create the frame on the event dispatching thread.
    SwingUtilities.invokeLater(new Runnable() {
        public void run() {
            new SwingFC();
        }
    });
}
```
7. The entire Swing-based file comparison program is shown here:

```java
/*
 * Try This 16-1

 A Swing-based file comparison utility.

*/

import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import java.io.*;

class SwingFC implements ActionListener {

    JTextField jtfFirst;  // holds the first file name
    JTextField jtfSecond;  // holds the second file name

    JButton jbtnComp; // button to compare the files

    JLabel jlabFirst, jlabSecond; // displays prompts
    JLabel jlabResult; // displays results and error messages

    SwingFC() {

        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Compare Files");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());
    }

}```
// Give the frame an initial size.
jfrm.setSize(200, 190);

// Terminate the program when the user closes the application.
jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

// Create the text fields for the file names.
JTextField jtfFirst = new JTextField(14);
JTextField jtfSecond = new JTextField(14);

// Set the action commands for the text fields.
jtfFirst.setActionCommand("fileA");
jtfSecond.setActionCommand("fileB");

// Create the Compare button.
JButton jbtnComp = new JButton("Compare");

// Add action listener for the Compare button.
jbtnComp.addActionListener(this);

// Create the labels.
JLabel jlabFirst = new JLabel("First file: ");
JLabel jlabSecond = new JLabel("Second file: ");
JLabel jlabResult = new JLabel(" ");

// Add the components to the content pane.
jfrm.add(jlabFirst);
jfrm.add(jtfFirst);
jfrm.add(jlabSecond);
jfrm.add(jtfSecond);
jfrm.add(jbtnComp);
jfrm.add(jlabResult);

// Display the frame.
jfrm.setVisible(true);
}

// Compare the files when the Compare button is pressed.
public void actionPerformed(ActionEvent ae) {
  int i=0, j=0;

  // First, confirm that both file names have
  // been entered.
  if(jtfFirst.getText().equals("")) {
    jlabResult.setText("First file name missing.");
    return;
  }
  if(jtfSecond.getText().equals("")) {
    jlabResult.setText("Second file name missing.");
    return;
  }
Use Anonymous Inner Classes or Lambda Expressions to Handle Events

Up to this point, the programs in this chapter have used a simple, straightforward approach to handling events in which the main class of the application has implemented the listener interface itself and all events are sent to an instance of that class. While this is perfectly acceptable, it is not the only way to handle events. For example, you could use separate listener classes. Thus, different classes could handle different events and these classes would be separate from the main class of the application. However, two other approaches offer powerful alternatives. First, you can implement listeners through the use of anonymous inner classes. Second, in some cases, you can use a lambda expression to handle an event. Let’s look at each approach.

Anonymous inner classes are inner classes that don’t have a name. Instead, an instance of the class is simply generated “on the fly” as needed. Anonymous inner classes make implementing some types of event handlers much easier. For example, given a JButton called jbtn, you could implement an action listener for it like this:

```java
jbtn.addActionListener(new ActionListener() {
    public void actionPerformed(ActionEvent ae) {
        // Handle action event here.
    }
});
```
Here, an anonymous inner class is created that implements the `ActionListener` interface. Pay special attention to the syntax. The body of the inner class begins after the `}` that follows `new ActionListener()`. Also notice that the call to `addActionListener()` ends with a `)` and a `;` just like normal. The same basic syntax and approach is used to create an anonymous inner class for any event handler. Of course, for different events, you specify different event listeners and implement different methods.

One advantage to using an anonymous inner class is that the component that invokes the class’ methods is already known. For instance, in the preceding example, there is no need to call `getActionCommand()` to determine what component generated the event, because this implementation of `actionPerformed()` will only be called by events generated by `jbtn`. You will see anonymous inner classes at work in the Swing applet shown in the following section.

In the case of an event whose listener defines a functional interface, you can handle the event by use of a lambda expression. For example, action events can be handled with a lambda expression because `ActionListener` defines only one abstract method, `actionPerformed()`. Using a lambda expression to implement `ActionListener` provides a compact alternative to explicitly declaring an anonymous inner class. For example, again assuming a `JButton` called `jbtn`, you could implement the action listener like this:

```java
jbtn.addActionListener((ae) -> {
    // Handle action event here.
});
```

As was the case with the anonymous inner class approach, the object that generates the event is known. In this case, the lambda expression applies only to the `jbtn` button.

Of course, in cases in which an event can be handled by use of a single expression, it is not necessary to use a block lambda. For example, here is an action event handler for the Up button in the `ButtonDemo` program shown earlier. It requires only an expression lambda.

```java
jbtnUp.addActionListener((ae) -> jlab.setText("You pressed Up.");
```

Notice how much shorter this code is compared with the original approach. It is also shorter than it would be if you explicitly used an anonymous inner class.

In general, you can use a lambda expression to handle an 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. To gain experience with each, try converting the event handlers in the foregoing examples to lambda expressions or anonymous inner classes.

**Create a Swing Applet**

The preceding example programs have been Swing-based applications. The second type of program that commonly uses Swing is the applet. Swing-based applets are similar to AWT-based applets described in Chapter 15, 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. Therefore, it includes
the various panes described earlier. As a result, 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 described in Chapter 15: init(), start(), stop(), and destroy(). Of course, you need to override only those methods that are needed by your applet.

In general, painting is accomplished differently in Swing than it is in the AWT. Thus, a Swing applet will not usually override the paint() method.

One other point: All interaction with components in a Swing applet must take place on the event-dispatching thread, as described in the preceding section. This threading issue applies to all Swing programs.

Here is an example of a Swing applet. It provides the same functionality as the push-button example shown earlier in this chapter, but it does so in applet form. It also uses anonymous inner classes to implement the action event handlers. Figure 16-6 shows the program when executed by appletviewer.

```
// 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=200 height=80>
</applet>
*/

public class MySwingApplet extends JApplet {
    JButton btnUp;
    JButton btnDown;
    JLabel jlab;

    // Initialize the applet.
    public void init() {
        //...
There are several 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. Notice that anonymous inner classes are used to implement the action event handlers.
can use these as a model for implementing other event handlers. One of the primary advantages is that
the object that causes the event is known because it is the object on which the anonymous inner class
is instantiated. Therefore, it is not necessary to obtain the action command to determine which button
generated the event. (Using a lambda expression would also provide the same advantage.) Finally, the
components are added to the content pane. Although this example is quite simple, this same general
approach can be used when building any Swing GUI that will be used by an applet.

Chapter 16 Self Test

1. In general, AWT components are heavyweight and Swing components are ____________.
2. Can the look and feel of a Swing component be changed? If so, what feature enables this?
3. What is the most commonly used top-level container for an application?
4. Top-level containers have several panes. To what pane are components added?
5. Show how to construct a label that contains the message "Select an entry from the list".
6. All interaction with GUI components must take place on what thread?
7. What is the default action command associated with a JButton? How can the action command be
   changed?
8. What event is generated when a push button is pressed?
9. Show how to create a text field that has 32 columns.
10. Can a JTextField have its action command set? If so, how?
11. What Swing component creates a check box? What event is generated when a check box is
    selected or deselected?
12. JList displays a list of items from which the user can select. True or False?
13. What event is generated when the user selects or deselects an item in a JList?
14. What method sets the selection mode of a JList? What method obtains the index of the first
    selected item?
15. To create a Swing-based applet, what class must you inherit?
16. Usually, Swing-based applets use invokeAndWait( ) to create the initial GUI. True or False?
17. Add a check box to the file comparer developed in Try This 15-1 that has the following text:
   Show position of mismatch. When this box is checked, have the program display the location of
   the first point in the files at which a mismatch occurs.
18. Change the ListDemo program so that it allows multiple items in the list to be selected.
19. Bonus challenge: Convert the Help class developed in Try This 4-1 into a Swing-based GUI
    program. Display the keywords (for, while, switch, and so on) in a JList. When the user selects
    one, display the keyword’s syntax. To display multiple lines of text within a label, you can use
    HTML. When doing so, you must begin the text with the sequence <html>.
text is automatically formatted as described by the markup. In addition to other benefits, using HTML enables you to create labels that span two or more lines. For example, this creates a label that displays two lines of text, with the string "Top" over the string "Bottom".

```
JLabel jlabhtml = new JLabel("<html>Top<br>Bottom</html>");
```

No answer is shown for this exercise. You have reached the point where you are ready to apply your Java skills on your own!
Chapter 17
Introducing JavaFX

Key Skills & Concepts
- Understand JavaFX’s concepts of a stage, a scene, a node, and a scene graph
- Know the JavaFX life-cycle methods
- Know the general form of a JavaFX application
- Understand how to launch a JavaFX application
- Create a Label
- Use Button
- Handle events
- Use CheckBox
- Work with ListView
- Create a TextField
- Add effects
- Apply transforms

In the fast-paced world of computing, change is constant, and the art and science of programming continue to evolve and advance. It should not then be surprising that Java’s GUI frameworks have
also participated in this process. Recall that Java’s original GUI framework was the AWT. It was soon followed by Swing, which offered a far superior approach. Although Swing has been very successful, it can be difficult to create the “visual sparkle” that many of today’s applications demand. Furthermore, the conceptual basis that underpins the design of GUI frameworks has advanced. To better handle the demands of the modern GUI and advances in GUI design, a new approach was needed. The result is JavaFX, Java’s next-generation GUI framework. This chapter provides an introduction to this powerful new system.

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 has been bundled with Java since JDK 7, update 4. The latest version of JavaFX is JavaFX 8, which is included 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, it refers to JavaFX 8.

Before we begin, it is useful to answer one question that naturally arises relating to JavaFX: Is JavaFX designed as a replacement for Swing? The answer is, essentially, Yes. However, Swing will be part of Java programming for some time to come. The reason is that there is a large amount of Swing legacy code. Furthermore, there are legions of programmers who know how to program for Swing. 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, and many Swing-based applications will migrate to JavaFX. Simply put: JavaFX is something that no Java programmer can afford to ignore.

NOTE
This chapter assumes that you have an understanding of GUI basics, including event handling, as introduced in Chapters 15 and 16.

JavaFX Basic Concepts
Before you can create a JavaFX application, there are several key concepts and features you must understand. Although JavaFX has similarities with Java’s other GUIs, the AWT and Swing, it has substantial differences. For example, like Swing, JavaFX components are lightweight and events are handled in an easy-to-manage, straightforward manner. However, the overall organization of JavaFX and the relationship of its main components differ significantly from either Swing or the AWT. Therefore, a careful reading of the following sections is recommended.

The JavaFX Packages
The JavaFX framework is 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 JavaFX 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. Each inherits Node. The layouts 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:

```java
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, it cannot, however, 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. 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 you use the program without creating a JAR file. Thus, it is included in the programs in this chapter.

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:
Although the skeleton is quite short, it can be compiled and run. It produces an empty window. However, 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 four 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: 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 programs in this chapter.

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( ):

myStage.setTitle("JavaFX Skeleton.");

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 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.
The following line uses the root node to construct a Scene:

```java
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:

```java
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:

```java
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:

```java
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 scene.

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, such as an HTML file or a Java Network Launch Protocol (JNLP) file.

In general, a JavaFX program is compiled like any other Java program. However, depending on the target execution environment, some additional steps may be required. For this reason, often the easiest way to compile a JavaFX application is to use an Integrated Development Environment (IDE) that fully supports JavaFX programming. If you just want to compile and test the JavaFX applications shown in this chapter, you can easily do so using the command-line tools. Just compile and run the application in the normal way, using javac and java. This creates a stand-alone application that runs on the desktop.
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 `stop()` method is also called on the application thread.

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 or an image. 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.

The `Label` constructor that we will use is shown here:

```java
Label(String str)
```

The string that is displayed is specified by `str`.

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 is part of Java’s Collections Framework. `List` defines a collection that represents a list of objects. Although a discussion of `List` and the Collections Framework is beyond the scope of this book, it is easy to use `ObservableList` to add child nodes. Simply call `add()` on the list of child nodes returned by `getChildren()`, passing in a reference to the node to add, which in this case is a label.

The following program puts the preceding discussion into action by creating a simple JavaFX application that displays a label:
Ask the Expert

Q: You have explained how to add a node to the scene graph. Is there a way to remove one?

A: Yes, 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. In general, `ObservableList` supports a wide range of list-management methods. Here are two examples. You can determine if the list is empty by calling
You can obtain the number of nodes in the list by calling `size()`. You will want to explore `ObservableList` on your own as you advance in your study of JavaFX.

This program produces the following window:

![Image](image.png)

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.

### 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. Event handling is important because 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 as shown in the preceding chapter, but it’s more streamlined. 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 introduce event handling in JavaFX. For this reason, the fundamentals of event handling and the button are described 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 encapsulates 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.
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)
```

In this case, `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).

### 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 example, we will use text-based buttons.

The `Button` constructor we will use is shown here:

```java
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 calling `setOnAction()` on the button. It has this general form:

```java
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 and the `Button` control. It uses two buttons and a label. The buttons are called Up and Down. Each time a button is pressed, the content of the label is set to display which button was pressed. Thus, it functions similarly to the `JButton` example in the preceding chapter. You might find it interesting to compare the code for each.
// 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("Use JavaFX Buttons and Events.");

        // 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, 300, 100);
    }
}
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 btnUp = new Button("Up");
Button btnDown = new Button("Down");
```

This creates two text-based buttons. The first displays the string Up; the second displays Down.

Next, an action event handler is set for each of these buttons. The sequence for the Up button is shown here:
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 Up button was pressed. Notice that this is done by calling the `setText()` method on the label. Events are handled by the Down button in the same way.

After the event handlers have been set, the `response` label and the buttons `btnUp` and `btnDown` are added to the scene graph by using a call to `addAll()`:

```java
rootNode.getChildren().addAll(btnUp, btnDown, 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 was 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. For example, here is the handler for the Up button, rewritten to use a lambda:

```java
btnUp.setOnAction((ae) ->
        response.setText("You pressed Up."));
```
Notice that the lambda expression is more compact than the anonymous inner class. (You will use lambda expressions when you modify this example as part of exercise 10 in the Self Test.)

Three More JavaFX Controls
JavaFX defines a rich set of controls, which are packaged in `javafx.scene.control`. You have already seen two of them: Label and Button. Here, we will look at three more: CheckBox, ListView, and TextField. As their names imply, they support a check box, a list control, and a text field. Combined, these provide a representative sampling of the JavaFX controls. They also help demonstrate several common techniques. Once you understand the basics, you will be able to explore the other controls on your own.

The controls described here provide functionality similar to that of the Swing controls presented by the preceding Swing chapter. As you work through this section, you might find it interesting to compare the way these controls are implemented by the two frameworks.

CheckBox
In JavaFX, the check box is encapsulated by the `CheckBox` class. Its immediate superclass is `ButtonBase`. Thus it is a special type of button. 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`). This state 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. To use the indeterminate state, you will need to explicitly enable it. This procedure is demonstrated in Try This 17-1. Here, we will examine the `CheckBox`’s traditional operation.

Here is the `CheckBox` constructor that we will use:

```
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.

