TEST REPORT
JUNE 2006

64-bit Black-Scholes financial workload performance and power consumption on uniprocessor Intel-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 servers using the following three processors:

- Intel Pentium D processor 840
- Intel Pentium D processor 950
- Intel Xeon processor 3070

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 Intel Xeon processor 3070-based server delivered 61.7 percent more performance/watt than the Intel Pentium D processor 950-based server (see Figure 1). (We calculated performance/watt using system-level power measurements.)
- The Intel Xeon processor 3070-based server delivered 18.4 percent higher peak performance than the Intel Pentium D processor 950-based server (see Figure 2).
- The Intel Xeon processor 3070-based server had 24.2 percent lower average power usage while running the Black-Scholes workload than the Intel Pentium D processor 950-based server (see Figure 5).

The optimum thread count for our testing was two on the Intel Xeon processor 3070-based server and the Intel Pentium D processor 950-based server. The reason is that each of these servers has one physical processor with two cores per processor, or two available execution units.

The Intel Pentium D processor 840-based server has one physical dual-core processor. Consequently, it, too, has two execution units available. Thus, we expected the optimum thread count for this server would also be two. In our testing, however, the optimum thread count proved to be four, though the improvement over two threads was small. We do not know the reason that four threads proved to be optimal.

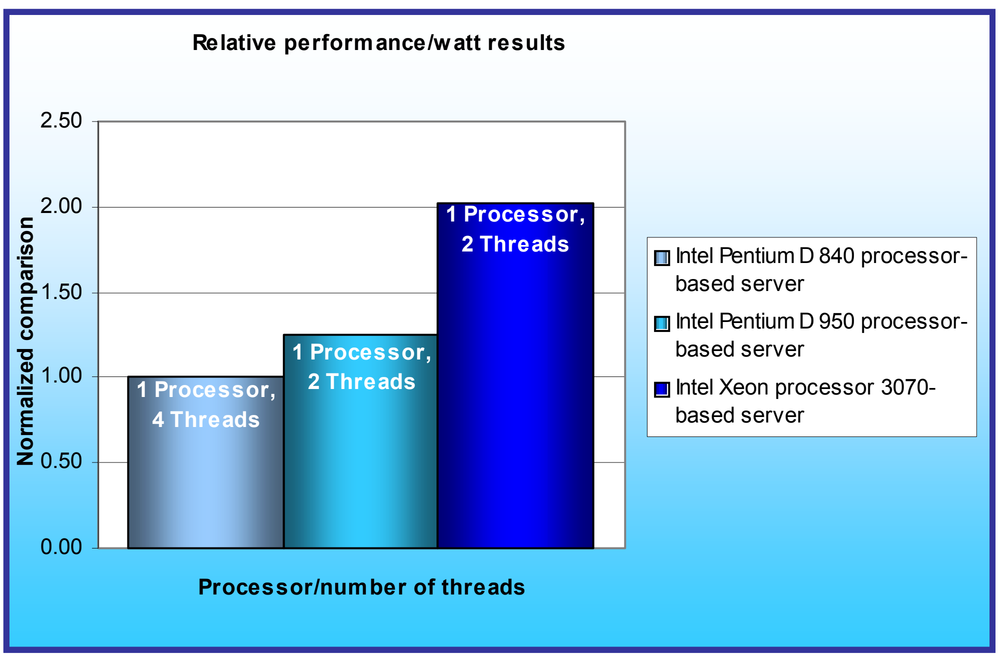

Figure 1: Performance/watt results of the test servers running the Black-Scholes workload. Higher numbers indicate better performance/watt.

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 = (3600 / (the benchmark's duration in seconds)) / (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.

