TEST REPORT
AUGUST 2007

64-bit Black-Scholes financial workload performance and power consumption on multi-processor Intel- and AMD-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 multi-processor servers using the following four processors:

- Dual-Core AMD* Opteron* processor 8220 (2.80GHz, 95W)
- Dual-Core Intel Xeon® processor 7140M (3.40GHz, 150W)
- Quad-Core Intel Xeon processor E7340 (2.40GHz, 80W)
- Quad-Core Intel Xeon processor L7345 (1.86GHz, 50W)

The Black-Scholes workload is multithreaded and allows users to specify the number of threads the program runs. Workload performance can increase as the number of threads increases, up to an optimum thread count, typically equal to the number of logical and physical processors available on the server. We refer to this as the optimum thread-to-processor configuration.

The optimum thread count for our testing was 8 on the Dual-Core AMD Opteron processor 8220 server and 16 on the remaining servers: Dual-Core Intel Xeon processor 7140M, Quad-Core Intel Xeon processor E7340, and Quad-Core Intel Xeon processor L7345. The difference in thread counts between the servers is due to the different number or execution units (logical and physical processors) on those servers. (We set Hyper-Threading Technology to On for the Dual-Core Intel Xeon processor 7140M.)

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 four servers. In this and the other performance charts in this section, we normalized the results for each workload to the time the slowest configuration

KEY FINDINGS

- The Quad-Core Intel® Xeon® processor E7340-based server delivered 160.6 percent more performance/watt than the Dual-Core Intel Xeon processor 7140M-based server (see Figure 1). (We calculated performance/watt using system-level power measurements.)
- The Quad-Core Intel Xeon processor L7345-based server delivered 128.5 percent more performance/watt than the Dual-Core Intel Xeon processor 7140M-based server (see Figure 1).
- The Quad-Core Intel Xeon processor E7340-based server delivered 72.9 percent more performance/watt than the Dual-Core AMD* Opteron* processor 8220-based server (see Figure 1).
- The Quad-Core Intel Xeon processor L7345-based server delivered 51.5 percent more performance/watt than the Dual-Core AMD Opteron processor 8220-based server (see Figure 1).

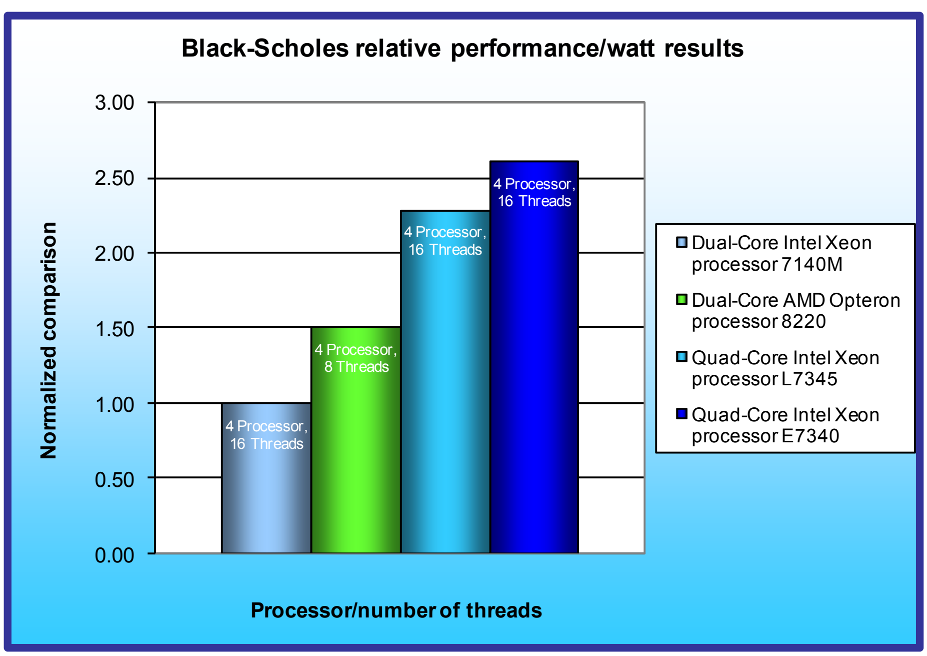

Figure 1: Performance/watt results for the test servers. Higher numbers are better.

