Itanium® 2-based Solutions and the x86 Architecture

Optimizing IT Value by Mixing and Matching Industry-Standard Server Platforms

ITANIUM® SOLUTIONS ALLIANCE

By understanding the relative strengths of the Intel® Itanium® 2 microarchitecture and the x86 architecture, businesses can integrate them together in their datacenters to maximize their IT capabilities and obtain the best value from their computing investments.

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Executive Summary

With the growing market success of Itanium® 2-based solutions and the integration of 64-bit extensions into x86-based processors, organizations now have a choice of two widely supported, industry-standard, 64-bit architectures. Which will be best for a particular implementation? In most cases, the right choice will be obvious.

- **Itanium 2-based solutions** are designed for data-intensive, business-critical applications, in which the highest levels of scalability, availability and security are required. Ideal workloads include large and demanding data-tier and transactional applications, as well as complex analytical applications that benefit from large shared memory and/or fast floating point performance. As workloads grow, these types of applications can typically be scaled most effectively on large, multi-processor server platforms.
- **x86-based solutions** are better suited for mainstream applications in the front-end and middle-tier of the enterprise infrastructure; and for workloads that can be distributed easily across multiple, smaller servers. This can include very demanding technical and analytical applications, as long as they can be broken down into relatively small, independent sub-processes that do not share substantial amounts of data.[1]

Both architectures have a vital role to play in today's enterprise datacenters. They can be integrated together very easily; are supported by a broad community of hardware and software vendors; and will continue to advance very rapidly in the years to come. By using them in combination, businesses can maximize the value and agility of their computing assets, and take advantage of industry-standard solutions at all levels of their infrastructure.

Two Industry-Standard Architectures

For many years, there was a clear demarcation between business-critical enterprise computing and mainstream business computing. Business-critical systems were based on RISC/UNIX architectures. Mainstream systems were predominantly based on the industry-standard 32-bit architecture commonly known as x86 (or IA-32). Though x86-based servers gradually moved up in the datacenter, large corporations continued to rely on RISC architectures to deliver the performance, scalability, availability and security needed for their most demanding commercial and technical applications.

More recently, two major developments have altered this traditional mix of computing options:

1. The emergence of Itanium 2-based servers has introduced a more flexible, affordable and standards-based alternative to RISC architectures.
2. 64-bit extensions and virtualization capabilities have been introduced into the x86 architecture.

Both developments offer enormous benefits for enterprise IT organizations, providing them with more powerful and flexible systems that help to reduce the total costs of acquiring, integrating and managing IT solutions. However, with two industry-standard, 64-bit architectures, how do IT organizations choose between them for particular application, workload and IT requirements? The short answer is that, with some qualification, the traditional distinctions still hold true (Figure 1).

- **Itanium 2-based systems** deliver the performance, scalability, availability, security and manageability needed for the most demanding, business-critical implementations, including high-end RISC replacement.
- **x86-based systems** offer leading performance for the enormous installed base of 32-bit applications. With recent advances, they also provide a flexible platform for scaling those applications (via 64-bit migration) and consolidating them (via virtualization) as workloads, datasets and IT requirements

[1] *For more information, see the white paper, Intel's Enterprise Processor Plans: Positioning the Xeon Processor and the Itanium Processor, by Vernon Turner, IDC, April 2004: http://www.intel.com/technology/64bitextensions/4071_intel_xeon_rev3.pdf*

evolve. In addition, they can be an excellent choice for migrating off many entry-level to mid-range RISC solutions.

Because of the 64-bit capabilities of x86-based systems, there is now some overlap for applications in the middle tier of the enterprise infrastructure (e.g., mid-size databases and transactional systems that are not business critical), and the best choice may not always be obvious. In such cases, it will be important to take a closer look at workloads, datacenter usage models and growth expectations to determine the best platform.

