Xserve G5

Technology Overview
September 2005

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Introduction

What's New?

- Single 2GHz or dual 2.3GHz PowerPC G5 processors using 90-nanometer process technology
- 1GHz or 1.15GHz frontside bus with independent data paths in and out of the processor
- Point-to-point system controller providing two independent frontside buses on dual processor systems
- Support for up to 16GB of 400MHz ECC memory
- Fast 133MHz PCI-X bus for Fibre Channel, RAID, SCSI, or cluster interconnect cards
- Dual Gigabit Ethernet interfaces on the main logic board
- Up to 1.5TB of internal storage using 80GB or 500GB Serial ATA (SATA) Apple Drive Modules running at 7200-rpm, or 74GB Apple Drive Module running at 10,000-rpm[1]

In May 2002, Apple introduced Xserve, a high-density, 1U rackmount server that was applauded for its value and versatility. In 2003, we built on that success with performance enhancements, more storage, and flexible build-to-order options. In January 2004, we gave this highly acclaimed server a huge burst of power by introducing the 64-bit PowerPC G5 processor—accelerating a wide range of intensive server chores and High Performance Computing (HPC) applications. Now we are pushing performance even further, increasing the speed and capacity of the Xserve G5 to meet customers' ever growing need for processing power.

With the debut of the PowerPC G5 in Apple's Power Mac G5, users were able to tackle projects never before possible on a desktop system. In fact, its performance was so remarkable that Virginia Tech chose the G5 processor as the engine for its supercomputing facility. Virginia Tech achieved such groundbreaking results that they quickly upgraded their 1100 systems to 2.3GHz Xserve G5 systems, attaining 12.25 teraflops and pioneering the way for the introduction of the 2.3GHz processor now available in the Xserve G5. Combining the superefficient PowerPC G5 with high-bandwidth, server-optimized system I/O and fast internal storage, Xserve G5 delivers outstanding computational performance in a 1U enclosure.

In addition to robust hardware features, Xserve G5 comes complete with an unlimited-client license for Mac OS X Server software, a host of powerful network services, and integrated remote management and monitoring tools. Easy to set up and easy to maintain, Xserve G5 with Mac OS X Server dramatically reduces the complexity of system administration and minimizes maintenance costs. For added peace of mind, Apple offers enterprise-class service and support products for Xserve G5 hardware and Mac OS X Server software, with a single vendor to call.

This uniquely Apple integration results in superior performance, unparalleled manageability, and increased uptime—enabling organizations to lower their total cost of ownership and reduce the pressure on network administrators. Whether in small or large businesses, higher education or K–12 schools, creative departments, or science and technology research centers, the affordable Xserve G5 is perfect for today's new breed of UNIX-based server solutions.

Product Overview

Xserve G5
Apple's Xserve G5 packs high-density PowerPC G5 computing power and fast, affordable storage in a 1U rack-optimized enclosure. Customers can choose from two standard server configurations and one cluster node configuration, as well as an array of build-to-order options.

Xserve RAID
Connect Xserve to Apple's affordable Xserve RAID storage solution for enormous capacity—up to 7TB[1]—and advanced data protection in a high-availability 3U enclosure.

Key Features

Xserve G5 combines 64-bit processors, a high-bandwidth system architecture, and massive storage with Apple's legendary ease of use. The following features make Xserve a robust, versatile server solution for businesses and institutions everywhere.

Single 2GHz or dual 2.3GHz processors. Each 64-bit PowerPC G5 processor features an optimized Velocity Engine unit, two floating-point units, and robust branch prediction logic. To get more work done faster, its superpipelined, superscalar architecture can handle large numbers of complex operations in parallel.

Gigahertz frontside bus. The ultrafast frontside bus, running at 1GHz or 1.15GHz, maximizes processor performance by transferring instructions and data at rates of up to 9.2GB/s. In dual processor systems, each PowerPC G5 has a dedicated frontside bus for a combined throughput of up to 18.4GB/s.

Advanced ECC memory technology. A 128-bit memory controller speeds data in and out of main memory at up to 6.4GB/s. Today's Xserve G5 supports 16GB of fast, 400MHz RAM with Error Correction Code (ECC) protection.

High-bandwidth I/O. Two open 64-bit PCI-X slots provide throughput of up to 1GB/s for PCI devices. Dual onboard Gigabit Ethernet interfaces and FireWire 800 ports offer high-performance connectivity and deployment flexibility.

Flexible storage. Three drive bays hold up to 1.5TB of fast, internal Serial ATA (SATA) storage[1] in hot-plug Apple Drive Modules.[2] Fast PCI-X slots and optional cards allow connection to external storage devices, including Apple's Xserve RAID storage system.

Innovative hardware monitoring. Dedicated monitoring hardware integrates with industry-leading software for remote monitoring of one or many Xserve G5 systems. The software can even send automatic notifications via email or pager.

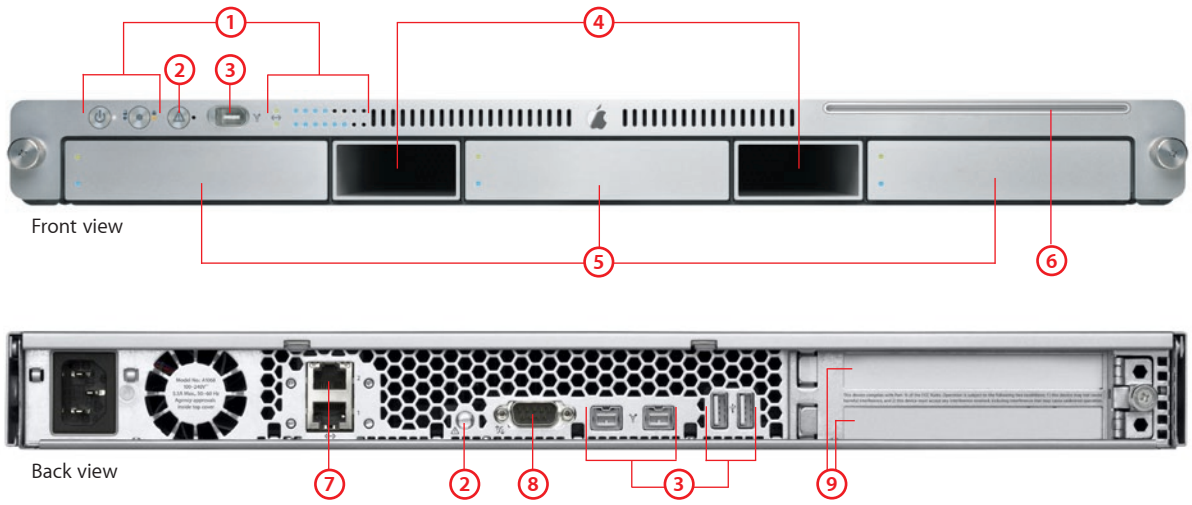
UNIX-based operating system. An unlimited-client license for Mac OS X Server,[2] complete with easy-to-use open source workgroup and Internet services, is included at no additional cost. Built on open standards, Mac OS X Server integrates seamlessly into enterprise infrastructures. What's more, Apple has written the latest version of Mac OS X Server to maximize the computing power of the 64-bit PowerPC G5.

Server-class support products. To minimize downtime, Apple offers a suite of enterprise-class support products, including onsite hardware repairs, advanced software support, and convenient spares kits.

Rack-Optimized Server Design

With enormous processing power and ample storage in a compact 1U-high, 19-inch-wide enclosure, Xserve G5 is designed from the ground up for performance, serviceability, and easy integration into a wide range of computing environments. The necessary rackmounting hardware is in the box, including rack rails with sliders, mounting brackets for industry-standard four-post racks and telco center-post racks, and complete setup instructions. For trouble-free servicing, the power cord connection has a cable-locking clip, and a cable management arm keeps cables with the system when you slide it out of a four-post rack.

Xserve G5 Server Configuration



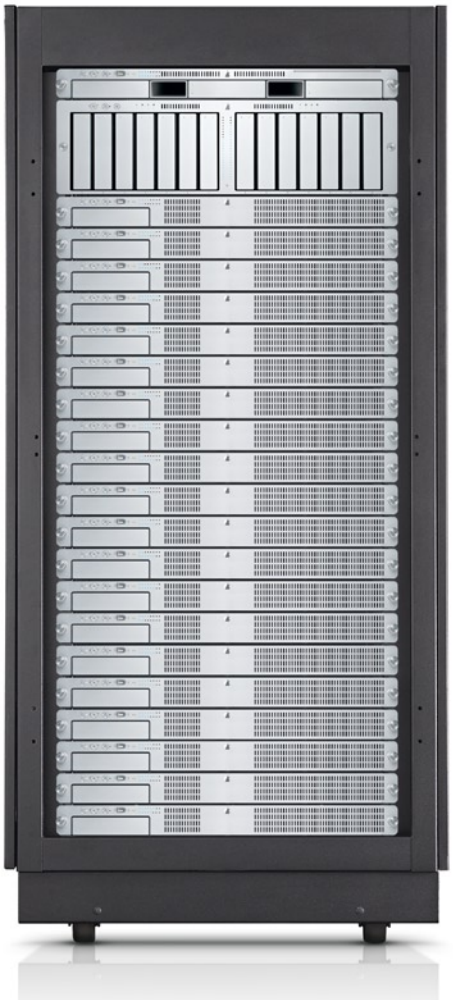
1. **Indicator lights.** Xserve G5 gives you continuous feedback on the status and activity of hardware components. Indicator lights display the health and status of power, enclosure lock, drives, Ethernet links, and processor, as well as drive and processor activity.
2. **System identifier.** Duplicate buttons on the front and back can be turned on manually or by using remote monitoring software, making it easy to locate a particular server in a rack. The buttons also illuminate if a system event occurs.
3. **FireWire and USB ports.** Xserve G5 has two FireWire 800 ports on the back and one FireWire 400 port on the front for high-speed connectivity to storage, backup devices, and other servers. Two USB 2.0 ports on the back connect to industry-standard peripherals.
4. **Air ducts.** A robust cooling system provides front-to-back airflow over high-performance system components. It uses large air ducts and an array of eight fans managed by a microcontroller. For minimal noise and power consumption, the fans run only as required to cool the system effectively. If a single fan fails, the others speed up to compensate.
5. **Drive bays.** Three bays support up to 1.5TB[1] of hot-plug Serial ATA internal storage on three independent channels.[2] Hot-plug support allows you to add storage without bringing down the server. Apple Drive Modules have LEDs that indicate drive status and health using Self-Monitoring, Analysis, and Reporting Technology (SMART) data.
6. **Optical drive.** The slot-loading Combo drive (DVD-ROM/CD-RW) is convenient for fast software installation and recovery, and the optional SuperDrive (DVD-R/CD-RW) permits the writing of DVD-Rs for quick and easy archive and backup.[2]
7. **Gigabit Ethernet interfaces.** Xserve G5 comes with dual Gigabit Ethernet links on the main logic board. These fast interfaces operate independently to provide deployment flexibility and support for large numbers of clients.
8. **Serial port.** The DB-9 serial port allows for system access through a serial console session, even when the network is down.
9. **PCI-X slots.** Two open 64-bit PCI-X slots allow you to add one card running at up to 133MHz or two cards running at up to 100MHz. Throughput of up to 1GB/s maximizes performance of transaction-intensive applications and high-performance networking and storage systems.