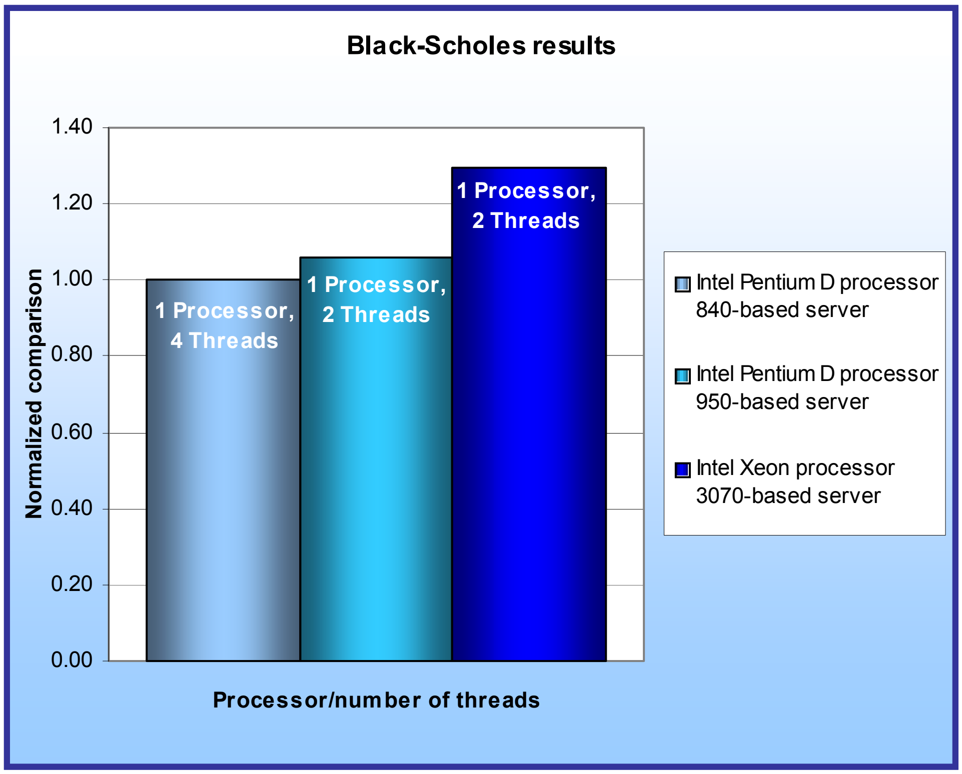

Figure 2: Normalized peak performance of the servers with the optimum thread-to-processor configurations with the Black-Scholes workload. Higher numbers are better.

As Figure 1 illustrates, the Intel Xeon processor 3070-based server delivered 61.7 percent more performance/watt than the Intel Pentium D processor 950-based server and 102.2 percent more performance/watt than the Intel Pentium D processor 840-based server.

Figure 2 illustrates the relative peak (dual-processor) performance of each server. The Intel Xeon processor 3070-based server finished the Black-Scholes workload in 7.1 seconds, 18.4 percent faster than the Intel Pentium D processor 950-based server, which finished the same workload in 8.7 seconds. The Intel Pentium D processor 950-based server was 22.8 percent faster than the Intel Pentium D processor 840-based server, which took 9.2 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 Intel Xeon processor 3070-based server achieved its peak performance while drawing less power—over 24 percent less—than the Intel Pentium D processor 950-based server.

