TEST REPORT
MAY 2006

64-bit Black-Scholes financial workload performance and power consumption on Intel- and AMD-processor-based servers

Executive summary

Intel Corporation (Intel) commissioned Principled Technologies (PT) to measure the performance of the 64-bit Black-Scholes financial application-based workload on dual-processor servers using the following three processors:

- 64-bit Intel Xeon Processor 3.60 GHz
- Dual-Core Intel Xeon Processor 5160
- Dual-Core AMD Opteron 285

The Black-Scholes kernel workload is multithreaded and allows users to specify the number of threads the program should run. Performance of the workload can increase as it runs with more threads, up to an optimum thread count, generally equal to the number of logical and physical processors available on the server. (We refer to this as the optimum thread-to-processor configuration.)

KEY FINDINGS

- The Dual-Core Intel Xeon Processor 5160-based server delivered almost 38 percent more performance/watt than the Dual-Core AMD Opteron 285-based server (see Figure 1). (We calculated performance/watt using system-level power measurements.)
- The Dual-Core Intel Xeon Processor 5160-based server delivered over 12 percent higher peak performance than the Dual-Core AMD Opteron 285-based server (see Figure 2).
- The Dual-Core Intel Xeon Processor 5160-based server had over 18 percent lower average power usage while running the Black-Scholes workload than the Dual-Core AMD Opteron 285-based server (see Figure 5).

The optimum thread count for our testing was four on the Dual-Core Intel Xeon Processor 5160-based server and the Dual-Core AMD Opteron 285-based server. The reason is that each of these servers has two physical processors with two cores per processor, or four available execution units.

The 64-bit Intel Xeon Processor 3.60 GHz-based server has two physical single-core processors, each of which supports Hyper-Threading Technology (HT Technology). Consequently, it, too, has four execution units available, though these are logical execution units. Thus, we expected the optimum thread count for this server would also be four. In our testing, however, the optimum thread count proved to be eight, though the improvement over four threads was small. We do not know the reason that eight threads proved to be optimal.

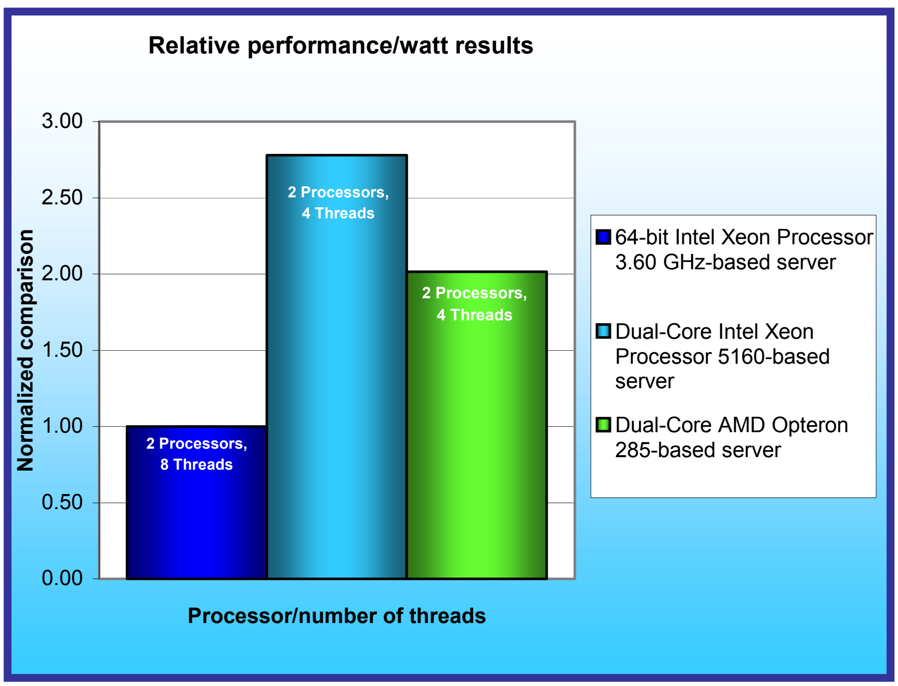

Figure 1: Performance/watt (dual-processor) results of the test servers running the Black-Scholes workload. Higher numbers indicate better performance/watt.

In this section, we discuss the best results for each server. For complete details of the performance of each server with varying thread counts, see the "Test results" section.