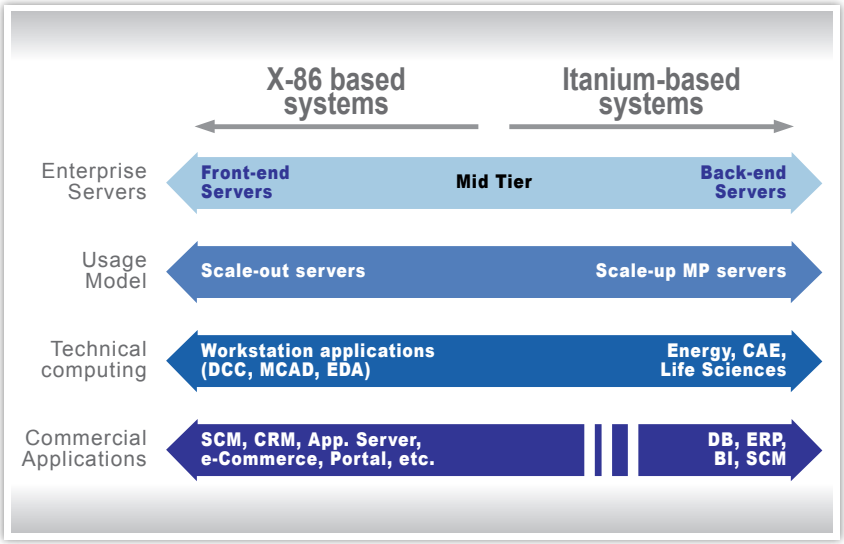

Figure 1. *Together, Itanium 2-based servers and x86-based servers deliver end-to-end support for enterprise computing on widely supported, industry-standard architectures.*

The remainder of this paper compares these two architectures in more detail, and provides additional insight into choosing the best platform for specific solutions (a summary of the comparison is shown in Table 1).

Table 1. Two Industry-Standard Architectures Targeting Different Needs

	Itanium 2-based Solutions	*x86-based Solutions*
Scalability[a] *Processors per server (max)* *Memory Addressability* *I/O (per processor)* *Cache (max per core)*	 *512* *1,000 TB* *10.6 GB/s* *9 MB (12 MB in Dual-Core configuration, available mid-2006)*	 *32* *1 TB* *4 GB/s* *8 MB (2 MB in current Dual-Core configuration)*
RAS[a] *(see Table 2)*	*- Comparable with high-end RISC solutions* *- Varies with component and system vendors*	*- Varies with processor, component and system vendors*
Performance[b] *TPC-C (best result)* *TPC-C (2-way server)* *SPECfp2000 (1 CPU)* *SPECint2000 (1 CPU)*	 *1,231,433* *200,829* *2712* *1590*	 *109,633* *109,633* *2132* *1956*
Parallelism *Threads (per core)*[b] *Instructions/clock cycle* [b] *Other advantages*	 *2* *6* *- Massive execution resources (128 general purpose registers, 128 floating point registers, 8 branch registers)* *- Shorter pipeline* *- Predication* *- Speculation* *- Cache hints* *- Data and instruction pre-fetch* *- Loop optimization*	 *2* *3* *- Deep out-of-order execution* *- Advanced branch prediction*
Ideal Workloads	*Computations, processes and transactions that:* *- Share data extensively* *- Can be executed in parallel as dependent subprocesses* *- Are floating-point intensive*	*Computations, processes and transactions that:* *- Do not share data extensively* *- Can be executed in parallel as independent subprocesses* *- Are integer intensive*

Development Environments	*Extensive development and optimization tools are available for Windows, Linux and UNIX environments.[c]*	*Extensive development and optimization tools are available for Windows, Linux and Macintosh environments.[c]*
Datacenter Usage Models	*- Best for scaling-up via large multi-processor servers - Ideal for consolidating 64-bit workloads, including mainframe, UNIX, Linux and Windows - Affordable platform for RISC modernization*	*- Best for scaling-out via clusters of 2- or 4-processor servers - Ideal for consolidating small- to medium-sized 32-bit and 64-bit workloads - Industry-standard alternative to entry-level and mid-range RISC solutions*
Ideal Applications	*- Large, mission-ciritcal data-tier applications (database, data mining, business intelligence) - Complex analytical and transactional applications (financial modeling, large ERP, etc.) - HPC applications that benefit from large, shared memory*	*- Front-end and infrastructure applications (Web servers, email, file and print, etc.) - Small- to medium-sized database and transactional applications - HPC applications that are optimized for parallel throughput on clustered systems*