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., less time to complete the workload with the specified number of threads).

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

$$\frac{\text{3,600/benchmark's duration in seconds}}{\text{average power consumption in watts during period of peak performance}}$$

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

As Figure 1 illustrates, the Quad-Core Intel Xeon processor E7340-based server delivered 160.6 percent more performance/watt than the Dual-Core Intel Xeon processor 7140M-based server and 72.9 percent more performance/watt than the Dual-Core AMD Opteron processor 8220-based server. The Quad-Core Intel Xeon processor L7345-based server delivered 128.5 percent more performance/watt than the Dual-Core Intel Xeon processor 7140M-based server and 51.5 percent more performance/watt than the Dual-Core AMD Opteron processor 8220-based server (see Figure 1).

Figure 2 shows the relative peak performance of each server. The Quad-Core Intel Xeon processor E7340-based server finished the Black-Scholes workload in 8.78 seconds, 40.4 percent faster than the Dual-Core Intel Xeon processor 7140M-based server, which finished the same workload in 14.73 seconds. This speed difference means a user would receive a solution 5.95 seconds faster with the Quad-Core Intel Xeon processor E7340-based server. The Quad-Core Intel Xeon processor E7340-based server was 36.5 percent faster than the Dual-Core AMD Opteron processor 8220-based server, which took 13.83 seconds to complete the same workload.

The Quad-Core Intel Xeon processor L7345-based server finished the Black-Scholes workload in 11.30 seconds, 23.3 percent faster than the Dual-Core Intel Xeon processor 7140M-based server, which finished the same workload in 14.73 seconds. This speed difference means a user would receive a solution 3.43 seconds faster with the Quad-Core Intel Xeon processor L7345-based server. The Quad-Core Intel Xeon processor L7345-based server was 18.3 percent faster than the Dual-Core AMD Opteron processor 8220-based server, which took 13.83 seconds to complete the same workload.

The Quad-Core Intel Xeon processor E7340-based server was 22.3 percent faster than the Quad-Core Intel Xeon processor L7345-based server.

Figure 3 plots the power usage of the four servers as they ran the benchmark. We captured power measurements during the period of peak performance. Lower power consumption is

