3DNow!™ Technology

Delivering Leading-Edge 3D Graphics and Multimedia Performance for the New Era of Realistic Computing

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Executive Summary

3DNow!™ technology is the first innovation to the x86 processor architecture that significantly enhances three-dimensional (3D) graphics and multimedia performance for today's mainstream Microsoft® Windows® compatible personal computers.

This White Paper explains how 3DNow! technology solves a critical problem in PC-based 3D graphics by widening the bottleneck in the graphics processing pipeline between the host CPU and the graphics accelerator. The White Paper also discusses how 3DNow! technology can enhance the performance of a wide range of non-graphical, floating-point-intensive applications.

The graphics pipeline begins with 3D modeling and geometry (transformation, lighting, and clipping), which are floating-point intensive, and ends with integer-intensive rendering or rasterization, which is handled primarily by 3D graphics accelerator cards. Today's high-performance graphics accelerators are so adept at rendering that the CPU often cannot keep pace in pumping data through the pipeline. Earlier stages of the graphics pipeline thus can create a bottleneck that hinders overall 3D graphics performance.

3DNow! technology eliminates the bottleneck and clears the way for more powerful software and hardware applications that will enable more productive, entertaining, and realistic PC platforms. Benefits of 3DNow! technology include faster frame rates on high-resolution scenes, superior physical modeling of real-world environments, sharper and more detailed 3D imaging, smoother video playback, and near theater-quality sound. Resulting applications will offer an optimum balance of productivity, performance, and enjoyment for mainstream PC users.

AMD has taken the lead in developing and bringing to market an innovative set of x86 instructions that open the traditional processing bottlenecks for floating-point and multimedia applications. With 3DNow! technology, more powerful hardware and software applications can bring a new level of 3D performance and realism to mainstream PCs. 3DNow! technology was defined and implemented cooperatively with Microsoft, other leading software developers, graphics hardware vendors, and x86 processor suppliers, and has garnered enthusiastic industry support. The technology is compatible with existing x86 software, including the large installed base of Windows operating systems and applications, and requires no operating system support, enabling 3DNow! optimized applications to work with all operating systems.

3DNow! technology is available now in the new AMD-K6®-2 processor and will be used in forthcoming AMD products, such as the AMD-K6-3 processors planned for 2H 1998 and the AMD-K7™ processor planned for 1999. Functional AMD-K6-2 silicon incorporating 3DNow! has been available to software developers and other industry partners since October 1997.

Introduction: The Impact of 3D Graphics on Personal Computing

3D graphics is the computer-based graphical representation of objects and scenes along three axes (height, width, and depth) to create the illusion of three dimensions on a flat, two-dimensional surface, such as a PC monitor.

Creating immersive, realistic 3D universes requires considerable computational horsepower involving a complex mix of floating-point and integer calculations. Until recently, powerful RISC workstations have been the platforms of choice for equally high-end 3D graphics applications—from Hollywood-caliber computer animation to computer-assisted design and engineering (CAD/CAE) to scientific modeling.

But change is afoot in the 3D graphics industry. In recent years, 3D has come of age in the mass-market world of personal computing. According to Jon Peddie Associates (JPA), 3D is currently the fastest growing market segment in the PC industry and is expected to double in size in the next two years. Enabling technologies include more powerful PC processors, higher-performance graphics accelerator cards, faster and less expensive memories, and 3D-optimized application programming interfaces (APIs), such as DirectX and OpenGL. These APIs create an open development environment for independent software vendors (ISVs).

Popular gaming titles comprised the initial wave of PC-based 3D applications. This is to be expected since arcade-quality games benefit visually from the power of 3D, and gamers typically are early adopters of "bleeding-edge" technology. 3D gaming software has sparked the demand for advanced multimedia technology in other PC application areas, including edutainment, business and personal productivity (word processing, spreadsheet modeling, presentation graphics), VRML and 3D on the Internet, photo image manipulation, soft DVD playback, voice recognition, and soft modems.

By the end of 1998 and beyond, floating-point-intensive 3D graphics capabilities are expected to become a mainstay in personal computing. 3D will also be the driving force behind tomorrow's Realistic Computing Platform—an emerging Windows compatible visual computing environment that will bring unprecedented 3D realism and performance to PC users.

