MULTI-CORE PROCESSORS— THE NEXT **EVOLUTION** IN COMPUTING

Multi-core processors represent a major evolution in computing technology. This important development is coming at a time when businesses and consumers are beginning to require the benefits offered by these processors due to the exponential growth of digital data and the globalization of the Internet. Multi-core processors will eventually become the pervasive computing model because they offer performance and productivity benefits beyond the capabilities of today's single-core processors.

Multi-core processors will also play a central role in driving important advancements in PC security and virtualization technologies that are being developed to provide greater protection, resource utilization, and value for the commercial computing market. General consumers, too, will have access to greater performance than ever before, which will significantly expand the utility of their home PCs and digital media computing systems. Multi-core processors will also have the benefit of offering performance without having to increase power requirements, which will translate into greater performance per watt.

Placing two or more powerful computing cores on a single processor opens up a world of important new possibilities. The next generation of software applications will likely be developed using multi-core processors because of the performance and efficiency they can deliver compared to single core processors. Whether these applications help professional animation companies produce more realistic movies faster for less money, or create breakthrough ways to make a PC more natural and intuitive, the widespread availability of hardware using multi-core processor technology will forever change the computing universe.

Multi-core processors exemplify AMD's vision to understand customers and deliver products that best meet their needs. AMD has been planning for this important evolution since the late 1990s when it first announced a strategy to place multiple cores on a single processor. Since AMD's multi-core processors will use the same straightforward and proven architecture available in single-core AMD64 processors, the company's multi-core processors will magnify the elegance of this design and offer the exceptional overall performance that AMD's customers expect.

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Section I

Multi-core Processor Evolution

Computer processor design has evolved at a constant pace for the last 20 years. The proliferation of computers into the mass market and the tasks we ask of them continue to push the need for more powerful processors. The market requirement for higher performing processors is linked to the demand for more sophisticated software applications. E-mail, for instance, which is now used globally, was only a limited and expensive technology 10 years ago. Today, software applications span everything from helping large corporations better manage and protect their business-critical data and networks to allowing PCs in the home to edit home videos, manipulate digital photographs, and burn downloaded music to CDs.

Tomorrow, software applications might create real-world simulations that are so vivid it will be difficult for people to know if they are looking at a computer monitor or out the window; however, advancements like this will only come with significant performance increases from readily available and inexpensive computer technologies.

AMD has planned for these computing advancements since the late 1990s when it first announced the company's current processor architecture. AMD designed its AMD64 processor architecture from the ground up to accommodate multiple cores on a single processor. Multi-core design offers enhanced overall system performance as well as a sophisticated platform to better tackle today's more complex software applications. AMD is leading the x86 computing industry to multi-core processors because:

- **Multi-core processors offer an immediate and cost-effective technology for solving today's processor design challenges—alleviating the by-products of heat and power consumption that exist when continually advancing single-core processor frequency, or 'clock speed'**
- **New 90-nanometer manufacturing processes have enabled AMD to develop processors that deliver sophisticated technology to customers interested in performance, flexibility, and value**
- **Multi-core processors will help to break through today's single-core performance limitations, and provide the performance capacity to tackle tomorrow's more advanced software**
- **Current operating systems such as Microsoft® Windows®, Linux, and Solaris are now capable of benefiting from multi-core processors**
- **Multi-core processors offer an ideal platform for enabling logical, incremental performance increases as market demands increase in the future**

Immediate customer benefits of multi-core processors:

- **Multi-core processors have the potential to run applications more efficiently than single-core processors—giving users the ability to keep working even while running the most processor-intensive tasks in the background, like searching a database, rendering a 3D image, ripping and burning music files to a CD, or downloading videos off the Web**
- **Multi-threaded software applications—programs that run multiple tasks (threads) at the same time to increase performance for heavy workload scenarios, such as data mining, mathematical analysis, and Web serving, are already positioned to take advantage of multi-core processors**
- **Multi-core processors offer increased productivity within the same computing infrastructure companies are using today**

Long-term benefits of multi-core processors:

- **Multi-core computers have the ability to run today's applications as well as tomorrow's more complex applications, which means that the hardware will retain its value over time**
- **The growing complexity of software, as well as the desire of users to run multiple applications at the same time, will accelerate widespread adoption of multi-core processor-based systems. This will give commercial applications**

the ability to handle large amounts of data and more users faster and more efficiently, while consumers will experience richer features and more functionality, especially for applications like digital media and digital content creation

- **Next-generation software applications will require the performance capacity provided by multi-core processors. Software destined to break barriers in the user experience, like voice recognition and/or artificial intelligence (AI), will be possible with multi-core processors**

- **Expanded roles for PCs due to increased performance capacity, multi-core processor-based PCs will be leveraged for new tasks, including serving as the hub for digital entertainment in the home**

Multi-core processor adoption

AMD is taking a lead in promoting software pricing practices based on a per-processor, and not on a per-core, model. Consistent with its long-standing tradition of championing technologies that truly benefit customers, AMD is working hard to ensure multi-core technology is available to customers who want the best-performing computer systems. AMD's efforts paid off in October 2004 when Microsoft announced that its server software, currently licensed on a per-processor model, will continue to be licensed on a per-processor pricing model. This policy set an important precedent that other software vendors are likely to follow, and helps ensure that the multi-core computer universe will be cost-effective.

