



Technical Brief

Lumenex Engine:
The New Standard in GPU Image
Quality

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Introduction to the Lumenex Engine

At NVIDIA we are extremely passionate about image quality. The people who design our award-winning NVIDIA® GeForce® graphics processors hail from a variety of backgrounds. Some came with experience in high-end workstation systems, where thousands of fine lines had to be rendered with the uttermost precision. Others spent their lives in CGI, where pixel shaders could run days on end to produce the right subtle effects that made great films like *The Incredibles* and *Cars*. When these engineers put their minds to design our next-generation architecture—the GeForce 8800—they set out to build a GPU with the best image processing engine in the world. They named the new technology the NVIDIA® Lumenex™ engine.

Lumenex comes from the two Latin words *luminosus* and *lumens*. It symbolizes the amazing quality of light—at once both bright and scintillating. Before the introduction of the GeForce 8800 GPU Series, PC-based graphics chips could not live up to this ideal for a variety of reasons. Chief among them was the conflict between rendering well and rendering quickly; graphics processors simply did not have the resources to render a scene in its most faithful representation without slowing to a crawl. The result was watered-down images that were neither crisp nor luminous.

The GeForce 8800 with the Lumenex engine solves these problems and raises image quality to the next level. The new Lumenex engine brings several key innovations:

- ❑ 16× Coverage Sampling Antialiasing (CSAA)
- ❑ 16× near-perfect angle-independent anisotropic filtering
- ❑ 16-bit and 32-bit floating-point texture filtering
- ❑ Fully orthogonal 128-bit high dynamic-range (HDR) rendering with all the above features
- ❑ A full 10-bit display pipeline

Lumenex Antialiasing Engine

Since NVIDIA introduced multisample antialiasing (MSAA) to the industry in 2001, gamers have embraced the new graphics possibilities with smooth edges and crisp textures. Over the years we continually improved our antialiasing engine, bringing features such as gamma-corrected antialiasing and transparency antialiasing for alpha textures. With the GeForce 8800 architecture, we were given the chance to completely rethink our antialiasing strategy and design a solution that sets a new standard in interactive graphics.

The current method of antialiasing relies on using multiple subpixel samples to calculate the color of object silhouettes. Storing and reading multiple samples from memory requires a proportionate increase in resources as the number of samples increases. For example, 4× multisampling requires four times the storage and ROP bandwidth as standard rendering. NVIDIA GPUs, having been designed with multisampling in mind, can perform 4× MSAA at high resolutions with little performance degradation. However, to attain even higher quality, antialiasing requires additional samples. This became infeasible on prior generations of hardware.

The Lumenex engine was designed with one goal in mind: to provide the highest image quality with the lowest performance impact. To realize this goal, we designed an antialiasing subsystem that employs a new algorithm called Coverage Sampling Antialiasing (CSAA). Unlike brute-force multisampling, Coverage Sampling Antialiasing uses intelligent coverage information to perform ultrahigh quality antialiasing without bogging down the memory system. CSAA is introduced in the GeForce 8800 GPUs.

The Lumenex engine sets a new standard in antialiasing by raising the total number of samples per pixel to 16—an ultrahigh quality often used in offline rendering. The resulting images show lines with near-perfect gradient, dramatically reduced shimmering, and unrivalled picture clarity.

In bandwidth-constrained scenarios, traditional GPUs slowed down drastically when rendering with 16× antialiasing. The Lumenex engine, however, was designed for high performance so the GeForce 8800 GTX actually performs 16× antialiasing at nearly the same speed as 4× traditional MSAA. This is a significant breakthrough for antialiasing in interactive graphics—for the first time, graphics can be rendered at near-CGI quality antialiasing with real-time framerates.

Case Study: *Battlefield 2*

Figure 1 is a screenshot from the popular game *Battlefield 2*. The screenshot was taken at 1600×1200 , a reasonably high resolution. But as evident in the highlighted boxes (please see enlargements in Figure 2), aliasing is still prevalent. This example illustrates why aliasing cannot be eliminated by merely increasing the screen resolution—there will always be lines and details fine enough to cause aliasing at any resolution.

