Microsoft® SQL Server 2005 Performance and Scalability Testing Using NetApp FAS920 Storage Systems

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TECHNICAL REPORT

Network Appliance, a pioneer and industry leader in data storage technology, helps organizations understand and meet complex technical challenges with advanced storage solutions and global data management strategies.

Abstract

The new release of the Microsoft SQL Server contains numerous enhancements designed to improve both overall performance and the ability to scale effectively as more storage systems are added to the configuration. This paper details two series of performance tests, run jointly by Microsoft and Network Appliance, which were designed to determine the effectiveness of the decision support system (DSS) enhancements in SQL Server 2005. Testing reveals significant gains in performance of SQL Server 2005 when compared with SQL Server 2000, as well as dramatic increases in scalability when more CPU resources are added to the configuration.

Table of Contents

List of Figures

List of Tables

Acknowledgments

Network Appliance would like to extend grateful thanks to Microsoft for its participation in the tests conducted for this technical report. Particular thanks to the SQL Server Performance Team for making available lab resources, expertise, and intensive support during the testing conducted in Redmond, WA.

Introduction

Microsoft SQL Server is used to support businesses in a number of mission-critical database processing functions, including online transaction processing (OLTP) and decision support system (DSS) workloads. The speed with which query results are returned when processing these workloads is directly affected by several key factors related to the

Database—including the nature of the queries (DSS or OLTP, for example) run against the database, the size and complexity of the database, and the type of processing being performed (such as joins or aggregations)

Hardware—commonly the speed and number of CPUs as well as the amount of memory; more rarely, the number of disks

Software—the efficiency of the application algorithms used to execute the queries

This paper summarizes the results of a series of tests conducted using SQL Server 2005 Beta 2 in DSS environments. See Table 1 for characteristics of DSS and OLTP workloads.

Characterized by long transactions with complex queries (either ad hoc or programmed, as with online analytical processing), DSS queries touch large amounts of data (often terabytes in size). As a consequence, DSS queries can potentially saturate both system CPUs and disk bandwidth.

Table 1) Characteristics of DSS and OLTP workloads.

DSS (Decision Support Systems)	OLTP (Online Transaction Processing)
Long transactions	Short transactions
Complex queries	Limited number of standardized queries
Large amounts of data accessed	Small amounts of data accessed
Combines data from different sources	Uses data from only one source
Indexing enables higher performance	Maintenance costs incurred with indexing

SQL Server 2005 Database Engine Enhancements

The database engine in Microsoft SQL Server 2005 has been extensively reworked to improve both absolute performance and multiprocessor scaling in DSS environments, without the need for the administrator to manually tune the system. A summary of these improvements follows.

Memory Management

Memory management is a critical part of server operations. Improvements in this area enhance overall server performance, particularly in DSS environments where large amounts of data are being accessed. There are several major improvements in SQL Server memory management that contribute to improved memory support for the complex, long-running, and resource-intensive queries critical to DSS workloads.

Uniform memory management. The uniform memory management framework in the SQL Server operating system layer provides common memory brokerage between different components of SQL Server, improving performance and providing flexible operations under a variety of memory pressures.

Dynamic memory management. SQL Server 2005 supports dynamic management of conventional, locked, and large-page memory. The new version of SQL Server also supports hot add memory, reducing the need for reboots.

Memory tracking. Major enhancements in memory tracking, such as external operating systemwide memory events and tracking of internal memory allocations between components, provide SQL Server 2005 with superior supportability features in memory management.

Query Processing

SQL Server 2005 provides major advances in query processing capabilities for decision support applications. Several major enhancements have been made to the execution environment, the query optimizer, and the query executor to improve query processing:

Execution environment. The major enhancement to the execution environment is a new plan stability feature. This feature allows query hints to be attached to queries at runtime, even when the application cannot be modified.