[a] Processors and platforms continue to evolve for both architectures, so all metrics in this table are subject to change without notice.
[b] Performance results are valid as of March 21, 2006. For the latest published results, visit http://www.tpc.org and http://www.spec.org/.
[c] Intel compilers, performance libraries, performance analyzers, and threading and clustering tools for Windows, Linux and Macintosh environments are available at www.intel.com/software. Software tools for UNIX environments are available through selected Itanium-based system vendors.

The EPIC Advantage

> *"The Itanium processor designers incorporated the best features of the CISC and RISC architectures to create the next wave of microarchitecture design—a design that has a lot of headroom and capability for future growth." — Mark Mayotte, director of Strategic Partnership Management Office, Hardware & Systems Division, HP.[2]*

The most important differences between the Intel Itanium 2 microarchitecture and the x86 architecture arise from the fact that the former is much younger. It was designed with a better understanding of today's computing challenges and the strategies that are most effective in addressing them.

Several disruptive changes have occurred since the x86 architecture was first introduced.

1. ***Frequency ramping*** has reached its natural limit, and can no longer be the primary source of future processor performance gains.
2. ***Memory performance*** has lagged far behind processor performance. Today's processors may be stalled for hundreds of clock cycles if they have to wait for data to be accessed from main memory.
3. ***Security needs*** have increased dramatically with the rise of the Internet.

The Intel Itanium 2 microarchitecture was designed to address each of these challenges, while delivering the scalability and availability needed for the most demanding and business-critical applications.

Better Performance through Parallelism

> *"Itanium can process more data in parallel, and in many cases double or triple the current performance found in x86, Sparc, PowerPC or AMD64." — Bill Worley, Jr., PhD and Peter J. Cranstone, from "The 64-bit Inflection Point," a Secure64 white paper.[3]*

The Intel Itanium 2 processor is based on the Explicitly Parallel Instruction Computing (EPIC) model, which

[2] From Alliance interview held March 2006
[3] Source: http://www.secure64.com/products/64-Bit_Inflect_White_Paper-FINAL1.pdf

was designed from the ground up to enable increasing amounts of work to be done in each clock cycle. This makes it less dependent on frequency ramping for ongoing performance improve.

Core advantages include:

- **More instructions per clock cycle —** An x86-based processor can execute up to three instructions per clock cycle. An Intel Itanium 2 processor can execute up to six. (Note: Intel's next-generation x-86-based processors include innovations that will allow additional instructions to be processed per cycle for certain instruction combinations. Instructions per cycle could also be increased in future Intel Itanium 2 processors.)
- **Enormous execution resources —** With 128 general purpose registers (versus only 16 in x86-based processors), the Intel Itanium 2 processor can sustain higher levels of parallel throughput. It can also hold more interim results in execution registers, rather than shuffling them back and forth between the memory and cache subsystems.
- **Advanced code optimization —** EPIC supports a number of advanced performance optimization strategies, such as predication, speculation, software pipelining, and out-of-order memory optimization (see the Appendix for details). These functions are implemented and managed by the software compiler, so the instruction stream is optimized for parallel throughput before it reaches the processor.

x86-based processors have fewer strategies available for optimizing parallel throughput. Though they are designed to enable out-of-order instruction execution, the processor itself must determine which instructions can be safely executed in parallel or out of sequence. Extensive processing resources are devoted to this task, and since it happens during runtime, the processor can only look a few instructions ahead to find opportunities for optimization.

An EPIC compiler, on the other hand, can look thousands of instructions ahead to find and exploit opportunities for parallelism. This helps to improve code efficiency. It also frees the Intel Itanium 2 processor to focus all of its resources on executing the optimized code stream as fast as possible.