High-Density Cluster Node Configuration

With the compute performance of two superscalar 2.3GHz PowerPC G5 processors, the Xserve G5 cluster node configuration is ideal for High Performance Computing (HPC) in scientific and technical environments, as well as for workgroup clusters and render farms. One dual processor node can execute over 10 billion double-precision floating-point operations per second, or more than 10 gigaflops per U. That means a rack filled with Xserve G5 systems can offer over 420 gigaflops of processing power. Single-precision floating-point performance is also remarkable: With a dual-pipeline Velocity Engine on each processor, the Xserve G5 cluster node can execute over 35 gigaflops. Best of all, by eliminating the cost of unneeded components, Apple has made this high-density 1U system extremely affordable.

For more information about Apple solutions for computational clusters, see www.apple.com/xserve/cluster.

Xserve G5 Cluster



An Xserve G5 cluster uses a dedicated server system as the head node, which can manage hundreds of Xserve cluster nodes. Apple's Xserve RAID adds high-performance, high-availability storage. Each cluster node has these robust features:

- **Computational power.** Dual 2.3GHz PowerPC G5 processors provide high-performance computation and superior scalability.
- **Fast PCI-X.** Two PCI-X slots support cluster interconnect technologies, such as InfiniBand and Myricom's Myrinet.
- **Dual Gigabit Ethernet.** Two onboard high-speed interfaces enable independent gigabit connections to the head node for network services and to the cluster interconnect for loosely coupled cluster environments.
- **FireWire 800.** Two FireWire 800 ports support small clusters using TCP/IP over FireWire. FireWire Target Disk Mode allows easy cloning of system configurations.
- **Advanced cooling system.** An array of eight fans keeps air flowing over high-performance processing components. Intelligent management of the fan array keeps noise and power consumption to a minimum.
- **Indicator lights.** Xserve G5 provides continuous, at-a-glance information about the health and status of the systems in the rack.
- **Built-in sensors.** Hardware sensors integrate with Server Monitor to provide easy monitoring of hundreds of systems from a single, intuitive interface.
- **Automatic setup.** Mac OS X Server makes it easy to set up an entire rack of systems automatically from a directory on the network or a USB or FireWire disk.
- **Startup options.** Front Panel Mode allows the system identifier button to be used for selecting startup options, such as booting from a network server or restoring default system settings.

Performance Overview

Apple's Xserve G5 is designed to deliver phenomenal performance with industry-leading ease of use. Thanks to 64-bit processing power, server-optimized I/O, and a high-throughput storage architecture, Xserve G5 is optimized for demanding server and cluster operations. To assess its performance, Apple compared preproduction Xserve G5 units with several currently available 1U servers.

Processor Performance

Featuring a dual-pipeline Velocity Engine and two double-precision floating-point units on each 64-bit PowerPC G5 processor, Xserve G5 can manage complex calculations crucial to users in image processing, media encoding, and scientific computing environments. In fact, the Velocity Engine on dual processor Xserve G5 systems can execute over 35 billion single-precision floating-point operations per second, or 35 gigaflops per U.

To demonstrate this superior processor performance, Apple tested Xserve G5 using popular benchmarks in the scientific computing community. The following results are based on benchmark testing performed in January 2005 by Apple in a laboratory setting using publicly available software. The server configurations outlined below were tested:

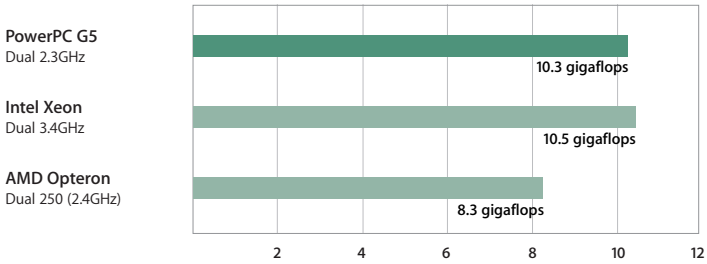
- **Apple Xserve G5.** Dual 2.3GHz PowerPC G5, 4GB of PC3200 SDRAM, three 80GB Apple Drive Modules, dual Gigabit Ethernet, and Mac OS X Server v10.3.7.
- **Dell PowerEdge 1850.** Dual 3.4GHz Xeon, 4GB of PC3200 SDRAM, two 74GB Ultra320 SCSI drives, dual Gigabit Ethernet, and Red Hat Enterprise Linux 3, update 3 ES x86.
- I**BM eServer x325.** Dual Opteron 250 (2.4GHz), 4GB of PC2700 SDRAM, two 74GB Ultra320 SCSI drives, dual Gigabit Ethernet, and Red Hat Enterprise Linux 3, update 3 ES (AMD 64-bit version).

For each system, Apple installed the operating system on one drive and used the other drive or drives to create a data volume. On the Xserve G5, the two remaining drives were configured as a single volume using RAID 0; the other systems used the single remaining drive for the data volume. The Xeon- and Opteron-based systems used 15,000-rpm drives.

LINPACK

Computers use double-precision floating-point mathematics to perform calculations requiring great numerical magnitude or extremely high decimal accuracy. Apple used the LINPACK benchmark to illustrate the benefits of the G5 processor's two floating-point units. LINPACK measures double-precision floating-point performance running a program that solves a dense system of linear equations.

LINPACK Benchmark: Double Precision



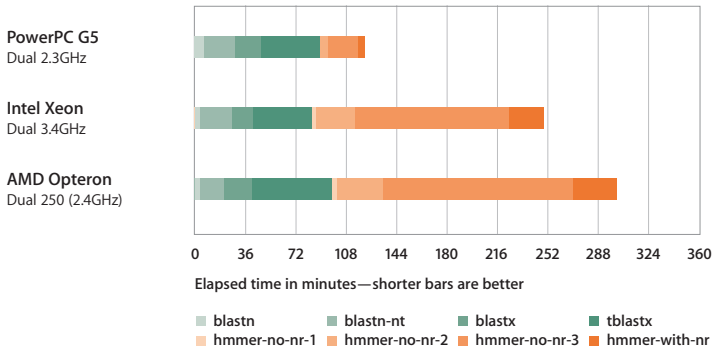
The dual 2.3GHz Xserve G5 is capable of 10.3 billion double-precision floating-point operations per second.

Testing conducted by Apple in January 2005 using preproduction Xserve G5 systems. All systems were configured with 4GB of RAM. Results based on the LINPACK benchmark (www.netlib.org/benchmark/1000d) using a matrix size of 15,000 and the following operating systems/compilers/math libraries: Xserve G5 = Mac OS X Server 10.3.7/XLF 040108a/Accelerate Framework; AMD Opteron = Red Hat Ent Linux 3, Update 3 ES AMD64/pgf90 5.2-4/libgoto_opt64p-r0.96; Intel Xeon = Red Hat Ent Linux 3, Update 3 ES x86/Intel ifort 8.1/Intel MKL 7.2.

Bioinformatics Benchmark System (BBSv3)

The Bioinformatics Benchmark System is based on current, popular applications and data sets from the bioinformatics community. As a result, this benchmark is representative of the day-to-day workload of a typical research scientist. The current benchmark uses bioinformatics application suites NCBI BLAST and HMMER as the workload. For this benchmark, Apple used FASTA databases dated January 1, 2005; NCBI BLAST version 2.2.10; and HMMER version 2.3.2.

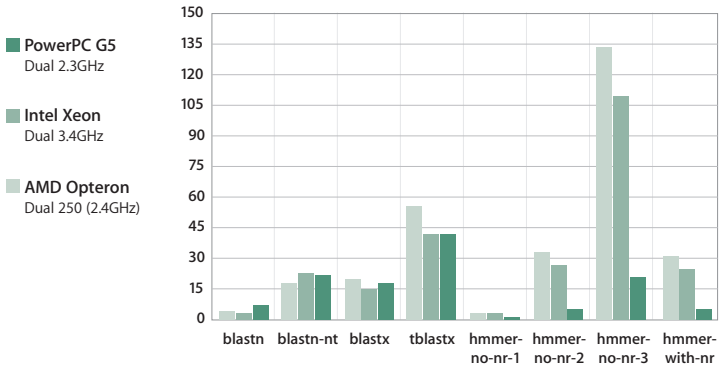
Bioinformatics Benchmark System (BBSv3): Dual Processor Summary



Testing conducted by Apple in January 2005 using preproduction Xserve G5 systems. All systems were configured with 4GB of RAM. Test results based on the Bioinformatics Benchmark System (BBSv3) at http://www.scalableinformatics.com/metadot/index.pl?iid=2190 using Jan 1, 2005 FASTA databases and NCBI BLAST version 2.2.10 available from ftp://ftp.ncbi.nlm.nih.gov/blast/executables and HMMER version 2.3.2 available from http://hmmer.wustl.edu.

For this series of tests, each application used the dual processor option available to each binary distribution ("-a 2" for BLAST and "--cpu 2" for HMMER). The BLAST tests used the query file supplied by the benchmark, cherry_tomato.fsa, and the blastn, blastx, and tblastx programs, and conducted searches against the formatted databases using Expectation Values ranging from 1.0e-10 to 1.0e-30. The HMMER tests calibrated the supplied globin.hmm profile search statistics using hmmcalibrate and fixed random sequence lengths of 400, 2000, and 8000; the tests also searched the nr sequence database using the supplied globin.hmm profile.

Bioinformatics Benchmark System (BBSv3): Dual Processor Details



Elapsed time in minutes—shorter bars are better

Testing conducted by Apple in January 2005 using preproduction Xserve G5 systems. All systems were configured with 4GB of RAM. Test results based on the Bioinformatics Benchmark System (BBSv3) at http://www.scalableinformatics.com/metadot/index.pl?iid=2190 using Jan 1, 2005 FASTA databases and NCBI BLAST version 2.2.10 available from ftp://ftp.ncbi.nlm.nih.gov/blast/executables and HMMER version 2.3.2 available from http://hmmer.wustl.edu.

Networking Throughput

To minimize bottlenecks and ensure maximum data throughput, Xserve G5 features a high-performance I/O architecture optimized for server tasks.

The following results are based on benchmark testing performed in January 2004 by Apple in a laboratory setting using publicly available software. These server configurations were tested:

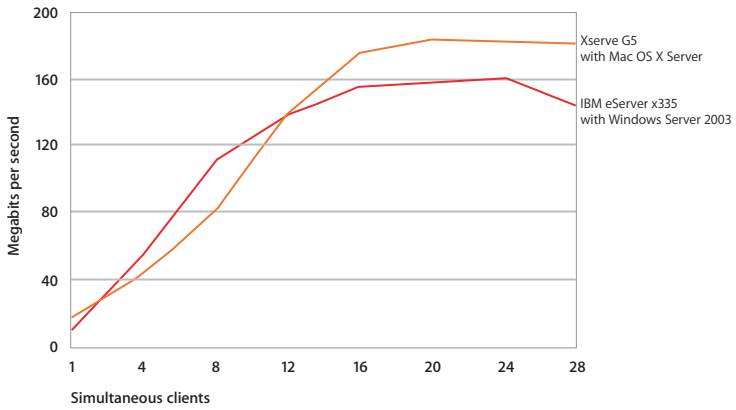
- **Apple Xserve G5.** Dual 2GHz PowerPC G5, 1GB of PC3200 SDRAM, three 250GB Apple Drive Modules, dual Gigabit Ethernet, and Mac OS X Server v10.3.2.
- **IBM eServer x325.** Dual Opteron 246 (2GHz), 1GB of PC2700 SDRAM, two 36GB Ultra320 SCSI drives, dual Gigabit Ethernet, and Red Hat Linux Enterprise 3 (AMD 64-bit version).
- **IBM eServer x335.** Dual 3.2GHz Xeon, 1GB of PC2100 SDRAM, two 36GB Ultra320 SCSI drives, dual Gigabit Ethernet, and Red Hat Linux 9.0 (unless otherwise indicated).