In the next section we see what a dramatic difference the Lumenex engine's Coverage Sampling Antialiasing makes to the image quality.



Image taken from *Battlefield 2*

Figure 1. Examples of aliasing

The three pairs of images shown in Figure 2 compare the results of default rendering and 16× CSAA. The crane without antialiasing is an awkward mixture of jagged edges and missing pixels. With 16× CSAA enabled, all edges are rendered smoothly and the fine lines on the right are accurately depicted.

The second image shows the improvements in high-contrast areas. The default rendering causes distracting discontinuities in the building's edges. With 16×xAA, the lines are perfectly smoothed out.

Finally, the third image depicts a special case—aliasing on alpha textures. Traditional antialiasing techniques cannot detect alpha textures so they are not effective on these objects. However, the Lumenex antialiasing engine supports transparency antialiasing, enabling smooth rendering of foliage, chain-linked fences, and other alpha textures.



Figure 2. Comparing results of default rendering and 16× CSAA

Case Study: *Half-Life 2*

Half-Life 2 shows complex indoor and outdoor environments with high-dynamic range lighting. With the GeForce 7 Series of GPUs, antialiasing could not be used in conjunction with high dynamic-range lighting. The Lumenex engine, however, handles all scenes equally well, providing the highest image quality with no limitations (Figure 3).



Image taken from *Half-Life 2*

Figure 3. Lumenex engine provides the highest image quality with no limitations

No AA vs. 4× MSAA vs. 16× CSAA

Figure 4 compares the differences between no antialiasing, traditional 4× multisampling, and 16× CSAA in *Half-Life 2*. Default rendering once again depicts crude, jagged edges. Nice relief is offered on the 4× MSAA, but the gradient steps are clearly visible. Far superior graduation is depicted on 16×, where jagged edges are smoothed out to produce a near-perfect transition.