Query optimizer. Responsible for finding the best plan for executing a query, the SQL Server 2005 query optimizer has been significantly improved for DSS environments. Specific improvements include

- Full optimization capability for partitioned tables, including partition elimination capabilities. This capability precludes the need to read partitions that contain rows unrelated to the query results.
- Plan forcing enables the user to direct the optimizer to choose a specific query plan.

Query executor. Responsible for running the query plan generated by the optimizer, the SQL Server 2005 executor has been enhanced in a number of ways. These include

- Full support for partitioned tables
- Improved hash join performance
- Improved nested loop performance
- Improved bitmap join optimizations

The SQL Server 2005 query processing capabilities for decision support applications represent a tremendous advance over the already strong decision support features of SQL Server 2000.

Test Environment

The following sections detail the server and storage configurations used in the SQL Server performance testing comparisons. For a schematic of the test deployments, see Figure 1.

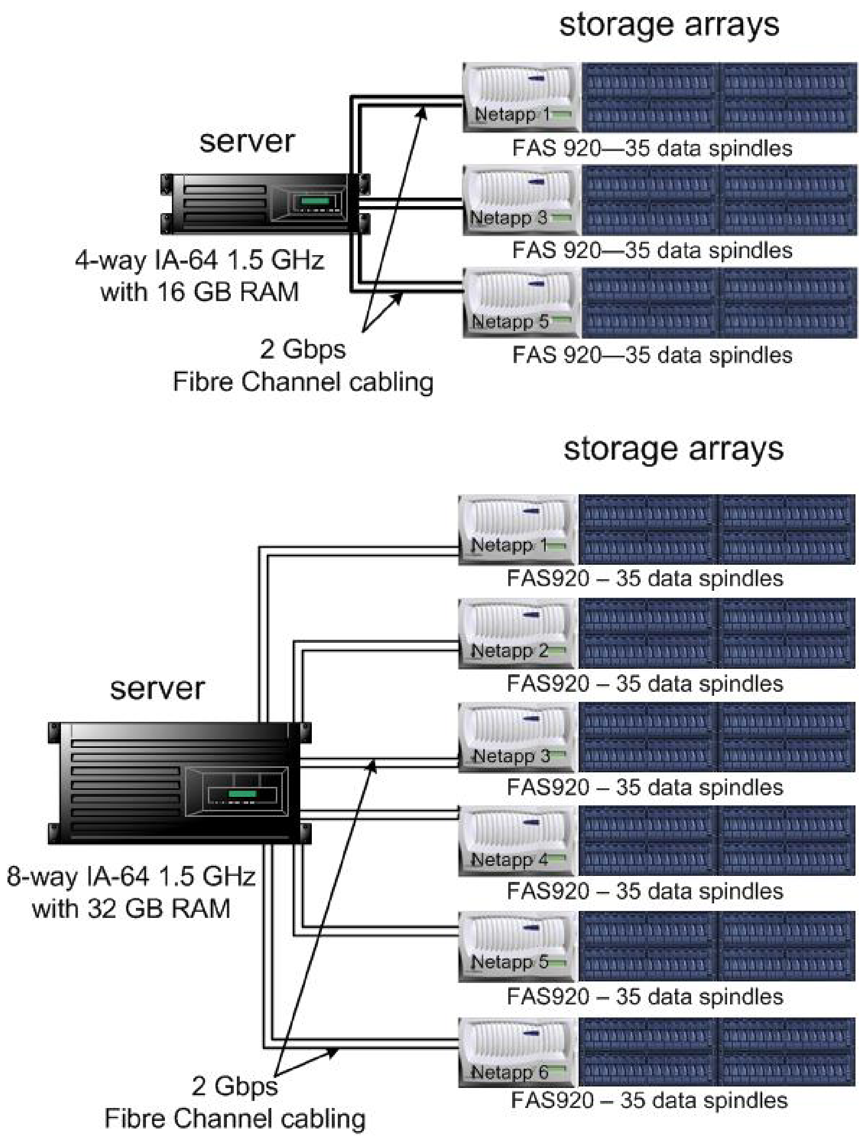

Figure 1) Schematic of four and eight-way servers with NetApp storage.

