Making the most of 64-bit computing, today
August 2004

IBM 64-Bit Computing Decision-Maker's Guide

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Executive Overview

If you have been wondering when the time would be right to begin migrating from your current 32-bit servers to 64-bit servers, the answer may be *now*.

Sixty-four-bit servers have been around for many years in the form of mainframes and UNIX®-based servers, such as the IBM @server™ pSeries® and predecessors. Yet in the Intel®-compatible world, 64-bit computing is a relatively new phenomenon, introduced with the Intel Itanium™ processor in 2000. The releases of the second-generation Itanium 2 processor, followed by AMD™ Opteron™ processors, eighth-generation IBM POWER® processors, and now an Intel Xeon™ processor with 64-bit extensions, have resulted in better price/performance and a wider array of 64-bit server offerings than ever before.

This broader choice offers users greater flexibility, yet at the same time introduces some confusion into the marketplace. Suddenly it isn't a straightforward decision as to which 64-bit solution to buy. Should you stick with the tried-and-true UNIX midrange solution with thousands of available 64-bit programs? Are you better off going with an Intel-based server, which may be less expensive hardware-wise and provides Microsoft® Windows® compatibility, but doesn't offer the same breadth of 64-bit applications? Perhaps, you could save even more money with an Opteron based server, but at the risk of straying from the Intel fold. If you have pSeries servers in your organization, possibly IBM PowerPC® blade servers running Linux® would serve you best. How do you choose? In many environments it's not an either/or decision; a *combination* of the above would be the optimum solution. Just as no one server is ideal for every customer environment, no single processor is optimal for all workloads.

Which 64-bit hardware will work best for you depends to some extent on your existing hardware and software environment. Also important are the relative strengths and weaknesses of various processors for different tasks, as well as their respective costs. Before we delve into the pros and cons of each 64-bit offering, a description of what 64-bit computing is—and how it might help you—is in order.

An Explanation of 64-bit Technology

By itself, 64-bit technology is not a reason to jump in the air and click one's heels. It's what you as a customer can *do* with "64-bitness" that makes it interesting. For one thing, it removes the hard limitation of 4GB of flat memory addressing per process. To access more than 4GB at a time, 32-bit processors have to resort to tricks like memory managers and overlays, which can significantly hurt performance. Using 64-bit addressing, servers theoretically can directly access as much as 16 exabytes (16 billion gigabytes!) of RAM. Of course, at present no computer can physically hold that much, but whether the server supports 16GB or 256GB, a single 64-bit application could access as much RAM as needed. Not all "64-bit" processors are created equal, however. While the new Xeon processor and Opteron have "64-bit extensions," their virtual memory addressing is "only" 48-bit (unlike the Itanium 2 and IBM PowerPC 970™, which have full 64-bit addressing)—but plenty for realistic use. These 64-bit extensions add useful features, such as 64-bit registers (plus more total registers) and 64-bit instructions, both of which can increase performance[1].

There is no doubt that certain jobs will benefit greatly from 64-bit operation, but it is equally certain that other tasks will see little, if any, improvement in performance from a switch to 64-bits. It is important to know which of your applications will and won't take advantage of these servers. Not only will this knowledge keep you from wasting money by migrating applications unnecessarily, it will also help you prioritize which applications to migrate first.

[1] To receive full benefit from 64-bit instructions requires recompiling applications using an optimized 64-bit compiler, and possibly rewriting parts of the applications.

Beyond these basics, there are specific architectural attributes of 64-bit processors that affect performance.

Software Considerations

What types of applications will and won't take advantage of the switch from 32-bit to 64-bit computing? In order from greatest to least benefit, the types are:

- **I/O intensive** — Any application that spends more time fetching data from devices than processing it: database *back*-end (such as IBM DB2® Universal Database, Microsoft SQL Server, and Oracle), e-commerce, CRM, ERP, SAP, SAS, various business-critical and vertical applications, and any other application that has large memory requirements. In general these applications should see significant performance improvements from 64-bit hardware, operating systems and device drivers, as well as the elimination of memory overlays and other performance inhibitors.
- **Compute-intensive —** High Performance Computing (HPC) and scientific/technical computing, including life sciences, geophysical research; high-end graphics rendering; streaming video, and any other application that spends more of its time processing data than retrieving it.
- **Gateway/security infrastructure —** SSL servers, directory services, Internet caching and database *front*-ends. These applications *may* obtain benefit from the switch. You should contact the individual software vendors to find out their plans for exploiting 64-bit features.
- **Standard infrastructure —** This class generally will see little benefit from 64-bit computing. Applications include file and print servers, low-volume/noncritical business applications, and legacy applications that are unlikely to be rewritten for 64 bits.