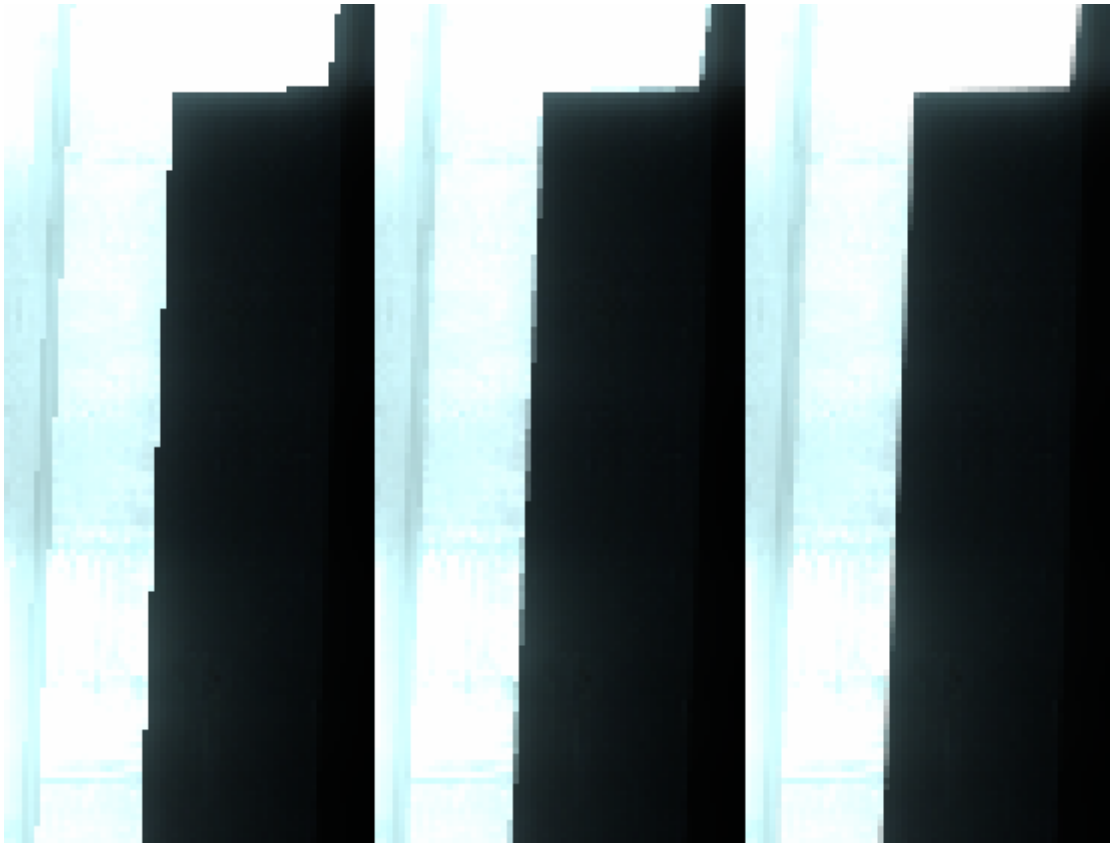


Figure 4. Comparing no AA vs. 4× MSAA vs. 16× CSAA

Incredible Performance

With Lumenex, high image quality doesn't mean low performance (Table 1). For most applications, 16× CSAA costs only 10 to 20 percent more than standard 4× MSAA.

Table 1. Comparing Performance

Resources	1600 × 1200, 4× MSAA	1600 × 1200, 16× CSAA
3DMark 2006	7419 3DMarks	7044 3DMarks
Call of Duty	93.6 FPS	88.0 FPS
FarCry	134.3 FPS	113.2 FPS
X3: The Reunion	78.9 FPS	67.0 FPS

Lumenex Texture Filtering Engine

Antialiasing removes artifacts on polygon edges, but the interior of polygons, where textures are applied, does not receive any treatment. To display textures with all their fine details, the GPU must perform high-quality texture filtering.

Textures represented in the 2D world rarely need filtering since one pixel in the texture corresponds to one pixel on the screen; at 100 percent view, the texture is depicted with perfect accuracy. Viewing the texture at 25 percent zoom requires resampling the image to fit into a smaller area. In this case, every 4 pixels need to be averaged down to 1, reducing the image to a quarter of its size. This is a very simple form of *texture filtering*.

In 3D applications, textures are almost never seen at 100 percent view and are frequently viewed at an angle relative to the screen. They usually recede from the viewer, much like the opening title of *Star Wars*. Textures in this oblique orientation are difficult to depict accurately. The GPU must take into account the angle at which the texture is facing the screen and take multiple samples from the texture at different locations. This process is known as *anisotropic texture filtering*.

Modern GPUs can take up to 128 texture samples for each screen pixel when conducting anisotropic texture filtering. This sampling provides high-quality filtering, but requires enormous bandwidth. Applied indiscriminately, it can dramatically slow down the application.

To get around this performance penalty, GPUs typically enable high-quality anisotropic filtering only on certain angles. For example, most games depict straight corridors with walls erected at 90 degrees. Likewise, most of the game geometry is placed perpendicular to the floor. Previous GPUs optimized their texture filtering engines by only filtering objects at these key angles. The result was that all objects parallel to the walls and ceiling were correctly filtered, but all objects at an angle received only approximate filtering. While this approach was a reasonable trade-off for the time, today's titles are quite a different story from the rectangular corridors and box rooms of the last generation. To enable the maximum image quality for today's games, far better texture filtering is required.

Case Study: *Unreal Tournament 2004*

Figure 5 is a scene from *Unreal Tournament 2004* that shows the limits of texture filtering on today's GPUs.

Figure 6 and Figure 7 show close-ups of the red box in Figure 5. The ramp is divided into three sections. Section A receives good filtering due to its simple 90 degree projection. However, sections B and C are on an angle so receive little filtering, resulting in blurred textures with little detail (Figure 6).