Clearing the Bottleneck in the 3D Graphics Pipeline

To understand where 3D computing has been and where it is headed, it is helpful to explore a fundamental concept: the *3D graphics processing pipeline*. Often likened to a "bucket brigade," the graphics pipeline involves a multi-step hand-off of instructions and operations between the host processor and the rendering engine, or graphics accelerator.

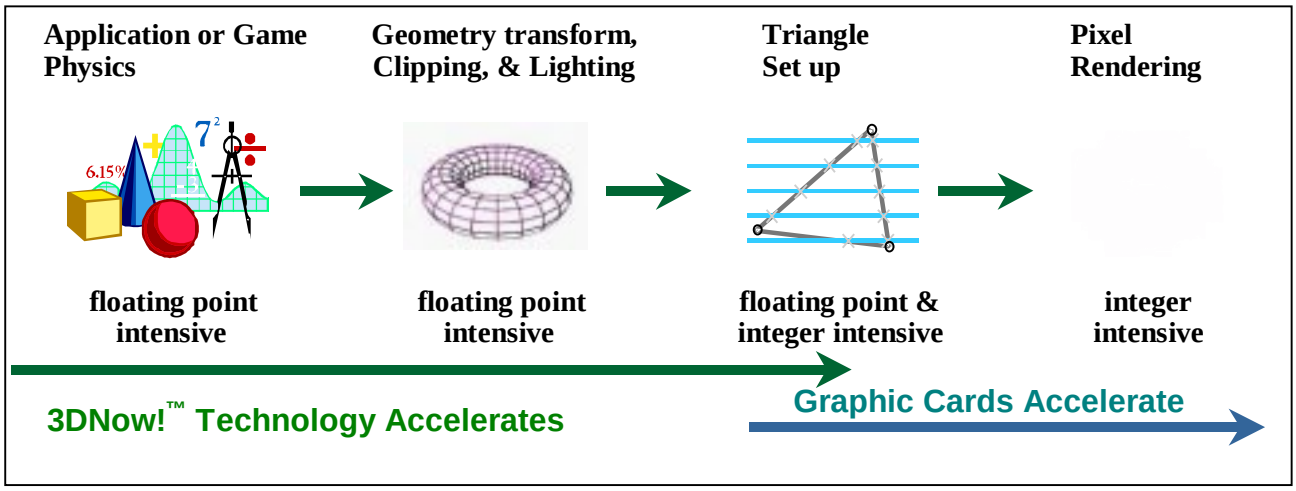

Figure 1: 3DNow! technology accelerates multimedia applications by relieving floating-point-intensive bottlenecks in the four-step 3D graphics processing pipeline.

Although various schools of thought define the graphics pipeline as having from two to four stages, this White Paper will focus on the following four distinct steps: *physics*, *geometry*, *setup*, and *rendering*.

- **Physics (Scene Management)** – A PC creates a 3D world from mathematical representations of physical objects that simulate the physical characterization and events of the many objects that comprise a real world. Computer-generated objects include all building blocks of this world, from the action set (people, cars, planes, etc.) to scenery (backgrounds, rooms, sky, etc.). Each object can behave like a real-life object because most characterizations can be determined mathematically through physics/physical representations. The computer-generated virtual world is a complete, 360-degree 3D view or object-coordinate—all done through mathematics. In other words, the PC visualizes all physical objects and the interaction of those objects from all points simultaneously. This is what occurs in PC gaming, but the same principles can be used to accelerate 3D graphics within non-gaming applications. Physics calculations are inherently floating-point intensive and are handled by software in the CPU.
- **Geometry** – Also handled primarily in the CPU, 3D geometry comprises several floating-point-intensive operations (transformation, lighting, and clipping) that transform representations from the object-coordinate system to the world-coordinate system. Think of this as moving from mathematical coordinates to creating polygons or triangles that represent an image in the virtual world. For example, a ball represented by a mathematical equation is translated to a set of triangles that looks like a ball. *Transformation* adds movement (zooming, rotation, etc.). *Lighting* is the application of light sources from specific locations on physical

objects, which impacts how objects are viewed and what shadows are cast. *Clipping* involves eliminating sections of objects that are obstructed by objects in front of them.