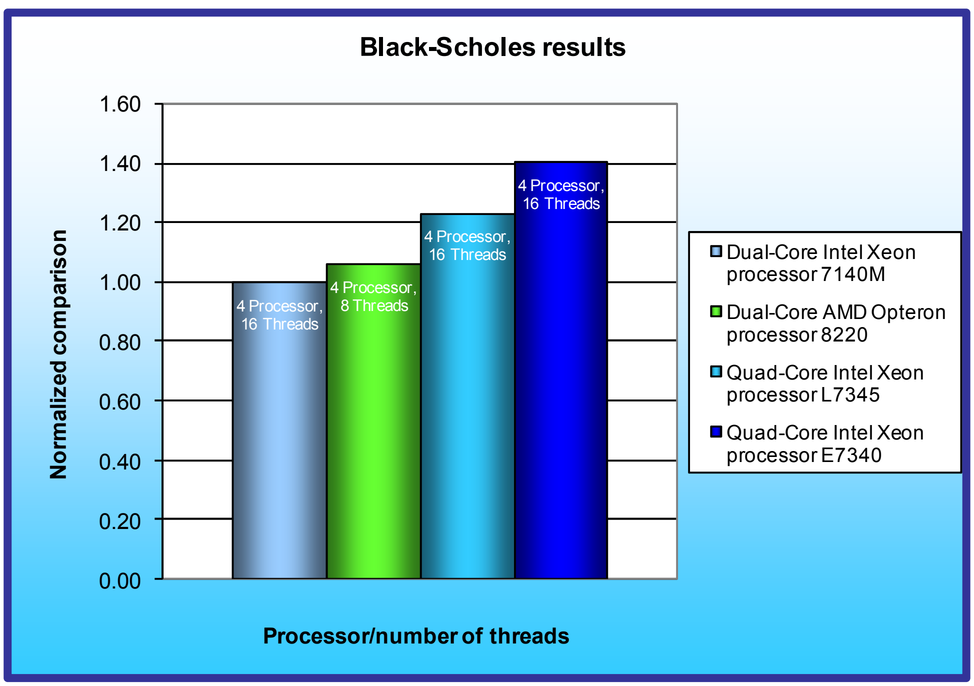

Figure 2: Normalized peak performance of the servers with optimum thread-to-processor configurations on the Black-Scholes workload. Higher numbers are better.

better. Figures 5 and 6 below detail the power usage of each server. (The drop in power consumption back to idle state for all servers occurred when they finished the workload.)