AMD plans to ship multi-core AMD Opteron™ processors for the server and workstation markets mid-2005 and dual-core processors for the client market in the second half of 2005. AMD has no immediate plans to replace all single-core processors with multi-core processors, but the benefits of multi-core processors in most scenarios will continue expanding.

Section II
Implications for the Enterprise

The corporate computing environment has witnessed dramatic changes in the last few years, with a shift from rapid expansion of IT infrastructure in support of growing business needs, to carefully managing existing assets and investing in new strategic technologies that provide specific competitive advantages. Information technology (IT) managers today are challenged with providing more services to more users, meeting ever-increasing performance expectations, storing and managing exponentially increasing amounts of data, better protecting the network, and ensuring system stability—all with limited possibility to expand data centers because of shrinking budgets. Key drivers for multi-core processors in Server/Workstation environments include:

- **Reliance on x86 architecture as the backbone of corporate IT networks is placing performance demands on today's servers to run a growing list of complex applications**

- **Data centers' performance requirements are growing while at the same time budget and logistical concerns deter physical expansion within many enterprises. Methods such as server consolidation and virtualization to better utilize existing resources have become appealing options to curtail costs**

- **Multi-threaded applications are expected to be adopted more broadly in the future. The need for multi-processor systems is growing in new areas**

- **Security has become a critical issue, requiring new classes of software applications and technologies that are uniquely served by multi-core processors. An increasingly effective approach to providing additional platform security is to leverage the power of virtualization technology to segregate trusted applications from untrusted ones**

- **Increased performance without increased power consumption is a critical need. Corporate IT managers also remain resolute in their need to add performance without increasing the physical footprint for hardware. Multi-core processor solutions address these needs by providing increased performance without increasing power or physical space requirements**

Extension of AMD64 architecture

AMD led the industry in 2003 when it launched the world's first 32- and 64-bit processor compatible with the x86 architecture. Thanks to its innovative Direct Connect Architecture, the AMD Opteron™ processor helps eliminate the bottlenecks inherent in a legacy front-side bus by directly connecting the processor, the memory controller, and the I/O to the central processor unit to enable improved overall system performance and efficiency. The elegance of this architecture lends itself perfectly to multi-core processor designs. And because AMD planned for these additions when the processor was initially designed, it is a logical step to directly connect two cores on a single processor. AMD's multi-core processors also use the same sockets and connections as their single-core relatives.

AMD multi-core

In August 2004, AMD was the first x86 processor manufacturer to demonstrate a fully functioning dual-core processor on a shipping platform. Although performance will vary based on the software application, corporate IT systems currently optimized for symmetrical multiprocessing (SMP) multi-threaded applications should see significant performance increases by using AMD multi-core processors. They are also inherently more capable of leveraging the benefits of multi-threaded applications because they are, essentially, multi-processor systems reduced down to single chips. Multi-core processors, whether installed in desktops, notebook PCs, workstations or servers, can play a significant role in enabling companies to deploy sophisticated new security and virtualization layers.

Servers

Multi-core AMD Opteron processors provide the best performance per watt for servers, and will enable hardware manufacturers to increase the processing capacity of their "rackable" server products—including their server blade designs that share common network, power, and cooling components. AMD's enterprise customers can deploy new server blade systems without having to increase the physical footprint of their computer system resources, plan for additional heat dissipation, or provide additional power. Multi-core processor-based servers will deliver more overall performance than those powered by single-core processors, while at the same time will be easier to manage because more processing capacity can be concentrated into fewer servers. For the same reason, multi-core servers will be less costly to operate.