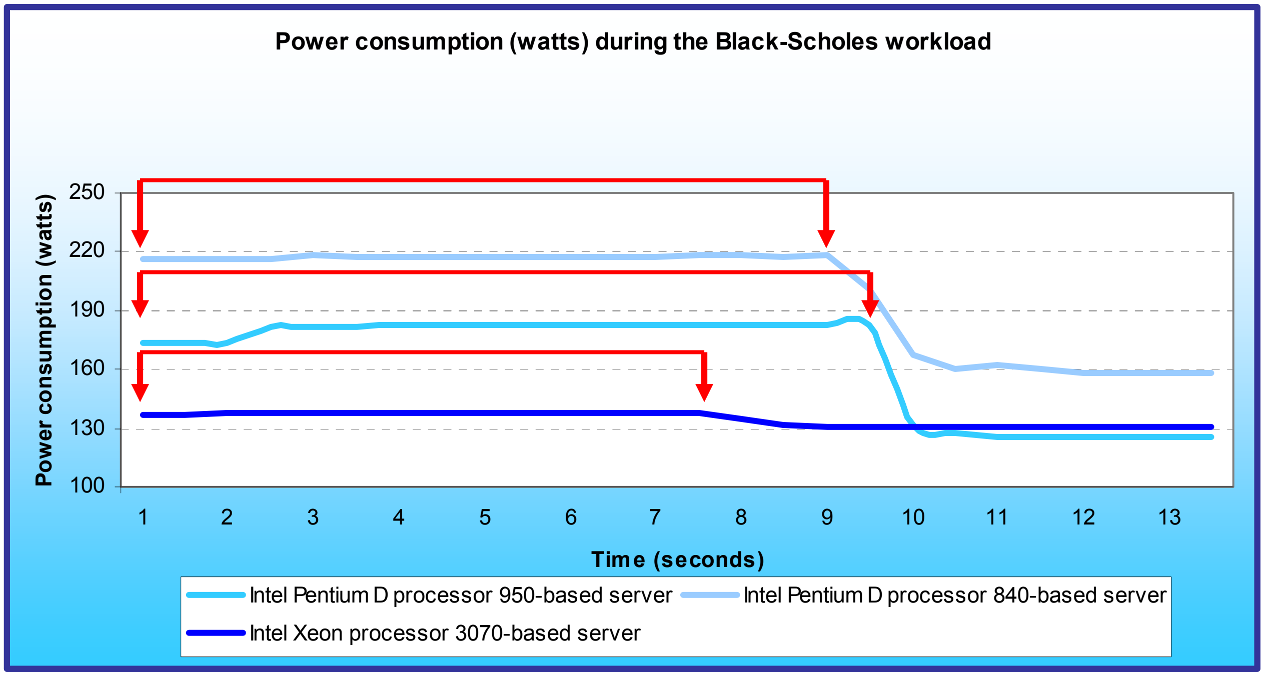

Figure 3: Power consumption (in watts) of each of the servers throughout the course of executing the Black-Scholes workload. Lower power consumption is better.

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 test servers, we used the compiler's "/favor:EM64T" 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
Intel Pentium D processor 840-based server	9.3	9.2	9.2
Intel Pentium D processor 950-based server	8.7	8.7	8.7
Intel Xeon processor 3070-based server	7.1	7.1	7.2

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 Intel Xeon processor 3070-based server and Intel Pentium D processor 950-based server achieved the fastest time with two threads, which means two threads is the optimum thread-to-processor configuration for these servers. In contrast, the Intel Pentium D processor 840 -based server achieved the fastest time with four threads, making four threads the optimum thread-to-processor configuration for that server.

Server / # of threads	2	4	8
Intel Pentium D processor 840-based server	215.3	214.1	211.2
Intel Pentium D processor 950-based server	181.1	181.8	181.7
Intel Xeon processor 3070-based server	137.8	136.7	136.5

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 Intel Xeon processor 3070-based server had over 24 percent lower average power usage during its fastest run of the workload (the one with two threads) than the Intel Pentium D processor 950-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.

Server	Idle power (watts)	Average power (watts)
Intel Pentium D processor 840-based server	132.6	214.1
Intel Pentium D processor 950-based server	123.4	181.1
Intel Xeon processor 3070-based server	128.1	137.2

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	Intel Pentium D processor 840-based server	Intel Pentium D processor 950-based server	Intel Xeon processor 3070-based server
Processor frequency (GHz)	3.20GHz	3.40GHz	2.66GHz
Front-side bus frequency (MHz)	800MHz	800MHz	1066MHz
Single/Dual-Core processors	Dual	Dual	Dual
Motherboard	Intel 3000 Chipset-based internal reference board	Intel 3000 Chipset-based internal reference board	Intel 3000 Chipset-based internal reference board
Chipset	Intel 3010 Chipset	Intel 3010 Chipset	Intel 3010 Chipset
RAM (8GB in each)	4 x 2GB PC2-4200	4 x 2GB PC2-4200	4 x 2GB PC2-4200
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 front-side bus reflects the capabilities of the three processors: The Intel Xeon processor 3070 uses a front-side bus speed of 1066 MHz. The Intel Pentium D processor 950 and Intel Pentium D processor 840 each have a front-side bus speed of 800 MHz.

With the following exception, we used the default BIOS settings on each server: we disabled the HW Prefetcher on all servers.