Figure 5. Filtering

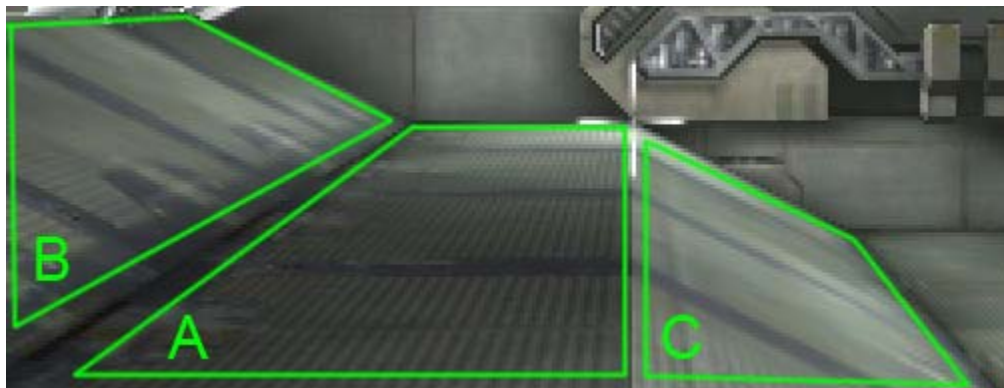


Figure 6. Regular texture filtering

The Lumenex engine delivers a more robust anisotropic filtering algorithm that accounts for all surfaces, regardless of their orientation. Figure 7 is the same image rendered on the GeForce 8800 GTX. Note how sections B and C are better defined.

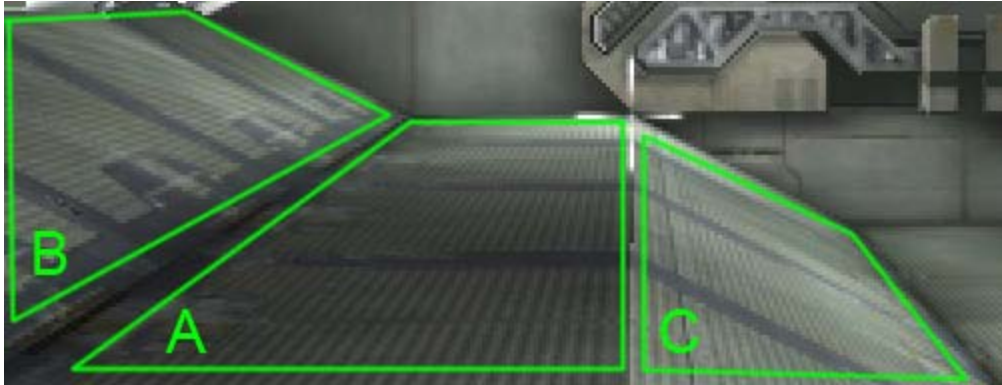


Figure 7. Anisotropic texture filtering on the GeForce 8800 GTX

Near-Perfect Results

To take the Lumenex engine to its limits we put it through the ‘torture test.’ This test consists of a cylindrical tunnel that effectively captures all possible angles that textures can be mapped to. If the hardware does not apply anisotropic filtering to all portions of the scene, artifacts are produced.

In Figure 8, the left scene is rendered with traditional texture filtering. The result shows glaring streaks appearing at 45 degree intervals. In a 3D scene, these areas would receive the lowest quality filtering.

The right side in Figure 8 is the Lumenex engine at work. The result is a near-perfect circle—the ideal result for this test. Translated to a 3D scene, this means near-perfect results at any angle.