Servers

All test systems ran Microsoft Windows® Server 2003 Datacenter Edition, which provides 64-bit capabilities. Two sets of database performance comparisons were made: First between SQL Server 2000 and SQL Server 2005 Beta 2, and second between four-processor and eight-processor server configurations both running SQL Server 2005. For full details, see Table 2.

Table 2) Server configuration.

Component	Details	
Operating system	Microsoft Windows Server 2003, Datacenter Edition for 64-bit Itanium-based systems	
Version	5.2.3790 Service Pack 1, v.1433, build 3790	
System type	Itanium based	
Database servers	Microsoft SQL Server 2000 Enterprise Edition, SP4 build Microsoft SQL Server 2005 post Beta 2, build 1099	
Page file space	2GB	
	4-way	8-way
Processor	4 * 1500MHz	8 * 1500MHz
Total physical memory	16GB	32GB
Total virtual memory	17.57GB	33.57GB

Storage

It was critical that SQL Server performance was truly stressed and that potential bottlenecks outside the server space were identified and eliminated prior to testing. While the servers had finite CPU and memory resources (essentially, they were fixed variables), it was important to use a storage subsystem architecture that would not introduce any I/O bottlenecks or scaling constraints during testing.

Test Setup

Network Appliance™ FAS920 fabric-attached storage systems provided externally attached storage for the test setup. (To simplify the test environment, switches were not used in this deployment.) All storage systems ran Data ONTAP™ version 6.5.2. Each FAS920 was configured with 56 x 72GB 15K RPM disks; of these, 35 spindles were configured to host four data LUNs[1] (see Figure 2 for an example of the configuration). More spindles were configured on the storage subsystems than would normally be required to support the workloads generated. Note that the storage system automatically distributes the data across all of the disks in the volume without the need for operator intervention.

The FAS920 includes a single Pentium® 4 Xeon CPU clocked at 2.0GHz and a 512K L2 cache. The newer, faster processors are the driving force behind FAS920 performance. The FAS920 storage appliance has 2GB RAM and 256MB NVRAM. The new direct memory access capability of the NVRAM 4 card enables it to read directly from main memory without using CPU cycles. Also, the larger capacity of the NVRAM 4 card means that more data can be flushed to disk when needed, further improving efficiency while the filer is under heavy write loads. See Table 3 for FAS920 system specifications.

[1] A LUN (logical unit number) is a portion of available storage configured and presented to the Windows operating system as a physical disk drive.

Table 3) NetApp FAS920 system specifications.

Component	Details
Processor	1 X 2.0GHz Pentium 4 Xeon, 512K L2 Cache Intel® P4
Memory	2GB
NVRAM	256MB NVRAM-4
PCI expansion slots	6
PCI-X 100 buses	4
Max. spindles	168

Network Appliance storage solutions provide advanced backup and recovery capabilities critical for keeping SQL Server databases highly available. SnapManager® for SQL Server reduces backup times using backups based on NetApp Snapshot™ copies. This technology allows simultaneous backups of multiple databases (of any size) and requires minimal disk space for each additional full backup.

Scalable NetApp SAN storage subsystems provide simple-to-manage, cost-effective, and reliable solutions for database infrastructures requiring mission-critical high availability solutions. Network Appliance storage solutions deliver availability in excess of 99.997%, as measured across its entire installed base. In addition, NetApp SAN solutions improve storage resource utilization, offer excellent data protection, and facilitate application testing.

Network Appliance SAN solutions deliver benefits including improved storage utilization, higher data availability, reduced management costs, and highly scalable capacity and performance. Overall, the NetApp Fibre Channel SAN solution provides reduced complexity, unequaled flexibility, and affordable disaster recovery to the storage environment.