The following program demonstrates check boxes. It displays four check boxes that represent different types of computers. They are labeled Smartphone, Tablet, Notebook, and Desktop. Each time a check-box state changes, an action event is generated. It is handled by displaying the new state (selected or cleared) and by displaying a list of all selected boxes.

```
// 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 CheckboxesDemo extends Application {

    CheckBox cbSmartphone;
    CheckBox cbTablet;
    CheckBox cbNotebook;
    CheckBox cbDesktop;

    Label response;
    Label selected;

    String computers;

    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 Check Boxes");

        // Use a vertical FlowPane for the root node. In this case,
        // vertical and horizontal gaps of 10.
        FlowPane rootNode = new FlowPane(Orientation.VERTICAL, 10, 10);

        // Center the controls in the scene.
        rootNode.setAlignment(Pos.CENTER);

        // Create a scene.
        Scene myScene = new Scene(rootNode, 230, 200);

        // Set the scene on the stage.
        myStage.setScene(myScene);

        Label heading = new Label("What Computers Do You Own?");

        // Create a label that will report the state change of a check box.
        response = new Label("\n");

        // Create a label that will report all selected check boxes.
        selected = new Label("\n");
    }
}
// Create the check boxes.
cbSmartphone = new CheckBox("Smartphone");
cbTablet = new CheckBox("Tablet");
cbNotebook = new CheckBox("Notebook");
cbDesktop = new CheckBox("Desktop");

// Handle action events for the check boxes.
cbSmartphone.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(cbSmartphone.isSelected())
            response.setText("Smartphone was just selected.");
        else
            response.setText("Smartphone was just cleared.");
        showAll();
    }
});

cbTablet.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(cbTablet.isSelected())
            response.setText("Tablet was just selected.");
        else
            response.setText("Tablet was just cleared.");
        showAll();
    }
});

cbNotebook.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(cbNotebook.isSelected())
            response.setText("Notebook was just selected.");
        else
            response.setText("Notebook was just cleared.");
        showAll();
    }
});

cbDesktop.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        if(cbDesktop.isSelected())
            response.setText("Desktop was just selected.");
        else
            response.setText("Desktop was just cleared.");
        showAll();
    }
});
The operation of this program is straightforward. Each time a check box is changed, an ActionEvent is generated. The handlers for these events first report whether the check box was selected or cleared. To do this, they call the isSelected() method on the event source. It returns true if the check box was just selected, and false if it was just cleared. Next, the showAll() method is called, which displays all selected check boxes.

There is one other point of interest in the program. Notice that it uses a vertical flow pane for the layout, as shown here:

```java
FlowPane rootNode = new FlowPane(Orientation.VERTICAL, 10, 10);
```

By default, FlowPane flows horizontally. A vertical flow is created by passing the value Orientation.VERTICAL as the first argument to the FlowPane constructor.

**Try This 17-1** Use the CheckBox Indeterminate State
As explained, by default, **CheckBox** implements two states: checked and unchecked. However, **CheckBox** also supports a third, indeterminate state, which can be used to indicate that the state of the box has not yet been set or that an option is not applicable to a situation. The indeterminate state for a check box must be explicitly enabled. It is not provided by default. Also, the event handler for the check box must also handle the indeterminate state. The project illustrates the process. It does so by adding support for the indeterminate state to the **Smartphone** check box in **CheckboxDemo** program, just shown.

1. To enable the indeterminate state in a check box, call `setAllowIndeterminate()`, shown here:
   ```java
   final void setAllowIndeterminate(boolean enable)
   ``
   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. Therefore, to enable the indeterminate state on the **Smartphone** check box, add this line:
   ```java
   cbSmartphone.setAllowIndeterminate(true);
   ```

2. To determine if a check box is in the indeterminate state, call `isIndeterminate()`, shown here:
   ```java
   final boolean isIndeterminate()
   ``
   It returns `true` if the check box state is indeterminate and `false` otherwise. The event handler for the check box will need to test for the indeterminate state. To do so, add it to the **Smartphone** event handler, as shown here:
   ```java
   cbSmartphone.setOnAction(new EventHandler<ActionEvent>() {
       public void handle(ActionEvent ae) {
           if (cbSmartphone.isIndeterminate())
               response.setText("Smartphone state is indeterminate.");
           else if (cbSmartphone.isSelected())
               response.setText("Smartphone was just selected.");
           else
               response.setText("Smartphone was just cleared.");

           showAll();
       }
   });
   ```

3. After making these changes, compile and run the program. Now, you can set the state of the **Smartphone** check box to indeterminate, as shown here:
Another commonly used control is the list view, which in JavaFX is encapsulated by `ListView`. A `ListView` can display a list of entries from which you can select one or more. One very useful feature of `ListView` is that scrollbars are automatically added when the number of items in the list exceeds the number that can be displayed within the control’s dimensions. Because of its ability to make efficient use of limited screen space, `ListView` is a popular alternative to other types of selection controls.

`ListView` is a generic class that is declared like this:

```java
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.

Here is the `ListView` constructor that we will use:

```java
ListView(ObservableList<T> list)
```

The list of items to be displayed is specified by `list`. It is an object of type `ObservableList`. As explained earlier, `ObservableList` supports a list of objects. By default, a `ListView` allows only one item in the list to be selected at any one time. You can allow multiple selections by changing the selection mode, but we will use the default, single-selection mode.

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 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`.

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:
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:

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.

A change listener is supported by the ChangeListener interface, which is packaged in javafx.beans.value. The ChangeListener interface defines only one method, called changed(). It is shown here:

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 list item that has just been selected.

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:

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:

final ReadOnlyObjectProperty<T> selectedItemProperty( )

You will add the change listener to this property by using the addListener() method on the returned property. The addListener() method is shown here:

void addListener(ChangeListener<? super T> listener)

In this case, T specifies the type of the property.

The following example puts the preceding discussion into action. It creates a list view that displays a list of computer types, allowing the user to select one. When one is chosen, the selection is displayed.
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.*;

public 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);

        // Center the controls in the scene.
        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 Computer Type");

        // Create an ObservableList of entries for the list view.
        ObservableList<String> computerTypes =
                FXCollections.observableArrayList("Smartphone", "Tablet", "Notebook",
                                                        "Desktop");
    }
}
Sample output is shown here.

Notice that a vertical scroll bar has been included so that the list can be scrolled to see all of its entries. As mentioned, when the contents of a ListView exceed its size, a scroll bar is automatically added. This makes ListView a very convenient control.

In the program, pay special attention to how the ListView is constructed. First, an ObservableList is created by this line:

```java
ObservableList<String> computerTypes = FXCollections.observableArrayList("Smartphone", "Tablet", "Notebook", "Desktop");
```

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> lvComputers = new ListView<String>(computerTypes);
```
The program then sets the preferred width and height of the control.

Now, notice how the selection model is obtained for \texttt{lvComputers}:

```java
MultipleSelectionModel<String> lvSelModel =
    lvComputers.getSelectionModel();
```

As explained, \texttt{ListView} uses \texttt{MultipleSelectionModel}, even when only a single selection is allowed. The \texttt{selectedItemProperty()} method is then called on the model and a change listener is registered, as shown here:

```java
lvSelModel.selectedItemProperty().addListener(
    new ChangeListener<String>() {
        public void changed(ObservableValue<? extends String> changed,
            String oldVal, String newVal) {
            // Display the selection.
            response.setText("Computer selected is " + newVal);
        }
    });
```

As a point of interest, the same basic mechanism used to listen for and handle change events can be applied to any control that generates change events.

---

**Ask the Expert**

**Q:** How do I enable multiple selections in a \texttt{ListView}?

**A:** When using a \texttt{ListView}, 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 by calling \texttt{setSelectionMode()} on the \texttt{ListView} model. It is shown here:

```java
final void setSelectionMode(SelectionMode mode)
```

In this case, \texttt{mode} must be either \texttt{SelectionMode.MULTIPLE} or \texttt{SelectionMode.SINGLE}. To enable multiple selections, use \texttt{SelectionMode.MULTIPLE}.

One way to get a list of the selected items is to call \texttt{getSelectedItems()} on the selection model. It is shown here:

```java
ObservableList<T> getSelectedItems()
```

It returns an \texttt{ObservableList} of the items. You could then cycle through the returned list using a \texttt{for} for each \texttt{for}, for example, to examine the items.

---

**TextField**
Controls such as Button, CheckBox, and ListView are, obviously, quite useful, but they all implement a means of selecting a predetermined option or action. Sometimes, however, 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 JavaFX 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 of a TextField 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 name. When the user presses ENTER while the text field has input focus, or presses the Get Name button, the string is obtained and displayed. Notice that a prompting message is also included.

```java
// 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 state of the
        // selected check box.
        response = new Label("Enter Name: ");

        // Create a button that gets the text.
        Button btnGetText = new Button("Get Name");

        // Create a text field.
        tf = new TextField(); // Create a text field.

        // Set the prompt.
        tf.setPromptText("Enter a name."); // Set the text field
        // prompting message.

        // Set preferred column count.
        tf.setPrefColumnCount(15); // Set the text field
        // column width.

        // Use a lambda expression to handle action events for the
        // text field. Action events are generated when ENTER is
Sample output is shown here:

![Sample output](image)

In the program, notice that lambda expressions are used as event handlers. Each handler consists of a single method call. This makes them perfect candidates for lambda expressions.

Ask the Expert

Q: What other text controls does JavaFX support?

A: Other text controls include **TextArea**, which supports multiline text, and **PasswordField**, which can be used to input passwords. You might also find **HTMLEditor** helpful.
ease with which effects and/or transforms can be used in JavaFX is one of its strongest features. Although the topic of effects and transforms is quite large, 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 the 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 to 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)
```

In this case, `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: **Reflection** and **BoxBlur**. However, the process of adding an effect is essentially the same no matter what effect you choose.

**BoxBlur** blurs the node on which it is used. It is called **BoxBlur** because it uses a blurring technique based on adjusting pixels within a rectangular region. The amount of blurring is under your control. To use a blur effect, you must first create a **BoxBlur** instance. **BoxBlur** supplies two constructors. Here is the constructor that we will use:

```java
BoxBlur(double width, double height, int iterations)
```

Here, `width` and `height` specify the size of box into which a pixel will be blurred. These values must be between 0 and 255, inclusive. Typically, these values are at the lower end of this range. The number of times that the blur effect is applied is specified by `iterations`, which must be between 0 and 3, inclusive. A default constructor is also supported, which sets the width and height to 5.0 and the iterations to 1.

After a **BoxBlur** instance has been created, the width and height of the box can be changed by using `setWidth( )` and `setHeight( )`, shown here:
final void setWidth(double width)
final void setHeight(double height)

The number of iterations can be changed by calling setIterations():
final void setIterations(int iterations)

By using these methods, you can change the blur effect during the execution of your program.

**Reflection** produces an effect that simulates a reflection of the node on which it is called. It is particularly useful on text, such as that contained in a label. **Reflection** gives you significant control over how the reflection will look. For example, you can set the opacity of both the top and the bottom of the reflection. You can also set the space between the image and its reflection, and the amount reflected. These can set by the following **Reflection** constructor:

Reflection(double offset, double fraction, double topOpacity, double bottomOpacity)

Here, `offset` specifies the distance between the bottom of the image and its reflection. The amount of the reflection that is shown is specified as a fraction, specified by `fraction`. It must be between 0 and 1.0. The top and bottom opacity is specified by `topOpacity` and `bottomOpacity`. Both must be between 0 and 1.0. A default constructor is also supplied, which sets the offset to 0, the amount to 0.75, the top opacity to 0.5, and the bottom opacity to 0.

The offset, amount shown, and opacities can also be changed during program execution. For example, the opacities are set using `setTopOpacity()` and `setBottomOpacity()`, shown here:

final void setTopOpacity(double opacity)
final void setBottomOpacity(double opacity)

The offset is changed by calling `setTopOffset()`:

final void setTopOffset(double offset)

The amount of the reflection displayed can be set by calling `setFraction()`:

final void setFraction(double amount)

These methods let you adjust the reflection during program execution.

**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 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:

    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 transforms may also be supported by the platform.) However, using the transforms list offers the greatest flexibility, and that is the approach demonstrated here.

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 through a specified angle around a specified point. These values can be set when a `Rotate` instance is created. For example, here is one `Rotate` constructor:

    Rotate(double angle, double x, double y)

In this case, `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 the rotation values after a `Rotate` object has been created, which is what the demonstration program shown in the next section will do. This is done by using the `setAngle()`, `setPivotX()`, and `setPivotY()` methods, shown here:

    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`. Using these methods, you can rotate a node during program execution. This can create a very dramatic effect.

`Scale` scales a node as specified by a scale factor. Thus, it changes a node’s size. `Scale` defines several constructors. Here is the one that we will use:

    Scale(double widthFactor, double heightFactor)

In this case, `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)
As before, \textit{widthFactor} specifies the scaling factor applied to the node’s width, and \textit{heightFactor} specifies the scaling factor applied to the node’s height. You might use these methods to change the size of a control during program execution, possibly to draw attention to it.

**Demonstrating Effects and Transforms**

The following program demonstrates the use of effects and transforms. It does so by creating three buttons and a label. The buttons are called Rotate, Scale, and Blur. Each time one of these buttons is pressed, the corresponding effect or transform is applied to the button. Specifically, each time you press Rotate, the button is rotated by 15 degrees. Each time you press Scale, the button size is changed. Each time you press Blur, the button is progressively blurred. The label illustrates the reflection effect. 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, reflection, and blurring.

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 scaleFactor = 0.4;
    double blurVal = 1.0;
```
// Create initial effects and transforms.
Reflection reflection = new Reflection();
BoxBlur blur = new BoxBlur(1.0, 1.0, 1);
Rotate rotate = new Rotate();
Scale scale = new Scale(scaleFactor, scaleFactor);

// Create push buttons.
Button btnRotate = new Button("Rotate");
Button btnBlur = new Button("Blur off");
Button btnScale = new Button("Scale");

Label reflect = new Label("Reflection Adds Visual Sparkle");

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 20 are used.
    FlowPane rootNode = new FlowPane(20, 20);

    // Center the controls in the scene.
    rootNode.setAlignment(Pos.CENTER);

    // Create a scene.
    Scene myScene = new Scene(rootNode, 300, 120);

    // Set the scene on the stage.
    myStage.setScene(myScene);

    // 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);

    // Set the reflection effect on the reflection label.
    reflection.setTopOpacity(0.7);
    reflection.setBottomOpacity(0.3);
    reflect.setEffect(reflection);

    // Handle the action events for the Rotate button.
    btnRotate.setOnAction(new EventHandler<ActionEvent>() {
        public void handle(ActionEvent ae) {
            // Add rotation to the btnRotate button.
            Add rotation to the btnRotate button.