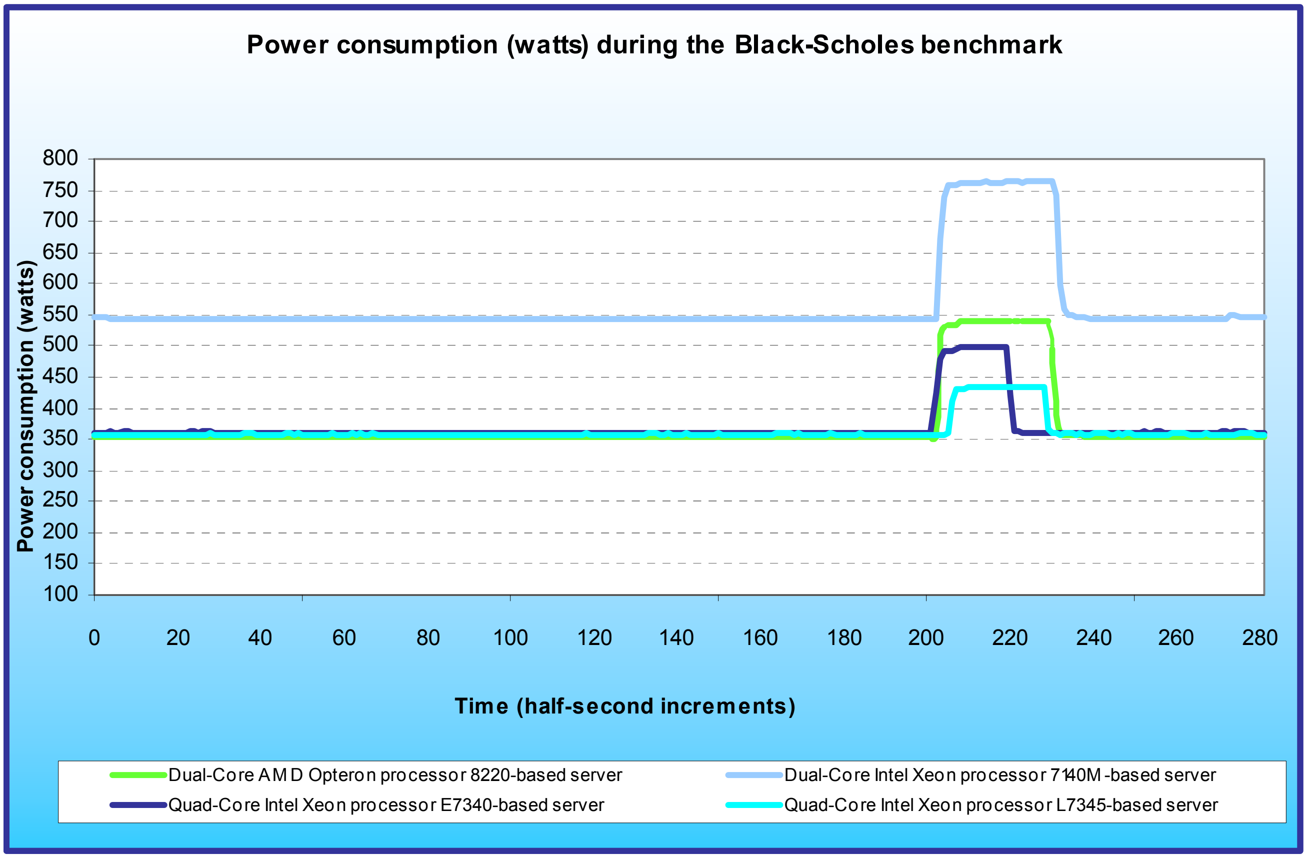

Figure 3: Power consumption (in watts) of the servers throughout the course of executing the Black-Scholes workload. Lower numbers are better.

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. Black-Scholes 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 the source and found no changes designed to favor one processor architecture over another. 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 2, 4, 8, and 16 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.

As Figure 4 shows, the Dual-Core AMD Opteron processor 8220-based server achieved its fastest completion times with 8 threads, making 8 threads the optimum thread-to-processor configuration for that server. For the other three servers, the optimum thread-to-processor configuration was 16.

Server/# of threads	2	4	8	16
Dual-Core AMD Opteron processor 8220	55.23	27.61	**13.83**	16.05
Dual-Core Intel Xeon processor 7140M	62.88	31.41	29.47	**14.73**
Quad-Core Intel Xeon processor E7340	69.97	35.16	17.58	**8.78**
Quad-Core Intel Xeon processor L7345	89.95	44.98	22.59	**11.30**

Figure 4: Median completion times (in seconds) of the servers with varying thread counts using the Black-Scholes workload. Lower times are better. The result for the optimum thread count for each server appears in bold.

Figure 5 details the average power consumption of the test servers during the median runs of our tests with 2, 4, 8, and 16 threads.

Server/# of threads	2	4	8	16
Dual-Core AMD Opteron processor 8220	396.1	441.8	531.8	513.9
Dual-Core Intel Xeon processor 7140M	606.9	670.4	671.3	752.9
Quad-Core Intel Xeon processor E7340	383.8	401.1	434.4	484.6
Quad-Core Intel Xeon processor L7345	368.8	375.7	395.2	429.6

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

Figure 6 details the power consumption, in watts, of the test servers while idle and during the median peak runs (at optimum thread count) of the benchmark.

Server	Idle power (watts)	Average power (watts)
Dual-Core AMD Opteron processor 8220	354.5	531.8
Dual-Core Intel Xeon processor 7140M	543.7	752.9
Quad-Core Intel Xeon processor E7340	358.9	484.6
Quad-Core Intel Xeon processor L7345	357.0	429.6

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 four server systems; Appendix A provides detailed configuration information.

Server	Dual-Core AMD Opteron processor 8220	Dual-Core Intel Xeon processor 7140M	Quad-Core Intel Xeon processor E7340	Quad-Core Intel Xeon processor L7345
Processor frequency (GHz)	2.8 GHz	3.4 GHz	2.4 GHz	1.86 GHz
Front-side bus frequency (MHz)	2000 MHz HyperTransport	800 MHz	1066 MHz	1066 MHz
Number of processor packages	4	4	4	4
Number of cores per processor package	2	2	4	4
Number of hardware threads per core	1	2	1	1
Motherboard	HP* PB729AE9QUD O49	Intel SE8500HW4	Intel S7000FC4UR	Intel S7000FC4UR
Chipset	NVIDIA* nForce4	Intel SE8500	Intel ID3600	Intel ID3600
RAM (16 GB in each)	16GB (16 x 1GB) PC2-5300 DDR2	16GB (16 x 1GB) PC2-5300 DDR2	16GB (16 x 1GB) PC2-5300 FB-DDR2	16GB (16 x 1GB) PC2-5300 FB-DDR2
Hard Drive	HP DH072ABAA6	Seagate* ST3146854LC	Seagate ST973401SS	Seagate ST973401SS

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

Intel configured and provided all four servers.

We used the default BIOS settings on each server.