Database Design

The test database was fully normalized and fully indexed on primary and foreign keys. The size of the database, including tables and indexes, was 560GB on disk.

Database Layout Info

SQL Server 2000 and 2005 Test Runs on 4-way System

Four LUNs (LUN0, LUN1, LUN2 and LUN3) of 400GB each were created in a single volume on three FAS920 storage systems (NetApp1, NetApp3 and NetApp 5) for laying out database files and log files and one LUN (LUN4) of 700GB was created on NetApp1 for flat files and database backup files. This resulted in the creation of a total of 12 400GB LUNs on three FAS920s with an additional 700GB LUN on one of the FAS920 storage systems. Figure 2 shows the physical and logical database layout on one of the three FAS920 systems used for the tests.

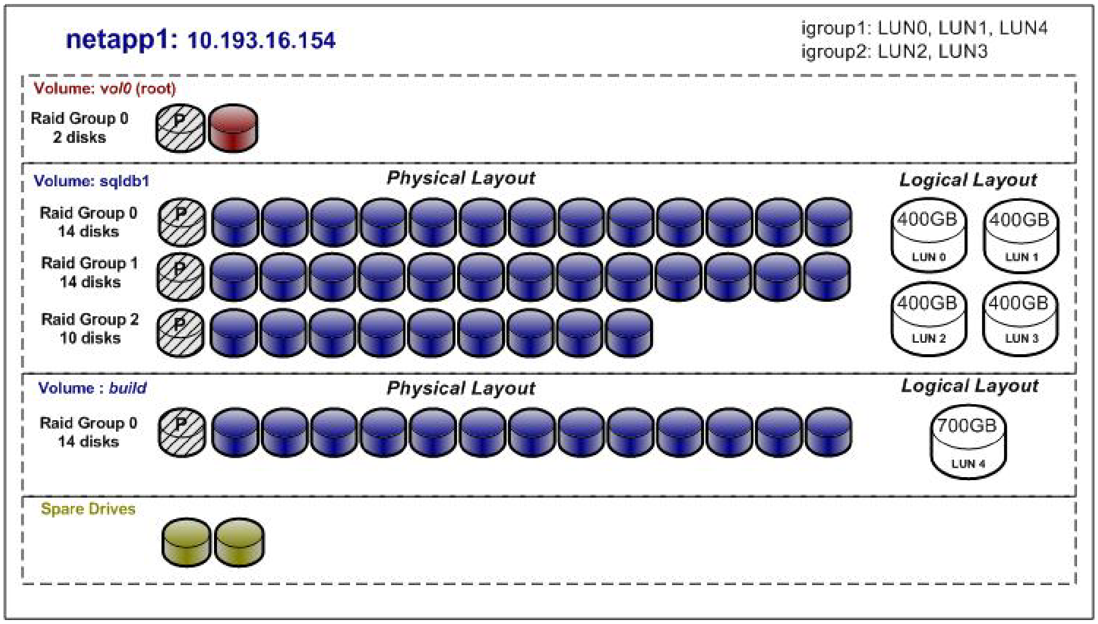

Figure 2) Disk layout for storage array FAS920-1.

The SQL Server database was comprised of 24 database files, and each LUN contained two database files as shown below. SQL Server database was distributed across all LUNs in order to obtain optimal performance for the 4-way system. See Table 4 and Table 6 for full details.

Table 4) 4-way system database layout.