            // Add scaling to the btnScale button.
            Add scaling to the btnScale button.

            // Set Reflection on the reflect label.
            Set Reflection on the reflect label.
        }
    });
// Each time a button is pressed, it is rotated 30 degrees
// around its center.
angle += 15.0;
rotate.setAngle(angle);
rotate.setPivotX(btnRotate.getWidth()/2);
rotate.setPivotY(btnRotate.getHeight()/2);
}
});

// Handle the action events for the Scale button.
btnScale.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        // Each time button is pressed, the button's scale is changed.
scaleFactor += 0.1;
        if(scaleFactor > 2.0) scaleFactor = 0.4;

        scale.setX(scaleFactor);
        scale.setY(scaleFactor);
    }
});

// Handle the action events for the Blur button.
btnBlur.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        // Each time button is pressed, its blur status is changed.
        if(blurVal == 10.0) {
            blurVal = 1.0;
            btnBlur.setEffect(null);
            btnBlur.setText("Blur off");
        } else {
            blurVal++;
            btnBlur.setEffect(blur);
            btnBlur.setText("Blur on");
        }
        blur.setWidth(blurVal);
        blur.setHeight(blurVal);
    }
});

// Add the label and buttons to the scene graph.
rootNode.getChildren().addAll(btnRotate, btnScale, btnBlur, reflect);

// Show the stage and its scene.
myStage.show();

Sample output is shown here:
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.

What Next?
Congratulations! If you have read and worked through the preceding 17 chapters, then you can call yourself a Java programmer. Of course, there are still many, many things to learn about Java, its libraries, and its subsystems, but you now have a solid foundation upon which you can build your knowledge and expertise.

Here are a few of the topics that you will want to learn more about:

- JavaFX and Swing—both are an important part of today’s Java programming environment.
- Event handling.
- Java’s networking classes.
- Java’s utility classes, especially its Collections Framework, which simplifies a number of common programming tasks.
- The Concurrent API, which offers detailed control over high-performance multithreaded applications.
- Java Beans, which supports the creation of software components in Java.
- Native methods.
- Servlets. If you will be writing high-powered web applications, then you will want to learn about servlets. Servlets are to the server what applets are to the browser.

To continue your study of Java, I recommend my book Java: The Complete Reference, Ninth Edition (Oracle Press/McGraw-Hill Professional, 2014). In it, you will find comprehensive coverage of the Java language, its key libraries, and many more example programs.

Chapter 17 Self Test

1. What is the top-level package name of the JavaFX framework?
2. Two concepts central to JavaFX are a stage and a scene. What classes encapsulate them?
3. A scene graph is composed of ________.
4. The base class for all nodes is ________.
5. What class will all JavaFX applications extend?
6. What are the three JavaFX life-cycle methods?
7. In what life-cycle method can you construct an application’s stage?
8. The `launch()` method is called to start a free-standing JavaFX application. True or False?

9. What are the names of the JavaFX classes that support a label and a button?

10. One way to terminate a free-standing JavaFX application is to call `Platform.exit()`. `Platform` is packaged in `javafx.Application`. When called, `exit()` immediately terminates the program. With this in mind, change the `JavaFXEventDemo` program shown in this chapter so that it has two buttons called Run and Exit. If Run is pressed, have the program display that choice in a label. If Exit is pressed, have the application terminate. Use lambda expressions for the event handlers.

11. What `JavaFX` control implements a check box?

12. `ListView` is a control that displays a directory list of files on the local file system. True or False?

13. Convert the Swing-based file comparison program in Try This 16-1 so it uses JavaFX instead. In the process, make use of another of JavaFX’s features: its ability to fire an action event on a button under program control. This is done by calling `fire()` on the button instance. For example, assuming a `Button` called `myButton`, the following will fire an action event on it: `myButton.fire()`. Use this fact when implementing the event handlers for the text fields that hold the names of the files to compare. If the user presses `ENTER` when in either of these fields, simply fire an action event on the Compare button. The event-handling code for the Compare button will then handle the file comparison.

14. Modify the `EffectsAndTransformsDemo` program so the Rotate button is also blurred. Use a blur width and height of 5 and an iteration count of 2.

15. On your own, experiment with other effects and transforms. For example, try the `Glow` effect and the `Translate` transform.

16. Continue to advance in your knowledge of Java. A good way to start is by examining Java’s core packages, such as `java.lang`, `java.util`, and `java.net`. Write sample programs that demonstrate their various classes and interfaces. In general, the best way to become a great Java programmer is to write lots of code.
Appendix A
Answers to Self Tests

Chapter 1: Java Fundamentals

1. What is bytecode and why is it important to Java’s use for Internet programming?
   Bytecode is a highly optimized set of instructions that is executed by the Java Virtual Machine. byteCode helps Java achieve both portability and security.

2. What are the three main principles of object-oriented programming?
   Encapsulation, polymorphism, and inheritance.

3. Where do Java programs begin execution?
   Java programs begin execution at main().

4. What is a variable?
   A variable is a named memory location. The contents of a variable can be changed during the execution of a program.

5. Which of the following variable names is invalid?
   The invalid variable is D. Variable names cannot begin with a digit.

6. How do you create a single-line comment? How do you create a multiline comment?
   A single-line comment begins with // and ends at the end of the line. A multiline comment begins with /* and ends with */.

7. Show the general form of the if statement. Show the general form of the for loop.
   The general form of the if:
if(condition) statement;

The general form of the for:

for(initialization; condition; iteration) statement;

8. How do you create a block of code?

A block of code is started with a { and ended with a }.

9. The moon’s gravity is about 17 percent that of the earth’s. Write a program that computes your effective weight on the moon.

```java
/*
   Compute your weight on the moon.
   Call this file Moon.java.
*/
class Moon {
   public static void main(String args[]) {
      double earthweight; // weight on earth
      double moonweight; // weight on moon
      earthweight = 165;
      moonweight = earthweight * 0.17;
      System.out.println(earthweight +
         " earth-pounds is equivalent to " +
         moonweight + " moon-pounds.");
   }
}
```

10. Adapt Try This 1-2 so that it prints a conversion table of inches to meters. Display 12 feet of conversions, inch by inch. Output a blank line every 12 inches. (One meter equals approximately 39.37 inches.)
11. If you make a typing mistake when entering your program, what sort of error will result?
   A syntax error.

12. Does it matter where on a line you put a statement?
   No, Java is a free-form language.

Chapter 2: Introducing Data Types and Operators

1. Why does Java strictly specify the range and behavior of its primitive types?
   Java strictly specifies the range and behavior of its primitive types to ensure portability across platforms.

2. What is Java’s character type, and how does it differ from the character type used by some other programming languages?
   Java’s character type is `char`. Java characters are Unicode rather than ASCII, which is used by some other computer languages.

3. A `boolean` value can have any value you like because any non-zero value is true. True or False?
   False. A boolean value must be either `true` or `false`.

4. Given this output,
use a single string to show the `println()` statement that produced it.

```java
System.out.println("One\nTwo\nThree");
```

5. What is wrong with this fragment?

```java
for(i = 0; i < 10; i++) {
    int sum;

    sum = sum + i;
}
System.out.println("Sum is: " + sum);
```

There are two fundamental flaws in the fragment. First, `sum` is created each time the block defined by the `for` loop is entered and destroyed on exit. Thus, it will not hold its value between iterations. Attempting to use `sum` to hold a running sum of the iterations is pointless. Second, `sum` will not be known outside of the block in which it is declared. Thus, the reference to it in the `println()` statement is invalid.

6. Explain the difference between the prefix and postfix forms of the increment operator.

   When the increment operator precedes its operand, Java will perform the increment prior to obtaining the operand’s value for use by the rest of the expression. If the operator follows its operand, then Java will obtain the operand’s value before incrementing.

7. Show how a short-circuit AND can be used to prevent a divide-by-zero error.

   ```java
   if((b != 0) && (val / b)) ... 
   ```

8. In an expression, what type are `byte` and `short` promoted to?

   In an expression, `byte` and `short` are promoted to `int`.

9. In general, when is a cast needed?

   A cast is needed when converting between incompatible types or when a narrowing conversion is occurring.

10. Write a program that finds all of the prime numbers between 2 and 100.
Does the use of redundant parentheses affect program performance?

No.

Does a block define a scope?

Yes.

Chapter 3: Program Control Statements

Write a program that reads characters from the keyboard until a period is received. Have the program count the number of spaces. Report the total at the end of the program.
2. Show the general form of the if-else-if ladder.

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

3. Given

```java
if(x < 10)
  if(y > 100) {
    if(!done) x = z;
    else y = z;
  }
else System.out.println("error"); // what if?
to what if does the last else associate?
```

The last else associates with if(y > 100).

4. Show the for statement for a loop that counts from 1000 to 0 by –2.

```java
for(int i = 1000; i >= 0; i -= 2) // ...
```

5. Is the following fragment valid?
for(int i = 0; i < num; i++)
    sum += i;

count = i;
No; i is not known outside of the for loop in which it is declared.

6. Explain what **break** does. Be sure to explain both of its forms.

   A **break** without a label causes termination of its immediately enclosing loop or **switch**
   statement. A **break** with a label causes control to transfer to the end of the labeled block.

7. In the following fragment, after the **break** statement executes, what is displayed?

   ```java
   for(i = 0; i < 10; i++) {
       while(running) {
           if(x<y) break;
           // ...
       }
       System.out.println("after while");
   }
   System.out.println("After for");
   ```

   After **break** executes, “after while” is displayed.

8. What does the following fragment print?

   ```java
   for(int i = 0; i<10; i++) {
       System.out.print(i + " ");
       if((i%2) == 0) continue;
       System.out.println();
   }
   ```

   Here is the answer:
   0 1
   2 3
   4 5
   6 7
   8 9

9. The iteration expression in a for loop need not always alter the loop control variable by a fixed
   amount. Instead, the loop control variable can change in any arbitrary way. Using this concept,
   write a program that uses a **for** loop to generate and display the progression 1, 2, 4, 8, 16, 32,
   and so on.
The ASCII lowercase letters are separated from the uppercase letters by 32. Thus, to convert a lowercase letter to uppercase, subtract 32 from it. Use this information to write a program that reads characters from the keyboard. Have it convert all lowercase letters to uppercase, and all uppercase letters to lowercase, displaying the result. Make no changes to any other character. Have the program stop when the user enters a period. At the end, have the program display the number of case changes that have taken place.

```java
// Change case.
class CaseChg {
    public static void main(String args[]) throws java.io.IOException {
        char ch;
        int changes = 0;

        System.out.println("Enter period to stop.");

        do {
            ch = (char) System.in.read();
            if(ch >= 'a' & ch <= 'z') {
                ch -= 32;
                changes++;
            System.out.println(ch);
            }
            else if(ch >= 'A' & ch <= 'Z') {
                ch += 32;
                changes++;
            System.out.println(ch);
            }
        } while(ch != '.');
 System.out.println("Case changes: " + changes);
    }
}
```

11. What is an infinite loop?
An infinite loop is a loop that runs indefinitely.
12. When using `break` with a label, must the label be on a block that contains the `break`?
   Yes.

Chapter 4: Introducing Classes, Objects, and Methods

1. What is the difference between a class and an object?
   A class is a logical abstraction that describes the form and behavior of an object. An object is a physical instance of the class.

2. How is a class defined?
   A class is defined by using the keyword `class`. Inside the `class` statement, you specify the code and data that comprise the class.

3. What does each object have its own copy of?
   Each object of a class has its own copy of the class’ instance variables.

4. Using two separate statements, show how to declare an object called `counter` of a class called `MyCounter`.
   
   ```java
   MyCounter counter;
   counter = new MyCounter();
   ```

5. Show how a method called `myMeth()` is declared if it has a return type of `double` and has two `int` parameters called `a` and `b`.
   ```java
   double myMeth(int a, int b) { // ...
   ```

6. How must a method return if it returns a value?
   A method that returns a value must return via the `return` statement, passing back the return value in the process.

7. What name does a constructor have?
   A constructor has the same name as its class.

8. What does `new` do?
   The `new` operator allocates memory for an object and initializes it using the object’s constructor.

9. What is garbage collection and how does it work? What is `finalize()`?
   Garbage collection is the mechanism that recycles unused objects so that their memory can be reused. An object’s `finalize()` method is called just prior to an object being recycled.

10. What is `this`?
    The `this` keyword is a reference to the object on which a method is invoked. It is automatically passed to a method.

11. Can a constructor have one or more parameters?
    Yes.

12. If a method returns no value, what must its return type be?
    `void`
Chapter 5: More Data Types and Operators

1. Show two ways to declare a one-dimensional array of 12 doubles.
   
   ```java
   double x[] = new double[12];
   double[] x = new double[12];
   ```

2. Show how to initialize a one-dimensional array of integers to the values 1 through 5.
   
   ```java
   int x[] = { 1, 2, 3, 4, 5 }
   ```

3. Write a program that uses an array to find the average of ten doubles values. Use any ten values you like.
   
   ```java
   // Average 10 double values.
   class Avg {
       public static void main(String args[]) {
           double nums[] = { 1.1, 2.2, 3.3, 4.4, 5.5,
                             6.6, 7.7, 8.8, 9.9, 10.1 };

           double sum = 0;
           for(int i=0; i < nums.length; i++)
               sum += nums[i];

           System.out.println("Average: " + sum / nums.length);
       }
   }
   ```

4. Change the sort in Try This 5-1 so that it sorts an array of strings. Demonstrate that it works.
5. What is the difference between the String methods `indexOf()` and `lastIndexOf()`?

The `indexOf()` method finds the first occurrence of the specified substring. `lastIndexOf()` finds the last occurrence.

6. Since all strings are objects of type String, show how you can call the `length()` and `charAt()` methods on this string literal: "I like Java".

As strange as it may look, this is a valid call to `length()`:

```java
System.out.println("I like Java".length());
```

The output displayed is 11. `charAt()` is called in a similar fashion.

