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

Executive summary

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

- Quad-Core AMD Opteron 2347 (1.9GHz)
- Quad-Core Intel Xeon E5345 (2.33GHz)
- Quad-Core Intel Xeon E5450 (3.0GHz)

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. All three servers achieved their fastest completion times with 8 threads, making 8 threads the optimum thread-to-processor configuration.

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 relative peak (dual-processor) performance/watt results of each server. The Quad-Core Intel Xeon E5450-based server delivered 90.6 percent more performance/watt than the Quad-Core AMD Opteron 2347-based server. In addition, the Quad-Core Intel Xeon E5450-based server achieved 117.5 percent the Quad-Core Intel Xeon E5345-based server.

KEY FINDINGS

- The Quad-Core Intel Xeon E5450-based server delivered 90.6 percent more performance/watt than the Quad-Core AMD Opteron 2347-based server (see Figure 1). (We calculated performance/watt using system-level power measurements.)
- The Quad-Core Intel Xeon E5450-based server delivered 117.5 percent more performance/watt than the Quad-Core Intel Xeon E5345-based server (see Figure 1). (We calculated performance/watt using system-level power measurements.)
- The Quad-Core Intel Xeon E5450-based server achieved a 124.9 percent jobs/hour performance increase over the Quad-Core AMD Opteron 2347-based server using the Black-Scholes workload (see Figure 2).
- The Quad-Core Intel Xeon E5450 -based server achieved a 106.9 percent jobs/hour performance increase over the Quad-Core Intel Xeon E5345-based server using the Black-Scholes workload (see Figure 2).

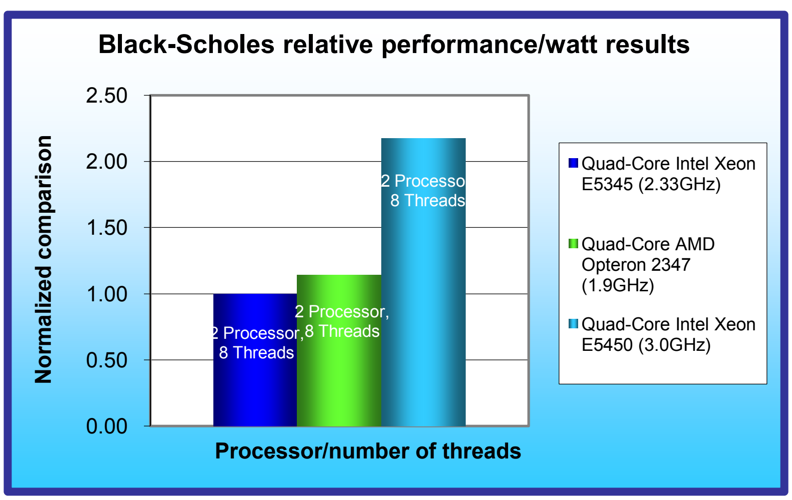

Figure 1: Performance/watt results of the test servers running the Black-Scholes workload. Higher numbers indicate better performance/watt.

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

Performance/watt = (3,600 / the benchmark's duration in seconds) / (average power consumption in watts during the period in which the benchmark was delivering peak performance)

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

Figure 2 presents the relative jobs/hour results of each server at its optimum thread count. To calculate jobs/hour, we used the following formula:

Jobs/hour = 3,600 / Black-Scholes workload completion time in seconds

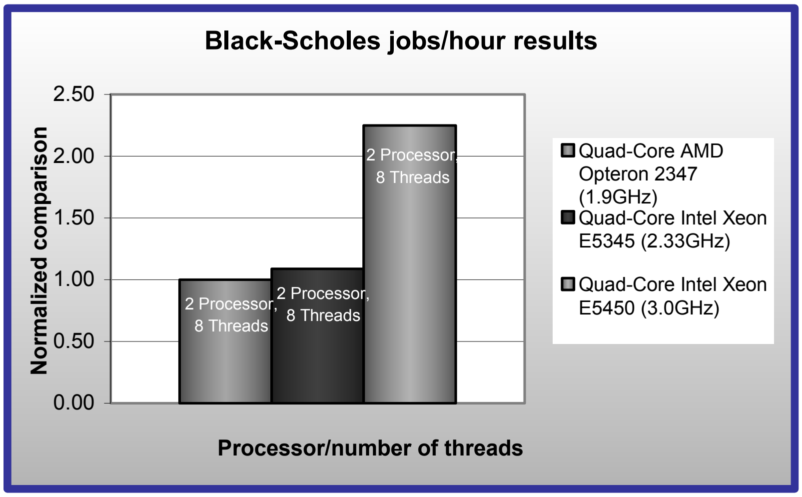

Figure 2: Normalized peak (dual-processor) performance of the servers with the optimum thread-to-processor configurations with the Black-Scholes workload. Higher numbers are better.