- **Triangle Setup** – This computationally demanding step requires both floating-point and integer operations. In essence, the host CPU hands off processing tasks to the 3D accelerator prior to rendering. Setup involves looking at a world-coordinate view from one perspective or point of view. In games, the most common view is first person, i.e., the user sitting at the keyboard. The resulting perspective is a 3D view of the world displayed on a 2D screen.
- **Rendering** – Also known as rasterization, this integer-intensive process creates discrete pixel representations and applies realistic textures to mathematical objects within the world to be displayed on a monitor. Rendering calculates on a per pixel basis the different color, shadow, and position information that will enable the viewer to perceive a 3D image on a 2D screen. The rendering process is performed mostly by the 3D graphics accelerator. In addition, MMX™ instructions in the CPU can be used to enhance rasterization.

Although a high-performance PC processor is capable of handling all the stages of the graphics pipeline, the final stage (rendering) has become the preferred domain of today's 3D accelerator boards. Depending on the application or system design, these increasingly powerful graphics engines also can be used to perform partial or full triangle setup. Ultimately, the PC processor and 3D graphics accelerator complement one another. Their computational competencies—the 3DNow! enhanced CPU for floating-point calculations and the graphics card and MMX technology for integer performance—dovetail in typical multimedia PCs.

A bottleneck in the graphics pipeline can occur when the CPU bogs down on complex floating-point calculations in the physics and geometry stages of the pipeline and cannot supply data fast enough to the graphics accelerator engaged in setup and/or rendering. In years past, when graphics acceleration was an emerging technology, the bottleneck was more pronounced at the rendering stage. However, the bottleneck has shifted to earlier stages in the pipeline because the CPU's x87 (floating-point) performance has not kept pace with recent advances in graphics accelerator technology. In fact, accelerators are doubling in performance about every 9 months.

The optimal solution is to enhance the processor's ability to handle floating-point intensive operations that dominate the early stages of the pipeline. 3DNow! technology was developed to do just that. It addresses the bottleneck with a new set of single precision floating-point instructions that accelerate physics and geometry operations, enabling the CPU to keep pace with graphics cards and deliver dramatically improved 3D performance and realism.

Inside 3DNow!™ Technology

The 3DNow! instruction set contains 21 instructions that support Single Instruction Multiple Data (SIMD) floating-point operations and includes SIMD integer operations, data prefetching, and faster MMX-to-floating-point switching. To enhance MPEG decoding, 3DNow! instructions include a specific SIMD integer instruction created facilitate pixel-motion compensation. The extra time needed to retrieve this data can be avoided by using the new 3DNow! instruction called PREFETCH. This instruction can ensure that the data is in the Level 1 cache when needed. To accelerate switching time between MMX and x87 code, the 3DNow! instructions include the FEMMS (Fast Entry/Exit Multimedia State) instruction, which eliminates much of the overhead involved during the switch between these two functional units. As an open standard, 3DNow! technology supports the IEEE 754 single precision data type.