We began our testing by installing a fresh copy of Microsoft Windows Server* 2003 Enterprise x64 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 Internet Explorer* 7 for Windows Server 2003 x64 Edition (KB933566)
- Security Update for Outlook* Express for Windows Server 2003 x64 Edition (KB929123)
- Security Update for Windows Server 2003 x64 Edition (KB935839)
- Security Update for Windows Server 2003 x64 Edition (KB935840)
- Security Update for Internet Explorer 6 for Windows Server 2003 x64 Edition (KB933566)
- Security Update for Windows Server 2003 x64 Edition (KB924667)
- Update for Windows Server 2003 x64 Edition (KB927891)
- Security Update for Windows Server 2003 x64 Edition (KB932168)
- Windows Internet Explorer 7.0 for Windows Server 2003 (x64)

- Security Update for Windows Server 2003 x64 Edition (KB930178)
- Security Update for Windows Server 2003 x64 Edition (KB925902)
- Update for Windows Server 2003 Service Pack 2 x64 Edition (KB931836)

We then installed the Microsoft .NET* Framework, version 3.0.4506.30 with the default options; it is available at http://msdn.microsoft.com/netframework/.

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 Microsoft Visual Studio 2005 and Intel compiler version 10.0.023 to build the 64-bit versions of the workload. To create the executables we used the following commands with both the AMD and Intel make files.

- nmake –f Makefile.Intel all
- nmake –f Makefile.AMD all

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

Make file for the server with AMD processors

```
#
# Application Name
#

APPNAME = black_scholes_custom_2pass

#
# compiler
#

CC = icl

#
# compilation options
#

CFLAGS = -c -O3 -Qparallel -Zi -Ob2
CPASS1 = -Qprof_gen
CPASS2 = -Qprof_use

#
# ARCH
#

ARCH = amd

#
# linker
#

LINK = xilink

#
# linker options
#

LOPTS = /out:$(APPNAME)_$(ARCH).exe /FIXED:no

#
# executable
#
```

```
all:    $(APPNAME)_$(ARCH).exe

clean:
        del BenchFunction.obj ConsoleTest.obj $(APPNAME)_$(ARCH).exe *.dyn *.dpi

BenchFunction.obj: BenchFunction.cpp
        $(CC) $(CFLAGS) $(CPASS1) BenchFunction.cpp

ConsoleTest.obj : ConsoleTest.cpp
        $(CC) $(CFLAGS) $(CPASS1) ConsoleTest.cpp

$(APPNAME)_$(ARCH).exe: clean BenchFunction.obj ConsoleTest.obj
        $(LINK) BenchFunction.obj ConsoleTest.obj $(LOPTS)
        $(APPNAME)_$(ARCH).exe 2

        $(CC) $(CFLAGS) $(CPASS2) BenchFunction.cpp
        $(CC) $(CFLAGS) $(CPASS2) ConsoleTest.cpp
        $(LINK) BenchFunction.obj ConsoleTest.obj $(LOPTS)
        $(APPNAME)_$(ARCH).exe 8
```

Make file for the server with Intel processors

```
#
# Application Name
#

APPNAME = black_scholes_custom_2pass

#
# compiler
#

CC = icl

#
# compilation options
#

CFLAGS = -c -O3 -Qparallel -Zi -Ob2
CPASS1 = -Qprof_gen
CPASS2 = -Qprof_use

#
# ARCH
#

ARCH = intel

#
# linker
#

LINK = xilink

#
# linker options
#

LOPTS = /out:$(APPNAME)_$(ARCH).exe /FIXED:no

#
# executable
#

all:    $(APPNAME)_$(ARCH).exe

clean:
        del BenchFunction.obj ConsoleTest.obj $(APPNAME)_$(ARCH).exe *.dyn *.dpi

BenchFunction.obj: BenchFunction.cpp
```

```
        $(CC) $(CFLAGS) $(CPASS1) BenchFunction.cpp

ConsoleTest.obj : ConsoleTest.cpp
        $(CC) $(CFLAGS) $(CPASS1) ConsoleTest.cpp

$(APPNAME)_$(ARCH).exe: clean BenchFunction.obj ConsoleTest.obj
        $(LINK) BenchFunction.obj ConsoleTest.obj $(LOPTS)
        $(APPNAME)_$(ARCH).exe 8

        $(CC) $(CFLAGS) $(CPASS2) BenchFunction.cpp
        $(CC) $(CFLAGS) $(CPASS2) ConsoleTest.cpp
        $(LINK) BenchFunction.obj ConsoleTest.obj $(LOPTS)
        $(APPNAME)_$(ARCH).exe 8
```