As Figure 2 illustrates, the Quad-Core Intel Xeon E5450-based server achieved 412.37 jobs/hour using the Black-Scholes workload. This is a 124.9 percent performance increase over the Quad-Core AMD Opteron 2347-based server, which achieved a result of 183.39 jobs/hour using the same workload.

The Quad-Core Intel Xeon X5450-based server produced a 106.9 percent performance increase over the Quad-Core Intel Xeon X5345-based server, which achieved 199.34 jobs/hour.

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 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.

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

Processor	2 threads	4 threads	8 threads	16 threads
Quad-Core AMD Opteron 2347 (1.9GHz)	221.2	242.8	278.5	275.3
Quad-Core Intel Xeon E5345 (2.33GHz)	308.8	322.3	345.5	341.5
Quad-Core Intel Xeon E5450 (3.0GHz)	287.7	308.6	328.6	331.0

Figure 4: 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 power consumption, in watts, of the test servers while idle and during the median peak runs (at optimum thread count) of the benchmark.

Processor	Idle power (watts)	Average power (watts)
Quad-Core AMD Opteron 2347 (1.9GHz)	203.0	278.5
Quad-Core Intel Xeon E5345 (2.33GHz)	292.8	345.5
Quad-Core Intel Xeon E5450 (3.0GHz)	267.0	328.6

Figure 5: 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.

As Figure 6 shows, all servers achieved their fastest completion times with 8 threads, which means 8 threads is the optimum thread-to-processor configuration for these servers.

Processor	2 threads	4 threads	8 threads	16 threads
Quad-Core AMD Opteron 2347 (1.9GHz)	79.86	40.03	19.63	21.23
Quad-Core Intel Xeon E5345 (2.33GHz)	71.89	36.08	18.06	19.89
Quad-Core Intel Xeon E5450 (3.0GHz)	34.50	17.39	8.73	9.67

Figure 6: Median completion times (in seconds) of the servers with varying thread counts using the Black-Scholes workload. Lower times are better.

Figure 7 shows the completion times in jobs/hour. All servers achieved their highest job/hour results with 8 threads.

Processor	2 threads	4 threads	8 threads	16 threads
Quad-Core AMD Opteron 2347 (1.9GHz)	45.08	89.93	183.39	169.57
Quad-Core Intel Xeon E5345 (2.33GHz)	50.08	99.78	199.34	181.00
Quad-Core Intel Xeon E5450 (3.0GHz)	104.35	207.02	412.37	372.29

Figure 7: Median completion times (in jobs/hour) of the servers with varying thread counts using the Black-Scholes workload. Higher is better.

Test methodology

Figure 8 summarizes some key aspects of the configurations of the test servers; Appendix A provides detailed configuration information.

Server	Quad-Core AMD Opteron 2347 (1.9GHz)	Quad-Core Intel Xeon E5345 (2.33GHz)	Quad-Core Intel Xeon E5450 (3.0GHz)
Processor frequency (GHz)	1.9	2.33	3.0
Front-side bus frequency (MHz)	2,000 HyperTransport	1,333	1,333
Number of processor packages	2	2	2
Number of cores per processor package	4	4	4
Number of hardware threads per core	1	1	1
Motherboard	Supermicro H8DMU+	Supermicro X7DBE+	Supermicro X7DBE+
Chipset	nForce Pro 3600	Intel 5000P	Intel 5000P
RAM	PC2-5300 DIMM	PC2-5300 FB-DIMM	PC2-5300 FB-DIMM
Hard drive	Western Digital WD1600YD	Western Digital WD1600YD	Western Digital WD1600YD

Figure 8: Summary of some key aspects of the server configurations.

Intel configured and provided all three servers.