More (and More Efficient) Memory and Cache

> ***"Itanium's cache sizes outstrip what whole systems used to have for their main memory." — Jonathan Eunice, Principal Analyst, Illuminata, Inc.[4]***

Processors based on the x86 architecture can directly address up to 1 terabyte of physical memory; Intel Itanium 2 processors can directly address up to 1 petabyte (1,000 terabytes). In addition, Intel Itanium 2 processors have larger and more efficient cache configurations. Since cache is several orders of magnitude faster than today's fastest memory subsystems, this can substantially reduce processor wait times, especially for memory-intensive applications. Cache also consumes much less power than logic circuits, so increasing the size and efficiency of the cache structure is a power-efficient way to increase overall performance.[5]

Higher Scalability

> ***"The Itanium microarchitecture was explicitly designed for scalable systems." — Mark Mayotte, director of Strategic Partnership Management Office, Hardware & Systems Division, HP.[6]***

The Intel Itanium 2 processor was built from the ground up to support systems with large numbers of processors and heavy, single-image workloads. In addition to its high parallelism and memory/cache

[4] *From Alliance interview held March 2006*
[5] *According to a recent article, the growing importance of cache is a key advantage of Intel Itanium 2 microarchitecture: "Time is on the side of the [Intel] Itanium [2 processor]. As new process technology was introduced, cache sizes have been growing very quickly during the past years, without introducing extra cost or high latency. No competitor has the advantages that Itanium has: 1. As caches get bigger, Itanium benefits more than the x86 competition. X86 CPUs target higher clock speeds and, as such, it is more difficult to use large low latency caches. 2. Intel has mastered as no other the skill to produce very dense and fast cache structures." Source: Itanium—is there light at the end of the tunnel?, by Johan De Gelas, November 9, 2005: http://www.linkselection.be/detframe.asp?doit=580939&what=Itanium-is-there-light-at-the-end-of-the-tunnel*
[6] *From Alliance interview held March 2006*

advantages, it has greater bandwidth for moving large amounts of data both within the processor and to and from the outside world. These intrinsic capabilities are extended by the chipsets that are designed for Itanium-based systems, which tend to be optimized for high-bandwidth and larger SMP designs.

In general, the x86 architecture is ideally suited to two and four processor servers. Though it has been successfully extended beyond that range, it requires considerably more effort in system design than for comparably sized Itanium-based servers, and the performance advantages of Itanium-based systems tend to increase fairly rapidly as the number of processors per server grows.

Better Security

> ***"Itanium is ideal for solving the security problems associated with delivering mission-critical content on the Web edge." — Bill Worley, Jr., PhD and Peter J. Cranstone, from "The 64-bit Inflection Point," a Secure64 white paper.[7]***

A number of advanced security capabilities were built into the Intel Itanium 2 microarchitecture, including support for four privilege levels, more than 16 million memory protection keys and the ability to compartmentalize memory. It also provides ultra-fast parallel throughput for encryption algorithms. These capabilities provide fundamental advantages for addressing many of today's security issues, and enable mainframe-class security on industry-standard Itanium 2-based servers. Software solutions will soon be available to help businesses take advantage of these capabilities to enhance the security and performance of existing applications and networks (for details, visit www.secure64.com).

Advanced RAS

> ***"The RAS features of Itanium architecture let you detect errors, correct them or workaround them, and just keep going. These capabilities are critical in any environment where downtime is not an option." — Mike Mitsch, general manager, Alliances & Strategy Solutions Platform Group, NEC.[8]***

The Impact of Multi-Core

Multi-core technology, in concert with software optimization, will be a critical component of future performance advances. x86-based processors are already available in Dual-Core versions, and Intel demonstrated a quad-core Intel® Xeon® processor at the 2006 Intel Developer Forum. The latest Intel Itanium 2 processor includes two cores, and development is underway on enhanced Dual-Core and quad-core designs.