Storage Appliance	LUN Location	LUN Size	Database Files
NetApp1	/vol/sqldb1/lun0	400GB	(database files 1 & 2)
	/vol/sqldb1/lun1	400GB	(database files 7 & 8)
	/vol/sqldb1/lun2	400GB	(database files 13 & 14)
	/vol/sqldb1/lun3	400GB	(database files 19 & 20)
	/vol/sqldb1/lun3	700GB	(rf_flatfiles & dbbackup files)
NetApp3	/vol/sqldb3/lun0	400GB	(database files 3 & 4)
	/vol/sqldb3/lun1	400GB	(database files 9 & 10)
	/vol/sqldb3/lun2	400GB	(database files 15 & 16)
	/vol/sqldb3/lun3	400GB	(database files 15 & 16)
NetApp5	/vol/sqldb5/lun3	400GB	(database files 5 & 6)
	/vol/sqldb5/lun1	400GB	(database files 11 & 12)

Storage Appliance	LUN Location	LUN Size	Database Files
	/vol/sqldb5/lun2	400GB	(database files 17 & 18)
	/vol/sqldb5/lun3	400GB	(database files 23 & 24 and log file)

SQL Server 2005 Test Runs on 8-way System

A total of 24 400GB LUNs and two 700GB LUNs were created on six FAS920 storage systems. See Appendix for physical and logical database layout on all six FAS920 systems used for the tests.

The SQL Server database was comprised of 48 database files, and each LUN contained two database files. As the test environment was scaled from 4-way system to 8-way system, the storage was also scaled to perform in this high-workload environment. See Table 5 and Table 6 for full details.

Table 5) Eight-way system database layout.

Storage Appliance	LUN Location	LUN Size	Database Files
NetApp1	/vol/sqldb1/lun0	400GB	(database files 1 & 2)
	/vol/sqldb1/lun1	400GB	(database files 13 & 14)
	/vol/sqldb1/lun2	400GB	(database files 25 & 26)
	/vol/sqldb1/lun3	400GB	(database files 37 & 38)
	/vol/sqldb1/lun3	700GB	(rf_flatfiles & dbbackup files)
NetApp2	/vol/sqldb2/lun0	400GB	(database files 3 & 4)
	/vol/sqldb2/lun1	400GB	(database files 15 & 16)
	/vol/sqldb2/lun2	400GB	(database files 27 & 28)
	/vol/sqldb2/lun3	400GB	(database files 39 & 40)
NetApp3	/vol/sqldb3/lun3	400GB	(database files 5 & 6)
	/vol/sqldb3/lun1	400GB	(database files 17 & 18)
	/vol/sqldb3/lun2	400GB	(database files 29 & 30)
	/vol/sqldb3/lun3	400GB	(database files 41 & 42)
NetApp4	/vol/sqldb4/lun0	400GB	(database files 7 & 8)
	/vol/sqldb4/lun1	400GB	(database files 19 & 20)
	/vol/sqldb4/lun2	400GB	(database files 31 & 32)
	/vol/sqldb4/lun3	400GB	(database files 43 & 44)
NetApp5	/vol/sqldb5/lun0	400GB	(database files 9 & 10)

Storage Appliance	LUN Location	LUN Size	Database Files
	/vol/sqldb5/lun1	400GB	(database files 21 & 22)
	/vol/sqldb5/lun2	400GB	(database files 33 & 34)
	/vol/sqldb5/lun3	400GB	(database files 45 & 46)
NetApp6	/vol/sqldb6/lun0	400GB	(database files 11 & 12)
	/vol/sqldb6/lun1	400GB	(database files 23 & 24)
	/vol/sqldb6/lun2	400GB	(database files 35 & 36)
	/vol/sqldb6/lun3	400GB	(database files 47 & 48 and log file)

Performance

The FAS920s provided the high-performance and low-latency access to storage needed to demonstrate the SQL Server 2005 abilities. These systems delivered around 250MB per second I/O each during large table scans.

In order to ensure that any observed performance gains were the result of changes to SQL Server only, default storage array settings were used for all tests. The only exception to this was to *disable* prefetch during sequential read, since both SQL Server 2000 and SQL Server 2005 already generate sufficiently deep prefetch, enabling full system performance.

Table 6) Storage configuration.