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 half-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 half-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 "/favor:EM64T" to build the executable.
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 Xeon 3070, Pentium D 950, or Pentium D 840, 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 test server systems, which we list in alphabetical order.

Processors	Intel Pentium D processor 840	Intel Pentium D processor 950	Intel Xeon processor 3070
System configuration information			
General			
Processor and OS kernel: (physical, core, logical) / (UP, MP)	1P2C2L / UP	1P2C2L / UP	1P2C2L / UP
Number of physical processors	1	1	1
Single/Dual-Core processors	Dual	Dual	Dual
System Power Management Policy	Always On	Always On	Always On
CPU			
Vendor	Intel	Intel	Intel
Name	Intel Pentium D processor 840	Intel Pentium D processor 950	Intel Xeon processor 3070
Stepping	7	4	4
Socket type	LGA775	LGA 775	LGA775
Core frequency (GHz)	3.20 GHz	3.40 GHz	2.66 GHz
Front-side bus frequency (MHz)	800 MHz	800 MHz	1066 MHz
L1 Cache	16KB + 12KB	16KB + 12KB	32KB + 32KB
L2 Cache	2MB (1MB per core)	4MB (2MB per core)	4MB (Shared)
Platform			
Vendor and model number	Intel Pentium D processor 840 server	Intel Pentium D processor 950 server	Intel Xeon processor 3070 server
Motherboard model number	Intel 3000 Chipset-based internal reference board	Intel 3000 Chipset-based internal reference board	Intel 3000 Chipset-based internal reference board
Motherboard chipset	Intel 3010 Chipset	Intel 3010 Chipset	Intel 3010 Chipset
Motherboard revision number	C0	C0	C0
Motherboard serial number	8MWH61400065	8MWH61400065	8MWH61400139
BIOS name and version	American Megatrends Inc. EXTWM210.86P, 5/23/2006	American Megatrends Inc. EXTWM210.86P, 5/23/2006	American Megatrends Inc. EXTWM210.86P, 5/23/2006
BIOS settings	Default	Default	Default
Chipset INF driver	8.1.1.1001	8.1.1.1001	8.1.1.1001
Memory module(s)			
Vendor and model number	Kingston KVR533D2E4/2G	Kingston KVR533D2E4/2G	Kingston KVR533D2E4/2G
Type	PC2-4200	PC2-4200	PC2-4200
Speed (MHz)	533 MHz	533 MHz	533 MHz
Speed in the system currently running @ (MHz)	400 MHz	400 MHz	533 MHz
Timing/Latency (tCL-tRCD-iRP-tRASmin)	3-3-3-9	3-3-3-9	4-4-4-12
Size	8192MB	8192MB	8192MB
Number of RAM modules	4	4	4
Chip organization	Double-sided	Double-sided	Double-sided
Channel	Dual	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 82801GB Serial ATA	Intel 82801GB Serial ATA	Intel 82801GB Serial ATA
Controller driver	Intel 7.0.0.1020	Intel 7.0.0.1020	Intel 7.0.0.1020
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	6/7/2006	6/7/2006	6/7/2006
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 ES1000	ATI ES1000	ATI ES1000
Chipset	ATI ES1000 PCI	ATI ES1000 PCI	ATI ES1000 PCI
BIOS version	01.00	01.00	01.00
Type	Integrated	Integrated	Integrated
Memory size	32MB	32MB	32MB
Resolution	1024 x 768	1024 x 768	1024 x 768
Driver	Microsoft 5.2.3790.1830	Microsoft 5.2.3790.1830	Microsoft 5.2.3790.1830
Network card/subsystem			
Vendor and model number	Intel PRO/1000 PM Dual Port Network adapter	Intel PRO/1000 PM Dual Port Network adapter	Intel PRO/1000 PM Dual Port Network adapter
Type	Integrated	Integrated	Integrated
Driver	Intel 9.3.28.0	Intel 9.3.28.0	Intel 9.3.28.0
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	Sony DDU1615	Sony DDU1615	Sony DDU1615
Type	DVD-ROM	DVD-ROM	DVD-ROM
Interface	Internal	Internal	Internal
USB ports			
# of ports	4	4	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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