Though the x86 architecture has an early lead in multi-core support, the Intel Itanium 2 microarchitecture has some clear advantages. In particular, it has a smaller and more power efficient processing core. This will make it easier to combine more cores in future designs, while reducing total power consumption and leaving more space on the chip for large cache configurations.[9]

The superior per-core performance of the Intel Itanium 2 processor will also be an advantage going forward. Though multi-core designs increase total throughput for multi-threaded workloads, they do not increase per-thread performance, which can be important to minimize latencies for individual transactions.

As more cores are introduced into both Intel Itanium 2 and x86-based processors, there may be some shift of ideal workloads

[7] Source: http://www.secure64.com/products/64-Bit_Inflect_White_Paper-FINAL1.pdf
[8] From Alliance interview held March 2006
[9] For more information, see the Itanium Solutions Alliance white paper, The EPIC Advantage: Why Intel® Itanium® 2 microarchitecture is ideal for multi-core performance scaling.

Itanium 2-Based Solutions vs. x86 Architecture, Table 2

RAS Feature	Intel Itanium® 2 Platforms	Typical Mainframe	Typical RISC	x86-based systems		
				Intel Xeon® MP Platforms	Intel Xeon® Platforms	Other x86 Systems
Cache ECC Coverage	√	√	√	√	√	√
Memory Single Device Error Correct	√	√	Select Vendors	√	√	√
Memory Retry on Double-Bit Error	√	√	√	√	√	
Error Recovery on Data Bus (ECC)	√	√	√	√		
Internal Logic Soft Error Checking	√	√	Select Vendors			
Bad/Poisoned Data Containment	√	√	Select Vendors			
Cache Reliability	√ (Intel® Cache Safe Technology)	√		2H 2006		
Memory Sparing	√	√	√	√	√	2006
Memory Mirroring	√			√	√	
Hot Plug I/O (PCI-X, PCI Express)	√	√	√	√	√	Select Vendors
Memory Hot Swap	√			√		
Processor Lockstep Support	√			√[a]		

Real-Time Protection | Fail Safe Systems | On-Line Repair | Real-Time Cross-Check

[a] *All time-frames, dates, and products are subject to change without further notification; 2 Lockstep is supported by selected vendors via enabled chipsets and platforms. Source: www.intel.com/business/bss/products/server/ras.pdf*

Table 2. *The Intel Itanium 2 processor incorporates market-leading RAS capabilities, and is integrated into enterprise-class platforms by many of today's most trusted server vendors.*

The Intel Itanium 2 processor was designed specifically for business-critical computing environments. In addition to its performance and scalability, it includes and extends the reliability, availability and serviceability (RAS) features built into today's best x86-based processors (see Table 2). It also includes an enhanced Machine Check Architecture (MCA), which provides a standards-based framework for error detection, containment and correction. This enables error messages to be passed efficiently between the hardware, firmware and operating system (OS). Since the interfaces are based on a published standard, component, system and OS vendors can extend their error-handling capabilities independently, while still enabling full interoperability at all levels of the solution stack. This will simplify future advances, and enable the RAS capabilities of Itanium 2-based solutions to evolve more rapidly.

The x86 Advantage

Though the x86 architecture is older than the Intel Itanium 2 microarchitecture and lacks many of its architectural advantages, it is the most widely deployed computing architecture in the world, and accounts for about 90 percent of all servers sold today. It has very broad and deep application and vendor support, and an enormous base of installed systems and optimized software. This brings economies of scale that cannot currently be matched by any other computing architecture, and will continue to drive investment and innovation by leading hardware and software vendors—along with widespread and ongoing customer deployments.

However, market pressures are not all one-sided. The total market for the kinds of business-critical computing solutions served by mainframe, high-end RISC and Itanium 2-based systems is actually larger than the market for mainstream, x86-based solutions.[10] This accounts for the broad vendor support for

[10] *Based on IDC data, the total market for x86-based system revenue is approximately $22B per year, while the market for larger scale, business-critical systems is about $28B per year. Source: IDC Server Tracker Q1 2005.*

Itanium 2-based systems. As market penetration continues to increase, it will likely lead to investment levels that rival the total investment in x86.