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.exe ,<# of threads> 1000000000 > <server name>_<# of threads>_<run no.>.txt, where
   a. 1000000000 is the number of steps
   b. <server name> is server name as appropriate
   c. <# of threads> is either 2, 4, 8, or 16 as appropriate
   d. <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 system configuration information

This appendix provides detailed configuration information about each of the test server systems, which we list in alphabetical order.

Servers	Dual-Core AMD Opteron processor 8220	Dual-Core Intel Xeon processor 7140M	Quad-Core Intel Xeon processor E7340	Quad-Core Intel Xeon processor L7345
General processor setup				
Number of processor packages	4	4	4	4
Number of cores per processor package	2	2	4	4
Number of hardware threads per core	1	2	1	1
System Power Management Policy	Always on	Always on	Always on	Always on
CPU				
Vendor	AMD	Intel	Intel	Intel
Name	AMD Opteron 8220	Dual-Core Intel Xeon MP 7140M	Quad-Core Intel Xeon E7340	Quad-Core Intel Xeon L7345
Stepping	3	8	B	B
Socket type	Socket F (1207)	mPGA604	mPGA604	mPGA604
Core frequency (GHz)	2.8 GHz	3.4 GHz	2.4 GHz	1.86 GHz
Front-side bus frequency (MHz)	2000 MHz HyperTransport	800 MHz	1066 MHz	1066 MHz
L1 Cache	64 KB + 64 KB (per core)	12 KB + 16 KB (per core)	32 KB + 32 KB (per core)	32 KB + 32 KB (per core)
L2 Cache	2 x 1 MB	2 x 1 MB	2 x 4 MB (each 4 MBs shared by 2 cores)	2 x 4 MB (each 4 MBs shared by 2 cores)
L3 Cache	NA	16 MB	NA	NA
Thermal Design Power (TDP, in watts)	95	150	80	50
Platform				
Vendor and model number	HP ProLiant* DL585 G2	Intel	Intel	Intel
Motherboard model number	PB729AE9QUDO49	SR4850HW4x	S7000FC4UR	S7000FC4UR
Motherboard chipset	NVIDIA nForce4	Intel SE8501	Intel ID3600	Intel ID3600
Motherboard revision number	A4	11	01	01
BIOS name and version	HP BIOS A07 (v2.10)	Intel Corporation SHW40.86B.P.12.00.0076, 02/15/2007	Intel SFC4UR.86B.01.00.0010.050420071510	Intel SFC4UR.86B.01.00.0010.050420071510
BIOS settings	Default	Default	Default	Default
Chipset INF driver	HP 1.0.0.0	Intel 8.3.0.1013	Intel 8.4.0	Intel 8.4.0
Memory module(s)				
Vendor and model number	Micron* MT18HTF12872PDY-667D2	ELPIDA* EBE10RD4AGFA-6E-E	Kingston* KVR667D2D8F5/1G	Kingston KVR667D2D8F5/1G