Figure 1 illustrates the performance/watt for each of the three servers. In this and the other performance charts in this section, we normalized the results for each workload to the time the slowest configuration took to complete that workload. The slowest system's result is thus always 1.00. By normalizing, we make each data point in these charts a comparative number, with higher results indicating better performance (i.e., faster times to complete the workload with the specified number of threads).

To calculate the performance/watt we used the following formula:

Performance/watt = the benchmark's score / average power consumption in watts during the time period in which the benchmark was delivering peak performance

This formula converts the elapsed time the benchmark took to complete into a runs (or jobs) per hour metric, which we then use to compute the performance/watt.

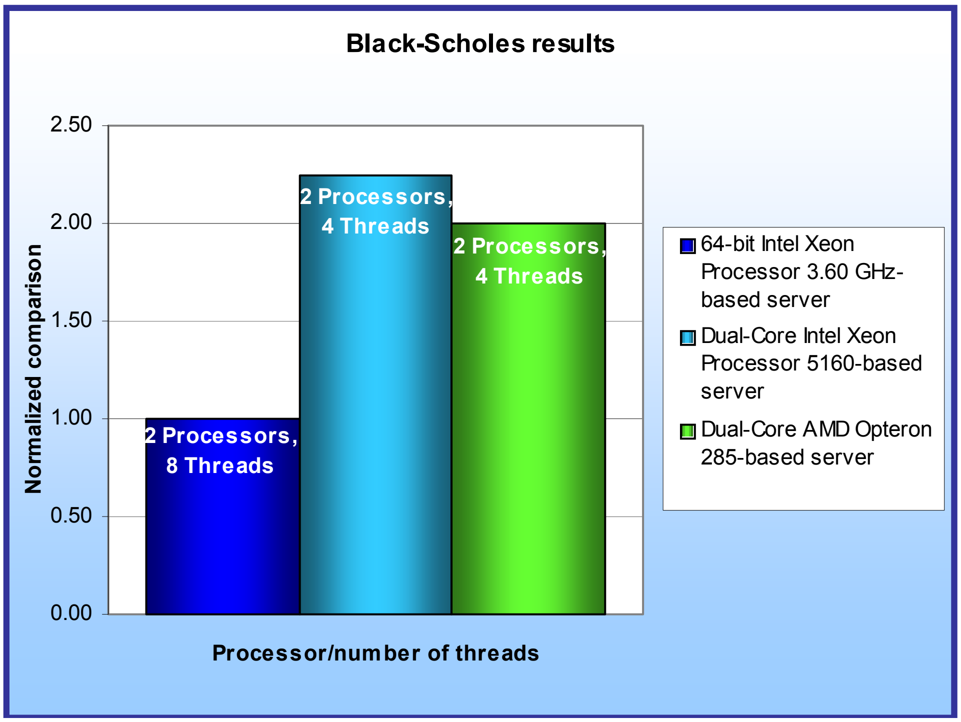

Figure 2: Normalized peak (dual-processor) performance of the servers with the optimum thread-to-processor configurations with the Black-Scholes workload. Higher numbers are better.

As Figure 1 illustrates, the Dual-Core Intel Xeon Processor 5160-based server delivered 37.9 percent more performance/watt than the Dual-Core AMD Opteron 285-based server and 177.9 percent more performance/watt than the 64-bit Intel Xeon Processor 3.60 GHz-based server.

Figure 2 illustrates the relative peak (dual-processor) performance of each server. The Dual-Core Intel Xeon Processor 5160-based server finished the Black-Scholes workload in 3.2 seconds, 12.5 percent faster than the Dual-Core AMD Opteron 285-based server, which finished the same workload in 3.6 seconds. The Dual-Core Intel Xeon Processor 5160-based server was 125 percent faster than the 64-bit Intel Xeon Processor 3.60 GHz-based server, which took 7.2 seconds to complete the same workload.

Figure 3 shows a plot of the power usage of the three servers as they were running the benchmark. The red lines indicate the power measurement interval, the time during which the server was delivering peak performance and during which we captured power measurements. Lower power consumption is better. The Dual-Core Intel Xeon Processor 5160-based server both started with a lower power consumption while idle and achieved its peak performance while drawing less power—over 18 percent less—than the Dual-Core AMD Opteron 285-based server.