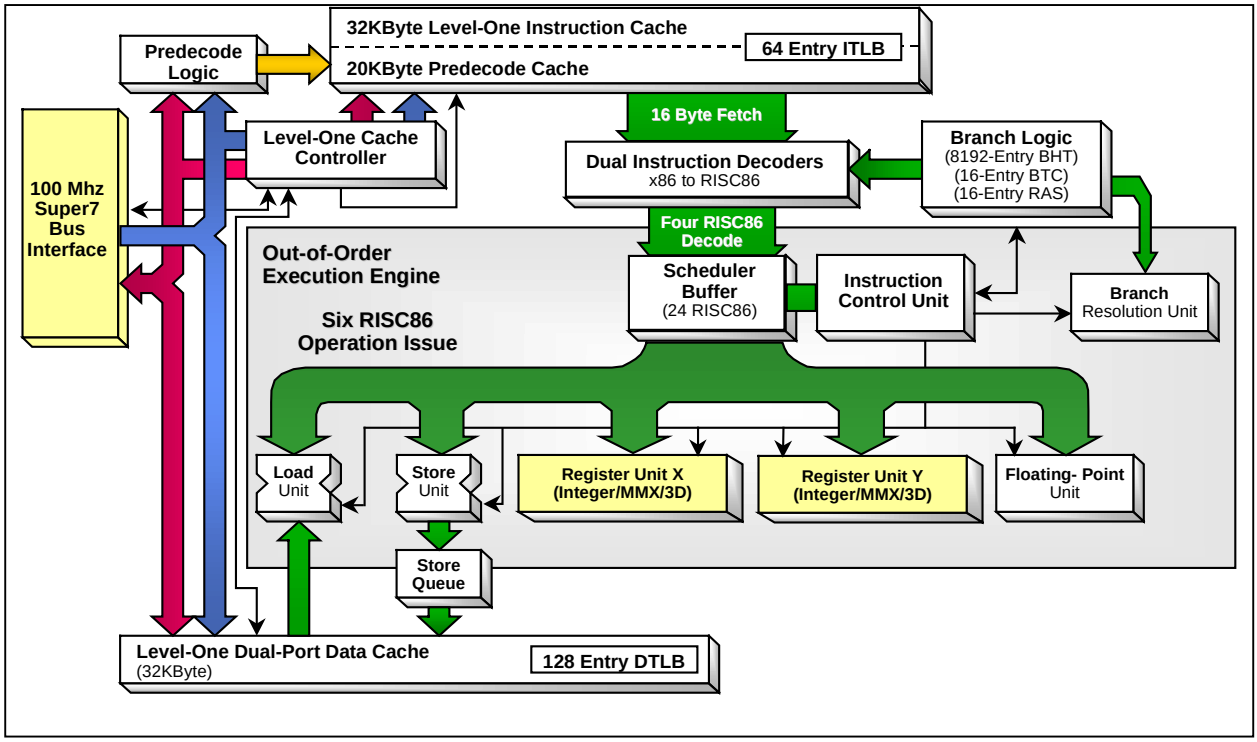

Figure 2: This AMD-K6-2 processor block diagram shows how the register units incorporate dual MMX and 3DNow! instructions.

The AMD-K6-2 processor microarchitecture features fully pipelined dual execution resources. The packed format supports two 32-bit floating-point values per 64-bit register, and instructions execute on each of the 32 bits as separate operations. The number of floating-point numbers that can be stored in memory is unlimited.

Much of the 3D performance boost from 3DNow! technology stems from its use of SIMD, a technique also used by MMX technology. Each instruction not only operates on two single-

precision floating-point operands, but the microarchitecture within the AMD-K6-2 processor can execute up to two 3DNow! instructions per clock through two register execution pipelines. This allows for a total of four floating-point calculations (adds, subtracts, or multiplies) per clock. Because the 3DNow! instructions use the same floating-point stack as the MMX technology instructions, task switching between 3DNow! operations and MMX is eliminated.

The complete multimedia units in the AMD-K6-2 processor combine the existing MMX instructions with the new 3DNow! instructions. Merging 3DNow! instructions with MMX enables x86 programs to contain both MMX (integer) and floating-point graphics instructions with no performance penalty for switching between MMX and 3DNow! (floating-point) units.

Although 3DNow! technology uses MMX registers, has similar encoding to MMX instructions, and can execute simultaneously with MMX instructions, it is altogether a different technology. MMX technology was developed to improve the integer-intensive operations used in rasterization. By the time MMX technology reached the market, graphics card technology had outpaced the rest of the system. While MMX technology can enhance integer-intensive applications, such as video editing and playback, today's state-of-the-art 3D graphics accelerator products have proven to provide the optimal performance boost for 3D applications. 3DNow! technology complements and enhances the performance of graphics accelerators by speeding up the floating-point-intensive, front-end stages of the pipeline.

To illustrate how pervasive floating-point operations are in 3D geometry, one transformation requires 25 multiplications and 18 additions to transform a single vertex (one point of a triangle). With multiple vertices per pixel in an 800 x 600-pixel display environment, the graphics pipeline must be able to process millions of triangle transformations per second. Clearly, there is a tremendous need for the new level of 3D computational horsepower that 3DNow! technology will deliver. The first silicon implementation to incorporate the new technology will be the AMD-K6-2 processor, planned for the second quarter of 1998. *(See the 3Dnow! Technology Roadmap section in this White Paper.)*

Benefits of 3DNow!™ Technology

3DNow! technology enables a more realistic, richer multimedia experience, with sharper and more lifelike 3D imaging, theater-quality AC-3 audio, and smoother MPEG2 video playback. The new technology supports more detailed physics-based modeling and simulations and results in better scene generation, e.g., more objects on screen with more detailed, accurate physical characteristics displayed at real-world speeds (more fluid motion). 3DNow! technology

complements existing 3D graphics hardware and relieves the bottleneck in 3D graphics pipeline by greatly enhancing floating-point-intensive physics, geometry, and triangle setup.