While many 32-bit applications may run somewhat faster on 64-bit hardware using a 64-bit operating system, the greatest benefits will be achieved by porting/upgrading 32-bit applications to versions that are optimized for 64 bits. This process, of course, won't be instantaneous (and is complicated by the need not only for 64-bit operating systems but also for 64-bit middleware and device drivers).

The normal life cycle for a server is to upgrade the hardware and software for as long as it makes economic sense and then to retire the server and replace it with newer hardware. This is a fairly straightforward procedure when the new server is similar to the one it replaces: The 32-bit software you ran on the previous server should run as well, if not better, on a new 32-bit server.

However, server upgrades can get bogged down in a morass of software versions when the upgrade isn't as straightforward. One day, when it's time for you to embrace 64-bit computing, you'll have to face the prospect of managing dual code bases: juggling 32-bit software on 32-bit servers and 32-bit and 64-bit software on 64-bit servers. How will you orchestrate the transition to go as smoothly as possible?

A dual-mode 32/64-bit processor, such as Opteron, the new Xeon or the PowerPC 970, gives you the flexibility to start out with 32-bit software running on a 32-bit OS. Then, as needs and budget dictate, you can upgrade to a 64-bit OS, still running the 32-bit applications. You will probably see a small performance increase in this environment, partly because the OS itself will run more efficiently with large amounts of RAM, and partly because the applications will no longer have to share the lower 4GB address range with the OS. (You may also be able to recompile the 32-bit applications to optimize them somewhat for the new 64-bit processors, to take advantage of new instructions.) Finally, as 64-bit applications become available, you can upgrade from the 32-bit versions, for yet another performance boost. The jump to Itanium 2 should only be attempted if you already have a complete 64-bit software stack ready (OS, device drivers, middleware and applications). The performance of 32-bit applications on Itanium 2 will be less than on many 32-bit servers—perhaps not worth the effort unless *most* of the server's application workload is 64-bit.

The greater speed and larger memory addressing of 64-bit OSes, combined with the enterprise scalability of 64-bit servers, such as the IBM @server xSeries™ 455 (scale up) or IBM @server BladeCenter (scale out), work together to simplify the consolidation of multiple servers. 64-bit computing serves as the ideal solution for the confluence of several trends: server consolidation (both physical and logical), server virtualization and Linux.

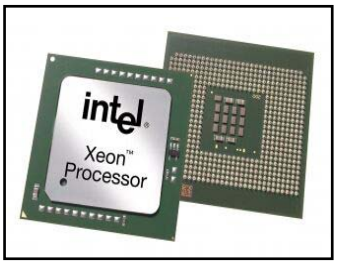
64-bit Hardware Architectures

Intel, AMD and IBM have very different design methodologies for their respective processors. As a result each excels at different tasks. It should be noted that above and beyond processor characteristics other important system features, such as integrated systems management, reliability, availability, ease of serviceability, option compatibility testing and warranty provisions are equally important in choosing a server. The presence and equality of these features should not be assumed. Due to the focus of this paper, such distinctions are left for other venues.

Intel Xeon

The Xeon processor with 64-bit extensions is currently offered in a broad array of IBM @server xSeries servers: the 2-way value x226 and performance x236 tower units, the 2-way 1U x336 and 2U x346 rack-optimized servers, as well as the 2-way IBM @server BladeCenter™ HS20 blade server. They are compatible with both 32-bit and 64-bit versions of Windows 2003, as well as Linux, offering great flexibility in terms of OS support.

Intel's mainstream server processor has for several years been the 32-bit Xeon. Now, in response to AMD's Opteron, Intel has created a version of the Xeon that offers 64-bit extensions called "Extended Memory 64 Technology" (EM64T). It offers advantages similar to the Opteron in terms of 32-bit x86 software compatibility, improved performance over the older 32-bit Xeon processors, and large memory addressing. The new Xeon processor has double the registers of its predecessors, resulting in improved performance. (The more registers there are, the less often the processor has to retrieve data from cache.) This enhancement alone helps increase performance by up to 7%, depending on the applications. An extended instruction set (SSE3) offers accelerated processing of video decoding and complex arithmetic. Xeon offers the highest clock frequencies in this group, which helps with certain types of applications, and its integer performance is now on par with the Itanium 2.