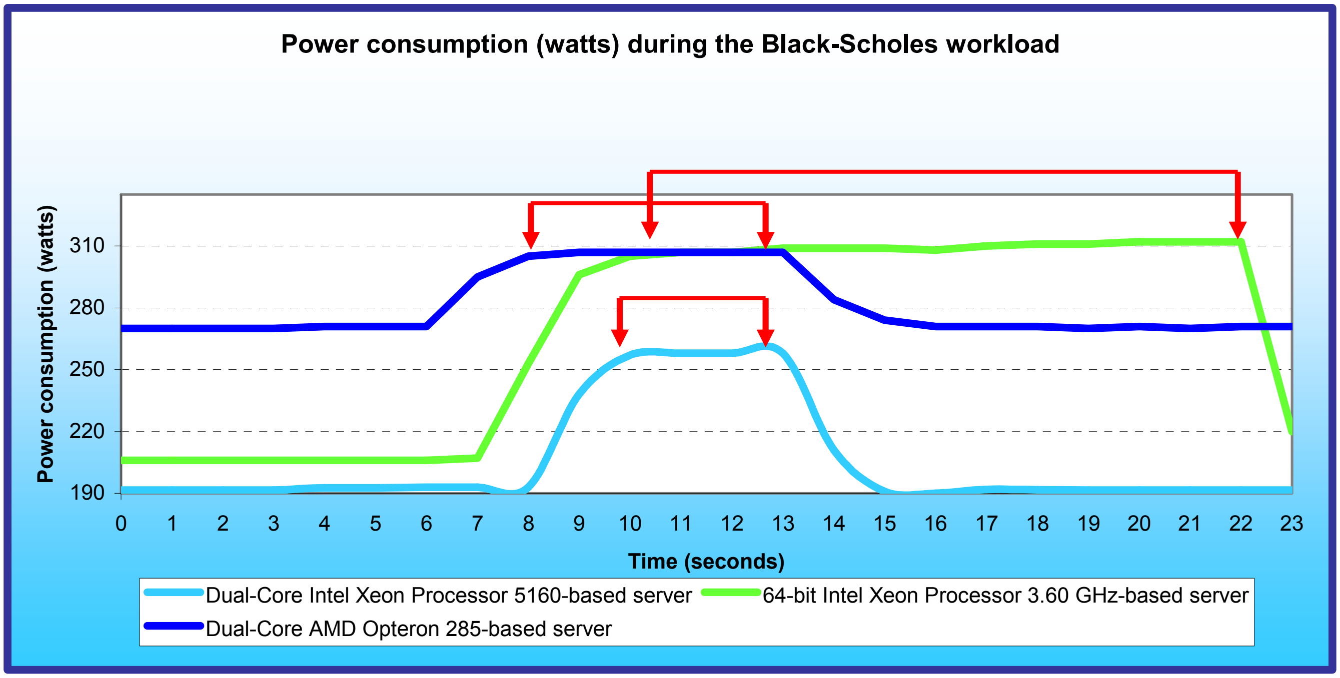

Figure 3: Power consumption (in watts) of each of the servers throughout the course of executing the Black-Scholes workload. Lower power consumption is better.

Workload

The Black-Scholes kernel workload is based on a financial modeling algorithm for the pricing of European-style options. After its publication in 1973 by Fisher Black, Myron Scholes, and Robert Merton, its impact was enormous and rapid. The benchmark consists of a kernel that implements a derivative of the Black and Scholes technique. SunGard developed the code, which uses a continuous-fraction technique that is more accurate than the traditional polynomial approximation technique. Intel provided an enhanced 32-bit version of the Black-Scholes Kernel to www.2cpu.com, which created a 64-bit version. Intel then provided the www.2cpu.com 64-bit source code we used to build the executables we employed in this report.

We reviewed that source and found no changes designed to favor one processor architecture over another.

We used Microsoft Visual Studio 2005 to compile this source code. To optimize the code for the 64-bit Intel Xeon Processor 3.60 GHz-based server and Dual-Core Intel Xeon Processor 5160-based server, we used the compiler's "/favor:EM64T" option. To optimize the code for the Dual-Core AMD Opteron 285-based server, we selected the compiler's "/favor:AMD64" option. In the Test methodology section, we present the details of how we compiled this source code.