Security

Viruses, worms, and spyware are constantly testing firewalls and other network protection measures, and can wreak havoc on computer systems. As a result, software and hardware designers have been collaborating to provide better security options. AMD pioneered Enhanced Virus Protection (EVP) technology that provides protection at the platform level when used in combination with Microsoft® Windows® XP Service Pack 2 (SP2) and the leading Linux distributions from SuSE and Red Hat. Available on all AMD64 processors, EVP is an important step to help users defend against some of the most common and damaging threats.*

AMD engineers continue to focus on ways to strengthen security, and have gone beyond EVP with multi-core AMD processors. Not only will systems powered by these processors be platform-protected from specific viruses when used as discussed above, but also AMD is bringing additional security features to all of its processors with a technology called Presidio. AMD multi-core processors using Presidio technology, coupled with appropriate operating system support, will be able to run more sophisticated security applications by better leveraging Direct Connect Architecture and virtualization technologies to provide increased performance capacity.

Virtualization

Virtualization—the use of software to allow workloads to be shared at the processor level by providing the illusion of multiple processors—is growing in popularity. Virtualization balances workloads between underused IT assets, minimizing the requirement to have performance overhead held in reserve for peak situations and the need to manage unnecessary hardware.

AMD multi-core processors are well suited to help companies implement virtualization because they offer the increased performance necessary to counter performance penalties. The architecture of AMD multi-core processors offers a critical advantage when building "virtual machines" by leveraging Direct Connect Architecture to deliver very high-performance memory-sharing between virtual machines hosted on multiple cores within a single processor.

*Enhanced Virus Protection will by default only protect the user's Windows® operating system. After properly installing the appropriate Windows release, users must enable the protection of their applications and associated files from memory buffer overrun attacks. Contact your application software vendor for information regarding use of the application in conjunction with Enhanced Virus Protection. AMD and Microsoft strongly recommend that users continue to use third-party anti-virus software as part of their security strategy.

AMD 64™

AMD is leading the processor industry to help simplify the implementation of virtualization with new technology, called Pacifica, scheduled to be launched in 2006. In cooperation with leading software companies offering virtualization solutions, like Microsoft and VMware, AMD Pacifica is designed to remove some of the complexity involved in implementing virtualization.

With help from AMD multi-core processors, companies can more easily implement virtualization across the entire corporate enterprise. Virtualization enables running different operating systems and applications on the same servers, greatly reducing hardware requirements and, perhaps more importantly, the strain on already overloaded IT managers. AMD multi-core processors can enable this powerful technology to be used more universally and with greater success.

Section III
PC Benefits

Five to 10 years ago, most people were using PCs to run word processing and spreadsheet programs, surf the Internet, and play games. During this time, even middle-of-the-road PCs were easily delivering the required levels of performance. However, in every year since, we have greatly expanded what we do with our computers. Today, we are regularly working with software applications that manipulate digital video and photographs, and new games are pushing boundaries in the area of real-life simulation. These exciting advancements have required high-performance PCs to run the latest, sophisticated applications.

Even with current PCs delivering unprecedented performance, there are still software applications that regularly tax the computer's ability to deliver instantaneous results—causing the all-too-familiar spinning icon, disk thrashing, and computer hesitation—resulting in user frustration. Most people understand there are physical limitations governing a processor's ability to deliver complex tasks in split seconds under certain scenarios, forcing users to wait for computers to execute one task before it allows the user to do something else. AMD multi-core processors can help greatly alleviate this condition.

Benefits of multi-core processors for PCs:

- **Multi-core processors can enable a digital lifestyle. Digital media entertainment, or digital life, is an exciting concept currently under collaborative development by Microsoft, Sony, and a number of other companies. This coming development will allow consumers to truly experience the abundance of rich, digital media in their homes. Although the possibilities of digital life are exciting, they require significant computer processing performance and multi-tasking capability. PCs with multi-core processors can deliver this performance and multi-tasking capability and will lend themselves to becoming the center of the digital home**

- **PCs can already be wirelessly integrated with cable desktop boxes and TVs throughout the home. With an AMD multi-core processor-based PC serving as the hub of a wireless home network, dad can be surfing the Web in the living room, while his daughter is downloading and playing MP3 audio files in her bedroom, and his son is playing a game on an appliance in the kitchen—all leveraging the high performance and multi-tasking benefits of AMD multi-core processors. This scenario will be delivered by a single, AMD-powered PC**

- **One computing challenge is not only in delivering the content, but also in creating it. Encoding and decoding digital media files can be cumbersome within the constraints of many single-core, processor-based systems. There is also the need to simultaneously deliver a simple, unified operating system capable of managing all the different appliances and electronics involved in the system, including all the TVs, stereos, and MP3 players. The digital life concept relies heavily on the multi-tasking capability of PCs powered with AMD multi-core processors. Although the peripheral technology is available today, the lack of PCs with adequate processing power is a key limitation to more widespread adoption**

- **Multi-tasking productivity—multi-core processor PC users will experience exceptional performance while executing multiple tasks simultaneously. The ability to do complex, multi-tasked workloads, such as creating professional digital content while checking and writing e-mails in the foreground, and also running firewall software or downloading audio files off the Web in the background, will allow consumers and workers to do more work in less time**