Itanium-based solutions also gain indirectly from the high-volume x86 market. Intel has developed one of the largest and most advanced silicon development and manufacturing infrastructures in the world based largely on the delivery of its Intel® Pentium®, Intel® Celeron® and Intel® Xeon® processor families, which are all based on x86 architecture. Development and manufacturing costs for Intel Itanium 2 processors are amortized over this broad investment. This will continue to help Intel and the wider vendor community ramp up the capability and volume of Itanium-based solutions, while maintaining affordable pricing structures for their customers.

In short, both architectures can be expected to see broad support and ongoing advances in the years ahead, and deliver increasing value to end-user organizations.

Choosing the Right Industry-Standard Platform

In general, use Itanium 2-based systems for:

- **New business-critical deployments —** Itanium 2-based systems are ideal for large, business-critical data-tier and transactional applications, including database, data mining, business intelligence, enterprise resource planning (ERP) and supply chain management (SCM). They are also ideal for many complex technical and analytical applications with large datasets, such as financial modeling and data visualization.
- **High-end RISC replacement —** Itanium 2-based systems offer comparable and in many cases superior capabilities to RISC systems, but on a more affordable and broadly supported industry-standard architecture. Solutions are emerging that will enable many thousands of existing RISC applications to run without change, and with near native performance, on Itanium 2-based systems (for more information, visit www.transitive.com).
- **Scaling up Windows and Linux implementations —** As businesses grow, existing applications often have to support more users, larger datasets and heavier workloads, which not only adds to performance and capacity requirements, but also increases the impact of system downtime. One solution is to deploy clustered x86-based systems as needs escalate. Another is to migrate to larger, multi-processor Itanium 2-based systems, which can enable a simpler and more consolidated hardware and software environment, to reduce operational costs.
- **Consolidating Mixed Workloads and Enterprise Applications—** Itanium 2-based systems are ideal for consolidating business-critical applications, as well as mixed OS environments that include mainframe and/or UNIX workloads, in addition to Linux and Windows. Many Itanium 2-based solution vendors offer sophisticated virtualization capabilities, including both soft and hard partitioning. True mainframe-class systems are also available, including platforms that can run applications written for the IBM z/OS* and OS/390* operating systems (for details, visit http://www.platform-solutions.com/).
- **Security-Sensitive Edge Applications—** Edge workloads tend to scale very easily across multiple servers, and are generally well-suited to x86-based systems. However, as businesses connect back-end applications to the Internet, the quantity and sensitivity of Internet-based communications increases. Software solutions are emerging that take advantage of the advanced performance and security features of Intel Itanium 2 microarchitecture to simultaneously accelerate throughput and increase security for business-critical edge communications (for more information, visit www.secure64.com).

In general, use x86-based systems for:

- **Scaling out front-end and many mid-tier applications —** Unless you require the higher scalability, availability or security of Itanium 2-based systems, the x86 architecture is likely to enable lower total

cost of ownership for these applications.

- **Optimizing performance for existing 32-bit applications —** x86-based systems deliver leading performance and price/performance for 32-bit applications. However, be aware that Itanium 2-based systems can also run these applications. This can simplify migrations, by enabling dependent 32-bit applications to run on the same Itanium 2-based server as the primary application, without code changes. For example, a 32-bit database management utility can be run on the same server as a business-critical 64-bit database, eliminating the need to deploy a second server.
- **64-bit migrations of many existing 32-bit applications —** Today's x86-based systems can support 32-bit applications running on either 32-bit or 64-bit operating systems. They can also support 64-bit applications running on 64-bit operating systems. These capabilities provide a very flexible 64-bit migration path for many applications that are already optimized for the x86 architecture. In addition, once applications have been migrated to 64-bits, it is relatively easy to port them to Itanium 2-based systems if and when required.
- **Consolidation of smaller applications and workloads —** Today's virtualization software solutions running on multi-core, 64-bit processor-based systems provide an excellent platform for consolidating many existing 32-bit applications, as well as some 64-bit applications, to increase hardware utilization and reduce server sprawl.