Test results

Figure 4 details the results of our tests with two, four, and eight threads using the Black-Scholes workload. For each test, we present the median run of the three individual test runs we executed. The test produces the time, in seconds, the server took to complete the workload; lower completion times are better.

Server / # of threads	2	4	8
64-bit Intel Xeon Processor 3.60 GHz-based server – 2 processors	8.2	7.4	7.2
Dual-Core Intel Xeon Processor 5160-based server – 2 processors	6.4	3.2	3.4
Dual-Core AMD Opteron 285-based server – 2 processors	7.1	3.6	3.8

Figure 4: Median completion times (in seconds) of the server with varying thread counts using the Black-Scholes workload. Lower times are better.

As Figure 4 shows, both the Dual-Core Intel Xeon Processor 5160-based server and Dual-Core AMD Opteron 285-based server achieved the fastest time with four threads, which means four threads is the optimum thread-to-processor configuration for these servers. In contrast, the 64-bit Intel Xeon Processor 3.60 GHz-based server achieved the fastest time with eight threads, making eight threads the optimum thread-to-processor configuration for that server.

Server / # of threads	2	4	8
64-bit Intel Xeon Processor 3.60 GHz-based server – 2 processors	287.1	306.3	304.7
Dual-Core Intel Xeon Processor 5160-based server – 2 processors	226.4	246.7	248.1
Dual-Core AMD Opteron 285-based server – 2 processors	286.3	302.4	304.1

Figure 5: Average power usage (in watts) of the test servers with varying thread counts running the Black-Scholes workload. Lower numbers are better.

Figure 5 details the average power consumption of the test servers during the median runs of our tests with two, four, and eight threads. The Dual-Core Intel Xeon Processor 5160-based server had over 18 percent lower average power usage during its fastest run of the workload (the one with four threads) than the Dual-Core AMD Opteron 285-based server.

Figure 6 details the power consumption, in watts, of the test servers while idle and during the median peak runs of the benchmark. The Dual-Core Intel Xeon Processor 5160-based server's power consumption while idle was 29 percent lower than that of the Dual-Core AMD Opteron 285-based server.

Server	Idle power (watts)	Average power (watts)
64-bit Intel Xeon Processor 3.60 GHz-based server – 2 processors	206.0	304.7
Dual-Core Intel Xeon Processor 5160-based server – 2 processors	192.1	246.7
Dual-Core AMD Opteron 285-based server – 2 processors	270.4	302.4

Figure 6: Average power usage (in watts) of the test servers while idle and during the median peak runs of the Black-Scholes workload. Lower numbers are better.

Test methodology

Figure 7 summarizes some key aspects of the configurations of the three server systems; Appendix A provides detailed configuration information.

Server	64-bit Intel Xeon Processor 3.60 GHz-based server	Dual-Core Intel Xeon Processor 5160-based server	Dual-Core AMD Opteron 285-based server
Processor frequency (GHz)	3.6GHz	3.0GHz	2.6GHz
Single/Dual-Core processors	Single	Dual	Dual
Motherboard	Intel SE7520AF2	Intel S5000PSL	UNIWIDE Technologies SS232-128-03
Chipset	Intel E7520 Chipset	Intel 5000P Chipset	NVIDIA nForce4 Chipset
RAM (8GB in each)	8 x 1GB PC2-3200	8 x 1GB PC-5300 FBDIMM	8 x 1GB PC-3200
Hard Drive	Western Digital WD1600YD	Western Digital WD1600YD	Western Digital WD1600YD

Figure 7: Summary of some key aspects of the server configurations.

Intel configured and provided all three servers.

The difference in RAM types reflects the capabilities of the three motherboards: The Intel SE7520AF2 motherboard offered a shared front-side bus speed of 800 MHz and contained DDR2 PC2-3200 400 MHz memory components. The Intel S5000PSL motherboard offered two independent front-side busses at a speed of 1333 MHz and contained Fully-Buffered DIMM (FBDIMM) modules that used commodity DDR2 PC2-5300 667MHz memory components. The UNIWIDE motherboard supported 184-pin DDR memory, and the highest memory speed available for the Dual-Core AMD Opteron 285-based server was DDR PC3200 400MHz RAM.