7. Expanding on the Encode cipher class, modify it so that it uses an eight-character string as the key.
8. Can the bitwise operators be applied to the `double` type?
   No.

9. Show how this sequence can be rewritten using the ? operator.
   ```java
   if(x < 0) y = 10;
   else y = 20;
   Here is the answer:
   y = x < 0 ? 10 : 20;
   ```

10. In the following fragment, is the & a bitwise or logical operator? Why?
    ```java
    boolean a, b;
    // ...
    if(a & b) ...
    ```
    It is a logical operator because the operands are of type `boolean`.

11. Is it an error to overrun the end of an array?
    Yes.
Is it an error to index an array with a negative value? 
Yes. All array indexes start at zero.

12. What is the unsigned right-shift operator?

>>> 

13. Rewrite the MinMax class shown earlier in this chapter so that it uses a for-each style for loop.

```java
// Find the minimum and maximum values in an array.
class MinMax {
    public static void main(String args[]) {
        int nums[] = new int[10];
        int min, max;

        nums[0] = 99;
        nums[1] = -10;
        nums[2] = 100123;
        nums[3] = 18;
        nums[4] = -978;
        nums[5] = 5623;
        nums[6] = 463;
        nums[7] = -9;
        nums[8] = 287;
        nums[9] = 49;

        min = max = nums[0];
        for(int v : nums) {
            if(v < min) min = v;
            if(v > max) max = v;
        }
        System.out.println("min and max: " + min + " " + max);
    }
}
```

14. Can the for loops that perform sorting in the Bubble class shown in Try This 5-1 be converted into for-each style loops? If not, why not?

No, the for loops in the Bubble class that perform the sort cannot be converted into for-each style loops. In the case of the outer loop, the current value of its loop counter is needed by the inner loop. In the case of the inner loop, out-of-order values must be exchanged, which implies assignments. Assignments to the underlying array cannot take place when using a for-each style loop.

15. Can a String control a switch statement?

   Beginning with JDK 7, the answer is Yes.

Chapter 6: A Closer Look at Methods and Classes

1. Given this fragment,
```java
class X {
    private int count;
```
is the following fragment correct?

class Y {
    public static void main(String args[]) {
        X ob = new X();

        ob.count = 10;
    }
}

No; a **private** member cannot be accessed outside of its class.

2. An access modifier must __________ a member’s declaration.
   
   precede

3. The complement of a queue is a stack. It uses first-in, last-out accessing and is often likened to a stack of plates. The first plate put on the table is the last plate used. Create a stack class called **Stack** that can hold characters. Call the methods that access the stack **push( )** and **pop( )**. Allow the user to specify the size of the stack when it is created. Keep all other members of the **Stack** class private. (Hint: You can use the **Queue** class as a model; just change the way that the data is accessed.)
// A stack class for characters.
class Stack {
    private char stck[]; // this array holds the stack
    private int tos; // top of stack

    // Construct an empty Stack given its size.
    Stack(int size) {
        stck = new char[size]; // allocate memory for stack
        tos = 0;
    }

    // Construct a Stack from a Stack.
    Stack(Stack ob) {
        tos = ob.tos;
        stck = new char[ob.stck.length];

        // copy elements
        for(int i=0; i < tos; i++)
            stck[i] = ob.stck[i];
    }

    // Construct a stack with initial values.
    Stack(char a[]) {
        stck = new char[a.length];

        for(int i = 0; i < a.length; i++) {
            push(a[i]);
        }
    }

    // Push characters onto the stack.
    void push(char ch) {
        if(tos==stck.length) {
            System.out.println(" -- Stack is full.");
            return;
        }

        stck[tos] = ch;
        tos++;
    }

    // Pop a character from the stack.
    char pop() {
        if(tos==0) {

Here is the output from the program:

Contents of stk1: JIHGFEDCBA
Contents of stk2: moT
Contents of stk3: JIHGFEDCBA
4. Given this class,
   ```java
class Test {
    int a;
    Test(int i) { a = i; }
}
```
write a method called `swap()` that exchanges the contents of the objects referred to by two `Test` object references.
```java
void swap(Test ob1, Test ob2) {
    int t;

    t = ob1.a;
    ob1.a = ob2.a;
    ob2.a = t;
}
```

5. Is the following fragment correct?
   ```java
class X {
    int meth(int a, int b) { ... }
    String meth(int a, int b) { ... }
}
```
   No. Overloaded methods can have different return types, but they do not play a role in overload resolution. Overloaded methods **must** have different parameter lists.

6. Write a recursive method that displays the contents of a string backwards.
   ```java
   // Display a string backwards using recursion.
   class Backwards {
     String str;

     Backwards(String s) {
       str = s;
     }

     void backward(int idx) {
       if(idx != str.length()-1) backward(idx+1);

       System.out.print(str.charAt(idx));
     }
   }
   class BWDemo {
     public static void main(String args[]) {
       Backwards s = new Backwards("This is a test");

       s.backward(0);
     }
   }
   ```

7. If all objects of a class need to share the same variable, how must you declare that variable?
Shared variables are declared as **static**.

8. Why might you need to use a static block?
   
   A static block is used to perform any initializations related to the class, before any objects are created.

9. What is an inner class?
   
   An inner class is a nonstatic nested class.

10. To make a member accessible by only other members of its class, what access modifier must be used?
    
    **private**

11. The name of a method plus its parameter list constitutes the method’s __________.
    
    signature

12. An int argument is passed to a method by using call-by-__________.
    
    value

13. Create a varargs method called sum() that sums the int values passed to it. Have it return the result. Demonstrate its use.
    
    There are many ways to craft the solution. Here is one:

    ```java
    class SumIt {
        int sum(int ... n) {
            int result = 0;
            for(int i = 0; i < n.length; i++)
                result += n[i];
            return result;
        }
    }
    
    class SumDemo {
        public static void main(String args[]) {
            SumIt siObj = new SumIt();
            int total = siObj.sum(1, 2, 3);
            System.out.println("Sum is " + total);
            total = siObj.sum(1, 2, 3, 4, 5);
            System.out.println("Sum is " + total);
        }
    }
    
    14. Can a varargs method be overloaded?
    
    Yes.
15. Show an example of an overloaded varargs method that is ambiguous.

Here is one example of an overloaded varargs method that is ambiguous:

```java
double myMeth(double ... v) { // ...

double myMeth(double d, double ... v) { // ...
```

If you try to call `myMeth( )` with one argument, like this,

```java
myMeth(1.1);
```

the compiler can’t determine which version of the method to invoke.

Chapter 7: Inheritance

1. Does a superclass have access to the members of a subclass? Does a subclass have access to the members of a superclass?

   No, a superclass has no knowledge of its subclasses. Yes, a subclass has access to all nonprivate members of its superclass.

2. Create a subclass of `TwoDShape` called `Circle`. Include an `area( )` method that computes the area of the circle and a constructor that uses `super` to initialize the `TwoDShape` portion.

   ```java
   // A subclass of TwoDShape for circles.
   class Circle extends TwoDShape {
       // A default constructor.
       Circle() {
           super();
       }

       // Construct Circle
       Circle(double x) {
           super(x, "circle"); // call superclass constructor
       }

       // Construct an object from an object.
       Circle(Circle ob) {
           super(ob); // pass object to TwoDShape constructor
       }

       double area() {
           return (getWidth() / 2) * (getWidth() / 2) * 3.1416;
       }
   }
   ```

3. How do you prevent a subclass from having access to a member of a superclass?

   To prevent a subclass from having access to a superclass member, declare that member as `private`.

4. Describe the purpose and use of the two versions of `super` described in this chapter.

   The `super` keyword has two forms. The first is used to call a superclass constructor. The general
form of this usage is
   super (param-list);

The second form of **super** is used to access a superclass member. It has this general form:
   super . member

5. Given the following hierarchy, in what order do the constructors for these classes complete their execution when a **Gamma** object is instantiated?
   
   ```java
   class Alpha { ... 
   class Beta extends Alpha { ... 
   Class Gamma extends Beta { ... 
   }
   ```

   Constructors complete their execution in order of derivation. Thus, when a **Gamma** object is created, the order is **Alpha, Beta, Gamma**.

6. A superclass reference can refer to a subclass object. Explain why this is important as it is related to method overriding.

   When an overridden method is called through a superclass reference, it is the type of the object being referred to that determines which version of the method is called.

7. What is an abstract class?

   An abstract class contains at least one abstract method.

8. How do you prevent a method from being overridden? How do you prevent a class from being inherited?

   To prevent a method from being overridden, declare it as **final**. To prevent a class from being inherited, declare it as **final**.

9. Explain how inheritance, method overriding, and abstract classes are used to support polymorphism.

   Inheritance, method overriding, and abstract classes support polymorphism by enabling you to create a generalized class structure that can be implemented by a variety of classes. Thus, the abstract class defines a consistent interface that is shared by all implementing classes. This embodies the concept of “one interface, multiple methods.”

10. What class is a superclass of every other class?

    The **Object** class.

11. A class that contains at least one abstract method must, itself, be declared abstract. True or False?

    True.

12. What keyword is used to create a named constant?

    **final**
Chapter 8: Packages and Interfaces

1. Using the code from Try This 8-1, put the ICharQ interface and its three implementations into a package called qpack. Keeping the queue demonstration class IQDemo in the default package, show how to import and use the classes in qpack.

To put ICharQ and its implementations into the qpack package, you must separate each into its own file, make each implementation class public, and add this statement to the top of each file.

```java
package qpack;
import qpack.*;
```

2. What is a namespace? Why is it important that Java allows you to partition the namespace?

A namespace is a declarative region. By partitioning the namespace, you can prevent name collisions.

3. Packages are stored in directories.

4. Explain the difference between protected and default access.

A member with protected access can be used within its package and by a subclass in any package.

A member with default access can be used only within its package.

5. Explain the two ways that the members of a package can be used by other packages.

To use a member of a package, you can either fully qualify its name, or you can import it using import.

6. “One interface, multiple methods” is a key tenet of Java. What feature best exemplifies it?

The interface best exemplifies the one interface, multiple methods principle of OOP.

7. How many classes can implement an interface? How many interfaces can a class implement?

An interface can be implemented by an unlimited number of classes. A class can implement as many interfaces as it chooses.

8. Can interfaces be extended?

Yes, interfaces can be extended.

9. Create an interface for the Vehicle class from Chapter 7. Call the interface IVehicle.
Variables declared in an interface are implicitly **static** and **final**. Can they be shared with other parts of a program?

Yes, interface variables can be used as named constants that are shared by all files in a program. They are brought into view by importing their interface.

A package is, in essence, a container for classes. True or False?

True.

What standard Java package is automatically imported into a program?

java.lang

What keyword is used to declare a default interface method?

default

Beginning with JDK 8, is it possible to define a static method in an interface?

Yes

Assume that the ICharQ interface shown in Try This 8-1 has been in widespread use for several years. Now, you want to add a method to it called **reset()**, which will be used to reset the queue to its empty, starting condition. Assuming JDK 8 or later, how can this be accomplished without breaking preexisting code?

To avoid breaking preexisting code, you must use a default interface method. Because you can’t know how to reset each queue implementation, the default **reset()** implementation will need to report an error that indicates that it is not implemented. (The best way to do this is to use an exception. Exceptions are examined in the following chapter.) Fortunately, since no preexisting code assumes that ICharQ defines a **reset()** method, no preexisting code will encounter that error, and no preexisting code will be broken.

How is a static method in an interface called?

A static interface method is called through its interface name, by use of the dot operator.
Chapter 9: Exception Handling

1. What class is at the top of the exception hierarchy?

   Throwable is at the top of the exception hierarchy.

2. Briefly explain how to use try and catch.

   The try and catch statements work together. Program statements that you want to monitor for exceptions are contained within a try block. An exception is caught using catch.

3. What is wrong with this fragment?

   ```java
   // ... 
   vals[18] = 10;
   catch (ArrayIndexOutOfBoundsException exc) {
       // handle error
   }
   ```

   There is no try block preceding the catch statement.

4. What happens if an exception is not caught?

   If an exception is not caught, abnormal program termination results.

5. What is wrong with this fragment?

   ```java
   class A extends Exception {
   ...
   }

   class B extends A {
   ...
   }

   // ...
   try {
       // ...
   } catch (A exc) {
       // ...
   } catch (B exc) {
       // ...
   }
   ```

   In the fragment, a superclass catch precedes a subclass catch. Since the superclass catch will catch all subclasses too, unreachable code is created.

6. Can an inner catch rethrow an exception to an outer catch?

   Yes, an exception can be rethrown.

7. The finally block is the last bit of code executed before your program ends. True or False?

   Explain your answer.

   False. The finally block is the code executed when a try block ends.

8. What type of exceptions must be explicitly declared in a throws clause of a method?

   All exceptions except those of type RuntimeException and Error must be declared in a throws clause.

9. What is wrong with this fragment?
MyClass does not extend Throwable. Only subclasses of Throwable can be thrown by throw.

10. In question 3 of the Chapter 6 Self Test, you created a Stack class. Add custom exceptions to your class that report stack full and stack empty conditions.

   // An exception for stack-full errors.
   class StackFullException extends Exception {
       int size;

       StackFullException(int s) { size = s; }

       public String toString() {
           return "\nStack is full. Maximum size is " +
                   size;
       }
   }

   // An exception for stack-empty errors.
   class StackEmptyException extends Exception {

       public String toString() {
           return "\nStack is empty.";
       }
   }
11. What are the three ways that an exception can be generated?

An exception can be generated by an error in the JVM, by an error in your program, or explicitly via a `throw` statement.

12. What are the two direct subclasses of `Throwables`?

`Error` and `Exception`
13. What is the multi-catch feature?

The multi-catch feature allows one `catch` clause to catch two or more exceptions.

14. Should your code typically catch exceptions of type `Error`?

No.

Chapter 10: Using I/O

1. Why does Java define both byte and character streams?

   The byte streams are the original streams defined by Java. They are especially useful for binary I/O, and they support random-access files. The character streams are optimized for Unicode.

2. Even though console input and output is text-based, why does Java still use byte streams for this purpose?

   The predefined streams, `System.in`, `System.out`, and `System.err`, were defined before Java added the character streams.

3. Show how to open a file for reading bytes.

   Here is one way to open a file for byte input:
   ```java
   FileInputStream fin = new FileInputStream("test");
   ```

4. Show how to open a file for reading characters.

   Here is one way to open a file for reading characters:
   ```java
   FileReader fr = new FileReader("test");
   ```

5. Show how to open a file for random-access I/O.

   Here is one way to open a file for random access:
   ```java
   RandomAccessFile randfile = new RandomAccessFile("test", "rw");
   ```

6. How do you convert a numeric string such as "123.23" into its binary equivalent?

   To convert numeric strings into their binary equivalents, use the parsing methods defined by the type wrappers, such as `Integer` or `Double`.