For each system, Apple installed the operating system on one drive and used the other drive or drives to create a data volume. On the Xserve G5, the two remaining drives were configured as a single volume using RAID 0. The Xeon- and Opteron-based systems used 15,000-rpm drives.

NetBench SMB

Xserve G5 provides the best balance of processor, network, and disk performance—critical for delivering file services to large numbers of network clients.

NetBench SMB: Windows File Serving

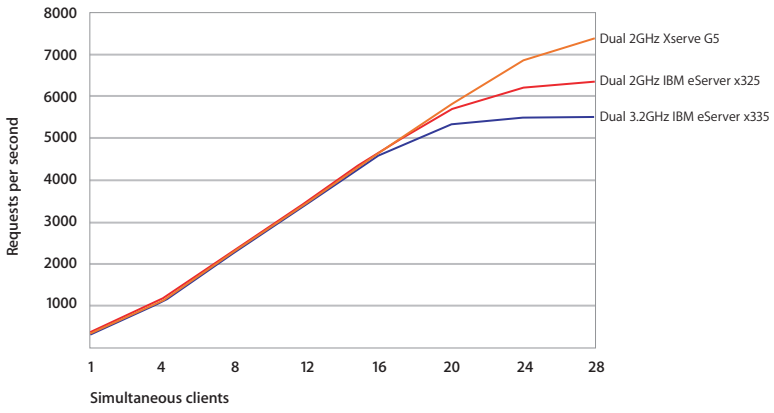


With more than 12 NetBench clients, Xserve G5 with Mac OS X Server delivers Windows file services significantly faster than the Xeon-based server with Windows Server 2003, and its performance remains high even as clients are added to the network.

WebBench

For fast network throughput, Xserve G5 features dual onboard Gigabit Ethernet controllers, as well as optimized network drivers and a high-performance BSD network stack in Mac OS X Server. Apple used WebBench from VeriTest to demonstrate the superior web server performance of Xserve G5 based on the number of connections each server can support.

WebBench: Apache Web Serving



Xserve G5 easily supports a large number of network connections. With more than 16 WebBench clients, it outperforms the Xeon- and Opteron-based servers, and its performance advantage increases as clients are added to the network.

Apple performed the NetBench and WebBench tests without the supervision or verification of VeriTest, which makes no representation or warranty of the results. VeriTest WebBench version 4.1 was used with the standard test suite STATIC_WB41.TST, with the threads variable set to 5 and with 28 client computers. For the WebBench test, Xserve G5 ran Apache 1.3; the IBM systems ran Apache 2.0.

PowerPC G5 Processor

Key Features

- 64-bit architecture, capable of addressing vast amounts of memory
- Native support for 32-bit applications
- Frontside bus up to 1.15GHz, allowing a constant flow of data in and out of the processor
- Dual independent frontside buses in dual processor systems
- Superscalar execution core supporting up to 215 in-flight instructions
- Velocity Engine for accelerated single-instruction, multiple-data (SIMD) processing
- Two floating-point units for high-speed double-precision calculations
- Advanced three-component branch prediction logic to increase processing efficiency

The breakthrough performance of the 64-bit PowerPC G5 is now available to Apple server customers. With 64-bit-wide data paths and registers, this revolutionary processor can address vast amounts of main memory, while handling multiple 64-bit integer and double-precision floating-point math calculations in a single pass. Its wide execution core manages immense operations in parallel, supporting up to 215 in-flight instructions.

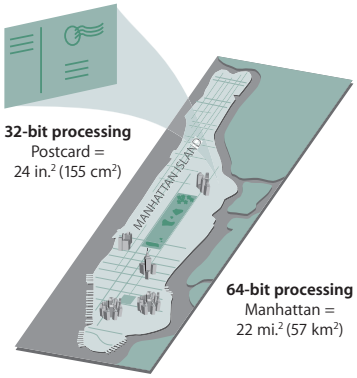
The PowerPC G5 boasts a next-generation architecture built for speed and massively parallel operations:

- The ability to address vast amounts of memory provides fast data access, boosting performance for 2D and 3D imaging, video rendering tasks, and transactionintensive workgroup and Internet services.
- A dual-channel frontside bus at half the speed of the processor provides high bandwidth to and from the rest of the system, allowing large numbers of tasks to run concurrently.
- Fast L1 and L2 caches, group instruction dispatching, deep queues, and threestage branch prediction logic increase processing efficiencies.
- A superscalar execution core with 12 functional units improves performance by executing multiple instructions per cycle in parallel.
- An optimized 128-bit Velocity Engine cranks through image editing tasks, high definition video transitions, media encoding, and complex scientific analysis.
- Two double-precision floating-point units accelerate 64-bit calculations for 3D visualization, research simulations, and multitrack audio creation.

The results are phenomenal. The PowerPC G5 boasts across-the-board performance enhancements that enable media applications and server transactions to run up to twice as fast. Best of all, existing 32-bit applications run natively on the PowerPC G5, so the transition to 64-bit processing is absolutely seamless. This enormous computing power is available on Apple systems today.

Apple and IBM Partnership

The PowerPC G5 is the product of a long-standing partnership between Apple and IBM, two companies committed to innovation and customer-driven solutions. In 1991, they co-created a PowerPC architecture that could support both 32-bit and 64-bit instructions. Leveraging this design, Apple went on to bring 32-bit RISC processing to desktop and portable computers, while IBM focused on developing 64-bit processors for enterprise servers. The PowerPC G5 represents a convergence of these efforts: Its design is based on the PowerPC instruction set, as well as the POWER Architecture that drives IBM's top-of-the-line enterprise servers.



4.3 billion times bigger
To grasp the enormous leap from 32-bit to 64-bit processing, imagine equating the range of numbers a processor can express with a two-dimensional area. A 32-bit processor can express a range of integers equal to the size of a postcard, while a 64-bit processor can express a range of integers larger than the island of Manhattan.

Support for more memory in Mac OS X Server
Mac OS X Server makes the most of the expanded memory capabilities of the PowerPC G5. Existing and new 32-bit applications can be allocated up to 4GB of memory, giving each server task dedicated space in the system's generous memory. New 64-bit applications can break the 4GB barrier, gaining access to enormous physical and virtual memory spaces.

The PowerPC G5 is fabricated in IBM's $3 billion, state-of-the-art facility in East Fishkill, New York. To get electronics so small requires miniaturization breakthroughs, and IBM's dedication to scientific research has made these advances possible. With industry-leading build, assembly, and test technology, IBM uses a 90-nanometer process to produce the PowerPC G5. More than 58 million silicon-on-insulator (SOI) transistors and ten layers of copper interconnects enable the processor to deliver tremendous performance. The use of these advanced technologies also means the PowerPC G5 draws less power and produces less heat—allowing Apple to pack two 64-bit 2.3GHz processors in a 1U form factor.

64-Bit Computing Power

The labels "32-bit" and "64-bit" characterize the width of a microprocessor's data stream, which is a function of the sizes of its registers and the internal data paths that feed the registers. A 64-bit processor moves data and instructions along 64-bit-wide data paths—compared with the 32-bit-wide paths on 32-bit processors, such as the Pentium 4 and Xeon. In addition, 64-bit processors have wide registers that can store extremely large or extremely precise 64-bit numbers.

The leap from 32-bit to 64-bit processing represents an exponential advance in computing power. With 32-bit registers, a processor has a dynamic range of 2^{32}, or 4.3 billion—which means it can express integers from 0 to 4.3 billion. With 64-bit registers, the dynamic range catapults to 2^{64}, or 18 billion billion—4.3 billion times larger than the range of a 32-bit processor.

Vast amounts of addressable memory
The move to 64-bit processing results in a similarly dramatic leap in the amount of memory supported. A memory address is a special kind of integer, which points to one byte in memory. Since memory addresses are computed in 64-bit registers capable of expressing integers up to 18 billion billion, the PowerPC G5 can theoretically address 16 exabytes (18 billion billion bytes) of virtual memory.

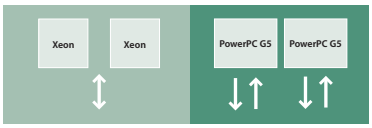
In practice, memory addressing is defined by the physical address space of the processor. The PowerPC G5, with 42 bits of physical address space, supports a colossal 2^{42} bytes, or 4 terabytes, of system memory. Although it's not currently feasible to purchase 4 terabytes of RAM, the advanced architecture of this processor allows for plenty of growth in the future.

Multiple high-precision calculations
With 64-bit-wide data paths and registers, the PowerPC G5 can execute multiple instructions on 64 bits of data—including huge integer calculations and double-precision floating-point mathematics—in every clock cycle. In contrast, a 32-bit processor has to split up any data larger than 32 bits and process it in multiple passes. This leap in performance, from 32-bit to 64-bit processing, brings previously unmanageable tasks into the realm of practicality, facilitating highly accurate calculations required for scientific analysis, technical research, 3D effects, and video encoding.

Next-Generation PowerPC Architecture

The PowerPC G5 is a highly parallel implementation of the PowerPC architecture, capable of handling large numbers of tasks at the same time. It's based on the execution core of the industry-leading IBM POWER Architecture that drives IBM's top-of-the-line enterprise servers. Apple collaborated with IBM to leverage this superscalar, superpipelined design for the next generation of personal computers and entry-level servers. The development of the PowerPC G5 builds on previous PowerPC designs, combining an optimized Velocity Engine unit, two double-precision floating-point units, advanced branch prediction logic, and a high-bandwidth frontside bus to support up to 215 simultaneous in-flight instructions.

Because the PowerPC instruction set was designed from the beginning to handle both 32-bit and 64-bit code, existing 32-bit applications run natively on PowerPC G5–based computers and servers. No software modification or optimization is required, and there's no need for emulation or translation software. In fact, most 32-bit applications run dramatically faster on the PowerPC G5.



Dual independent frontside buses
The dual-channel frontside bus allows data to travel to and from the PowerPC G5 processor at the same time. And in dual processor systems, each PowerPC G5 has its own dedicated interface to maximize throughput—compared with dual Xeon-based systems, in which the processors must share a single bus.