Another hardware difference between the servers was the number of processor cores, though all three systems offer four processing threads. The 64-bit Intel Xeon Processor 3.60 GHz-based server contained single-core processors with HT Technology. The Dual-Core Intel Xeon Processor 5160- and Dual-Core AMD Opteron 285-based server contained dual-core processors.

With the following exceptions, we used the default BIOS settings on each server: we disabled the HW Prefetcher and the Adjacent Cache Line Prefetcher on the Dual-Core Intel Xeon Processor 5160-based server. These options were disabled by default on the 64-bit Intel Xeon processor 3.60 GHz-based server and were not available on the Dual-Core AMD Opteron 285-based server.

We began our testing by installing a fresh copy of Microsoft Windows 2003 Server, x64 Enterprise Edition Service Pack 1 on each server. We followed this process for each installation:

1. Assign a computer name of “Server”.
2. For the licensing mode, use the default setting of five concurrent connections.
3. Enter a password for the administrator log on.
4. Select Eastern Time Zone.
5. Use typical settings for the Network installation.
6. Use “Testbed” for the workgroup.

We applied the following updates from the Microsoft Windows Update site:

- Security Update for Windows Server 2003 x64 Edition (KB908531)
- Cumulative Security Update for Internet Explorer for Windows Server 2003 x64 Edition (KB912812)

- Security Update for Windows Server 2003 x64 Edition (KB911562)
- Cumulative Security Update for Outlook Express for Windows Server 2003 x64 Edition (KB911567)
- Security Update for Windows Media Player Plug-in (KB911564)
- Security Update for Windows Server 2003 x64 Edition (KB911927)
- Security Update for Windows Server 2003 x64 Edition (KB913446)
- Security Update for Windows Server 2003 x64 Edition (KB908519)
- Security Update for Windows Server 2003 x64 Edition (KB912919)
- Security Update for Windows Server 2003 x64 Edition (KB896424)
- Security Update for Windows Server 2003 x64 Edition (KB900725)
- Security Update for Windows Server 2003 x64 Edition (KB902400)
- Security Update for Windows Server 2003 x64 Edition (KB904706)
- Security Update for Windows Server 2003 x64 Edition (KB901017)
- Security Update for Windows Server 2003 x64 Edition (KB890046)
- Security Update for Windows Server 2003 x64 Edition (KB899587)
- Security Update for Windows Server 2003 x64 Edition (KB899591)
- Security Update for Windows Server 2003 x64 Edition (KB893756)
- Security Update for Windows Server 2003 x64 Edition (KB899588)
- Security Update for Windows Server 2003 x64 Edition (KB901214)
- Security Update for Windows Server 2003 x64 Edition (KB896422)
- Security Update for Windows Server 2003 x64 Edition (KB896358)
- Security Update for Windows Server 2003 x64 Edition (KB896428)
- Update for Windows Server 2003 x64 Edition (KB910437)
- Update for Windows Server 2003 x64 Edition (KB898715)

We then installed the Microsoft .NET Framework, version 2.0.50727 with the default options; it is available at http://msdn.microsoft.com/netframework/.

Power measurement configuration

To record each server's power consumption during each test, we used an Extech Instruments (www.extech.com) 380803 Power Analyzer / Datalogger. We connected the power cord from the server under test to the Power Analyzer's output load power outlet. We then plugged the power cord from the Power Analyzer's input voltage connection into a power outlet.

We used the Power Analyzer's Data Acquisition Software (version 2.11) to capture all recordings. We installed the software on a separate Intel–processor-based PC, which we connected to the Power Analyzer via an RS-232 cable. We captured power consumption at one-second intervals.

To gauge the idle power usage, we recorded the power usage while each server was running the operating system but otherwise idle.

We then recorded the power usage (in watts) for each server during the testing at one-second intervals. To compute the average power usage, we averaged the power usage during the time the server was producing its peak performance results. We call this time the power measurement interval. See Figures 3 (power consumption over time), 5 (power consumption at different thread counts), and 6 (idle and average peak power) for the results of these measurements.

Installation of the Black-Scholes 64-bit version kernel workload

Intel supplied the Black-Scholes 64-bit kernel workload compressed in a zip file. We unzipped the file's contents into a directory on a system separate from the servers under test. The folder contained C++ source code files and make files.