7. Write a program that copies a text file. In the process, have it convert all spaces into hyphens. Use the byte stream file classes. Use the traditional approach to closing a file by explicitly calling `close()`.
/* Copy a text file, substituting hyphens for spaces.

This version uses byte streams.

To use this program, specify the name
of the source file and the destination file.
For example,

java Hyphen source target
*/

import java.io.*;

class Hyphen {
    public static void main(String args[]) {
        int i;
        FileInputStream fin = null;
        FileOutputStream fout = null;

        // First make sure that both files have been specified.
        if(args.length != 2) {
            System.out.println("Usage: Hyphen From To");
            return;
        }

        // Copy file and substitute hyphens.
        try {
            fin = new FileInputStream(args[0]);
            fout = new FileOutputStream(args[1]);

            do {
                i = fin.read();

                // convert space to a hyphen
                if((char)i == ' ') i = '-';

                if(i != -1) fout.write(i);
            } while(i != -1);

            catch (IOException exc) {
                System.out.println("I/O Error: " + exc);
            }
        } finally {
            try {
                if(fin != null) fin.close();
            } catch (IOException exc) {
                System.out.println("Error closing input file.");
            }

            try {
                if(fout != null) fout.close();
            } catch (IOException exc) {
                System.out.println("Error closing output file.");
            }
        }
    }
}
8. Rewrite the program in question 7 so that it uses the character stream classes. This time, use the try-with-resources statement to automatically close the file.

/* Copy a text file, substituting hyphens for spaces.

This version uses character streams.

To use this program, specify the name of the source file and the destination file.
For example,

java Hyphen2 source target

*/

import java.io.*;

class Hyphen2 {
    public static void main(String args[])
        throws IOException
    {
        int i;

        // First make sure that both files have been specified.
        if(args.length !=2 ) {
            System.out.println("Usage: CopyFile From To");
            return;
        }

        // Copy file and substitute hyphens.
        // Use the try-with-resources statement.
        try (FileReader fin = new FileReader(args[0]);
            FileWriter fout = new FileWriter(args[1]))
        {
            do {
                i = fin.read();
                // convert space to a hyphen
                if((char)i == ' ') i = '-';

                if(i != -1) fout.write(i);
            } while(i != -1);
            catch(IOException exc) {
                System.out.println("I/O Error: " + exc);
            }
        }
    }
}

9. What type of stream is System.in?

InputStream

10. What does the read() method of InputStream return when the end of the stream is reached?

-1

11. What type of stream is used to read binary data?
DataInputStream

12. Reader and Writer are at the top of the ____________ class hierarchies.
character-based I/O

13. The try-with-resources statement is used for ____________ ____________ ____________.
automatic resource management

14. If you are using the traditional method of closing a file, then closing a file within a finally block
is generally a good approach. True or False?

True

Chapter 11: Multithreaded Programming

1. How does Java’s multithreading capability enable you to write more efficient programs?

Multithreading allows you to take advantage of the idle time that is present in nearly all
programs. When one thread can’t run, another can. In multicore systems, two or more threads can
execute simultaneously.

2. Multithreading is supported by the ____________ class and the ____________ interface.

Multithreading is supported by the Thread class and the Runnable interface.

3. When creating a runnable object, why might you want to extend Thread rather than implement Runnable?

You will extend Thread when you want to override one or more of Thread’s methods other than
run( ).

4. Show how to use join( ) to wait for a thread object called MyThrd to end.

MyThrd.join();

5. Show how to set a thread called MyThrd to three levels above normal priority.

MyThrd.setPriority(Thread.NORM_PRIORITY+3);

6. What is the effect of adding the synchronized keyword to a method?

Adding synchronized to a method allows only one thread at a time to use the method for any
given object of its class.

7. The wait( ) and notify( ) methods are used to perform ____________________.

interthread communication

8. Change the TickTock class so that it actually keeps time. That is, have each tick take one half
second, and each tock take one half second. Thus, each tick-tock will take one second. (Don’t
worry about the time it takes to switch tasks, etc.)

To make the TickTock class actually keep time, simply add calls to sleep(), as shown here:
// Make the TickTock class actually keep time.

class TickTock {

    String state; // contains the state of the clock

    synchronized void tick(boolean running) {
        if(!running) { // stop the clock
            state = "ticked";
            notify(); // notify any waiting threads
            return;
        }

        System.out.print("Tick ");

        // wait 1/2 second
        try {
            Thread.sleep(500);
        } catch(InterruptedException exc) {
            System.out.println("Thread interrupted.");
        }

        state = "ticked"; // set the current state to ticked
        notify(); // let tock() run
        try {
            while(!state.equals("tocked"))
                wait(); // wait for tock() to complete
        } catch(InterruptedException exc) {
            System.out.println("Thread interrupted.");
        }
    }
}
9. Why can’t you use `suspend()`, `resume()`, and `stop()` for new programs?

The `suspend()`, `resume()`, and `stop()` methods have been deprecated because they can cause serious run-time problems.

10. What method defined by `Thread` obtains the name of a thread?

   `getName()`

11. What does `isAlive()` return?

   It returns `true` if the invoking thread is still running, and `false` if it has been terminated.

Chapter 12: Enumerations, Autoboxing, Static Import, and Annotations

1. Enumeration constants are said to be `self-typed`. What does this mean?

   In the term `self-typed`, the “self” refers to the type of the enumeration in which the constant is defined. Thus, an enumeration constant is an object of the enumeration of which it is a part.

2. What class do all enumerations automatically inherit?
The `Enum` class is automatically inherited by all enumerations.

3. Given the following enumeration, write a program that uses `values()` to show a list of the constants and their ordinal values.

```java
enum Tools {
    SCREWDRIVER, WRENCH, HAMMER, PLIERS
}

The solution is

```java
enum Tools {
    SCREWDRIVER, WRENCH, HAMMER, PLIERS
}

class ShowEnum {
    public static void main(String args[]) {
        for(Tools d : Tools.values()) {
            System.out.print(d + " has ordinal value of " +
                d.ordinal() + '\n');
        }
    }
}
```

4. The traffic light simulation developed in Try This 12-1 can be improved with a few simple changes that take advantage of an enumeration’s class features. In the version shown, the duration of each color was controlled by the `TrafficLightSimulator` class by hard-coding these values into the `run()` method. Change this so that the duration of each color is stored by the constants in the `TrafficLightColor` enumeration. To do this, you will need to add a constructor, a private instance variable, and a method called `getDelay()`. After making these changes, what improvements do you see? On your own, can you think of other improvements? (Hint: Try using ordinal values to switch light colors rather than relying on a `switch` statement.)

The improved version of the traffic light simulation is shown here. There are two major improvements. First, a light’s delay is now linked with its enumeration value, which gives more structure to the code. Second, the `run()` method no longer needs to use a `switch` statement to determine the length of the delay. Instead, `sleep()` is passed `tlc.getDelay()`, which causes the delay associated with the current color to be used automatically.

```java
// An improved version of the traffic light simulation that
// stores the light delay in TrafficLightColor.

// An enumeration of the colors of a traffic light.
enum TrafficLightColor {
    RED(12000), GREEN(10000), YELLOW(2000);

    private int delay;

    TrafficLightColor(int d) {
        delay = d;
    }
```
int getDelay() { return delay; }

// A computerized traffic light.
class TrafficLightSimulator implements Runnable {
    private Thread thrd; // holds the thread that runs the simulation
    private TrafficLightColor tlc; // holds the current traffic light color
    boolean stop = false; // set to true to stop the simulation
    boolean changed = false; // true when the light has changed

    TrafficLightSimulator(TrafficLightColor init) {
        tlc = init;

        thrd = new Thread(this);
        thrd.start();
    }

    TrafficLightSimulator() {
        tlc = TrafficLightColor.RED;

        thrd = new Thread(this);
        thrd.start();
    }

    // Start up the light.
    public void run() {
        while(!stop) {
            // Notice how this code has been simplified!
            try {
                Thread.sleep(tlc.getDelay());
            } catch(InterruptedException exc) {
                System.out.println(exc);
            }

            changeColor();
        }
    }

    // Change color.
    synchronized void changeColor() {
        switch(tlc) {
            case RED:
                tlc = TrafficLightColor.GREEN;
                break;
            case YELLOW:
                tlc = TrafficLightColor.RED;
                break;
            case GREEN:
                tlc = TrafficLightColor.YELLOW;
        }

        changed = true;
        notify(); // signal that the light has changed
    }
5. Define boxing and unboxing. How does autoboxing/unboxing affect these actions?

Boxing is the process of storing a primitive value in a type wrapper object. Unboxing is the process of retrieving the primitive value from the type wrapper. Autoboxing automatically boxes a primitive value without having to explicitly construct an object. Auto-unboxing automatically retrieves the primitive value from a type wrapper without having to explicitly call a method, such as `intValue()`.

6. Change the following fragment so that it uses autoboxing.

```java
Short val = new Short(123);
```

The solution is

```java
Short val = 123;
```

7. In your own words, what does static import do?

Static import brings into the global namespace the static members of a class or interface. This means that static members can be used without having to be qualified by their class or interface.
8. What does this statement do?
   import static java.lang.Integer.parseInt;
   The statement brings into the global namespace the `parseInt()` method of the type wrapper `Integer`.

9. Is static import designed for special-case situations, or is it good practice to bring all static members of all classes into view?
   Static import is designed for special cases. Bringing many static members into view will lead to namespace collisions and destructure your code.

10. An annotation is syntactically based on a/an ________________.
    interface

11. What is a marker annotation?
    A marker annotation is one that does not take arguments.

12. An annotation can be applied only to methods. True or False?
    False. Any type of declaration can have an annotation. Beginning with JDK 8, a type use can also have an annotation.

Chapter 13: Generics

1. Generics are important to Java because they enable the creation of code that is
   A. Type-safe
   B. Reusable
   C. Reliable
   D. All of the above
   D. All of the above

2. Can a primitive type be used as a type argument?
   No, type arguments must be object types.

3. Show how to declare a class called `FlightSched` that takes two generic parameters.
   The solution is
   ```java
   class FlightSched<T, V> {
   }
   ```

4. Beginning with your answer to question 3, change `FlightSched`'s second type parameter so that it must extend `Thread`.
   The solution is
   ```java
   class FlightSched<T, V extends Thread> {
   }
   ```

5. Now, change `FlightSched` so that its second type parameter must be a subclass of its first type parameter.
   The solution is
   ```java
   class FlightSched<T, V extends T> {
   }
6. As it relates to generics, what is the ? and what does it do?
   The ? is the wildcard argument. It matches any valid type.

7. Can the wildcard argument be bounded?
   Yes, a wildcard can have either an upper or lower bound.

8. A generic method called MyGen( ) has one type parameter. Furthermore, MyGen( ) has one
   parameter whose type is that of the type parameter. It also returns an object of that type
   parameter. Show how to declare MyGen( ).

   The solution is
   
   <T> T MyGen(T o) { // ...

9. Given this generic interface
   interface IGenIF<T, V extends T> { // ...
   show the declaration of a class called MyClass that implements IGenIF.

   The solution is
   
   class MyClass<T, V extends T> implements IGenIF<T, V> { // ...

10. Given a generic class called Counter<T>, show how to create an object of its raw type.
    
    To obtain Counter<T>’s raw type, simply use its name without any type specification, as shown
    here:
    Counter x = new Counter;

11. Do type parameters exist at run time?
    
    No. All type parameters are erased during compilation, and appropriate casts are substituted.
    This process is called erasure.

12. Convert your solution to question 10 of the Self Test for Chapter 9 so that it is generic. In the
    process, create a stack interface called IGenStack that generically defines the operations push( )
    and pop( ).

    // A generic stack.

    interface IGenStack<T> {
       void push(T obj) throws StackFullException;
       T pop() throws StackEmptyException;
   }

    // An exception for stack-full errors.
    class StackFullException extends Exception {
       int size;

       StackFullException(int s) { size = s; }
    }
}
public String toString() {
    return "\nStack is full. Maximum size is " +
    size;
}

// An exception for stack-empty errors.
class StackEmptyException extends Exception {
    public String toString() {
        return "\nStack is empty.";
    }
}

// A stack class for characters.
class GenStack<T> implements IGenStack<T> {
    private T stk[]; // this array holds the stack
    private int tos; // top of stack

    // Construct an empty stack given its size.
    GenStack(T[] stkArray) {
        stk = stkArray;
        tos = 0;
    }

    // Construct a stack from a stack.
    GenStack(T[] stkArray, GenStack<T> ob) {
        tos = ob.tos;
        stk = stkArray;

        try {
            if(stk.length < ob.stk.length)
                throw new StackFullException(stk.length);
        }
        catch(StackFullException exc) {
            System.out.println(exc);
        }

        // Copy elements.
        for(int i=0; i < tos; i++)
            stk[i] = ob.stk[i];
    }

    // Construct a stack with initial values.
    GenStack(T[] stkArray, T[] a) {
        stk = stkArray;

        for(int i = 0; i < a.length; i++) {
            try {

            }
```java
push(a[i]);
}
catch(StackFullException exc) {
    System.out.println(exc);
}
}

// Push objects onto the stack.
public void push(T obj) throws StackFullException {
    if(tos==stack.length)
        throw new StackFullException(stack.length);

    stack[tos] = obj;
    tos++;
}

// Pop an object from the stack.
public T pop() throws StackEmptyException {
    if(tos==0)
        throw new StackEmptyException();

    tos--;
    return stack[tos];
}

// Demonstrate the GenStack class.
class GenStackDemo {
    public static void main(String args[]) {
        // Construct 10-element empty Integer stack.
        Integer iStore[] = new Integer[10];
        GenStack<Integer> stk1 = new GenStack<Integer>(iStore);

        // Construct stack from array.
        String name[] = {"One", "Two", "Three"};
        String strStore[] = new String[3];
        GenStack<String> stk2 =
            new GenStack<String>(strStore, name);

        String str;
        int n;

        try {
            // Put some values into stk1.
            for(int i=0; i < 10; i++)
                stk1.push(i);
```
13. What is `<>`?

The diamond operator.

14. How can the following be simplified?

```java
MyClass<Double, String> obj = new MyClass<Double, String>(1.1, "Hi");
```

It can be simplified by use of the diamond operator as shown here:

```java
MyClass<Double, String> obj = new MyClass<>((1.1, "Hi");
```

Chapter 14: Lambda Expressions and Method References
1. What is the lambda operator?
   The lambda operator is →.