Component	Details	
Operating system	Data ONTAP 6.5.2	
Storage interconnect	Emulex LightPulse 9002 and 9802 HBAs (Queue depth set to the maximum of 254)	
Storage Data Link Rate	2Gbps	
	4-way	**8-way**
Processor	3 * Network Appliance FAS920	6 * Network Appliance FAS920
Disks	114 * 72GB 15K RPM Drives	228 * 72GB 15K RPM Drives
LUNs	12 * 400GB and 1*700GB	24 * 400GB and 2*700GB
Database files	24	48

DSS Testing Queries

A number of typical decision support queries were run to stress the system and to evaluate changes as the system scaled. These queries, all of which differ from one another, were chosen for their complexity, their diversity in terms of data access patterns and query parameters, and because they access a large proportion of the available data. All queries were run as separate job requests. Note that all of these queries benefit from effective memory management.

Profit enhancement (PE): This query provides the total increase in profits, had certain discounts not been offered on products sold during a specified time period. The PE query assists in determining future product discounts.

Stress characteristics

I/O intensive

Intensive scan indexing required

Cost-efficient suppliers (CE): This query lists the supplier's details for purchasing a specified part, from lowest to highest cost. The CE query identifies the supplier offering a specific part at the lowest cost, and can help a business identify the appropriate supplier in a given geographic region.

Stress characteristics

Complex query

Query plan and optimization critical

High-value customers (HV): This query lists the top *N* number of customers based on their order history. The HV query ranks customers based on the quantity of their orders, thereby helping to identify the most valuable customers for the company.

Stress characteristics

High number of random reads

Requires intensive nested loop joins

Specified product profit (SP): This query provides annual profit summaries for a specified product, itemized by geographic region. The SP query helps a company determine its most profitable product by geographic region.

Stress characteristics

Complex query

Query plan and optimization critical

Pricing summary (PS): This query provides a total count and total price of all products sold during a specified time period. The time period was selected such that approximately 95% of the table was scanned. The PS query measures the total amount of business sales during the specified time frame.

Stress characteristics

Numerous floating point calculations

Expression evaluation performance critical

Unshipped order summary (UO): This query is used to extract a summary of a specified number of highest revenue generating orders not shipped by specified date. For example, if N=20, the query must return the highest 20 returns (unless fewer than 20 rows qualify for the SQL statement, in which case all rows must be returned). This query assists in identifying the shipment priority to meet company revenue goals.

Stress characteristics

Random reads

Requires intensive nested loop and hash joins

Late received orders (LR): This query provides a summary breakdown of products shipped to the customer prior to promised delivery date but not received on time. The LR query, which summarizes late orders by shipping method, helps in selecting the best shipping method to ensure future on-time deliveries.

Stress characteristics

Random reads

Requires intensive nested loop and hash joins

Test Results

The following graphs summarize the results of the DSS testing performed on SQL Server 2000 and SQL Server 2005.

SQL Server 2000 and SQL Server 2005 Performance Comparisons

For each query, tests were first run on SQL Server 2000 using a four-processor IA-64 platform, and then on SQL Server 2005 using the same physical configuration.

Comparative Execution Times

Figure 3 shows the execution times for high value customers (intensive joins), specified product profit (complex query), pricing summary (intensive floating point calculations), unshipped orders (intensive joins), and late received orders (high random reads). In all cases, execution times for queries run on SQL Server 2005 were faster than those run on SQL Server 2000, indicating significant performance improvements. The execution times for the remaining two variables, cost-efficient suppliers and profit enhancement (not shown) are not significantly different, although in both cases, the SQL Server 2005 numbers are incrementally better.