In addition, Xeon supports DDR2 memory and PCI-Express (PCI-E) adapter slots—unlike Opteron, Itanium 2, and the PowerPC 970. Like PowerPC 970 it offers an 800MHz front-side bus (compared to Itanium 2's 400MHz FSB).

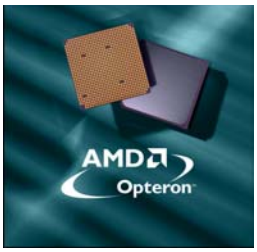
However, it is still a Xeon at heart and lacks the Opteron processor's integrated memory controller, greater memory bus bandwidth and other performance enhancements. Plus, Xeon's floating-point unit (FPU) suffers in comparison to the ones in Itanium-2 and PowerPC 970 (however the higher clock speed mitigates this somewhat). Still, this is the safest all-around choice for 64-bit computing, offering high-speed 32-bit computing today, an easy upgrade path to 64-bit computing when you are ready, and the Intel logo on the chip.

AMD Opteron

The Opteron processor is currently offered in the 2-way 1U IBM @server 325 rack-optimized server. It is compatible with both 32-bit and 64-bit versions of Windows 2003 and Linux, offering great flexibility in terms of OS support. (Look for OSes that specify Opteron support to take full advantage of the processor's features.)

As the "little kid on the block" AMD is forced by necessity to be innovative. They couldn't just offer a me-too product and hope to compete against Intel. The result is an Opteron product line that is faster than Xeon in some configurations and running certain applications, and at a fraction of the cost of Itanium 2. This offers customers an attractive price/performance option that Intel lacks.

In an Opteron-based server, memory has its own high-speed path to the processor, rather than having to share the FSB with other devices. Not only that, but because each Opteron contains its own integrated memory controller, installing a second Opteron means having *two* high-speed data paths to memory, effectively providing up to double the throughput. (Having an integrated memory controller also reduces memory latency for faster memory access.) By comparison, adding a second Intel processor merely adds to the congestion of the existing FSB. In addition, like the new Xeon processor, the Opteron has double the number of registers of the traditional 32-bit Xeon processors. Also like Xeon, Opteron's FPU lacks the performance of Itanium-2 and PowerPC 970.



Opteron should have a performance advantage over Xeon in large-memory configurations (more than 2GB *per processor*). In this environment, the larger memory bus bandwidth is more of a factor than Xeon's higher clock speed. In smaller memory configurations with highly reusable data, Xeon should be faster. Opteron, like the new Xeon processor with 64-bit extensions, extends the original Intel x86 core used in 32-bit Intel processors. What this means for users is that the Opteron can natively run both 32-bit and 64-bit x86 software, concurrently, at extremely high levels of performance.

Intel Itanium 2

IBM currently offers the Itanium 2 processor in the rack-optimized x382 server and the x455 scalable enterprise server. These servers are compatible with 64-bit versions of Windows 2003 and Linux. (Look for Itanium 2 or "IPF"—for Itanium processor family—versions of these OSes.)

Unlike Xeon and Opteron, which simply extended the Intel x86 instruction set to 64 bits, Intel took a different tack for 64-bit computing in Itanium 2, replacing it with a new and entirely different instruction set. Because Intel chose to optimize the Itanium 2 for 64-bit computing exclusively, the result is that 64-bit performance is outstanding; however 32-bit applications are forced to run in a special 32-bit x86 emulation mode, resulting in subpar 32-bit performance. This disparity in performance tends to make the Itanium 2 unsuitable in an environment that is still primarily using line-of-business 32-bit applications.

The Itanium 2 processor is a workhorse at 64-bit floating point (FP) operation. Between its large L3 cache and 64-bit-optimized architecture, it performs exceptionally well on applications that require heavy FP processing, such as high-performance technical/scientific computing.

The Itanium 2 processor contains not only a 256K L2 cache, but also an L3 cache in the range of 1.5MB to 6MB in size. This allows it to limit cache misses and improves performance. The x455 server goes Intel one better, by also offering an integrated *L4* cache for even greater performance—64MB per four-processor chassis; 256MB for a 16-way x455 configuration. A big differentiator between the Itanium-2 based IBM servers and our other 64-bit offerings is in scalability. If your 64-bit processing needs require massive amounts of memory or more than two processors then the x455 server would be your best choice. The multichassis x455 supports up to *224GB* (56GB per chassis). This allows a large data set to be held largely or entirely in RAM during processing.