2. What is a functional interface?
   A functional interface is an interface that contains one and only one abstract method.

3. How do functional interfaces and lambda expressions relate?
   A lambda expression provides the implementation for the abstract method defined by the functional interface. The functional interface defines the target type.

4. What are the two general types of lambda expressions?
   The two types of lambda expressions are expression lambdas and block lambdas. An expression lambda specifies a single expression, whose value is returned by the lambda. A block lambda contains a block of code. Its value is specified by a return statement.

5. Show a lambda expression that returns true if a number is between 10 and 20, inclusive.
   (n) -> (n > 9 && n < 21)

6. Create a functional interface that can support the lambda expression you created in question 5. Call the interface MyTest and its abstract method testing().
   ```java
   interface MyTest {
     boolean testing(int n);
   }
   ```

7. Create a block lambda that computes the factorial of an integer value. Demonstrate its use. Use NumericFunc, shown in this chapter, for the functional interface.
   ```java
   interface NumericFunc {
     int func(int n);
   }

   class FactorialLambdaDemo {
     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 3 is " + factorial.func(5));
       System.out.println("The factorial of 5 is " + factorial.func(9));
     }
   }
   ```

8. Create a generic functional interface called MyFunc<T>. Call its abstract method func(). Have
func() return a reference of type T. Have it take a parameter of type T. (Thus, MyFunc will be a generic version of NumericFunc shown in the chapter.) Demonstrate its use by rewriting your answer to 7 so it uses MyFunc<T> rather than NumericFunc.

interface MyFunc<T> {
    T func(T n);
}

class FactorialLambdaDemo {
    public static void main(String args[]) {
        // This block lambda computes the factorial of an int value.
        MyFunc<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.func(3));
        System.out.println("The factorial of 3 is " + factorial.func(5));
        System.out.println("The factorial of 5 is " + factorial.func(9));
    }
}

9. Using the program shown in Try This 14-1, create a lambda expression that removes all spaces from a string and returns the result. Demonstrate this method by passing it to changeStr(). Here is the lambda expression that removes spaces. It is used to initialize the remove reference variable.

```
StringFunc remove = (str) -> {
    String result = "";
    for(int i = 0; i < str.length(); i++)
        if(str.charAt(i) != ' ') result += str.charAt(i);
    return result;
};
```

Here is an example of its use:

```
outStr = changeStr(remove, instr);
```

10. Can a lambda expression use a local variable? If so, what constraint must be met?

Yes, but the variable must be effectively final.

11. If a lambda expression throws a checked exception, the abstract method in the functional interface must have a throws clause that includes that exception. True or False?

True
12. What is a method reference?
   A method reference is a way to refer to a method without executing it.

13. When evaluated, a method reference creates an instance of the ____________ ____________
    supplied by its target context.

14. Given a class called MyClass that contains a static method called myStaticMethod(), show
    how to specify a method reference to myStaticMethod().

    MyClass::myStaticMethod

15. Given a class called MyClass that contains an instance method called myInstMethod() and
    assuming an object of MyClass called mcObj, show how to create a method reference to
    myInstMethod() on mcObj.

    mcObj::myInstMethod

16. To the MethodRefDemo2 program, add a new method to MyIntNum called
    hasCommonFactor(). Have it return true if its int argument and the value stored in the invoking
    MyIntNum object have at least one factor in common. For example, 9 and 12 have a common
    factor, which is 3, but 9 and 16 have no common factor. Demonstrate hasCommonFactor() via
    a method reference.

    Here is MyIntNum with the hasCommonFactor() method added:

    ```java
    class MyIntNum {
        private int v;

        MyIntNum(int x) { v = x; }

        int getNum() { return v; }

        // Return true if n is a factor of v.
        boolean isFactor(int n) {
            return (v % n) == 0;
        }

        boolean hasCommonFactor(int n) {
            for(int i=2; i < v/i; i++)
                if( ((v % i) == 0) && ((n % i) == 0) ) return true;
            return false;
        }
    }
    ```

    Here is an example of its use through a method reference:

    ```java
    ip = myNum::hasCommonFactor;
    result = ip.test(9);
    if(result) System.out.println("Common factor found.");
    ```

17. How is a constructor reference specified?
A constructor reference is created by specifying the class name followed by :: followed by new. For example, MyClass::new.

18. Java defines several predefined functional interfaces in what package?
   
   java.util.function

Chapter 15: Applets, Events, and Miscellaneous Topics

1. What method is called when an applet first begins running? What method is called when an applet is removed from the system?

   When an applet begins, the first method called is init(). When an applet is removed, destroy() is called.

2. Explain why an applet must use multithreading if it needs to run continually.

   An applet must use multithreading if it needs to run continually because applets are event-driven programs which must not enter a “mode” of operation. For example, if start() never returns, then paint() will never be called.

3. Enhance Try This 15-1 so that it displays the string passed to it as a parameter. Add a second parameter that specifies the time delay (in milliseconds) between each rotation.

   /* A simple banner applet that uses parameters.
   *
   import java.awt.*;
   import java.applet.*;
   */

   <applet code="ParamBanner" width=300 height=50>
public class ParamBanner extends Applet implements Runnable {
    String msg;
    int delay;
    Thread t;
    boolean stopFlag;

    // Initialize t to null.
    public void init() {
        String temp;

        msg = getParameter("message");
        if (msg == null) msg = "Java Rules the Web ";

        temp = getParameter("delay");

        try {
            if (temp != null)
                delay = Integer.parseInt(temp);
            else
                delay = 250; // default if not specified
        } catch (NumberFormatException exc) {
            delay = 250; // default on error
        }

        t = null;
    }

    // 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(delay);
                if(stopFlag)
                    break;
            }
        }
    }
}
4. Extra challenge: Create an applet that displays the current time, updated once per second.

To accomplish this, you will need to do a little research. Here is a hint to help you get started:
One way to obtain the current time is to use a Calendar object, which is part of the java.util package. (Remember, Oracle provides online documentation for all of Java’s standard classes.) You should now be at the point where you can examine the Calendar class on your own and use its methods to solve this problem.

// A simple clock applet.

import java.util.*;
import java.awt.*;
import java.applet.*;
/*
<object code="Clock" width=200 height=50>
</object>
*/

public class Clock extends Applet implements Runnable {
    String msg;
    Thread t;
    Calendar clock;

    boolean stopFlag;

    // Initialize
    public void init() {
5. Briefly explain Java’s delegation event model.

In the delegation event model, a source generates an event and sends it to one or more listeners. A listener simply waits until it receives an event. Once received, the listener processes the event and then returns.

6. Must an event listener register itself with a source?

Yes; a listener must register with a source to receive events.

7. Extra challenge: Another of Java’s display methods is `drawLine()` . It draws a line in the currently selected color between two points. It is part of the Graphics class. Using `drawLine()` ,
write a program that tracks mouse movement. If the button is pressed, have the program draw a
continuous line until the mouse button is released.

/* Track mouse motion by drawing a line
   when a mouse button is pressed. */

import java.awt.*;
import java.awt.event.*;
import java.applet.*/

<applet code="TrackM" width=300 height=100>
</applet>

public class TrackM extends Applet
   implements MouseListener, MouseMotionListener {

   int curX = 0, curY = 0; // current coordinates
   int oldX = 0, oldY = 0; // previous coordinates
   boolean draw;

   public void init() {
      addMouseListener(this);
      addMouseMotionListener(this);
      draw = false;
   }

   // The next three methods are not used, but must
   // be null-implemented because they are defined
   // by MouseListener. */

   // Handle mouse entered.
   public void mouseEntered(MouseEvent me) {
   }

   // Handle mouse exited.
   public void mouseExited(MouseEvent me) {
   }

   // Handle mouse click.
   public void mouseClicked(MouseEvent me) {
   }
8. Briefly describe the `assert` keyword.

The `assert` keyword creates an assertion, which is a condition that should be true during program execution. If the assertion is false, an `AssertionError` is thrown.

9. Give one reason why a native method might be useful to some types of programs.

A native method is useful when interfacing to routines written in languages other than Java, or when optimizing code for a specific run-time environment.

Chapter 16: Introducing Swing

1. In general, AWT components are heavyweight and Swing components are lightweight.

2. Can the look and feel of a Swing component be changed? If so, what feature enables this?

   Yes. Swing’s pluggable look and feel is the feature that enables this.

3. What is the most commonly used top-level container for an application?

   `JFrame`

4. Top-level containers have several panes. To what pane are components added?
5. Show how to construct a label that contains the message "Select an entry from the list".
   JLabel("Select an entry from the list")

6. All interaction with GUI components must take place on what thread?
   event-dispatching thread

7. What is the default action command associated with a JButton? How can the action command be changed?
   The default action command string is the text shown inside the button. It can be changed by calling `setActionCommand()`.

8. What event is generated when a push button is pressed?
   ActionEvent

9. Show how to create a text field that has 32 columns.
   JTextField(32)

10. Can a JTextField have its action command set? If so, how?
    Yes, by calling `setActionCommand()`.

11. What Swing component creates a check box? What event is generated when a check box is selected or deselected?
    JCheckBox creates a check box. An ItemEvent is generated when a check box is selected or deselected.

12. JList displays a list of items from which the user can select. True or False?
    True

13. What event is generated when the user selects or deselects an item in a JList?
    ListSelectionEvent

14. What method sets the selection mode of a JList? What method obtains the index of the first selected item?
    `setSelectionMode()` sets the selection mode. `getSelectedIndex()` obtains the index of the first selected item.

15. To create a Swing-based applet, what class must you inherit?
    JApplet

16. Usually, Swing-based applets use `invokeAndWait()` to create the initial GUI. True or False?
    True

17. Add a check box to the file comparer developed in Try This 16-1 that has the following text: Show position of mismatch. When this box is checked, have the program display the location of the first point in the files at which a mismatch occurs.
A Swing-based file comparison utility.

This version has a check box that causes the location of the first mismatch to be shown.

```java
import java.awt.*;
import java.awt.event.*;
import javax.swing.*;
import java.io.*;

class SwingFC implements ActionListener {

    JTextField jtfFirst; // holds the first file name
    JTextField jtfSecond; // holds the second file name
    JButton jbtnComp; // button to compare the files
    JLabel jlabFirst, jlabSecond; // displays prompts
    JLabel jlabResult; // displays results and error messages
    JCheckBox jcbLoc; // check to display location of mismatch

    SwingFC() {

        // Create a new JFrame container.
        JFrame jfrm = new JFrame("Compare Files");

        // Specify FlowLayout for the layout manager.
        jfrm.setLayout(new FlowLayout());

        // Give the frame an initial size.
        jfrm.setSize(200, 220);

        // Terminate the program when the user closes the application.
        jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

        // Create the text fields for the file names.
        jtfFirst = new JTextField(14);
        jtfSecond = new JTextField(14);
    }
```
// Set the action commands for the text fields.
jtfFirst.setActionCommand("fileA");
jtfSecond.setActionCommand("fileB");

// Create the Compare button.
JButton jbtnComp = new JButton("Compare");

// Add action listener for the Compare button.
jbtnComp.addActionListener(this);

// Create the labels.
JLabel jlabFirst = new JLabel("First file: ");
JLabel jlabSecond = new JLabel("Second file: ");
JLabel jlabResult = new JLabel(" ");

// Create check box.
JCheckBox jcbLoc = new JCheckBox("Show position of mismatch");

// Add the components to the content pane.
jfrm.add(jlabFirst);
jfrm.add(jtfFirst);
jfrm.add(jlabSecond);
jfrm.add(jtfSecond);
jfrm.add(jcbLoc);
jfrm.add(jbtnComp);
jfrm.add(jlabResult);

// Display the frame.
jfrm.setVisible(true);
}

// Compare the files when the Compare button is pressed.
public void actionPerformed(ActionEvent ae) {
    int i=0, j=0;
    int count = 0;

    // First, confirm that both file names have
    // been entered.
    if(jtfFirst.getText().equals("")) {
        jlabResult.setText("First file name missing.");
        return;
    }
    if(jtfSecond.getText().equals("")) {
        jlabResult.setText("Second file name missing.");
        return;
    }
    }
18. Change the ListDemo program so that it allows multiple items in the list to be selected.

   // Demonstrate multiple selection in a JList.

   import javax.swing.*;
   import javax.swing.event.*;
   import java.awt.*;
   import java.awt.event.*;

   class ListDemo implements ListSelectionListener {

JList<String> jlst;
JLabel jlab;
JScrollPane jscrlp;

// Create an array of names.
String names[] = { "Sherry", "Jon", "Rachel",
                    "Sasha", "Josselyn", "Randy",
                    "Tom", "Mary", "Ken",
                    "Andrew", "Matt", "Todd" };

ListDemo() {
    // Create a new JFrame container.
    JFrame jfrm = new JFrame("JList Demo");

    // Specify a flow Layout.
    jfrm.setLayout(new FlowLayout());

    // Give the frame an initial size.
    jfrm.setSize(200, 160);

    // Terminate the program when the user closes the application.
    jfrm.setDefaultCloseOperation(JFrame.EXIT_ON_CLOSE);

    // Create a JList.
    jlst = new JList<String>(names);

    // By removing the following line, multiple selection (which
    // is the default behavior of a JList) will be used.
    // jlst.setSelectionMode(ListSelectionModel.SINGLE_SELECTION);

    // Add list to a scroll pane.
    jscrlp = new JScrollPane(jlst);

    // Set the preferred size of the scroll pane.
    jscrlp.setPreferredSize(new Dimension(120, 90));

    // Make a label that displays the selection.
    jlab = new JLabel("Please choose a name");

    // Add list selection handler.
    jlst.addListSelectionListener(this);

    // Add the list and label to the content pane.
    jfrm.add(jscrlp);
    jfrm.add(jlab);

    // Display the frame.
Chapter 17: Introducing JavaFX

1. What is the top-level package name of the JavaFX framework?
   javafx

2. Two concepts central to JavaFX are a stage and a scene. What classes encapsulate them?
   Stage and Scene

3. A scene graph is composed of ________.
   nodes

4. The base class for all nodes is ________.
   Node

5. What class will all JavaFX applications extend?
6. What are the three JavaFX life-cycle methods?
   ```
   init(), start(), and stop()
   ```

7. In what life-cycle method can you construct an application’s stage?
   ```
   start()
   ```

8. The `launch()` method is called to start a free-standing JavaFX application. True or False?
   True

9. What are the names of the JavaFX classes that support a label and a button?
   ```
   Label and Button
   ```

10. One way to terminate a free-standing JavaFX application is to call `Platform.exit()`. `Platform` is packaged in `javafx.Application`. When called, `exit()` immediately terminates the program. With this in mind, change the `JavaFXEventDemo` program shown in this chapter so that it has two buttons called Run and Exit. If Run is pressed, have the program display that choice in a label. If Exit is pressed, have the application terminate. Use lambda expressions for the event handlers.