Up to 1.15GHz Frontside Bus

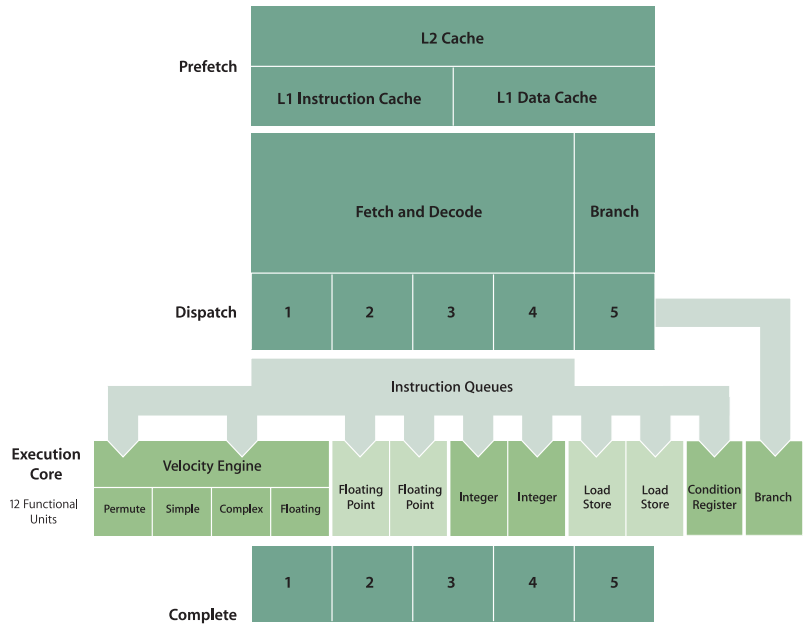
The performance advantages of the PowerPC G5 begin with an innovative Double Data Rate (DDR) frontside bus that speeds up communication between the processor and the memory controller. Unlike conventional processor interfaces, which carry data in only one direction at a time, this dual-channel frontside bus has two 32-bit point-to-point links (64 bits total): One link travels into the processor and another travels from the processor, which means no wait time while the processor and the system controller negotiate which will use the bus or while the bus switches direction. This elastic interface self-tunes during startup for optimal signal quality.

On a 2.3GHz PowerPC G5, the frontside bus operates at 1.15GHz for a total theoretical bandwidth of up to 9.2GB/s per processor. Dual PowerPC G5 systems get twice the bandwidth (18.4GB/s), because each processor has a dedicated frontside bus.

Fast Access to Data and Instructions

The PowerPC G5 features processing innovations that optimize the flow of data and instructions—making it ideal for streaming media, manipulating HD video, rendering 3D effects, serving databases, and hosting web applications, as well as for compute-intensive simulations and scientific analysis. Large caches and instruction preparation in the processor maximize performance as instructions are dispatched into the execution core and data is loaded into the registers.

PowerPC G5 Architecture



Prefetch

Prefetching improves processor performance by retrieving and caching data and instructions before they're demanded by the processor, ensuring optimal utilization of each processor cycle. The PowerPC G5 anticipates the need for data and instructions and prefetches them into its large L1 and L2 caches. To protect the integrity of data and instructions, L1 cache is parity-protected and L2 cache is protected using Error Correction Code (ECC) logic.

Fetch and decode

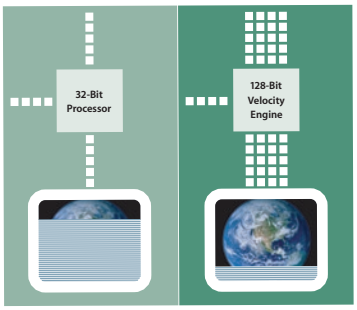
A low-latency 512K L2 cache provides fast access to data and instructions—at rates up to 64GB per second. Instructions are fetched from the L2 cache into a direct-mapped 64K L1 instruction cache. At the same time, 32K of write-through, two-way associative L1 data cache can fetch up to eight active data streams simultaneously.

Up to eight instructions per clock cycle are fetched from the L1 instruction cache for decoding. Decoding divides each instruction into smaller suboperations, giving the processor more freedom to schedule execution of code in parallel.

Group formation and dispatch

Before instructions are dispatched into the functional units, they are arranged, in program order, into groups of up to five. The PowerPC G5 dispatches these packaged groups to the queues in the execution core, where they are broken into individual instructions for out-of-order processing. When operations on the data are complete, the PowerPC G5 recombines the instructions into the original groups of five.

This grouping scheme enables the PowerPC G5 to track—and keep organized—an unusually large number of instructions with greater efficiency. By tracking groups rather than individual instructions, it can manage up to 100 instructions within the core simultaneously, in addition to 100-plus instructions in the various fetch, decode, and queue stages, for a total of 215 in-flight instructions.



The Velocity Engine can manipulate 128 bits of data per clock cycle, up to four times more than a 32-bit processor's general processing unit.

Fused multiply-add
The floating-point units in the PowerPC G5 are able to complete both a multiply operation and an add operation as part of the same machine instruction, thereby accelerating matrix multiplication, vector dot products, and other scientific computations. This instruction is referred to as fused multiply-add, or "fmadd," and is considered a basic building block for data-intensive floating-point computation.

The following computation can be completed by a fused multiply-add instruction in one pass through either of the two floating-point units in the G5:

T = (a * b) + c

On other processors, two instructions are required. The first is a multiply instruction:

U = (a * b)

The product "U" would be used later by a second instruction, an addition, to complete the computation:

V = U + c

Thus, in processors with comparable clock speeds, the computation of "(a * b) + c" can be completed twice as fast using fused multiply-add.

What's more, on the G5, round-off occurs just once in the computation of "T," while on other processors, round-off occurs twice, both in the computation of "U" and in the computation of "V," so fused multiply-add can deliver a more accurate result.

Issue queues
The PowerPC G5 includes eight deep issue queues that maximize the utilization of each functional unit. Individual instructions are issued to the appropriate functional unit at up to ten instructions per clock cycle. Each functional unit has a dedicated issue queue, where multiple instructions are sequenced for processing.

Superscalar Execution Core

At the heart of the PowerPC G5 is a superscalar execution core, composed of 12 functional units that execute different types of instructions concurrently for massive data throughput.

128-bit Velocity Engine
This powerful 128-bit vector processing unit accelerates data manipulation by applying a single instruction to multiple data at the same time, known as SIMD processing. Vector processing is useful for transforming large sets of data and other computationally intensive tasks, such as manipulating 3D images, rendering a video effect, encoding live media, or encrypting data. For example, when a designer uses a filter to apply a motion blur to an image, each pixel of the image must be changed according to the same set of instructions—a highly repetitive processing task.

The Velocity Engine on the PowerPC G5 has been optimized with two independent queues. It uses the same set of 162 instructions implemented in the PowerPC G4, enabling it to accelerate existing Mac OS X applications that have been optimized for the Velocity Engine. While operating concurrently with the integer and floating-point units, the Velocity Engine also supports highly parallel internal operations—for simultaneous processing of up to 128 bits of data in four 32-bit integers, eight 16-bit integers, sixteen 8-bit integers, or four 32-bit single-precision floating-point values.

Double-precision floating-point units
Today's powerful applications demand both precision and performance. That's why the PowerPC G5 has twice the double-precision floating-point hardware of the PowerPC G4, enabling it to complete at least two 64-bit mathematical calculations per clock cycle. In fact, each of its two floating-point units can perform both an add and a multiply with a single instruction, as well as full-precision square root calculations, for dramatic acceleration of complex computations.

Double-precision floating-point math is critical in research simulations and in many of the applications used to manipulate or render 3D graphics and video content. Weather prediction is one example of a highly iterative computing task that requires floating-point math. Large-scale models simulate weather patterns over time by measuring multiple influences, such as atmospheric pressure and airflow, at various instants and recalculating the model every minute. The floating-point capabilities of the PowerPC G5 provide the precision and performance to deliver accurate results within a useful timeframe.

Integer units
Integer units perform basic arithmetic and logic operations—such as add, subtract, multiply, and compare—which are used in virtually all computer functions, as well as in imaging, video, and audio applications. The PowerPC G5 has two integer units capable of both simple and complex instructions involving 32-bit or 64-bit data. What's more, they take full advantage of the processor's 64-bit registers and data paths to complete simple 64-bit integer calculations in a single clock cycle.

Machined for math
Virginia Tech gained international honors for building the fastest supercomputer at any academic institution in the world—using a cluster of original Power Mac G5 computers.[3] System X, a new cluster using 1100 64-bit dual processor Xserve G5 servers, operates at 12.25 teraflops.

Dedicated register files
To provide fast access to data, the PowerPC G5 is equipped with three sets of high-performance, low-latency register files: one containing 64-bit registers for integer calculations, one with 64-bit registers for floating-point calculations, and one with 128-bit registers for vector calculations. Each register file holds 32 registers for architected values, as well as 48 rename, or proxy, registers.

Load/store units
Load/store units perform memory-access operations, loading data into the registers of each functional unit and, after processing, storing the new data in L1 cache, L2 cache, or main memory as appropriate. With two load/store units, the PowerPC G5 is able to keep its wide instruction window filled with data for maximum processing efficiency.

Since the PowerPC G5 is capable of handling more than 200 in-flight operations, it needs a robust storage mechanism for the data associated with those instructions. While the instructions are being scheduled in the core, the load/store units load the associated data from L1 cache into the data registers behind the units that will be processing the data. To improve processing efficiency, the PowerPC G5 features a large number of rename registers that act as proxies, or placeholders, until the appropriate data arrives for execution. The instruction is held in queue, allowing other operations to take place until the actual data is loaded into the registers.

Condition register unit
When instructions have finished executing, they have the option to store information about their outcome in the processor's 32-bit condition register for future reference. The condition register can hold up to eight condition codes, which describe the outcome of eight different instructions. To improve the flow of data throughout the execution core, subsequent operations—such as branch instructions—can consult the condition register for the results of earlier operations.

The condition register unit performs logical operations related to the condition register. Programmers can manipulate and compare condition codes using a collection of PowerPC instructions, which are executed in this special functional unit. These comparisons are normally handled by an integer unit in other processors. With a dedicated functional unit for condition code comparisons, the PowerPC G5 effectively reduces the workload of its two integer units.

Branch prediction unit
Advanced processors use branch prediction and speculative instruction execution to keep processing resources constantly in use. A branch is a question in the processing queue: Which instruction should go next? Branch prediction anticipates the answer; and speculative execution schedules that instruction. If the prediction is correct, the processor works more efficiently, because the instruction has executed before it is required. If the prediction is incorrect, the processor must clear the unneeded branch, as well as any related data and instructions, resulting in an empty space called a pipeline bubble. Pipeline bubbles reduce performance as the processor marks time waiting for the next instruction.

The branch prediction unit on the PowerPC G5 uses innovative three-component logic to reduce pipeline bubbles and maximize processor efficiency. The success or failure of each prediction is captured in three large 16K branch history tables—local, global, and selector—that are used to improve the accuracy of future branch predictions.

Local branch prediction takes place as individual instructions are fetched into the processor and the types of branches are recorded in the local branch history table. Global branch prediction occurs at the same time: Branches are identified in their processing context, relating to preceding and subsequent operations; and the results are recorded in the global branch history table. The third, "selector" history table identifies which prediction type, local or global, was more accurate in predicting the outcome of each branch. This dynamic local/global/selector branch history scheme can predict branch processes with a high degree of accuracy, allowing the PowerPC G5 to efficiently use every processing cycle.

Designed for Symmetric Multiprocessing

Dual processors provide the high-density power and scalability required by applications in audio and video production; rendering, encoding, and compression farms; and research and computational clustering environments. Traditional server tasks also benefit from the increased bandwidth provided by multiprocessing, as many assorted transactions that use network file services, serve web pages, access databases, and authenticate users can be processed concurrently.

The PowerPC G5 is designed for symmetric multiprocessing. Dual independent frontside buses allow each processor to handle its own tasks at maximum speed with minimal interruption. At the same time, this high-performance bus interface enables each processor to discover and access data in the other processor's caches, a technique called intervention, or snooping. Cache intervention guarantees cache coherency, which ensures that the processor always fetches the correct data, even if it has been modified and is stored in the cache of the other processor.