With the following exceptions, we used the default BIOS settings on each server. On the Quad-Core Intel Xeon X5345-based server we disabled Adjacent Cache Line Prefetch, Hardware Prefetcher, and High Bandwidth FSB; enabled C1 Enhanced Mode; and set Processor Power Management to GV1/GV3 on. On the Quad-Core Intel Xeon X5450-based server we disabled Adjacent Cache Line Prefetch and Hardware Prefetcher; enabled C1 Enhanced Mode; and set Processor Power Management to GV1/GV3 on. On the Quad-Core AMD Opteron 2347-based server changed the ACPI Version Features to ACPI v3.0 and enabled PowerNow!

We began our testing by installing a fresh copy of Microsoft* Windows* Server 2003 R2, Enterprise* x64 Edition Service Pack 2 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 (KB938127)
- Cumulative Security Update for Internet Explorer 6 for Windows Server 2003 x64 Edition (KB939653)
- Windows Internet Explorer 7 for Windows Server 2003 x64 Edition and Windows XP x64 Edition
- Security Update for Outlook Express for Windows Server 2003 x64 Edition (KB941202)
- Security Update for Windows Server 2003 x64 Edition (KB933729)
- Windows Malicious Software Removal Tool x64 - October 2007 (KB890830)

- Security Update for Windows Server 2003 x64 Edition (KB936021)
- Update for Windows Server 2003 x64 Edition (KB933360)
- Security Update for Windows Server 2003 x64 Edition (KB938127)
- Security Update for Windows Server 2003 x64 Edition (KB921503)
- Security Update for Windows Server 2003 x64 Edition (KB936782)
- Update for Windows Server 2003 x64 Edition (KB932596)
- Security Update for Windows Server 2003 x64 Edition (KB926122)
- Security Update for Windows Media Player 6.4 (KB925398)
- Update for Windows Server 2003 x64 Edition (KB936357)
- Cumulative 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 Windows Server 2003 x64 Edition (KB924667)
- Update for Windows Server 2003 x64 Edition (KB927891)
- Security Update for Windows Server 2003 x64 Edition (KB932168)
- Security Update for Windows Server 2003 x64 Edition (KB930178)
- Security Update for Windows Server 2003 x64 Edition (KB925902)

After the installation of the Microsoft updates, we made the following changes to the system:

- Changed the power scheme to "Server Balanced Processor Power and Performance."
- Disabled screensaver.

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/.

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 second intervals.

To gauge the idle power usage, we recorded the power usage for two minutes 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 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 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 servers 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 by processor name.

Servers	Quad-Core AMD Opteron 2347 (1.9GHz)	Quad-Core Intel Xeon E5345 (2.33GHz)	Quad-Core Intel Xeon E5450 (3.0GHz)
General processor setup			
Number of processor packages	2	2	2
Number of cores per processor package	4	4	4
Number of hardware threads per core	1	1	1
System Power Management Policy	Server Balanced Processor Power and Performance	Server Balanced Processor Power and Performance	Server Balanced Processor Power and Performance
CPU			
Vendor	AMD	Intel	Intel
Name	Opteron 2347	QuadCore Intel Xeon E5345	Quad-Core Intel Xeon E5450
Stepping	BA	G	C
Socket type	Socket F (1207)	771 LGA	771 LGA
Core frequency (GHz)	1.9	2.33GHz	3.0GHz
Front-side bus frequency (MHz)	2,000 HyperTransport	1,333 MHz	1,333 MHz
L1 cache	64 KB + 64 KB (per core)	32 KB + 32 KB (per core)	32 KB + 32 KB (per core)
L2 cache	4 x 512 KB (512 KB per core)	2 x 4MB (each 4MB shared by 2 cores)	2 x 6MB (each 6MB shared by 2 cores)
L3 cache	2MB (shared by all four cores)	N/A	N/A
Thermal design power (TDP, in watts)	95	80	80
Platform			
Vendor and model number	Supermicro SuperServer 2021M-UR+B	Supermicro SuperServer 6025B-TR+	Supermicro SuperServer 6025B-TR+
Motherboard model number	H8DMU+	X7DBE+	X7DBE+
Motherboard chipset	nForce Pro 3600	Intel 5000P	Intel 5000P
Motherboard revision number	1.00	2.01	2.01
BIOS name and version	American Megatrends (2.0c)	Phoenix Technologies (1.3c)	Phoenix Technologies (1.3c)
BIOS settings	Enabled PowerNow!, ACPI Version Features to ACPI v3.0	Disabled Hardware Prefetcher and High Bandwidth FSB, Enabled C1 Enhanced Mode, Set Processor Power Management to GV1/GV3 Only	Disabled Hardware Prefetcher, Enabled C1 Enhanced Mode, Set Processor Power Management to GV1/GV3 Only
Chipset INF driver	NVIDIA 4.57	Intel 8.2.0.1008	Intel 8.2.0.1008
Memory module(s)			
Vendor and model number	Hyundai HYMP525P72BP4-Y5	Kingston KVR667D2D4F5/2G	Kingston KVR667D2D4F5/2G