Application areas that stand to benefit from the power of 3DNow! technology include:

- Arcade-quality 3D games
- Edutainment software with 3D images
- Web VRML and web site development tools
- Business document, presentation, and spreadsheet tools
- CAD/CAE packages
- 3D audio processing
- Speech recognition software
- Soft modems
- Soft DVD
- Software drivers for popular 3D graphics controllers
- MPEG2 video playback
- Dolby AC-3 (digital surround-sound algorithm that handles audio portion of DVD movies).

Ultimately, 3DNow! technology will benefit the entire industry:

- Software developers get access to open technology that lets them decide how they want to innovate and differentiate and enables them to implement new, computation-intensive software features that heretofore would have choked the graphics pipeline.
- PC OEMs and resellers get a processor that delivers better 3D performance than Pentium® II at a better system price point.
- Hardware developers get a complementary solution that enhances the effectiveness and integer performance of graphics accelerators used in mainstream system configurations.
- PC users get faster, more visually immersive applications at better price points. In essence, mainstream personal computing will become more entertaining and productive as users get the latest in technology at a reasonable price for a practical purpose.

Implementing 3DNow!™ Technology in 3D Applications

There are two levels in which software developers can implement 3DNow! technology in 3D applications: directly through native optimization with optimized design tools and indirectly by ensuring that their code supports optimized application programming interfaces (APIs).

Optimizing code to take advantage of 3DNow! technology can result in a significant boost in 3D performance. A prime example of a hard-coded application is DreamWorks Interactive's

forthcoming Trespasser game, which will directly incorporate 3DNow! technology to provide the next level of first-person gaming realism.

To facilitate application development with 3DNow! technology, AMD provides ISVs with a software development kit (SDK) that contains a comprehensive set of development tools and utilities (Microsoft and AMD assemblers, Windows emulators, C++ macros, etc.), technical documentation (code optimization application notes and technical manuals), and software libraries (with full source code). Numerous third-party development tools that fully support the 3DNow! instruction set and data types are also available to ISVs. (*For technical details on optimizing software applications for 3DNow! technology, go to the "Developers' Connection" area of the AMD web site, www.amd.com. The "Software Developers' Support" section in this area includes several useful PDF documents, including the 3DNow! Technology Manual.)*

An alternative way developers can tap the power of 3DNow! technology is by ensuring that their future applications will support the latest API releases optimized for 3DNow! instructions. An API is a set of routines that an application program uses to request and carry out lower-level services performed by the computer's operating system. Developers can write their code once for the API, which enables their program to run on anyone's hardware.

Fully optimized APIs and software tool libraries that support 3DNow! technology are planned for 1998. For example, future applications that leverage Microsoft's forthcoming DirectX 6.0 API and upcoming releases of the OpenGL API will benefit from better 3D performance because these APIs will be optimized for 3DNow! technology.

DirectX, a set of Windows APIs that facilitate multimedia content development, offers software developers a broad array of comprehensive, device-independent services. DirectX also includes Direct3D, a complete set of API services for real-time 3D graphics. An enabling API for games and other 3D applications, Direct3D includes an optimized software-only rendering engine and transparent access to 3D hardware acceleration. DirectX 6.0, the next generation of Microsoft's multimedia APIs, will feature a number of new leading-edge multimedia capabilities, including additional Direct3D features and support for 3DNow! Technology. *(For details on how applications are optimized for 3DNow! technology with the DirectX and Direct3D APIs, see the AMD White Paper, "3DNow! Technology in Microsoft DirectX 6.0.")*

OpenGL—an open, alternative multi-platform 3D graphics API pioneered by Silicon Graphics—is being optimized for 3DNow! technology. Already an industry standard for high-end 3D workstations, OpenGL is becoming popular with many PC game developers. Microsoft distributes OpenGL libraries free of charge with every Windows 95 and Windows NT® operating

system. In addition, Microsoft and Silicon Graphics have agreed to jointly define, develop, and deliver new graphics technologies as part of a project code-named "Fahrenheit."