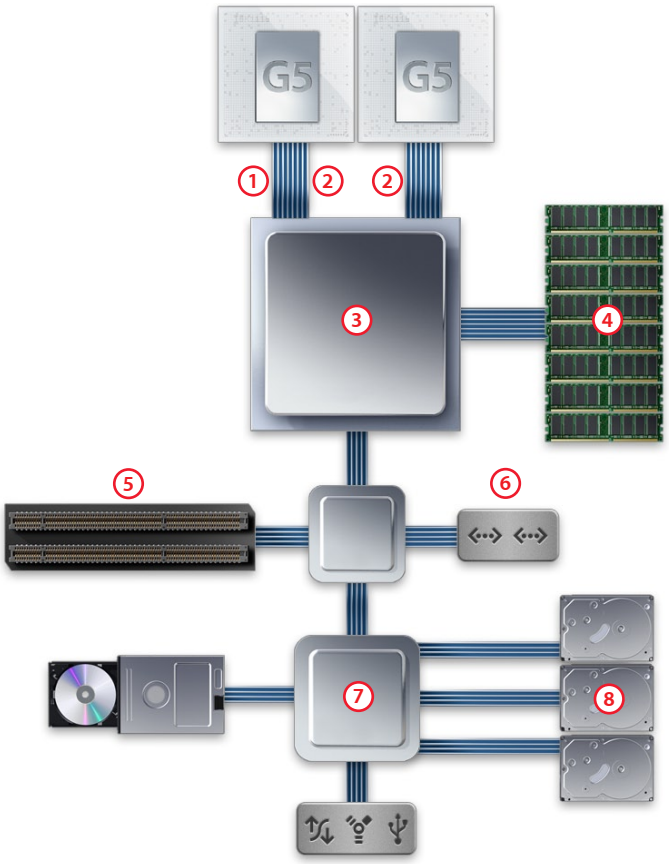
For maximum efficiency, dual PowerPC G5 systems work with the operating system to schedule priorities. With sophisticated multiprocessing capabilities built in, Mac OS X and Mac OS X Server dynamically manage multiple processing tasks across the two processors. This allows dual PowerPC G5 systems to accomplish up to twice as much as a single-processor system in the same amount of time, without requiring any special optimization of the application.

High-Bandwidth Server Architecture

The PowerPC G5 is only part of the Xserve performance story. Xserve G5 features dual independent frontside buses to keep data moving in and out of each processor, and a superefficient point-to-point system controller allows data to move directly between all subsystems. Bandwidth is further enhanced by a 400MHz, 128-bit memory bus and a high-speed HyperTransport interface that connects the PCI-X controller and the I/O subsystems to the system controller. Together these advanced technologies provide the power and throughput for demanding Internet applications, robust network infrastructure solutions, and high-performance computational clustering environments.

Server-Optimized Architecture

1. **Gigahertz frontside bus.** Runs at half the speed of the processor and provides up to 9.2GB/s bandwidth between the processor and the rest of the system.
2. **Dual independent frontside buses.** Provide up to 18.4GB/s aggregate bandwidth in dual processor systems.
3. **Advanced system controller.** Uses a point-to-point architecture to enable data to pass directly between subsystems.
4. **400MHz ECC memory.** Uses a 128-bit-wide data path to support high-speed PC3200 SDRAM with Error Correction Code (ECC) protection.
5. **PCI-X expansion.** Supports two high-performance 100MHz PCI-X cards or one 133MHz PCI-X card, providing total throughput of up to 1GB/s.
6. **Dual onboard Gigabit Ethernet.** Provides two independent ports, as well as hardware support for VLAN, jumbo frames, and TCP, IP, and UDP hardware checksum.
7. **High-performance I/O controller.** Integrates three fast Serial ATA (SATA) drive controllers and FireWire 800 interfaces using a HyperTransport interconnect.
8. **Serial ATA storage.** Supports up to 1.5TB of affordable hot-plug internal storage[1] using three independent, high-performance 150MB/s SATA drive controllers.[4]



Gigahertz Frontside Bus

To harness the power of the G5 processor, a 64-bit Double Data Rate (DDR) frontside bus speeds up communication between the PowerPC G5 and the memory controller. Unlike conventional processor interfaces, which carry data in only one direction at a time, this dual-channel frontside bus has two 32-bit point-to-point links: One link travels into the processor and another travels from the processor, which means no wait time while the processor and the system controller negotiate which will use the bus or while the bus switches direction. This elastic interface self-tunes during startup for optimal signal quality.

On the 2.3GHz PowerPC G5, the frontside bus operates at 1.15GHz for a total theoretical bandwidth of up to 9.2GB/s. Dual processor systems get an even greater performance boost, because each PowerPC G5 has a dedicated frontside bus. This results in a maximum aggregate raw bandwidth of 18.4GB/s on dual 2.3GHz Xserve G5 systems. This is nearly three times the 6.4GB/s maximum throughput of Itanium 2–based systems and Xeon-based systems. Because there's a dedicated data path in each direction, transaction-intensive server operations execute fast and without contention for data—so the processor doesn't sit idle, waiting for data to arrive.

On dual processor systems, the two independent frontside buses allow each PowerPC G5 to handle its own tasks at maximum speed with minimal interruption. They also enable each processor to discover and access data in the other processor's caches, a technique called intervention, or snooping. Cache intervention guarantees cache coherency, which ensures that the processor fetches the correct data, even if the data has been modified and is stored in the cache of the other processor.

Point-to-Point System Controller

An advanced system controller is central to the overall performance of Xserve G5. This revolutionary application-specific integrated circuit (ASIC)—one of the industry's fastest—is built using the same state-of-the-art IBM process technology as the PowerPC G5. A superefficient point-to-point architecture provides each primary subsystem with dedicated throughput to main memory, so massive amounts of data can traverse the system without contention for bandwidth. In contrast, subsystems on Xeon-based servers must share bandwidth, which can result in time-consuming arbitration while they negotiate for access across a common data path.

Advanced ECC Memory Technology

Xserve G5 maximizes the efficiency of its computing power with an advanced 128-bit DDR memory architecture and support for up to 16GB of RAM. This high-speed, high-capacity memory architecture enables video encoding, transaction-intensive networking, and scientific applications to perform radically faster. What's more, it works with ECC logic in the system controller to protect data from corruption or errors.

Double Data Rate (DDR) memory
Xserve G5 features a 128-bit memory controller that supports 400MHz DDR SDRAM. With fast DDR memory and a wider 128-bit interface that addresses two banks of SDRAM at a time, Xserve G5 can reach a memory throughput of up to 6.4GB/s—more than double the throughput of the G4-based Xserve. For even greater performance, direct memory access (DMA) works with the point-to-point system controller, so subsystems can access main memory without having to interact with the processor.

2GB DIMM support
Xserve G5 supports 2GB DIMMs, allowing the system to accommodate up to 16GB of memory.

Support for up to 16GB of RAM
Xserve G5 comes standard with 512MB or 1GB of DDR SDRAM. Main memory is scalable up to 16GB in eight DIMM slots, allowing you to increase memory as application and networking requirements increase. More main memory enables the system to run strenuous processes simultaneously and to accommodate spikes in demand. Enormous files and data sets can be loaded into RAM for rapid processing by the PowerPC G5—without having to access disk storage. Data can be retrieved from memory 40 times faster than from the hard drive. In fact, accessing the first critical word of data from memory is 60,000 times faster than from a hard drive, so manipulation and analysis of data can be performed at remarkable speeds.

ECC protection
Xserve G5 uses Error Correction Code (ECC) logic to protect the system from data corruption and transmission errors. Each DIMM has an extra memory module that stores checksum data for every transaction. The system controller uses this ECC data to identify single-bit errors and corrects them on the fly, helping to prevent unplanned system shutdowns and protecting data integrity. In the rare event of multiple-bit errors, the system controller detects the error and triggers a system notification to prevent bad data from corrupting further operations.

For additional protection, the ECC modules on the DIMMs integrate with Server Monitor software. If error rates exceed a defined threshold, which typically indicates a hardware problem, Server Monitor can alert the administrator for fast resolution.

High-Performance PCI-X Expansion

PCI expansion options
Built-to-order Xserve G5 configurations can include the following:

- Apple Fibre Channel PCI-X Card
- Hardware RAID PCI card
- Apple PCI-X Gigabit Ethernet Card
- Dual-channel Ultra320 SCSI PCI-X card
- PCI VGA video card

Xserve G5 features the latest 133MHz PCI-X expansion protocol with throughput of up to 1GB/s. PCI-X operates more efficiently than PCI, resulting in more usable bandwidth at any PCI-X bus speed—ideal for connecting to high-performance networking, storage, and backup devices using optional SCSI and Fibre Channel cards. For fast data access, the PCI-X bus connects to the system controller using a high-speed, dual-channel HyperTransport bus with a throughput of up to 4.8GB/s (2.4GB/s each way).

Two open 64-bit PCI-X slots allow you to add one card running at up to 133MHz or two cards running at up to 100MHz. The PCI-X specification is designed to support 3.3V signaling and is compatible with Universal 33MHz and 66MHz PCI cards.[4]

Dual Onboard Gigabit Ethernet

Apple extends the networking performance of Xserve G5 with a high-performance Ethernet controller on the main logic board. This advanced controller includes two independent 10/100/1000BASE-T Ethernet interfaces, each with its own interrupt, on a dedicated 64-bit, 133MHz PCI-X bus. The result is tremendous networking bandwidth and no contention for data with the I/O subsystems.

In addition, the Gigabit Ethernet controller provides these networking features:

- Hardware-generated TCP, IP, and UDP checksum detects packet corruption and transmission errors.
- 802.1q VLAN (Virtual LAN) tags allow Xserve G5 to be a member of multiple virtual networks and to provide unique network services to each one.
- A large 64K packet buffer per interface supports jumbo frames, or packets up to 9K, to reduce system overhead and increase throughput of all network activities.

Dual Gigabit Ethernet ports deliver near-line-rate throughput of up to 980Mb/s per port, alleviating bottlenecks even with very large files and expediting mail, web, file, and printer sharing services. Together with the multihoming function in Mac OS X Server, dual network ports enable Xserve G5 to serve more client systems; provide redundant links; or support an isolated management network that is independent of a client services network. Dual Gigabit Ethernet also enables the high-speed network interconnect required by many computational cluster deployments.

Additional Connectivity

The Xserve G5 architecture uses the HyperTransport protocol to connect the I/O controller to the system controller. The Serial ATA controller, optical drive, and FireWire, USB 2.0, and serial ports are all integrated through a bidirectional 800MHz HyperTransport interconnect for a maximum throughput of 1.6GB/s.

Xserve G5 offers industry-standard interfaces for connecting I/O devices:

- **Dual FireWire 800 ports.** Two FireWire 800 ports on the back panel and one FireWire 400 port on the front panel connect to high-bandwidth FireWire (IEEE 1394) devices, such as storage devices and audio and video input devices. In addition, TCP/IP over FireWire can be used to create small clusters, and FireWire Target Disk Mode allows easy cloning of system configurations.
- **DB-9 serial port.** An industry-standard 9-pin serial port allows for system access through a serial console session.
- **Two USB 2.0 ports.** USB ports on the back panel connect to keyboards, mice, speakers, and other industry-standard peripheral devices.
- **Optical drive.** For software installation and recovery, a slot-loading Combo drive (DVD-ROM/CD-RW) comes standard on server configurations. A SuperDrive (DVD-R/CD-RW) is available as an alternative for customers who need to write DVD-R data, providing an easy way to back up as much as 4.7GB of data on a DVD-R.