IBM PowerPC 970

The PowerPC 970 processor is currently offered in 2-way IBM BladeCenter JS20 blade servers. It is compatible with 64-bit versions of Linux and IBM AIX® 5L™.

Like Itanium 2, the PowerPC 970 didn't evolve from the Intel x86 architecture. It inherits tremendous strength as the fifth generation of IBM PowerPC processors[2]. Using an industry-first combination of silicon-on-insulator (SOI), strained silicon and copper wiring technologies (all pioneered by IBM), the PowerPC 970 uses less power and produces less heat than other 64-bit processors. (See *Table 1*.) Other members of the POWER processor family drive IBM iSeries™ mid-range servers and IBM pSeries supercomputers[3].

The PowerPC 970 processor's heritage means that it can support many of the Linux and AIX enterprise and scientific/technical computing applications developed for other POWER and PowerPC processor-based servers, as well as many Linux-based applications developed for Intel-architecture servers. Whether your application set is migrating down from 64-bit midrange or mainframe UNIX (e.g., Solaris, HP/UX, AIX), or up from 32-bit Linux, the PowerPC 970 can handle it. This architecture-spanning capability offers customers great flexibility in deployment. Because the PowerPC 970 is available in a blade server form-factor, one BladeCenter chassis can be deployed with JS20 blade servers running a mixture of 32-bit and 64-bit Linux and UNIX operating systems and application sets alongside 32-bit and 64-bit Xeon-based HS20 blade servers running Windows and Linux applications.

If you already own iSeries or pSeries servers and are looking for a cost-effective departmental server to run the same applications, JS20 blade servers are an attractive rackable complement to iSeries and pSeries tower servers. In most cases, 32-bit x86 Linux applications can be recompiled for 64-bit Linux for the PowerPC. Similarly, most 64-bit Linux applications written for POWER servers can be recompiled for 64-bit PowerPC use. Depending on how closely UNIX applications hew to full POSIX compliance, they too may be migrated to 64-bit Linux for the PowerPC with little or no rewriting.

Processor Comparison

Table 1 compares the major features of each processor to give you a better idea of which processor/server combination best fits your specific needs. (Significant distinctions are highlighted in bold.)

Features	Xeon w/ EM64T	Opteron	Itanium 2	PowerPC 970
Servers featuring these processors[4]	x226/x236/x336/ x346/HS20	e325	x382/x455	JS20
Form factors available	**1U** (x336), **2U** (x346), **4U** (x226), **5U** (x236), **30mm Blade** (HS20)	**1U**	**2U** (x382) **4U** (x455)	**30mm Blade**

[2] Nearly 45% (224) of the servers currently listed among the Top 500 supercomputers in the world are IBM servers, which together account for more than 50% of the total processing power represented by the 500 servers. Seventy-five IBM POWER and PowerPC processor-based servers are listed, including three of the top ten; already one BladeCenter JS20-based server is included (at #398) despite its recent release: http://www.top500.org/list/2004/06.

[3] The ubiquitous POWER family not only provides the engine for the Apple G4 and G5 servers, it is also widely used in consumer goods, such as present or future game consoles from Nintendo, Sony and Microsoft, and as embedded processors in the automotive, telecommunications and other industries. In fact, more than 18 million POWER and PowerPC processors were shipped in 2003.

[4] This table describes the subset of capabilities supported by both the processor and the server. A processor may support capabilities in excess of those supported by the server in which it is used.