    ```java
    // Demonstrate Platform.exit().
    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) {
    ```
What JavaFX control implements a check box?

**CheckBox**

ListView is a control that displays a directory list of files on the local file system. True or False?

False. ListView displays a list of items from which the user can choose.

Convert the Swing-based file comparison program in Try This 16-1 so it uses JavaFX instead. In the process, make use of another of JavaFX's features: its ability to fire an action event on a button under program control. This is done by calling `fire()` on the button instance. For example, assuming a Button called `myButton`, the following will fire an action event on it: `myButton.fire()`. Use this fact when implementing the event handlers for the text fields that hold the names of the files to compare. If the user presses ENTER when in either of these fields, simply fire an action event on the Compare button. The event-handling code for the Compare button will
// A JavaFX version of the file comparison program shown in
// Try This 16-1.

import javafx.application.*;
import javafx.scene.*;
import javafx.stage.*;
import javafx.scene.layout.*;
import javafx.scene.control.*;
import javafx.event.*;
import javafx.geometry.*;
import java.io.*;

public class JavaFXFileComp extends Application {

    TextField tfFirst; // holds the first file name
    TextField tfSecond; // holds the second file name

    Button btnComp; // button to compare the files

    Label labFirst, labSecond; // displays prompts
    Label labResult; // displays results and error messages

    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("Compare Files");

        // 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, 180, 180);

Set the scene on the stage.
myStage.setScene(myScene);

Create the text fields for the file names.
tfFirst = new TextField();
tfSecond = new TextField();

Set preferred column sizes.
tfFirst.setPrefColumnCount(12);
tfSecond.setPrefColumnCount(12);

Set prompts for file names.
tfFirst.setPromptText("Enter file name.");
tfSecond.setPromptText("Enter file name.");

Create the Compare button.
btnComp = new Button("Compare");

Create the labels.
labFirst = new Label("First file: ");
labSecond = new Label("Second file: ");
labResult = new Label(" ");

Use lambda expressions to handle action events for the
text fields. These handlers simply fire the Compare button.
tfFirst.setOnAction( (ae) -> btnComp.fire());
tfSecond.setOnAction( (ae) -> btnComp.fire());

Handle the action event for the Compare button.
btnComp.setOnAction(new EventHandler<ActionEvent>() {
    public void handle(ActionEvent ae) {
        int i=0, j=0;

        // First, confirm that both file names have
        // been entered.
        if(tfFirst.getText().equals("")) {
            labResult.setText("First file name missing.");
            return;
        }
        if(tfSecond.getText().equals("")) {
            labResult.setText("Second file name missing.");
            return;
        }

        // Then, perform the comparison...
    }
});
14. Modify the **EffectsAndTransformsDemo** program so the Rotate button is also blurred. Use a blur width and height of 5 and an iteration count of 2.

To add blur to the Rotate button, first create the **BoxBlur** instance like this:

```
BoxBlur rotateBlur = new BoxBlur(5.0, 5.0, 2);
```

Then add the following line:

```
btnRotate.setEffect(rotateBlur);
```

After making these changes, the Rotate button will be blurred and can also be rotated.
Appendix B
Using Java’s Documentation Comments

As explained in Chapter 1, 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 a plain-text font.</td>
</tr>
<tr>
<td>{@literal}</td>
<td>Displays information as-is, without processing HTML styles.</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 to only 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:
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:

```
@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.
```

The `@exception` tag describes an exception to a method. It has the following syntax:

```
@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 be used only in documentation for a method or constructor.

```
@inheritDoc
This tag inherits a comment from the immediate superclass.
```

The `@link` tag provides an in-line link to additional information. It has the following syntax:

```
@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
The `@linkplain` tag inserts an in-line link to another topic. The link is displayed in plain-text font. Otherwise, it is similar to `@link`.
```

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:
Here, *description* is the text that is embedded.

### @param
The [@param](#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](#param) tag can be used only in documentation for a method, a constructor, or a generic class or interface.

### @return
The [@return](#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](#return) tag can be used only in documentation for a method.

### @see
The [@see](#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](#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.
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.

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.

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.

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.

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;

    System.out.println("Enter value to be squared: ");
    val = ob.getNumber();
    val = ob.square(val);

    System.out.println("Squared value is " + val);
}
& (bitwise AND)
& (Boolean logical AND)
&& (short-circuit AND)
* 
multiplication operator
used in import statement
@ (annotation syntax)
@ tags (javadoc)
\ used for character escape sequences (backslash character constants)
| (bitwise OR)
| (Boolean logical OR)
|| (short-circuit OR)
[ ]
^ (bitwise exclusive OR)
^ (Boolean logical exclusive OR)
::
::
constructor reference syntax
method reference syntax
{} 
=
== (relational operator)
versus equals( )
! (Boolean logical unary NOT)
!=
/ 
/** */
/** */
// 
< 
<> 
diamond operator (type inference)
generic type parameter syntax
<<
<=
-
->, lambda (or arrow) operator
--
% ()
and casts
and operator precedence
used with this
. (dot operator)
… (variable-length argument syntax)
+
    addition
    concatenation operator
++
?
ternary operator
wildcard argument specifier
>
>>
>>>
>=
; (semicolon)
~ (bitwise NOT)
_ (underscore) used with integer or floating-point literals

A

abs( )
Abstract method(s)
    and lambda expressions
abstract type modifier
Abstract Window Toolkit. See AWT (Abstract Window Toolkit)
AbstractButton class
Access control
    and Java’s default access
    and interfaces
    and packages
Access modifiers
Accessor methods
Action command string
Action events
ActionEvent class
    JavaFX
ActionListener interface
actionPerformed( )
add( )
addActionListener( )
addAll( )
addKeyListener( )
addListener( )
addMouseListener( )
addMouseMotionListener( )
addTypeListener( )
Affine class
AND operator
  bitwise (&)
  Boolean logical (&)
  short-circuit or conditional-and (&&)
Annotation interface
Annotations
  built-in, table of
  marker
  type use
API (Application Programming Interface), Java
API, Concurrent
Applet
  architecture
  AWT-based versus Swing
  basics
  characteristics of an
  event-driven nature of an
  executing
  and the Internet
  life-cycle methods
  and main( )
  output to a status window
  passing parameters to
  request for repainting
  signed
  skeleton
  string output to
  Swing
  viewer
Applet class
  methods, table of
applet package
APPLET tag, HTML
appletviewer
  status window, using
Application class
Application launcher
args parameter to main( )
Arguments
  command-line
  passing
  type. See Type argument(s)
  variable-length. See Varargs
wildcard. See Wildcard arguments

Arithmetic operators

ArithmeticException

Array(s)

boundaries
declaration syntax, alternative
“fail-soft,” example of a
for-each for loop and
and generics
initializing
irregular
length instance variable of
multidimensional
as a lambda expression parameter, using an
as objects, implemented
one-dimensional
searching an unsorted
sorting
of strings
and varargs

Array reference variables

assigning

declaring

ArrayIndexOutOfBoundsException

Arrow (or lambda) operator (–>)

ASCII character set

Assembly language

assert keyword

Assertion

AssertionError

Assignment operator(s)

=  

bitwise shorthand

compound

shorthand arithmetic and logical (op=)

Assignment(s)

array reference variables and

automatic type conversions in

object reference variables and

Autoboxing/unboxing

definition of the terms

and expressions

and generics

and methods

when to use
AutoCloseable interface
Automatic resource management
AWT (Abstract Window Toolkit)
   and applets
   limitations of
   and Swing
AWTEvent class

Backslash character constants
Banner applet example program
Binary to specify an integer literal, using
BinaryOperator<T> predefined functional interface
Bitwise operators
Blocks, code
   static
   synchronized
Boolean class
boolean data type
   and bitwise operators
   default value of a
   and logical operators
   and relational operators
Border layout
BorderLayout
BorderPane class
BoxBlur class
   program demonstrating
Boxing. See also Autoboxing/unboxing
break statement
   and the for-each for loop
   as a form of goto
Bubble sort
Buffer
   and console output
   file output
   and NIO
BufferedReader class
Button class
ButtonBase class
Buttons. See Push buttons, JavaFX; Push buttons, Swing
Buzzwords, Java
Byte class
byte data type
C

and Java, history of
C++ and Java
C# and Java
Call-by-reference versus call-by-value
Case sensitivity and Java
case statement
Casts
  and generics
  instanceof with, using
catch statement(s)
  and the more-precise (final) rethrow feature
  multi-catch feature of the
  multiple, using
  and rethrown exceptions
changed( )
ChangeListener interface
Channels
char data type
  as an integral type
Character class
Character(s)
  constants (literals)
  escape sequences
  from the keyboard, inputting
charAt( )
Charsets
Check box, JavaFX
  indeterminate state of a, enabling the
Check boxes, Swing
CheckBox class
Class class
.class file
class keyword
Class(es)
  abstract
  anonymous inner
  constructor. See Constructor(s)
data type, as a
definition of the term
event. See Classes, event
final
general form of a
generic. See Generic class
and generic interfaces
that inherits a superclass, general form of a
inner
instance of a
and interfaces
libraries
member. See Member, class
name and source file name
nested
well-designed
Classes, event
commonly used, table of
CLASSPATH
clear( )
Client/server relationships, Internet
clone( )
close( )
Closeable interface
Closures (lambda expressions)
Code blocks. See Blocks, code
Code, unreachable
Collections Framework
Comments
documentation
Comparable<T> interface
compareTo( )
Compilation unit
Compiler, Java
Component class
Components
class names for Swing, table of
and the event-dispatching thread
heavyweight
lightweight
Concurrency utilities
Concurrent API
Conditional-and operator
Conditional-or operator
Console class
Console I/O
close( )
const
Constants
e numeration
using final to create named
using an interface to define shared
Constructor(s)
in a class hierarchy, order of execution of
default
e numeration
generic
overloading
references
and super( )
and this( )
Consumer<T> predefined interface
Container class
Container(s)
top-level
lightweight versus heavyweight
 panes
Containment hierarchy
Content pane
adding a component to a
continue statement
Control class
Control statements. See Statements, control
Control(s), JavaFX
text
currentThread( )

D

Data engines
Data structures
Data type(s)
class as a
See also Type(s); Types, primitive
DataInput interface
DataInputStream class
methods defined by, table of commonly used
DataOutput interface
DataOutputStream class
methods defined by, table of commonly used
Deadlock
Decrement operator (—−)
default statement
Delegation event model
   applet programming using the
event, definition of a
   and JavaFX
@Deprecated built-in annotation
destroy( )
Destructors
Diamond operator (< >)
Directories and packages
DISPOSE_ON_CLOSE
do-while loop
DO NOTHING ON CLOSE
Dot operator (.)
Double class
double data type
   and bitwise operators
doubleValue( )
drawString( )
Dynamic method dispatch

Effect class
Effects
   list of some built-in
   program demonstrating
else
Encapsulation
Enum class
class
= = relational operator and
as a class type
constants
constructor
definition of the term
final variables versus
and inheritance
and instance variables
and methods
ordinal value
restrictions
values in switch statements, using
variable, declaring an
equals()
   versus ==
Erasure
   and ambiguity errors
er. See also System.err standard error stream
Error class
Errors
   ambiguity
   compile-time, causes of
   raw types and run-time
   run-time
   syntax
   See also Exception; Exception handling; Exceptions, standard built-in
Escape sequences, character
Event class
Event classes. See Classes, event
Event handling
   and action events
   anonymous inner classes for, using
   applets and
   AWT
   and item events
   and JavaFX
   lambda expressions for, using
   and list selection events
   and mouse and mouse motion events
   separate listener classes, using
   Swing
   See also Delegation event model
Event listener interfaces
   table of commonly used
EventHandler interface
EventObject class
Exception
   conditions that generate an
   consequences of an uncaught
   definition of the term
   from a lambda expression, throwing an
   suppressed
Exception class
Exception handling
   benefits of
   block, general form of
   and chained exceptions
   and creating custom exceptions
and the default exception handler
features added by JDK 7
and the final (more-precise) rethrow feature
versus error codes
when to use
Exceptions, standard built-in
  checked, table of
  unchecked, table of
EXIT_ON_CLOSE
Expressions
  and autoboxing/unboxing
extends
  and bounded wildcard arguments
to create a bounded type, using
false
File comparison utility example
  console-based
  Swing-based
File(s)
  close( ) to close a, using
  I/O
  pointer
  random-access
  source
  try-with-resources to automatically close a, using
FileInputStream class
FileNotFoundException
FileOutputStream
FileReader class
FileWriter class
final
to prevent class inheritance
to prevent method overriding
variables
finalize( )
  versus C++ destructors
finally block
  to close a file, using a
Float class
float data type
  and bitwise operators
Floating-point literals
Floating-point types
    and strictfp
floatValue( )
Flow layout
FlowLayout
FlowPane class
for loop
    enhanced. See For-each version of for loop
    variations
For-each version of for loop
    break statement and
    and collections
    general form
    to search unsorted arrays
Fork/Join Framework
format( )
FORTRAN
Frank, Ed
Function<T,R> predefined functional interface
Functional interface(s)
    generic
    predefined
FXCollections class

G

Garbage collection
    program demonstrating
Generic class
    constructor
    example program with one type parameter
    example program with two type parameters
    general form of a
    and raw types
    and static members
    and Throwable
Generic constructors
Generic interfaces
Generic method
Generics
    and ambiguity errors
    and arrays
    and autoboxing/unboxing
    and casts
    and compatibility with pre-generics (legacy) code
and exception classes
restrictions on using
type safety and
getActionCommand()
getCause()
getChildren()
getClass()
getContentPane()
getGraphics()
getItem()
getName()
getParameter()
getPriority()
getSelectedIndex()
getSelectedIndices()
getSelectedItems()
getSelectionModel()
getSuppressed()
getText()
getTransforms()
getX()
getXOnScreen()
getY()
getYOnScreen()
Glass pane
Gosling, James
goto keyword
goto statement, using labeled break as a form of a
Graphical user interface (GUI)
    and applets
    and JavaFX
    programs and event handling
    and Swing
Graphics class
GridPane class

H

handle()
hashCode()
hasNextX methods, Scanner’s
Heavyweight
    components
    containers
Hexadecimal literals
Hierarchical classification and inheritance

Hierarchy
contains
multilevel

Hoare, C.A.R.

HotSpot

HTML (Hypertext Markup Language) file
and applets
and javadoc

HTMLEditor JavaFX control

Identifiers

if statement

    nested

if-else-if ladder

    switch statement versus

implies clause

    and bounded types

import statement

    and static import

in. See also System.in standard input stream

Increment operator (++)

Indentation style

indexOf()

Inheritance

    and abstract classes and methods
    basics of
    and constructors
    and enumerations
    final and
    and interfaces
    member access and
    multilevel
    and multiple superclasses

init()

initCause()

InputMismatchException

InputStream class

    methods, table of

InputStreamReader class

Instance of a class
See also Object(s)
Instance variables
definition of the term
dot operator to access, using the enum ration
final
hiding
inheritance and private
and lambda expressions
as unique to their object
using super to access hidden
using this to access hidden
instanceof operator
int
Integer class
Integer(s)
literals
interface keyword
used in an annotation declaration
Interface methods
default
static
traditional
Interface(s)
event listener. See Event listener interfaces
general form of
generic
implementing
and inheritance
methods. See Interface methods
reference variables
variables
Internet
client/server relationships
and portability
and security
Interpreter, Java
InterruptedException
intValue( )
invokeAndWait( )
invokeLater( )
I/O
applets and user
binary data
channel-based
console
file
new (NIO)
random-access
streams. See Stream(s), I/O
io package. See java.io package
IOException
isAlive( )
isIndeterminate( )
isSelected( )
isUpperCase( )
Item events
ItemEvent class
ItemListener interface
itemStateChanged( )
Iteration statements

J

JApplet container
Java
API
Beans
and C
and C++
and C#
compiler
design features (buzzwords)
and dynamic compilation
history of
IDEs
and the Internet
as an interpreted language
interpreter
keywords
look and feel (metal)
as a strongly typed language
and the World Wide Web

java (Java interpreter)
Java Development Kit (JDK)
.java filename extension
Java Foundation Classes (JFC)
Java Network Launch Protocol (JNLP)
java package
Java Virtual Machine (JVM)
Java: The Complete Reference, Ninth Edition

Java

java.applet package
java.awt package
java.awt.event package
  event classes, table of commonly used
  event listener interfaces, table of commonly used
java.io package
java.io.IOException. See also IOException
java.lang package
java.lang.annotation package
java.lang.Enum
java.net package
java.nio package
java.nio.channels package
java.nio.charset package
java.nio.file package
java.nio.file.attribute package
java.nio.file.spi package
java.util package
java.util.concurrent package
java.util.function package
java.util.List
java.util.stream package
javac (Java compiler)
javadoc utility program
  tags, list of
JavaFX
  event handling
  layout panes
  life-cycle methods
  nodes. See Node(s), JavaFX
packages
scene
scene graph
Script
stage
  versus Swing
JavaFX application
  compiling and running a
  skeleton
  thread
javafx.application package
javafx.beans.value package
javafx.collections package
See also Push buttons, Swing

JCheckBox component
JComponent class
JDialog container
JDialog container
adding a component to a
JLabel component
JList component
join( )
JPanel container
javax.swing.JRootPane container
javax.swing.JScrollPane container
javax.swing.JTextField component
javax.swing.JTextField component
action command string of a
javax.swing.JToggleButton class
Jump statements
Just In Time (JIT) compiler
Java Virtual Machine (JVM). See Java Virtual Machine (JVM)
JWindow container

K

Keywords, Java

L

Label
with break, using a
with continue, using a
JavaFX
Swing
Label class
Labeled class
Lambda expression(s)
  as arguments, passing
  block
  body
  definition of the term
  event handling using
  and exceptions
  expression
  parameters
  target type
  target type context
  and variable capture

lastIndexOf( )
launch( )
Layered pane
Layout manager
  for a content pane, default
LayoutManager interface
LayoutManager2
interface
length instance variable of arrays
length( )
Libraries, class
Lightweight
  components
  containers
List class
List selection event
ListView, JavaFX
  change events, handling
  multiple selections in a, enabling
  scroll bars
Listener, delegation event model
Lists, Swing
ListSelectionEvent class
ListSelectionListener interface
ListSelectionModel interface
ListView class
Literals
Lock
Logical operators
long
Long class
Loops
  break to exit, using
  criteria for choosing the right
  do-while
  for. See for loop
  infinite
  nested
  while

main( )
  and applets
  and command-line arguments
  and JavaFX applications
  and Swing applications

Math class
MAX_PRIORITY
Member, class
  access and inheritance
  controlling access to
  dot operator to access
  static
  and static import
Member, using super to access a superclass
Memory
  allocation using new
  leaks
Menu bar, Swing
Metadata
  See also Annotation(s)
Method references
  to generic methods
  to instance methods
  to static methods
Method(s)
  abstract. See Abstract Method(s)
  accessor
  anonymous, lambda expression as an
  and autoboxing/unboxing
  built-in
  calling
  default interface
dispatch, dynamic
dot operator and
and enumerations
extension
final
general form of
generic
and interfaces. See also Interface methods
lambda expressions to pass executable code to, using
native
overloading
overriding. See Overriding, method
and parameters. See also Parameters
parsing
passing objects to
recursive
reference. See Method references
returning from a
returning objects from
returning a value from
scope defined by
signature
static
super to access hidden superclass, using
synchronized
and the throws clause
and type parameters
varargs. See Varargs
variable-arity
MIN_PRIORITY
Model-Delegate architecture, Swing
Model-View-Controller (MVC) architecture
Modulus operator (%)
Monitor
Mouse and mouse motion events, handling
mouseClicked( )
mouseDragged( )
mouseEntered( )
MouseEvent class
mouseExited( )
MouseListener interface
MouseMotionListener interface
mouseMoved( )
mousePressed( )
mouseReleased( )
Multicore systems
and the Fork/Join Framework
MULTIPLE_INTERVAL_SELECTION
MultipleSelectionModel class
Multitasking
operating system implementation of
process-based versus thread-based
Multithreaded programming
and deadlock
and multicore versus single-core systems
and synchronization. See Synchronization
and threads. See Thread(s)
effective use of
MVC (Model-View-Controller) architecture

Name hiding
Namespace
default (global)
packages and
static import and
Narrowing conversion
native modifier
Naughton, Patrick
Negative numbers, representation of
nextX methods, Scanner’s
new
and abstract classes
and type inference
NIO (New I/O) system
Node class
Node(s), JavaFX
effects and transforms to alter the look of, using
root
text
NORM_PRIORITY
NOT operator
bitwise unary (~)
Boolean logical unary (!)
notify()
notifyAll()
null
Number class
NumberFormatException
Oak
Object
  creating an
to a method, passing an
monitor
returning an
Object class
  and erasure
  and functional interfaces, public methods of the
Object initialization
  with another object
  with a constructor
Object reference variables
  and assignment
  declaring
  and dynamic method dispatch
  to a method, effect of passing
to superclass reference variables, assigning subclass
OBJECT tag, HTML
Object-oriented programming (OOP)
observableArrayList( )
ObservableList
ObservableValue
Octal literals
One’s complement (bitwise unary NOT) operator
Operator(s)
  ? ternary
  arithmetic
assignment. See Assignment operator(s)
  bitwise
  diamond (<>)
  logical
  parentheses and
  precedence, table of
  relational
OR operator (||)
  bitwise
  Boolean logical
OR operator, short-circuit or conditional-or (||)
Ordinal value of enumeration constant
ordinal( )
out. See also System.out standard output stream
OutputStream class
methods, table of
OutputStreamWriter class
Overloading
  constructors
  methods
Overriding, method
  and dynamic method dispatch
  final to prevent, using
  and polymorphism

P

package statement
Package(s)
  and access control
  default (global)
  defining a
  and directories
  importing
paint( )
Panel class
Panes, container
PARAM
Parameters
  applets and
  final
  lambda
  and overloaded constructors
  and overloaded methods
  type. See Type parameter(s)
  variable-length
Parent class
parseDouble( )
parseInt( )
Pascal
PasswordField JavaFX control
PATH environmental variable
Peers
Pipeline for actions on stream API stream data
Pluggable look and feel
Pointers
Polymorphism
  and dynamic method dispatch, run-time
  and interfaces
  and overloaded methods
and overridden methods
Portability problem
Pos enumeration
pow( )
Predicate<T> predefined functional interface
print( )
printf( )
println( )
printStackTrace( )
PrintStream class
PrintWriter class
private access modifier
   and inheritance
   and packages
Programming
   art of
   concurrent
   multithreaded. See Multithreaded programming
object-oriented
parallel
structured
protected access modifier
   in C++ versus Java
   and packages
public access modifier
   and interfaces
   and packages
Push buttons, JavaFX
Push buttons, Swing
   action command string of

Q

Queue(s)
   example program
   generic, creating a
   interface, creating a
Quicksort algorithm

R

RandomAccessFile class
Raw types
read( )
Reader class
   methods defined by, table of
readInt( )
readLine( )
readPassword( )
Recursion
Reflection class
    program demonstrating
Relational operators
remove( )
removeActionListener( )
removeKeyListener( )
removeTypeListener( )
repaint( )
    demonstration program
replace( )
resume( )
return statement
    and block lambdas
Root pane
Rotate class
    program demonstrating
run( )
    overriding
    using a flag variable with
Runnable interface
    implementing the
Run-time
    exception
    system, Java
    type information
RuntimeException class

SAM (Single Abstract Method) type
Scale class
    program demonstrating
Scanner class
Scene class
Scene graph
Scientific notation
Scopes
Scroll bars
Scroll panes
Security problem
seek( )
selectedItemProperty( )
Selection statements
SelectionMode
SelectionModel class
Selectors (NIO)
Separable model architecture, Swing
Servlets
setActionCommand( )
setAlignment( )
setAllowIndeterminate( )
setAngle( )
setBottomOpacity( )
setCharAt( )
setDefaultCloseOperation( )
setEffect( )
setFraction( )
setHeight( )
setIterations( )
setLayout( )
setName( )
setOnAction( )
setPivotX( )
setPivotY( )
setPrefColumnCount( )
setPreferredSize( )
setPrefHeight( )
setPrefSize( )
setPrefWidth( )
setPriority( )
setPromptText( )
setRotate( )
setScaleX( )
setScaleY( )
setScene( )
setSelectionMode( )
setSize( )
setText( )
setTitle( )
setTopOffset( )
setTopOpacity( )
setTranslateX( )
setTranslateY( )
setVisible( )
setWidth( )
setX( )
setY()
Shear class
Sheridan, Mike
Shift operators, bitwise
Short class
short data type
shortValue()
show()
showAll()
showStatus()
Signature of a method
SINGLE_INTERVAL_SELECTION
SINGLE_SELECTION
sleep()
Source
delegation event model
table of file
Spurious wakeup
sqrt()
Stacks
and polymorphism
Stage class
start()
Statements
null
Statements, control
iteration
jump
selection
static
and generics
Static import
stop()
defined by the Applet class
defined by the Application class
deprecated Thread method
Stream interface
Stream, stream API
Stream(s), I/O
definition of the term
predefined
Streams, byte
classes, table of
using
Streams, character
String class
methods, some
String(s)
arrays of
concatenating
constructing
definition of the term
immutability of
length, obtaining
literals
as objects
reading
representations of numbers into binary format, converting
searching
switch, used to control a
StringBuffer class
StringBuilder class
Subclass, definition of
substring( )
Sun Microsystems
super
and bounded wildcard arguments
default interface method implementation, used to refer to a
and superclass members
super( )
and superclass constructors
and this( )
Superclass, definition of
suspend( )
Swing
applet example
application, example of a simple
and the AWT
components, table of class names for
containers and components, relationship between
file comparison utility
and JavaFX
and MVC architecture
programs, event-driven nature of

Swing: A Beginner’s Guide
SwingUtilities class
switch statement
using enumeration values in a
using a string to control a

Synchronization
and deadlock
race condition and
via a synchronized block
via a synchronized method

synchronized keyword
used with a block
used with a method

Syntax errors
System class
System.console( )
System.err standard error stream
System.in standard input stream
System.in.read( )
System.out standard output stream
and static import

T

Templates, C++
Text class
Text field, JavaFX
Text field, Swing
action command string
and action listeners
TextArea JavaFX control
TextField class
TextInputControl class
this
this( )
Thread class
constructors
extending the
Thread(s)
application
child
communication among
creating
and deadlock
definition of the term
event-dispatching
launcher
main
possible states of priorities
race condition and
and spurious wakeup
suspending, resuming, and stopping
synchronization. See Synchronization terminates, determining when a
throw
Throwable class
and chained exceptions
and generic classes
methods defined by, table of commonly used
throws
toString()
toLowerCase()
toupperCase()
Transform class
Transforms
program demonstrating
transient modifier
Translate class
ture
True and false in Java
try block(s)
and finally
nested
try-with-resources
Two’s complement
Type argument(s)
and bounded types
and generic functional interfaces
type inference and
and type safety
See also Wildcard arguments
Type inference
and constructor references
the diamond operator (<>) and
and lambda expressions
and a method reference to a generic method
Type parameter(s)
and bounded types
and erasure
instance of a, cannot create an
and primitive types
and static members
used with a class
used with a method
Type safety
  and generics
  and raw types
  and wildcard arguments
Type(s)
  bounded
  casting
  checking
  class as a data
  conversion, automatic
  inference. See Type inference
  information, run-time
  numeric, default value of
  promotion in expressions
  raw
  reference, default value of
  simple or elemental
Type(s), primitive
  and binary I/O
  table of
  and type parameters
  wrappers
Types, parameterized
  versus C++ templates

UI delegate
UnaryOperator<T> predefined functional interface
Unboxing. See also Autoboxing/unboxing
Unchecked warnings and raw types
Underscores with integer and floating-point literals, using
Unicode
update( )

V
valueChanged( )
valueOf( )
values( )
Varargs
  and ambiguity
  methods, overloading
  parameter, declaring a
Variable(s)
capture
character
declaration
definition of the term
dynamic initialization of
effectively final
eumeration
final
initializing
instance. See Instance variables
interface
interface reference
name hiding and
object reference. See Object reference variables
scope and lifetime of
static
transient
volatile
Virtual functions (C++)
void
methods
volatile modifier

W

wait( )
Warth, Chris
Web browser
   executing applet in
      using status window of
while loop
Widening conversion
Wildcard arguments
   bounded
Window, using the applet viewer or browser status
WindowConstants interface
World Wide Web
Wrappers, primitive type
write( )
Writer class
   methods defined by, table of
writeDouble( )
XOR (exclusive OR) operator (^)
  bitwise
  Boolean logical
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