- **PC security can be enhanced because multi-core processors can run more sophisticated virus, spam, and hacker protection in the background without performance penalties**

- **Cool and quiet—the enhanced performance offered by multi-core processors will come without the additional heat and fan noise that would likely accompany performance increases with single-core processor machines**

Section IV
Software Designers and Users in Win-Win Situation

For years, independent software vendors delivered imaginative and robust solutions to solve real-world problems, benefiting both businesses and general consumers. Businesses rely on constantly improving software for automating exceedingly complex processes, including those dealing with e-commerce and information management. Consumers are doing more complex tasks on their PCs, including manipulating digital photographs and media, and running cutting-edge games. The sheer number of new applications, and the exciting functionality they provide, is a credit to software engineers. However, in their quest to design more sophisticated applications, while at the same time making them easier to use and more cost-effective, these professionals are regularly pushing the limits of current processor capacity.

Multi-core processors will solve many of the challenges currently facing software designers by delivering significant performance increases at a time when they need it most. With increasing competition and market demands, engineers need to provide more functionality into their designs in less time. Whether enhancing and updating large, enterprise applications or developing the next-generation PC game, software developers are acutely aware of the computational requirements during each phase of creation.

One particularly frustrating process is compiling software after the code has been written. Compiling is notorious for overloading computer processor capacity and causing, in many cases, lengthy development cycles. During these periods, software engineers are at the mercy of their computer resources. In many cases, the speed at which software code is being compiled results in greater productivity for the programmer. Overall, that translates into a more efficient software development cycle.

AMD's multi-core processors, in combination with new compiler optimizers, will reduce compiling times by as much as 50 percent. The time savings offered by better system performance will give software developers a critical advantage in meeting time-to-market demands.

Software vendors also can use more multi-threaded design methods for delivering enhanced features. With the advent of multi-core processors, and the anticipated widespread adoption of multi-core computer platforms by businesses of all sizes, as well as with general consumers, software vendors will have a much larger marketplace to distribute new and improved applications.

Even with the added difficulty and complexity of developing multi-threaded applications, by using this design method software vendors will have new opportunities to better differentiate their solutions from competitors and better optimize their software for better performance. As a result, AMD believes a significant number of multi-threaded applications will become available over the next few years, expanding the possibilities of the next "killer app."

Due to the combined efficiencies of more powerful hardware and this more ingenious software, engineers might do things like create more natural interfaces between man and machine. Voice and/or handwriting recognition, already evolving quickly, could finally provide the intended benefit and become mainstream. Improved security for PCs that use fingerprint or retina recognition might be more commonplace, offering more effective protection and

eliminating the need for users to remember passwords. Also, engineers working with artificial intelligence (AI) are almost certain to make great discoveries in the next few years by using the added performance of multi-core processors and multithreaded applications.

Section V
AMD Multi-core Architecture Advantages

AMD began designing the first x86 multi-core processors in the late 1990s, and was the first company to announce plans to deploy multiple x86 64-bit processors on a single die. AMD expects to be the first to introduce dual-core processors for the server and workstation market in mid-2005. Dual-core processors for the client market are expected to follow, beginning in the second half of 2005.

The AMD64 architecture is the key enabler for this advancement. AMD64 represents a new class of computing because it enables a single architecture to offer peak performance across 32- and 64-bit environments. AMD64 allows end users to run their existing 32-bit applications and operating systems at peak performance, while providing a migration path to 64 bits.

AMD's multi-core processors are nearly absolute in their simplicity. AMD scrapped the front-side bus (FSB) architecture favored by the competition and instead used a more innovative design called Direct Connect Architecture, which helps reduce the real challenges and bottlenecks of system architectures at the processor level.

While the AMD64 architecture offers real performance benefits for single-core processors, its inherent benefits and elegant design are magnified when applied to multi-core processors. AMD Direct Connect Architecture helps eliminate bottlenecks and reduce latency in a flexible design that is unmatched in the industry. And, because the same manufacturing processes will be used to produce multi-core AMD64 processors, the power envelope for multi-core processors will fit into the current sockets and power infrastructures. This eliminates the time and expense for platform manufacturers to redesign their components to allow for the new processors, which represent costs that would have been passed on to their customers. It also makes it easier for system builders to have readily available parts to build their branded products.

As with AMD's leadership in 64-bit computing, multi-core processors will provide real-world customer benefit, and value without disruptions to its manufacturer partners or end users. Multi-core processors represent a natural evolution of processor design, offering significant performance gains at a time when software is ready to leverage it, and enhancing capabilities beyond what is possible with single-core processors.