An Emerging Standard Winning Broad Industry Support

AMD pioneered 3DNow! technology in collaboration with key development partners, including Microsoft, and a host of ISVs and independent hardware vendors (IHVs), to benefit the entire PC industry. 3DNow! was defined with significant input from leading ISVs to ensure that they would use the 3D enhancement instructions they helped define and optimize. To date, hundreds of ISVs have attended 3DNow! developer conferences held on three continents, and a growing number of ISVs are writing code for 3DNow! technology today. In addition, AMD is working with leading 3D hardware accelerator developers, including Nvidia, 3Dfx, and ATI, to ensure that their software drivers and other products take advantage of 3DNow! technology.

Game developers are among the first software developers to employ 3DNow! technology because computer gamers are early adopters of leading-edge technology. For example, Incoming by Rage, Microsoft's Baseball 3D, Imagine Studios' Ares Rising, and other PC games are being optimized for 3DNow! technology. DreamWorks Interactive, a joint venture between Microsoft and DreamWorks SKG, is optimizing its forthcoming Trespasser game (the first-person digital sequel to the blockbuster film, "The Lost World") for 3DNow! technology. AMD is also working with action game maker Digital Anvil through a strategic technology alliance to make 3DNow! a standard platform for game developers. Digital Anvil will incorporate 3DNow! into future gaming titles under development. In addition, non-gaming productivity applications, such as Viewpoint Data Lab's LiveArt 98, have been optimized for 3DNow! technology.

AMD supports development partners through a dedicated consulting group and comprehensive development program and provides an array of software development tools and resources that make it faster and easier to optimize code for 3DNow! technology. AMD has sampled functional AMD-K6-2 processor silicon to development partners since October 1997 and is open to licensing 3DNow! technology to industry partners and competitors alike.

3DNow! Technology Roadmap

3DNow! technology, an industry first for PC-based 3D multimedia enhancement, is now available in AMD-K6-2 processor-based PCs well ahead of any other comparable technology. AMD and its industry partners are providing the benefits of 3DNow! technology at mainstream price points beginning late in the first half of 1998, and the technology is expected to proliferate into lower priced systems (approaching the sub-$1,000 market category) by the 1998 Christmas buying season.

AMD has introduced the AMD-K6-2 processor (a 9.3-million transistor device with 81 sq. mm die size), with initial clock speeds of 333, 300, and 266 MHz. New AMD-K6-2 processor-based systems will support the Accelerated Graphics Port (AGP) specification, offer a 100-MHz bus to main memory and the L2 cache, and include superscalar MMX capability. Boosting the bus speed to 100 MHz will improve L2 cache bandwidth and speed by 50 percent, which is expected to yield approximately a 10 percent system performance boost by itself.

The AMD-K6-3 processor (21.3 million transistors on 135 sq. mm die) is planned for 2H 98, with clock speeds expected to reach 400 MHz. Additional processor enhancements include an on-chip, full-speed 256K backside L2 memory cache and support for an optional external L3 cache for ultra-high-end performance.

The AMD-K7 processor, planned for 1999, also will incorporate 3DNow! technology and will feature a module that uses a single-edge connector mechanically similar to Intel's Slot 1. The new processor will incorporate the high-performance Alpha 21264 bus, which AMD has licensed from Digital Equipment Corporation.

AMD Overview

AMD is a global supplier of integrated circuits for the personal and networked computer and communications markets. AMD produces processors, flash memories, programmable logic devices, and products for communications and networking applications. The world's second-leading supplier of Windows compatible PC processors, AMD has shipped more than 100 million x86 microprocessors, including 55 million Windows compatible processors in the last five years.

Founded in 1969 and based in Sunnyvale, California, AMD has sales and marketing offices worldwide and manufacturing facilities in Sunnyvale; Austin, Texas; Bangkok, Thailand; Penang, Malaysia; Singapore; and Aizu-Wakamatsu, Japan. AMD had revenues of $2.4 billion in 1997. (NYSE: AMD).

Cautionary Statement

This White Paper contains forward-looking statements that involve risks and uncertainties that could cause actual results to differ materially, including the market acceptance and successful production ramp of AMD processors, the impact of competitive products and pricing, the timely development of wafer fabrication process technologies, the effect of changing economic conditions, and such risks and uncertainties detailed from time to time in the company's SEC reports.