Servers	Dual-Core AMD Opteron processor 8220	Dual-Core Intel Xeon processor 7140M	Quad-Core Intel Xeon processor E7340	Quad-Core Intel Xeon processor L7345
Type	PC2-5300 DDR2	PC2-5300 DDR2	PC2-5300 FB-DDR2	PC2-5300 FB-DDR2
Speed (MHz)	667 MHz	667 MHz	667 MHz	667 MHz
Speed in the system currently running @ (MHz)	667 MHz	400 MHz	667 MHz	667 MHz
Timing/Latency (tCL-tRCD-iRP-tRASmin)	5-5-5-15	3-3-3-9	5-5-5-15	5-5-5-15
Size	16382 MB	16382 MB	16382 MB	16382 MB
Number of RAM modules	16	16	16	16
Chip organization	Double-sided	Double-sided	Double-sided	Double-sided
Hard disk				
Vendor and model number	HP DH072ABAA6	Seagate ST3146854LC	Seagate ST973401SS	Seagate ST973401SS
Number of disks in system	1	1	1	1
Size	72 GB	146.8 GB	73.4 GB	73.4 GB
Buffer Size	16 MB	8 MB	8 MB	8 MB
RPM	15,000	15,000	10,000	10,000
Type	SAS	SCSI	SAS	SAS
Controller	Smart Array P400 Controller	LSI Logic PCI-X Ultra320 SCSI	Intel 631xESB/6321ESB/3100 Chipset Serial ATA Storage Controller – 2680	Intel 631xESB/6321ESB/3100 Chipset Serial ATA Storage Controller – 2680
Driver version	HP 6.6.0.64	Microsoft 5.2.3790.3959	LSI* 2.8.0.64	LSI 2.8.0.64
Operating system				
Name	Microsoft Windows Server 2003 Enterprise x64 Edition	Microsoft Windows Server 2003 Enterprise x64 Edition	Microsoft Windows Server 2003 Enterprise x64 Edition	Microsoft Windows Server 2003 Enterprise x64 Edition
Build number	3790	3790	3790	3790
Service Pack	SP2	SP2	SP2	SP2
File system	NTFS	NTFS	NTFS	NTFS
Kernel	ACPI	ACPI	ACPI	ACPI
Language	English	English	English	English
Microsoft DirectX version	9.0c	9.0c	9.0c	9.0c
Graphics				
Vendor and model number	ATI* ES1000	ATI Radeon* 7000	ATI ES1000	ATI ES1000
Chipset	ES1000	ATI Radeon 7000 PCI	ES1000	ES1000
BIOS version	BK-ATI VER008.005.013.000	BK-ATI VER008.004.037.001	BK-ATI VER008.005.031.000	BK-ATI VER008.005.031.000
Type	Integrated	Integrated	Integrated	Integrated

Servers	Dual-Core AMD Opteron processor 8220	Dual-Core Intel Xeon processor 7140M	Quad-Core Intel Xeon processor E7340	Quad-Core Intel Xeon processor L7345
Memory size	32 MB	16 MB	32 MB	32 MB
Resolution	1024x768	1024x768	1024x768	1024x768
Driver version	ATI 8.24.3.0	ATI 6.14.10.6508	ATI 8.24.3.0	ATI 8.24.3.0
Network card/subsystem				
Vendor and model number	HP NC371i Multifunction Gigabit Server Adapter	Broadcom* BCM5704 dual NetXtreme* Gigabit Adapter	Intel PRO/1000 EB/Intel 82575EB	Intel PRO/1000 EB/Intel 82575EB
Type	Integrated	Integrated	Integrated	Integrated
Driver version	HP 3.0.5.0	Microsoft 7.98.0.0	Intel 9.9.8.0/Intel 10.0.15.0	Intel 9.9.8.0/Intel 10.0.15.0
Optical drive				
Vendor and model number	TEAC* DW-224E-R	Philips* SDR089	Optiarc* DVD-ROM DDU810A	Optiarc DVD-ROM DDU810A
USB ports				
Number	4	5	5	5
Type	USB 2.0	USB 2.0	USB 2.0	USB 2.0
Power supplies				
Total number	1	1	1	1
Wattage of each	1300	1470	1570	1570
Cooling fans				
Total number	6	4	8	8
Dimensions	120 mm	120 mm	4x80 mm + 4x120mm	4x80 mm + 4x120mm
Voltage	12 V	12 V	12 V	12 V
Amps	3.9 A	3.3 A	4 x 1.76 A + 4 x 3.3 A	4 x 1.76 A + 4 x 3.3 A

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

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