We used the Visual Studio project Intel provided to build the 64-bit versions of the workload with Microsoft Visual Studio 2005 as follows:

1. Double click the black_scholes_x64.vcproj file. Visual Studio automatically opens.

2. In the Solution Explorer pane, right-click black_scholes_x64, and select Properties
3. From inside the "black_scholes_x64 Property Pages" dialog, click the "Configuration Manager..." button.
4. From the "Active solution configuration:" drop-down menu, choose "Optimized_x64".
5. From the "Active solution platform:" drop-down menu, choose "x64".
6. Close the Configuration Manager.
7. While still inside the "black_scholes_x64 Property Pages" dialog, expand the C/C++ properties, and click "Command Line".
8. In the "Additional options:" text box, type either "/favor:EM64T" or "/favor:AMD64" to build the executable for the 64-bit Intel Xeon Processor 3.60 GHz-based server and the Dual-Core Intel Xeon Processor 5160-based server or the Dual-Core AMD Opteron 285-based server, respectively.
9. Click "OK" to close the "black_scholes_x64 Property Pages" dialog.
10. From the "Build" menu, select "Rebuild Solution".

We used the Microsoft Visual Studio 2005 to build 64-bit versions of the “Optimized_x64” executables. Intel provided the source code. As part of the process of building the executables, we needed to specify options for the compiler. We used the options in the project for the Optimized_x64 executable we received. (Per Intel, the staff at www.2cpu.com started with the 32-bit version of the Black-Scholes kernel workload and created this 64-bit version).

Once we built the executables, we created a folder on each server under test called BlackScholes and stored the executables in that folder.

Black-Scholes kernel workload switches/parameters

This workload provides the following switches, which we set as appropriate for each test run:

- */numThreads* or */t* This option designates the number of threads the workload should run. We set this to the number of threads we wanted in each test.
- *Number of steps* This option designates the number of steps the workload should use to calculate the option price.

By default, the workload assumes the following values:

- Number of threads: 4
- Number of steps: 100,000,000

This workload defaults to four threads regardless of the number of logical processors available on the server.

Running the Black-Scholes kernel workload

We rebooted the server before each individual test and then followed this process to run the test:

1. Open a DOS command window.
2. Navigate to the C:\BlackScholes folder.
3. Enter the following command:
   “blackscholes_x64.exe ,<# of threads> > <server name>_<# of threads>_<run no.>.txt, where
    a. <server name> is either Intel or AMD, as appropriate
    b. <# of threads> is either 2, 4, or 8 as appropriate
    c. <run no.> is either 1, 2, or 3 (we ran each test three times)

Each execution of the workload generates a text file that includes how long the workload took to complete. We recorded that time as the result for each run.

Appendix A – Test server configuration information

This appendix provides detailed configuration information about each of the three test server systems.

Processors	64-bit Intel Xeon Processor 3.60 GHz	Dual-Core Intel Xeon Processor 5160	Dual-Core AMD Opteron 285
System configuration information			
General			
Processor and OS kernel: (physical, core, logical) / (UP, MP)	2P2C4L / MP	2P4C4L / MP	2P4C4L / MP
Number of physical processors	2	2	2
Single/Dual-Core processors	Single	Dual	Dual
System Power Management Policy	Always On	Always On	Always On
CPU			
Vendor	Intel	Intel	AMD
Name	64-bit Intel Xeon Processor 3.60 GHz	Dual-Core Intel Xeon Processor 5160	Dual-Core AMD Opteron 285
Stepping	3	4	2
Socket type	mPGA-604	LGA 775	940
Core frequency (GHz)	3.6 GHz	3.0 GHz	2.6 GHz
Front-side bus frequency (MHz)	800 MHz	1333 MHz Dual Independent Busses (DIB)	2000 MHz HyperTransport
L1 Cache	16KB + 12KB	32KB + 32KB	64KB + 64KB
L2 Cache	2MB	4MB (Shared)	2MB (1MB per core)
Platform			
Vendor and model number	64-bit Intel Xeon Processor 3.60 GHz server	Dual-Core Intel Xeon Processor 5160 server	Dual-Core AMD Opteron 285 server
Motherboard model number	Intel SE7520AF2	Intel S5000PSL	UNIWIDE_SS232-128-03
Motherboard chipset	Intel E7520 Chipset	Intel 5000P Chipset	NVIDIA nForce4 Chipset
Motherboard revision number	C4	92	A3
Motherboard serial number	KRA145100053	QTFMHN61400072	WTOPHTSA01020
BIOS name and version	American Megatrends Inc. SE7520AF20.86B.P.10.00.0109.02082006139	American Megatrends Inc. S5000.86B.01.00.0036, 4/4/2006	American Megatrends Inc. 080012, 3/21/2006
BIOS settings	Default	HW Prefetcher and Adjacent Cache Line Prefetcher disabled	Default
Chipset INF driver	7.2.2.1006	7.3.0.1010	6.7
Memory module(s)			
Vendor and model number	Infineon HYS72T128000HR-5-A	Micron MT18HTF12872FDY	Corsair CMX1024RE-32000
Type	PC2-3200	FB-DIMM using PC2-5300 components	PC-3200