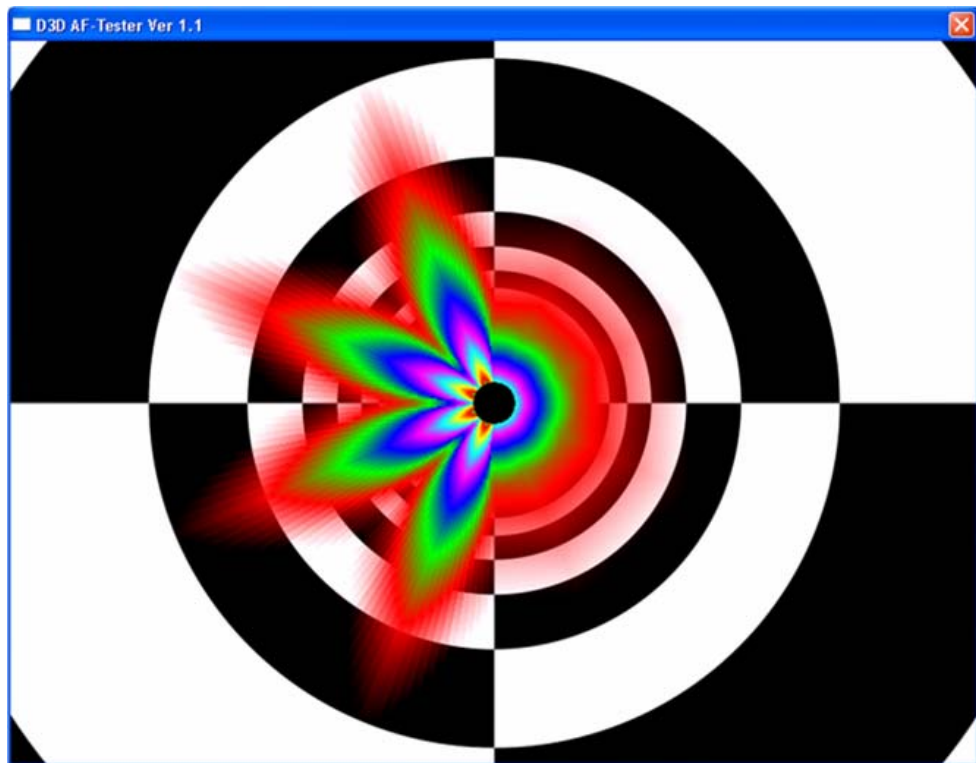


Figure 8. Default anisotropic texture filtering (GeForce 7 Series on left, GeForce 8 Series on right)

128-Bit High Dynamic-Range Rendering

High dynamic-range (HDR) rendering is a technique used to render scenes with large variations of brightness, producing images that exhibit lifelike contrast and tone. Almost all of today's popular games employ HDR rendering—*FarCry*, *Half-Life 2: Episode One*, and *The Elder Scrolls IV: Oblivion* are just a few examples. Most HDR graphics engines employ 16 bits per color component (red, green, blue, and alpha) or a total of 64 bits for high dynamic-range rendering. While this is fine today, future applications will require greater precision.

The Lumenex engine is designed for the highest level of precision by offering 32-bit floating-point precision for each color component, or a total of 128 bits for high dynamic-range rendering—a level of accuracy that exceeds many film renderers (Figure 9). This format is also especially useful for scientific computing, where 32-bit precision is a common standard. By offering 32-bit scalar precision and 128-bit vector precision, the Lumenex engine is fully prepared for tomorrow's advanced applications.



Image courtesy of Masaki Kawase

Figure 9. High dynamic-range rendering

10-Bit Display Pipeline

Today's displays use 8 bits of information for each primary color, allowing a total of 16.7 million colors to be displayed. The human eye, however, is sensitive to a much greater range of colors and brightness.

To bring the full spectrum of colors to life, the Lumenex engine is built with a full 10-bit display pipeline. This allows over a billion unique colors to be displayed—sixty-four times more than the standard 8-bit color. With the next generation of 10-bit content and displays, the Lumenex engine will be able to display images of amazing depth and richness.

Conclusion

The Lumenex engine sets a new standard in image quality. It introduces the industry's highest quality antialiasing with $16\times$ CSAA, enabling studio-quality rendering with lightening-fast performance.

Texture filtering is taken to a new level with near-perfect results at every angle, allowing next-generation games to be rendered with the highest level of detail. Combined with full support for 128-bit HDR rendering and a 10-bit display subsystem, the Lumenex engine represents the new gold standard in image quality.



Image Courtesy of Futuremark



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