Servers	Quad-Core AMD Opteron 2347 (1.9GHz)	Quad-Core Intel Xeon E5345 (2.33GHz)	Quad-Core Intel Xeon E5450 (3.0GHz)
Type	PC-5300 DDR2	PC2-5300 FB-DDR2	PC2-5300 FB-DDR2
Speed (MHz)	667 MHz	667 MHz	667 MHz
Speed in the system currently running @ (MHz)	667 MHz	667 MHz	667 MHz
Timing/Latency (tCL-tRCD-iRP-tRASmin)	5-5-5-15	5-5-5-15	5-5-5-15
Size	16,384 MB	16,384 MB	16,384 MB
Number of RAM modules	8	8	8
Chip organization	Double-sided	Double-sided	Double-sided
Hard disk			
Vendor and model number	Western Digital WD1600YD	Western Digital WD1600YD	Western Digital WD1600YD
Number of disks in system	1	1	1
Size	160 GB	160 GB	160 GB
Buffer size	16 MB	16 MB	16 MB
RPM	7,200	7,200	7,200
Type	SATA-II	SATA-II	SATA-II
Controller	NVIDIA MCP55 SATA Controller	Intel 631xESB/6321ESB Serial ATA Storage Controller	Intel 631xESB/6321ESB Serial ATA Storage Controller
Driver version	5.2.3790.1830	8.2.0.1008	8.2.0.1008
Operating system			
Name	Microsoft Windows Server 2003 R2, Enterprise x64 Edition	Microsoft Windows Server 2003 R2, Enterprise x64 Edition	Microsoft Windows Server 2003 R2, Enterprise x64 Edition
Build number	3790	3790	3790
Service Pack	SP2	SP2	SP2
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	9.0c	9.0c	9.0c
Graphics			
Vendor and model number	ATI ES1000 (RN50)	ATI ES1000 (RN50)	ATI ES1000 (RN50)
Chipset	ES1000	ES1000	ES1000
BIOS version	BK-ATI VER008.005.007.001	BK-ATI VER008.005.007.001	BK-ATI VER008.005.007.001
Type	Integrated	Integrated	Integrated
Memory size	16 MB	16 MB	16 MB
Resolution	1,024 x 768	1,024 x 768	1,024 x 768
Driver version	8.24.3.0	8.24.3.0	8.24.3.0
Network card/subsystem			
Vendor and model number	NVIDIA nForce Networking Controller	Intel PRO/1000 EB Network Connection with I/O Acceleration	Intel PRO/1000 EB Network Connection with I/O Acceleration
Type	Integrated	Integrated	Integrated
Driver version	NVIDIA 65.3.1.0	Intel 9.7.34.0	Intel 9.9.8.0/Intel 10.0.15.0

Servers	Quad-Core AMD Opteron 2347 (1.9GHz)	Quad-Core Intel Xeon E5345 (2.33GHz)	Quad-Core Intel Xeon E5450 (3.0GHz)
Optical drive			
Vendor and model number	MATSHITA DVD-ROM SR-8178	MATSHITA DVD-ROM SR-8178	MATSHITA DVD-ROM SR-8178
USB ports			
Number	4	4	4
Type	USB 2.0	USB 2.0	USB 2.0
Power supplies			
Total number	2	2	2
Wattage of each	700W	700W	700W
Cooling fans			
Total number	3	3	3
Dimensions	80mm	80mm	80mm
Voltage	12V	12V	12V
Amps	1.1 A	1.1 A	1.1 A

Figure 9: Detailed system configuration information for the three test servers.

Principled Technologies, Inc.
1007 Slater Road, Suite 250
Durham, NC 27703
www.principledtechnologies.com
info@principledtechnologies.com