Speed (MHz)	400MHz	667MHz	400MHz
Speed in the system currently running @ (MHz)	400MHz	667MHz	400MHz
Timing/Latency (tCL-tRCD-iRP-tRASmin)	3-3-3-11	5-5-5-12	3-3-3-8
Size	8192MB	8192MB	8192MB
Number of RAM modules	8	8	8
Chip organization	Double-sided	Double-sided	Double-sided
Channel	Single	Dual	Dual
Hard disk			
Vendor and model number	Western Digital WD1600YD	Western Digital WD1600YD	Western Digital WD1600YD
Number of disks in system	1	1	1
Size	160GB	160GB	160GB
Buffer Size	16MB	16MB	16MB
RPM	7200	7200	7200
Type	SATA	SATA	SATA
Controller	Intel 82801EB Ultra ATA	Intel 631xESB Serial ATA	NVIDIA nForce4 Serial ATA
Controller driver	Intel 6.3.0.1005	Intel 7.3.0.1010	NVIDIA 5.10.2600.552
Operating system			
Name	Microsoft Windows 2003 Server, x64 Enterprise Edition	Microsoft Windows 2003 Server, x64 Enterprise Edition	Microsoft Windows 2003 Server, x64 Enterprise Edition
Build number	3790	3790	3790
Service Pack	SP1	SP1	SP1
Microsoft Windows update date	5/5/2006	5/5/2006	5/5/2006
File system	NTFS	NTFS	NTFS
Kernel	ACPI Multiprocessor x64-based PC	ACPI Multiprocessor x64-based PC	ACPI Multiprocessor x64-based PC
Language	English	English	English
Microsoft DirectX version	DirectX 9.0c	DirectX 9.0c	DirectX 9.0c
Graphics			
Vendor and model number	ATI Rage XL	ATI ES1000	ATI Rage XL
Chipset	ATI Rage XL PCI	ATI ES1000 PCI	ATI Rage XL PCI
BIOS version	GR-xlints3y.019-4.333	BK-ATI VER008.005.023.000	GR-xlacrs3p.003-4.328
Type	Integrated	Integrated	Integrated
Memory size	8MB	8MB	8MB
Resolution	1024 x 768	1024 x 768	1024 x 768
Driver	ATI 6.14.10.6024	ATI 6.14.10.6553	ATI 6.14.10.6025
Network card/subsystem			
Vendor and model number	Intel PRO/1000 MT Dual Port Network adapter	Intel PRO/1000 EB Network Connection	Broadcom dual NetXtreme Gigabit
Type	Integrated	Integrated	Integrated
Driver	Intel 8.6.17.0	Intel 9.3.28.0	Broadcom 8.48.0.0
Additional card information	2 x Intel PRO/1000 PT Dual Port Server Adapter	2 x Intel PRO/1000 PT Dual Port Server Adapter	2 x Intel PRO/1000 PT Dual Port Server Adapter
Additional card type	PCI – Express	PCI – Express	PCI – Express

Additional card driver	Intel 9.3.28.0	Intel 9.3.28.0	Intel 9.3.28.0
Optical drive			
Vendor and model number	Samsung TS-H325A	LITE-ON SOHD-16P9SV	Samsung SN-124
Type	DVD/CD-ROM	DVD/CD-ROM	CD-ROM
Interface	Internal	Internal	Internal
USB ports			
# of ports	5	6	4
Type of ports (USB 1.1, USB 2.0)	USB 2.0	USB 2.0	USB 2.0

Figure 8: Detailed system configuration information for the three test servers.

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