Features	Xeon w/ EM64T	Opteron	Itanium 2	PowerPC 970
Maximum scale-up	2-way	2-way	2-way (x382) **16-way** (4 x455 chassis)	2-way
Maximum processor rack density[5]	**168** (HS20); 84 (x336)	84	42	**168**
Maximum clock rate[6]	**3.6GHz**	2.4GHz	1.5GHz	1.6GHz
FSB speed	**800MHz** (except HS20); 533MHz (HS20)	N/A (HyperTransport Tunnel)	400MHz	**800MHz**
L1 cache size	16K (data/instruction) + 16K uOps Trace	**128K** (64K data; 64K instruction)	32K (data & instruction)	**96K** (32K data; 64K instruction)
L2 cache size	**1MB**	**1MB**	256K	512K
L3 cache size	N/A	N/A	**1.5-6MB**	N/A
L4 cache size	N/A	N/A	**64MB** (x455 only)	N/A
32-bit processing	Native x86	Native x86	**Emulated x86**	Native PowerPC 32
64-bit processing	Native x86-64	Native x86-64	Native EPIC-64	Native PowerPC 64
Data registers	16 floating point; 16 general purpose	16 floating point; 16 general purpose	**128** floating point; **128** general purpose	**80** floating point; **80** general purpose
Virtual/real addressing	48/40-bit	48/40-bit	**64/50-bit**	**64/42-bit**
Number of FP ops (FLOPS) per cycle (per CPU)	2	2	**4**	**4**
SIMD instruction set	SSE3	SSE2/3DNow	N/A	VMX[7]
Type of memory supported	**DDR2-400 (PC2-3200)**	DDR-333 (PC2700)	DDR-266 (PC2100)	DDR-333 (PC2700)
Uni/2-way memory bus bandwidth	6.4GB/sec / 6.4GB/sec	**5.3GB**/sec **/** **10.6GB**/sec	6.4GB/sec / 6.4GB/sec	6.4GB/sec / 6.4GB/sec
System memory capacity[8]	8GB (HS20); 16GB (x226[9]/x236/ x336/x346)	12GB	16GB (x382) **224GB** (x455)	4GB
I/O slots supported	PCI (x226/x236/ HS20); PCI-X (x226/x236/ x336/x346); **PCI-E** (x226/x236/ x336/x346)	PCI-X	PCI-X	PCI
Processor manufacturing process	**90nm**	130nm	130nm	130nm

[5] The maximum number of servers installable in a 42U rack multiplied by the maximum number of processors per server.

[6] Maximum clock rate of processors offered for these models as of August 2, 2004. Some models may use processors running at a lower clock rate.

[7] Also called AltiVec by Motorola and Velocity Engine by Apple.

[8] Although not a function of the processor architecture, maximum system memory capacity can affect your decision of which server is best suited to your needs.

[9] When 4GB DDR2 DIMMs are available.

Features	Xeon w/ EM64T	Opteron	Itanium 2	PowerPC 970
Thermal design power (maximum)	103W per CPU	89W per CPU	107W per CPU	**<50W** per CPU
32-bit NOS support	Windows/Linux/ **Netware**	Windows/Linux/ **Netware**	N/A	Linux
64-bit NOS support	Windows/Linux	Windows/Linux	Windows/Linux	Linux/**AIX**
64-bit NOS availability	• MS Windows Server 2003 x86-64: **1Q/05** • RHEL 3.0 x86-64 • SLES 9 x86-64: **11/04**	• MS Windows Server 2003 x86-64: **1Q/05** • RHEL 3.0 AMD64 • SLES 8 AMD64	• MS Windows Server 2003 (for Itanium) Enterprise and Datacenter Editions • RHEL AS 2.1/3.0 Itanium • SCO Linux Server 4.0 Itanium • SLES 8 IPF • Turbolinux ES 8 Itanium	• AIX 5L: **Q3/04** • SCO Linux Server 4.0 • SLES 8 (SP3) • Turbolinux ES 8

Table 1. *64-bit processor comparison*

What Does This All Mean to You?

Opteron, Xeon and PowerPC 970 are 64-bit processors that run 32-bit software with performance comparable to, or in many cases better than, 32-bit processors. In some cases, servers using these processors cost little more than 32-bit servers. This means you can buy a 64-bit server today to run your 32-bit software, and when you're ready for the switch to 64-bit computing you can simply upgrade your operating system, applications and programming tools to 64-bit versions in a staged migration. Then *voilà*! You'll have 64-bit servers without expensive hardware upgrades or replacement.

In many cases you may see a performance boost when you upgrade from your current 32-bit server to 64-bit hardware, even running your current 32-bit OS; then another increase when you upgrade your server to a 64-bit OS running the same 32-bit applications, and yet another when you upgrade the applications to 64-bit versions.