Affordable, Scalable Storage

Up to 1.5TB of storage
Each Xserve G5 has three drive bays for up to three hot-plug Apple Drive Modules.[2]

Exponential growth in the creation and distribution of digital content is driving the need for high-capacity storage in business and education. Large databases, digital video footage, immense scientific data sets, and uncompressed audio all place enormous demands on server storage resources.

Xserve G5 addresses these growing requirements by providing up to 1.5TB of affordable internal storage capacity.[1] With each Apple Drive Module on an independent Serial ATA (SATA) drive channel and connected to a high-speed I/O system, the Xserve storage subsystem scales without compromising performance. This unique architecture delivers the best balance of performance, reliability, capacity, and price.

Internal storage comparison

Server	Apple Xserve G5	Dell PowerEdge 1850	IBM eServer x336	Sun Sun Fire V20z
Maximum internal storage capacity	1.5TB (three 500GB drives)	600GB (two 300GB drives)	292GB (two 146GB drives)	600GB (two 300GB drives)
Onboard disk controller for internal drives	Three independent SATA	Ultra320 SCSI	Ultra320 SCSI	Ultra320 SCSI
Hot-plug drives	Yes	Yes	Yes	Yes
Cost of additional drives*	$649 (500GB)	$829 (300GB)	$989 (300GB)	$895 (300GB)
Cost per GB	$1.30	$2.77	$3.30	$2.99

* Based on suggested retail prices published on manufacturers' websites as of August 20, 2005.

Xserve G5 offers affordable internal storage that scales to twice the capacity of most other 1U servers on the market.

SATA Drive Technology

Xserve G5 features sophisticated 150MB/s SATA drive controllers, each with a dedicated SATA bus to a single Apple Drive Module. In the original Xserve—and before Serial ATA became available—Apple pioneered a point-to-point storage architecture using Parallel ATA. This innovative design eliminated the single-threaded operation of the typical ATA master/slave configuration and delivered superior performance at a much lower cost than that of SCSI-based systems.

Xserve G5 advances to a SATA-based storage subsystem that provides the same multithreaded system operation. Multithreading enables the system to send commands to multiple drives at once for the fastest possible throughput. An independent drive architecture also isolates the drives electrically, preventing a single drive failure from

causing unavailability or performance degradation of the surviving drives—a common problem with multidrive SCSI implementations. The end result is a storage architecture that provides tremendous throughput and excellent storage scalability.

Apple Drive Module
Xserve G5 uses reliable, high-performance Apple Drive Modules to provide cost-effective, high-capacity system storage.

Hot-plug Apple Drive Modules
The three Xserve drive bays[2] provide affordable storage expansion using 80GB or 500GB SATA Apple Drive Modules running at 7200-rpm, or 74GB Apple Drive Module running at 10,000-rpm.[1] Apple Drive Modules feature robust hot-plug connectors called Single Connector Attachment (SCA) II that protect the connecting pins from bending when drives are inserted or removed. Hot plugging allows administrators to add storage without bringing down the server: Insert a new Apple Drive Module at any time and it's instantly available to the server. This flexibility is made possible by tight integration between system hardware and software.

Apple Drive Modules feature a unique handle design for fast, easy installation and a positive locking mechanism to hold them tightly in place after insertion. The drive carrier employs a drive mounting technique that increases drive isolation and reduces vibration. Carefully tested and qualified to ensure maximum performance and reliability, Apple Drive Modules work seamlessly with the sophisticated Xserve monitoring sensors and Server Monitor remote monitoring software.

Monitoring of drive health
Xserve hardware and software work together to provide industry-leading remote monitoring and alert capabilities. The server operating system reads Self-Monitoring, Analysis, and Reporting Technology (SMART) data from each hard drive. SMART data allows the drive to report its health and enables Server Monitor software to warn the administrator of a prefailure condition—providing the opportunity to back up critical data and replace the hard drive before a failure occurs. For local monitoring, each Apple Drive Module has two LEDs, one for drive activity and one for drive health.

Software and Hardware RAID Options

Affordable and easy-to-install drive modules make it simple to expand Xserve systems to meet growing storage needs over time. For even greater storage capacity or to share storage among multiple servers, high-throughput PCI-X slots enable users to connect to external rackmount storage and backup systems, including SCSI devices and Apple's Xserve RAID.

Software RAID in Mac OS X Server
Using software RAID built into Mac OS X Server, the three Apple Drive Modules can be striped or mirrored for improved performance or data redundancy.[2]

- **RAID 0, or striping.** Increases storage performance dramatically by distributing data across two or three Apple Drive Modules and enabling the drives to read and write data concurrently. Drive striping takes full advantage of the three independent drive channels and utilizes the I/O capabilities of Mac OS X Server.
- **RAID 1, or mirroring.** Provides a high level of data protection by creating a real-time, exact duplicate of the contents of one Apple Drive Module on a second drive. With the volume promotion feature in Mac OS X Server v10.4, you can upgrade a single drive to a RAID 1 mirror without needing to back up and reformat the drive. If a mirrored drive fails, the system can rebuild the array in the background, while continuing to serve data. The independent drive architecture and software RAID combine to provide RAID 1 protection with no performance penalty.

For additional protection or higher performance, Mac OS X Server on Xserve can boot from a mirrored or striped volume.

Apple Fibre Channel PCI-X Card
Xserve RAID connects to a host Xserve G5 system using the dual-port 2Gb Apple Fibre Channel PCI-X Card (sold separately), for easy integration into copper or optical infrastructures.

Optional hardware RAID PCI card

For enhanced storage performance and data protection, the hardware RAID PCI card provides RAID levels 0, 1, and 5 using a hardware RAID controller and 64MB of battery-backed, ECC cache memory. When Xserve is configured with three 500GB Apple Drive Modules and the hardware RAID PCI card, it offers 1TB of internal, RAID 5–protected storage in a 1U form factor—unmatched in the industry. This compact solution provides affordable protected RAID storage for small to medium-size storage requirements.

Xserve RAID storage solution

For massive capacity and advanced data protection and availability features, Xserve connects to the Xserve RAID storage system using the Apple Fibre Channel PCI-X Card. Xserve RAID holds up to 14 hot-swap Apple Drive Modules, for up to 7TB[1] of storage in a rack-optimized 3U enclosure. The innovative Apple-designed architecture combines affordable, high-capacity ATA drive technology with a dual 2GB Fibre Channel SFP interface for fast, reliable data access, even at distances of up to 500 meters. Redundant components further increase data protection and system availability. With easy-to-use tools for remote setup and management, this powerful RAID system provides a cost-effective answer to the growing storage requirements of businesses and institutions.

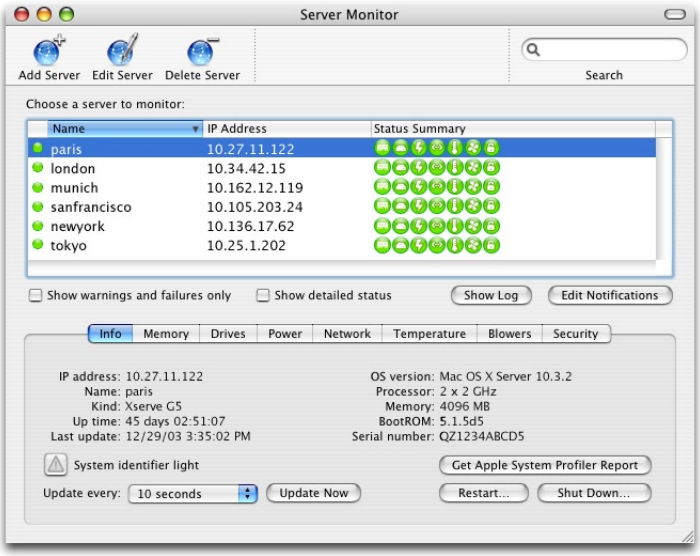
Integrated Hardware Monitoring

Remote monitoring
Server Monitor allows administrators to review information on hundreds of Xserve systems from any Internet-connected Mac OS X system.

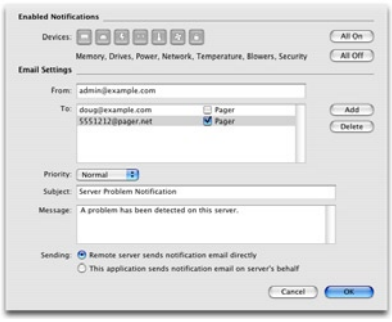
Xserve G5 includes built-in remote monitoring capabilities that enable network administrators to stay in touch with their Xserve systems from anywhere on the network or over the Internet. Xserve monitoring tools run over TCP/IP using robust password authentication to protect management data and server deployments from unauthorized access.

With 38 sensors in the enclosure, Xserve G5 is the most instrumented server in its class. Embedded hardware sensors integrate with Apple's sophisticated Server Monitor software to check the condition of critical subsystems, such as memory, fans, power supplies, and Ethernet links. Temperature measurements for hard drives, processors, memory, PCI, power supply, and incoming ambient temperature are processed using three dedicated microcontrollers and three dedicated communication buses on the logic board.

To maximize server uptime, Server Monitor aids in the early identification and easy diagnosis of system problems. This powerful application uses data from the hardware sensors to continuously report on the status of all Xserve subsystems, for servers on the network. If operating conditions for any component exceed predefined thresholds, Server Monitor can instantly send notification via email or email-capable pager, so network administrators can respond quickly to prevent or repair the problem.



Server Monitor can monitor hundreds of servers using a single, intuitive interface. Each server is identified by name and IP address (or DNS host name), and at-a-glance summary information (green—OK, yellow—warning, red—error) indicates the status of individual components. A click on any icon displays detailed status and performance information.

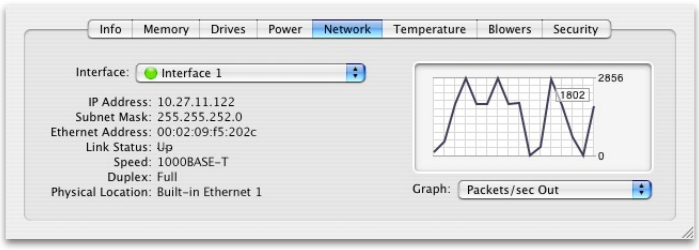


Automatic notifications
Server Monitor can send a customized email to alert specified individuals when operating conditions exceed predefined thresholds. Short text messages can be sent to email-capable pagers, cell phones, or PDAs; full-text details can be sent to email clients or full-function PDAs.

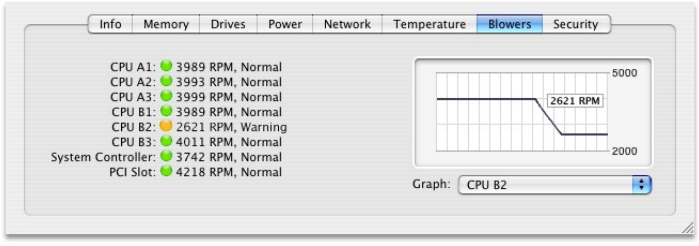
Xserve Remote Diagnostics
Xserve G5 includes a new set of server-class diagnostic tools that support hardware profiling and advanced diagnostics, as well as remote, headless operation.

Server Monitor provides instant access to status and performance details, including these individual server attributes, subsystems, and system variables:

- **Info.** Lists key attributes of the server: name, IP address, device kind, operating system version, processor type, amount of memory, firmware version, uptime, last monitoring update, and hardware serial number.
- **Memory.** Displays the size, speed, and type of memory installed in each system, as well as ECC error counts.
- **Drives.** Provides the status of each of the server's hard drives, including SMART data for predictive failure notification.
- **Power.** Shows the current, voltage, and processor power, as well as a historical line graph for each supply rail. It also provides uninterruptible power supply (UPS) information and status when available.
- **Network.** Indicates the status of active network links, network stack, and link settings and provides a historical line graph for each link.