Vendor Support

The differences between Intel Itanium 2 microarchitecture and the x86 architecture are largely reflected in the kinds of systems and solutions available on each. The majority of x86-based systems are configured with two or four processors, though systems with 8, 16 or even 32 processors are available from selected vendors. The Intel Itanium 2 processor is available in servers with up to 512 processors, and vendors tend to configure these systems with more memory, I/O and RAS features (redundant and hot-plug power, cooling fans, network cards, etc.).

At the highest level, vendors are using Itanium 2-based systems to support their UNIX and mainframe-class operating environments, which typically have highly advanced virtualization, monitoring and management capabilities, and may support hardware as well as software partitioning.

This differential vendor support can help to simplify IT platform decisions. However, there will continue to be cases where large x86-based systems are appropriate, such as when consolidating large numbers of 32-bit applications. There will also be times when small Itanium 2-based systems are appropriate, such as when supporting heavy, security-sensitive communications at the network edge.

Combining Architectures

Businesses today face a broad continuum of computing requirements, particularly in enterprise environments where front-end, departmental and branch office servers may have limited workloads, while back-end systems may have to handle terabytes of data and hundreds of simultaneous users. Together, Itanium- and x86-based systems provide complementary, industry-standard architectures that can cover the full range of requirements.

Integration is very straightforward, and the two architectures have much in common in terms of administrative, management and development environments. This is especially true when both platforms are used to run the same operating system, which makes it exceptionally easy to scale up existing Windows or Linux solutions from x86-based servers to larger, Itanium-based systems. Engineers and technicians will find their knowledge and skills transfer easily between the two worlds. There is also a great deal of overlap in application and vendor support. This enables IT organizations to take a very tactical approach to platform choice, mixing and matching systems as appropriate to address specific requirements.

By choosing the best architecture for each implementation, businesses can optimize the total value of their investment. By taking advantage of two complementary, industry-standard architectures, they can create a more cost-effective, flexible and consistent hardware environment that can help them simplify operations and reduce total costs.

Conclusion

Most large organizations will find that both Itanium 2-based solutions and x86-based solutions are needed to optimize the performance and value of their computing environments.

- **Itanium 2-based systems** will deliver the performance, scalability, availability, security and manageability needed for the most demanding, business-critical implementations, including high-end RISC replacement.
- **x86-based systems** will continue to offer leading performance for the enormous installed base of 32-bit applications, and for consolidation and 64-bit migration of this installed base (as well as for many new 32-bit and 64-bit applications).

Both architectures will continue to evolve, and throughput for many workloads will increase dramatically with emerging Dual-Core and multi-core processors. The most successful IT organizations will understand the strengths of each architecture, and integrate them judiciously to maximize IT capabilities and business value.

Appendix

The EPIC computing model of Itanium 2-based systems provides a number of advanced capabilities that are used to improve parallel processing, and increase total throughput, including:

- **Predication —** Instead of waiting for conditional branches (if/then statements) to be resolved, the processor can execute both branches simultaneously. x86 processors must try to predict the most likely outcome, and suffer a performance hit whenever a prediction is wrong.
- **Speculation —** Data can be loaded before the load command occurs in the instruction code, which can substantially reduce memory latencies (the data is dynamically checked when the actual load command occurs, and updated if necessary).
- **Software Pipelining —** Software loops (the reiterative execution of a single instruction sequence) are a core element in many applications. The x86 architecture “unrolls” software loops to create multiple copies. With its many registers, EPIC is able to recognize and execute multiple loop iterations in parallel, without the resource-intensive unrolling process.
- **Out-of-Order Memory Optimization —** x86 requires very strict, in-order memory accesses at all times. Intel Itanium 2 microarchitecture has a much more relaxed model, yet can explicitly enforce in-order memory access when needed. This enables significant performance optimizations, while still preserving data integrity.

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