If you are ready for 64-bit computing today, then *any* of the four choices, including Itanium 2, may be right for you, depending on your needs and budget. Because different types of software stress different computational characteristics (floating-point vs. integer, memory bandwidth vs. I/O bandwidth, cache utilization, 64-bit instructions, etc.) to different degrees, no one processor is best for all purposes. Here are some guidelines that may help you decide between them:

For 64-bit *high-performance technical/scientific computing*, consider:

- **x226/x236/x336/x346/HS20** for applications such as **Snoop3D**, **GAMESS**, **POP** (Parallel Ocean Program), **NAMD**, as well as others that benefit from **high clock rates**
- **e325** for applications such as **MGF**, **Snoop3D** and others requiring outstanding performance on **2D fast Fourier transforms**, or large memory bandwidth (such as **STREAM**)
- **x382/x455** for applications such as **MGF**, **HMMER**, **NAMD** and those requiring outstanding performance on double-precision arithmetic (such as **Linpack**) or **FP** operations
- **JS20** for applications such as **Snoop3D**, **POP** (Parallel Ocean Program), **GAMESS**, **HMMER, BLAST**, **FASTA** and other bioinformatics and proteomics applications, as well as those requiring outstanding performance on **1D fast Fourier transforms**, double-precision arithmetic (such as **Linpack**) or **FP** operations; especially if a **blade server** form factor is desired

For 64-bit *business/infrastructure* needs, consider:

- **x226/x236/x336/x346/HS20** for applications such as **CRM**, **MCAD** (mechanical computer-aided design), **EDA** (electronic design automation) as well as **legacy 32-bit Windows/Linux** applications (file/print, workgroup, e-mail, web services, etc.) and any other that would benefit from **high clock rates**
- **e325** for applications such as **database back-end, CAE** (computer-aided engineering and **financial modeling,** as well as **legacy 32-bit Windows/Linux** applications (file/print, workgroup, e-mail, etc.) and those that can benefit from **large memory bandwidth**
- **x382/x455** for applications such as **large compute-intensive databases** (including **data mining**), **ERP**, **financial modeling**, **BI** (business intelligence), **CAE**, **OLTP** (online transaction processing) and those that **scale up** efficiently beyond 2-way, require more than 16GB of RAM or can benefit from **large cache** sizes (x455 only)
- **JS20** for applications that make heavy use of **floating-point** or **double-precision arithmetic**, including legacy **Solaris/HP-UX/AIX** applications; especially if a **blade server** form factor is desired

This paper concentrated on 2-way and larger servers for comparison purposes. However, if your 64-bit computing needs are small for now, IBM also offers 64-bit *uniprocessor* servers featuring the new **Pentium 4** processor with **EM64T**. If you are looking for a 4U tower server that is easily convertible to rack use, consider the x206; for a 1U rack-optimized server, consider the x306. IBM also offers **IntelliStation**® workstations that use EM64T-based Pentium 4 and Xeon processors, as well as workstations that feature Opteron and IBM POWER processors. For customers in the telecommunications industry, IBM offers **BladeCenter-T**, a NEBS-compliant chassis that can house the same 32-bit and 64-bit HS20 and 32-bit (4-way) HS40 (and, by the end of 2004, JS20) blade servers as the standard BladeCenter chassis.

Conclusion

Many server vendors offer the choice of Xeon vs. Itanium 2. A few also offer Opteron. IBM is the only vendor to offer customers an array of 64-bit servers that spans Xeon, Itanium 2, Opteron *and* PowerPC processors. Regardless of which processor technology offers you the best combination of price, performance and function, we have the solution.

Additional Information

For more information on IBM @server directions, products and services, visit our Web site at:

- http://**ibm.com**/eserver/xseries for more on the **BladeCenter** and **BladeCenter-T** chassis and **HS20** blade server, as well as the **x206**, **x226** and **x236** tower servers, the **x306**, **x336**, **x346** and **x382** rack-optimized servers, and the **x455** scalable enterprise server
- http://**ibm.com**/servers/eserver/opteron/325/index.html for more on the Opteron-based **e325**
- http://**ibm.com**/servers/eserver/bladecenter/js20/more_info.html for more on the PowerPC 970 processor-based **JS20**
- http://**ibm.com**/servers/eserver/clusters for information about IBM @server **1350 clusters** using **e325** and xSeries servers
- http://**ibm.com**/products/us for information about IBM IntelliStation workstations

From any of the product pages, select **Literature** (in the blue navigation bar on the left) for links to the various types of documentation available.

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Maximum internal hard disk and memory capacities may require the replacement of any standard hard drives and/or memory and the population of all hard disk bays and memory slots with the largest currently supported drives available. When referring to variable speed CD-ROMs, CD-Rs, CD-RWs and DVDs, actual playback speed will vary and is often less than the maximum possible.