- **Temperature.** Provides the values of the ten enclosure and processor temperature sensors, as well as a historical line graph for each sensor reading.
- **Blowers.** Shows the revolutions per minute and status of the eight fans, including a historical line graph for each one. In the case of a single blower failure, the other fans speed up to compensate, allowing the server to continue to run, while also notifying the system administrator.



- **Security.** Displays the security status of the Xserve enclosure. Xserve G5 features a hardware enclosure lock that prevents drives from being removed, as well as software-based I/O port security that allows administrators to disable CD mounting, removal of hard drives, or use of USB and FireWire devices.

In addition, Server Monitor records a log of activities and messages for each monitored Xserve. The log provides the times Server Monitor attempted to contact the server and whether a connection was successful. It also shows changes in server status. For asset tracking or support logging, a System Profiler report can be saved for a selected server or multiple servers.

Mac OS X Server Version 10.4

Mac OS X Server v10.4
Key features include:

- PowerPC G5–optimized kernel and numerical libraries
- Automatic Setup for configuring multiple servers
- Journaled HFS for enhanced server availability and fault resilience
- Server Admin application for easy setup and monitoring of services
- Open Directory for delivering enterprise directory and authentication services
- Single sign-on using Kerberos
- Samba 3 for supporting Windows users
- Postfix mail server for Mac and Windows users
- VPN server for Mac and Windows users
- JBoss application server for running J2EE-based applications
- 64-bit addressing
- Built-in distributed computing architecture

Features of Mac OS X Server for Xserve G5

- 802.1q VLAN support
- Background rebuilding of software RAID mirrors
- RAID volume promotion
- Server Monitor
- Customizable keyboard and mouse security options
- Xserve Remote Diagnostics

Xserve G5 ships with Mac OS X Server version 10.4, the fifth major release of Apple's award-winning server operating system. Mac OS X Server provides open source, standards-based workgroup and Internet services without the complexity inherent in Linux and other UNIX-based solutions. Hardware and software work together to deliver powerful, scalable solutions for supporting Mac, Windows, and Linux workgroups; deploying powerful Internet services; and hosting enterprise applications—all with an ease of use that is uniquely Apple. And with the unlimited-client license, there are no additional per-seat fees for connecting more users.[4] This kind of power has never been easier to put to work—or easier to integrate into your organization.

Optimized for the PowerPC G5

On all systems, Mac OS X Server features a high-performance 64-bit file system that supports HFS+ (and HFS+ journaled) file systems up to 16TB, so you can create very large, single file systems for massive databases, image archives, and digital video storage. In addition, Apple has written version 10.4 to take maximum advantage of the PowerPC G5, enabling current 32-bit applications to benefit immediately from the key advances of 64-bit processing. On PowerPC G5–based systems, Mac OS X Server can utilize the processor's 64-bit instructions and registers. It also includes 64-bit math and vector libraries that accelerate audio, video, and image processing, as well as large number operations—so existing applications that use these built-in libraries get an automatic performance boost.

64-Bit Computing
64-bit computing is the next big step in providing greater computing power to solve even the most challenging tasks. It gives scientists, engineers, and other power users the tools to address problems that are billions of times larger than the ones that can be solved with 32-bit systems. Mac OS X Server v10.4 brings the power of 64-bit computing to mainstream servers. Its 64-bit addressing offers access to massive amounts of memory, transcending the 4GB memory limitation of 32-bit systems. And its 64-bit optimized math libraries provide high-performance, extremely accurate mathematical calculations.

Built-in Network Services

Mac OS X Server includes a complete suite of robust solutions for file and print, Internet and web, networking, workgroup management, and directory services. Apple has integrated and tested the latest open source technologies—such as OpenLDAP, Postfix, Apache, and JBoss—making them easy to deploy right out of the box.

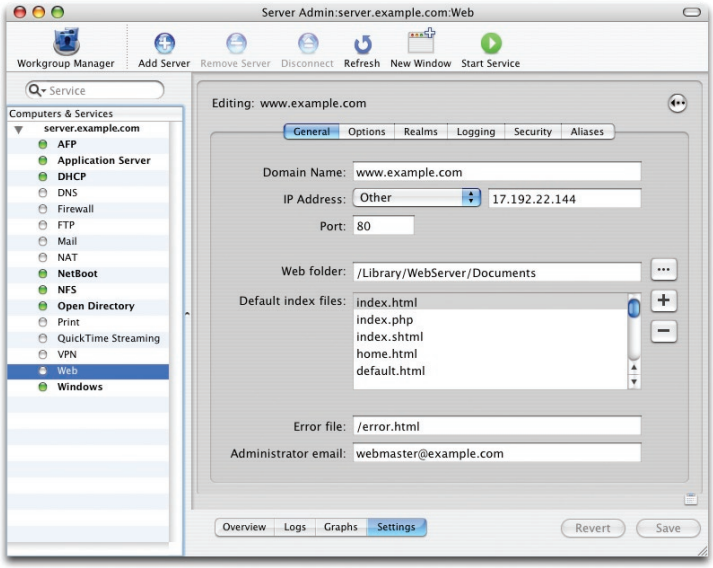
PowerPC G5–optimized libraries
To optimize application performance on the PowerPC G5, Mac OS X includes math, vector, and image processing routines:

- Double-precision transcendental functions (libm)
- Vectorized transcendental functions (vMathLib)
- 128-bit integer math (vBigNum)
- Basic Linear Algebra Subprograms (BLAS)
- Linear Algebra Package (LAPACK)
- Vectorized digital signal processing (vDSP)
- Vector image processing (vImage)

Built on open standards, Mac OS X Server is compatible with existing network and computing infrastructures. Samba 3, the new version of the popular open source SMB/CIFS server, provides reliable file and printer sharing for Windows clients, as well as support for NT Domain services. The built-in directory services architecture is based on LDAPv3, allowing Mac OS X Server systems to host LDAP directory services or integrate with any network that uses LDAP directory services. In addition, Mac OS X Server includes compatibility with legacy directory service solutions such as NIS, as well as proprietary solutions such as Active Directory. What's more, the open source UNIX-based foundation makes it easy to port and deploy existing tools to Mac OS X Server.

Innovative Remote Management

Mac OS X Server comes with innovative remote management tools that provide a consistent, unified interface for setting up and managing the built-in services. The Server Admin application enables network administrators to securely manage services on multiple servers at the same time—all from the same easy-to-use application.



Administrators can use Server Admin on any Internet-connected Mac OS X computer to install software updates (including system software), set preferences, and configure workgroup and Internet services—such as Samba 3, Apache, DHCP, Postfix, and QuickTime Streaming Server.

High-availability services
To minimize downtime and maximize data protection, Mac OS X Server includes high-availability features such as software RAID, directory replication, file system journaling, a two-node IP failover service, and "watchdog" features such as automatic restart of the server and individual services.

Mac OS X Server also makes it easy to monitor services remotely. Server Admin displays the current status of services running on Xserve systems. Administrators can read access and error logs, view charts of traffic patterns, and graph the performance of individual network services and file throughput—providing valuable information for planning and allocating network resources.

For administrators who prefer to manage from a terminal, Mac OS X Server includes Secure Shell (SSH2) technology for encrypted and authenticated login. Xserve G5 is equipped with a DB-9 (9-pin) serial port, giving UNIX-savvy administrators a way to access the system through a serial console session even when network services are down. Command-line tools allow administrators to remotely install software, run Software Update, or set system and network preferences. In addition, Mac OS X Server supports industry-standard Simple Network Management Protocol (SNMP) for integrating with third-party products, such as HP OpenView.

Software Development for the PowerPC G5

Integrated development for Mac OS X and Mac OS X Server
Apple's robust Xcode tools make it easy to build high-performance applications for the PowerPC G5 processor.

Xcode, Apple's development toolset, makes it easy to optimize applications for the massively parallel execution core of the PowerPC G5. An enhanced version of GCC (GNU Compiler Collection) incorporates the machine model for the PowerPC G5, taking full advantage of the PowerPC instruction grouping and supporting the enhanced math hardware functions. By recompiling with Xcode and the GCC 4.0 compiler, developers can get improved code generation that keeps the processor's integer and floating-point units constantly fed with instructions.

GCC 4.0 generates PowerPC G5–optimized code that also executes efficiently on G4 and G3 systems. This allows developers to build and qualify a single version of their applications for both 32-bit and 64-bit PowerPC-based systems. In addition, GCC 4.0 includes autovectorization capabilities. Previously, developers had to create code for the Velocity Engine vector processing unit by hand. Now the compiler can generate vector-based code automatically, delivering superior application performance while requiring less work for the developer.

For advanced performance optimization, Xcode includes Computer Hardware Understanding Development (CHUD) tools. These powerful tools measure and evaluate performance, identifying specific areas of an application that can benefit significantly from the capabilities of the PowerPC G5. For example, the MONster tool provides direct access to integrated performance counters on the G5, which test the efficiency of application code by measuring its impact on the processor.

For more information about development resources for the PowerPC G5 processor, see developer.apple.com.

Service, Support, and Training Options

Every Xserve G5 comes with a one-year limited warranty and 90 days of up-and-running telephone support. In addition, the AppleCare website publishes in-depth product information, training on hardware and software installation and configuration, and technical resources, including the AppleCare Knowledge Base, discussions, and downloadable software on Apple's Featured Software site.

For critical server deployments, Apple also offers a comprehensive range of service and support options for Xserve hardware and Mac OS X Server software. For more information about these AppleCare products, see www.apple.com/server/support.

AppleCare Premium Service and Support Plan

This server-class support product provides up to three years of up-and-running telephone and email support and onsite hardware service. Apple technical support experts are available 24 hours a day to help you determine whether you're experiencing a hardware failure or a Mac OS X Server configuration issue. In either case, Apple will work to get systems up and running quickly. And because Apple hardware and software are uniquely integrated, there's only one vendor to call.

The AppleCare Premium Service and Support Plan delivers up-and-running telephone and email support within 30 minutes—24 hours a day, 7 days a week. The hardware repair coverage provides onsite response within 4 hours during business hours and next-day onsite response when you contact Apple after business hours (terms apply).[5] For added peace of mind, you'll have the assurance that Apple-authorized technicians will perform repairs using genuine Apple parts.

The AppleCare Premium Service and Support Plan can be purchased at any time while Xserve G5 is still under its original one-year warranty. However, since coverage ends three years after the hardware purchase date, you'll get maximum advantage when you make both purchases at the same time.

Convenient replacement modules
Problem resolution is fast with AppleCare Service Parts Kits for Xserve G5 (sold separately).

AppleCare Service Parts Kit

Xserve G5 is designed for quick and easy swapping of crucial parts; no special tools or training certifications are needed. AppleCare Service Parts Kits let system administrators keep key components handy to address the most common hardware failures. Each kit has a logic board, a power supply, a PCI fan unit, and a fan array module. When the AppleCare Premium Service and Support Plan is combined with an AppleCare Service Parts Kit, technical support experts can often help troubleshoot and fix systems right over the phone—day or night—eliminating the need for an onsite technician.

Mac OS X Server Software Support

Apple also offers support programs for Mac OS X Server that extend beyond the up-and-running support provided by the AppleCare Premium Service and Support Plan. Apple technical support experts can provide consultative phone and email support for Mac OS X Server integration and migration issues, as well as help with command-line configuration.

Mac OS X Server Maintenance Program
This subscription program makes it easy to manage software expenditures while benefiting from the latest technologies and improvements. With one easy payment, you'll receive major Mac OS X Server software upgrades for three years.

Three levels of Mac OS X Server Software Support are available, depending on the number of incidents supported and desired response time. Each plan provides one year of coverage.

- **Select** covers up to 10 incidents with 4-hour response[6] for priority 1 issues (server down), 12 hours a day, 7 days a week. Support for additional incidents can be purchased as needed.
- **Preferred** covers an unlimited number of incidents with 2-hour response[6] for priority 1 issues, 12 hours a day, 7 days a week, and assigns a technical account manager to the organization.
- **Alliance** covers an unlimited number of incidents at multiple locations with 1-hour response[5] for priority 1 issues, 24 hours a day, 7 days a week. This plan includes an onsite review by an Apple technical support engineer.

Training and Certification Programs

Apple offers comprehensive instruction on Mac OS X and Mac OS X Server, covering such topics as client management, system troubleshooting, and cross-platform network configuration. A combination of lectures, demonstrations, and hands-on exercises, classes are taught by Apple Certified Trainers with real-world experience and dynamic presentation skills. Classes are offered at Apple Authorized Training Centers, as well as at customer locations.

Once IT professionals have acquired the requisite skills, Apple certification programs provide tangible evidence of their technical expertise. For more information about Apple training and certification programs, visit www.apple.com/training.

Purchasing Information

Standard Configurations

Xserve G5 is available in three standard configurations to meet the needs of server and cluster deployments in education and business.

	Server configurations		**Cluster node**
Order number	**M9743LL/A**	**M9745LL/A**	**M9742LL/A**
Processor	2GHz PowerPC G5	Dual 2.3GHz PowerPC G5	Dual 2.3GHz PowerPC G5
Frontside bus	1GHz	1.15GHz per processor	1.15GHz per processor
ECC memory	1GB PC3200 DDR (400MHz)	1GB PC3200 DDR (400MHz)	512MB PC3200 DDR (400MHz)
Maximum memory	16GB	16GB	16GB
Hot-plug storage (Serial ATA)	Three drive bays supporting up to 1.5TB using 80GB or 500GB Apple Drive Modules at 7200-rpm, or 74GB Apple Drive Module at 10,000-rpm; one 80GB drive preinstalled[1]		One drive bay with 80GB drive preinstalled[1]
Optical drive	Combo drive (DVD-ROM/CD-RW) or optional SuperDrive (DVD-R/CD-RW)		—
Networking	Two onboard Gigabit Ethernet interfaces (10/100/1000BASE-T)		
PCI expansion	Two open 64-bit PCI-X slots supporting one card at up to 133MHz or two cards at up to 100MHz		
Ports	Two FireWire 800, two USB 2.0, one DB-9 (back panel); one FireWire 400 (front panel)		
Mac OS X Server software	Unlimited-client edition	Unlimited-client edition	10-client edition
Also included	Mounting screws with M5 and 10/32-inch threads; caged nuts; cable management arm for four-post racks; agency-approved 12-foot power cable		
Service and support	90 days of toll-free telephone support and one-year limited warranty; optional extended service and support products		

Build-to-Order Options

Customers can order a custom-configured Xserve G5 with the following options.

- Memory: 512MB, 1GB, 2GB, 4GB, 6GB, 8GB, 16GB
- Internal storage: 80GB or 500GB Apple Drive Modules running at 7200-rpm, or 74GB Apple Drive Module running at 10,000-rpm[1]
- Optical drive: Combo drive (DVD-ROM/CD-RW), SuperDrive (DVD-R/CD-RW)
- PCI cards: Apple Fibre Channel PCI-X Card (includes SFP to SFP cables), hardware RAID PCI card, Apple PCI-X Gigabit Ethernet Card, dual-channel Ultra320 SCSI PCI-X card, PCI VGA video card

Compute power with Mac ease of use
The Apple Workgroup Cluster enables researchers to harness the vast computational power of a PowerPC G5–based cluster.

Related Products

- Xserve RAID, available in 1TB, 3.5TB, and 7TB configurations[1]
- AppleCare Premium Service and Support Plan
- AppleCare Service Parts Kit
- Mac OS X Server Maintenance Program
- Third-party products, including racks, switches, and UPS devices

For up-to-date information on these and other products that enhance Xserve deployments, visit www.apple.com/store or call 800-MY-APPLE.

Apple Workgroup Cluster

Apple makes it easy for researchers to benefit from the power of computational clustering. The Apple Workgroup Cluster is a powerful computational cluster—with a choice of 4, 8, 16, or 32 Xserve G5 cluster nodes—that is easy to deploy. Every component is prequalified and fully integrated—from the servers, to the operating systems, to the cabling—to ensure maximum compatibility and performance. The cluster includes industry-leading management and monitoring tools, such as Server Admin and Apple Remote Desktop, to simplify the administrative process without compromising power and flexibility. And it's designed to scale easily, so you can add nodes and storage as your needs evolve. For information, visit www.apple.com/xserve/cluster.

Technical Specifications

Hardware

Processor

- Single 2GHz or dual 2.3GHz PowerPC G5 processors
  - PowerPC processor architecture with 64-bit data paths and registers
  - Native support for 32-bit application code
  - 512K on-chip L2 cache running at processor speed
  - Dual-pipeline Velocity Engine for 128-bit single-instruction, multiple-data (SIMD) processing
  - Two independent double-precision floating-point units and two integer units
  - Advanced three-stage branch prediction logic
- 64-bit, 1GHz or 1.15GHz frontside bus per processor, supporting up to 18.4GB/s data throughput
- Point-to-point system controller with support for ECC memory

Memory

- 128-bit data paths for up to 6.4GBs memory throughput
- Data protection using Error Correction Code (ECC) logic
- Eight slots supporting up to 16GB of DDR SDRAM using the following DIMMs (in pairs):
  - 256MB DIMMs (PC3200, 400MHz ECC)
  - 512MB DIMMs (PC3200, 400MHz ECC)
  - 1GB DIMMs (PC3200, 400MHz ECC)
  - 2GB DIMMs (PC3200, 400MHz ECC)

I/O connections

- Two open 12-inch, 64-bit PCI-X slots, running at up to 133MHz with one card installed or up to 100MHz with two cards installed; support for 32-bit or 64-bit 3.3V Universal PCI cards running at 33MHz or 66MHz[4]
- PCI and PCI-X cards available as build-to-order options for Xserve G5 include the following:
  - Apple Fibre Channel PCI-X Card
  - Hardware RAID PCI card
  - Apple PCI-X Gigabit Ethernet Card
  - Dual-channel Ultra320 SCSI PCI-X card
  - PCI VGA video card
- Two independent 10/100/1000BASE-T (Gigabit) RJ-45 Ethernet interfaces on main logic board
- Two FireWire 800 ports on back panel and one FireWire 400 port on front panel; 15W total power
- Two USB 2.0 ports (480Mbs each)
- One DB-9 serial port (RS-232)

Storage

- Three internal drive bays on independent 150MBs Serial ATA channels (server configurations; empty drive bays contain blank modules); or one internal drive bay on 150MB/s Serial ATA channel (cluster node configuration)
- Up to 1.5TB of internal storage[1] using hot-plug Apple Drive Modules (server configurations), available in the following capacities:
  - 80GB 7200-rpm SATA with 8MB disk cache
  - 500GB 7200-rpm SATA with 16MB disk cache
  - 74GB 10,000-rpm SATA with 8MB disk cache
- Support for reading SMART data from Apple Drive Modules for prefailure notification
- Slot-loading Combo drive (DVD-ROM/CD-RW) or optional SuperDrive (DVD-R/CD-RW)[2]

Rack support

- Fits EIA-310-D–compliant, industry-standard 19-inch-wide racks, including:
  - Four-post racks: 24 inches, 26 inches, and from 29 to 36 inches deep
  - Two-post telco racks (center-mount brackets included)
- Cable management arm for four-post rack
- Front-to-back cooling for rack enclosure

Electrical requirements

- Line voltage: universal input (90V to 264V AC), power factor corrected
- Maximum input current: 4A (90V to 132V) or 2A (180V to 264V)
- Frequency: 47Hz to 63Hz, single phase
- Output power: 400W

Environmental requirements and approvals

- Operating temperature: 50° to 95° F (10° to 35° C)
- Storage temperature: –40° to 116° F (–40° to 47° C)
- Relative humidity: 5% to 95% noncondensing
- Maximum altitude: 10,000 feet
- FCC Class A approved

Size and weight

- Height: 1.73 inches (4.4 cm)
- Width: 17.6 inches (44.7 cm) for mounting in standard 19-inch rack
- Depth: 28 inches (71.1 cm)
- Weight: 33.3 pounds (15.11 kg); 36.6 pounds (16.62 kg) with three Apple Drive Modules[7]

Software

Mac OS X Server

- Unlimited-client edition (server configurations); or 10-client edition (cluster node configuration)

Included services

- File and printer sharing: Mac (AFP, AppleTalk PAP), Windows (SMB/CIFS), UNIX and Linux (NFS, LPR/LPD), Internet (FTP, WebDAV)
- Directory services: Open Directory 2 (OpenLDAP, Kerberos, SASL), NT Domain Controller (Samba 3)
- Networking and security: DNS server (BIND 9), DHCP server, NTP server, Firewall (IPFW), WINS, VPN server (L2TP, PPTP)
- Mail services: SMTP (Postfix), POP and IMAP (Cyrus), Berkeley DB for indexing, SSL/TLS encryption (OpenSSL), mailing lists (Mailman), webmail (SquirrelMail)
- Web hosting: Apache web server, SSL/TLS (OpenSSL), WebDAV, server-side includes (SSIs), PHP, Perl, Ruby, Python, MySQL 4
- Application services: JBoss application server (EJB), Apache Tomcat (JavaServer Pages, Java Servlets), Java virtual machine (J2SE), Apache Axis (SOAP, WSDL Web Services), WebObjects 5.2 Deployment
- Media streaming: QuickTime Streaming Server (MPEG-4, MP3, AAC, RTP/RTSP), QuickTime Broadcaster, QuickTime Streaming Server Publisher, unicast and multicast
- Workgroup management: Workgroup Manager, NetBoot, Network Install
- Remote management: Server Monitor, Server Admin, SNMPv3, command-line tools

For More Information

For more information about Xserve G5 and other Apple server solutions, visit www.apple.com/server.

[1]For hard drive capacity measurements, 1GB = 1 billion bytes and 1TB = 1 trillion bytes; actual formatted capacity less. Maximum capacity of 1.5TB achieved through use of three 500GB Apple Drive Modules (server configurations only). [2]Server configurations only; the cluster node configuration has one drive bay and no optical drive and includes a 10-client license for Mac OS X Server. [3]Based on TOP500 List of Supercomputer Sites, November 2003. [4]Check with manufacturer for compatibility. [5]A separate AppleCare Premium Service and Support Plan must be purchased for each Xserve system to be covered. To qualify, systems must be within the one-year hardware warranty. Coverage ends three years after date of Xserve purchase. Actual onsite response time and availability of onsite service depend on location; see www.apple.com/support/products/premium for details. Local telephone fees may apply; telephone numbers and hours of operation may vary and are subject to change. [6]Response times are not guaranteed. [7]Weight varies by configuration and manufacturing process.

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