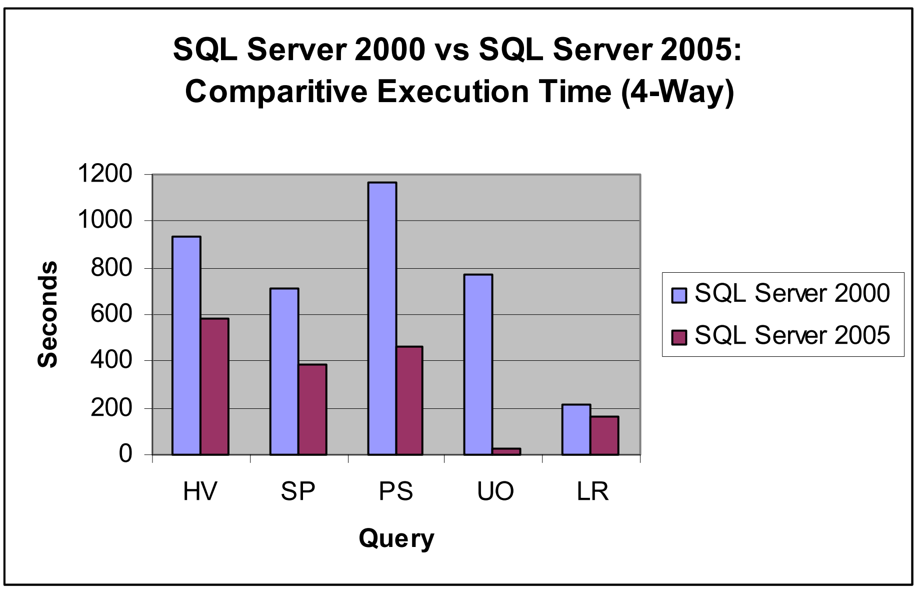

Figure 3) Comparative execution times for HV, SP, PS, UO, and LR queries.

Note that the combination of SQL Server 2005 and NetApp storage is particularly powerful. SQL Server 2005 was able to structure the data and the I/O requests more efficiently, delivering a throughput boost on disk-limited queries of between 4% and 20%.

Disk Read Performance

Figure 4 compares total disk read throughput (megabytes/second) for SQL Server 2000 and SQL Server 2005. For all query types, SQL Server 2005 disk reads are either equivalent or dramatically faster than the equivalent test in SQL Server 2000.

The increase in disk read throughput was especially high for the unshipped order query, demonstrating very effective utilization of the disk subsystems. In addition to query execution improvements, the query optimizer generated a very effective plan utilizing data correlation optimizations.

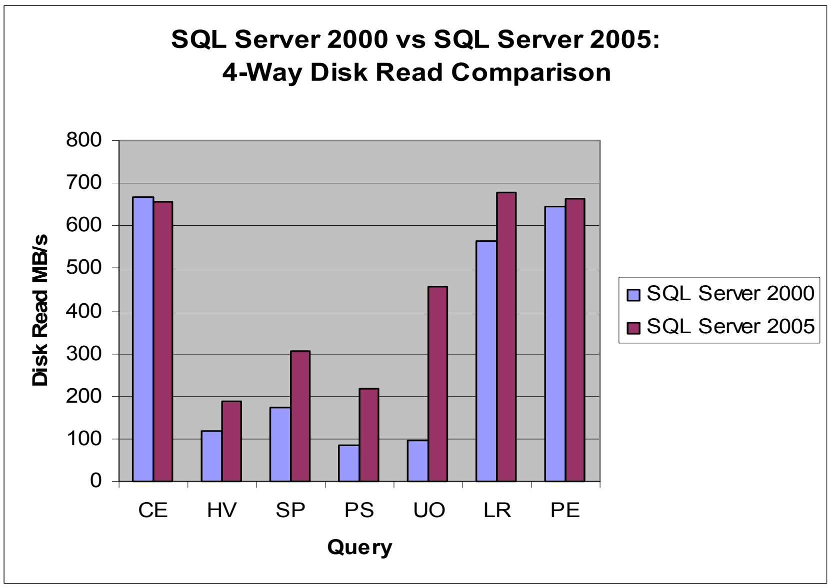

Figure 4) Comparison of total disk I/O.

Processor Utilization

SQL Server 2005 delivers a faster query response than SQL Server 2000, but at what cost? Data was also collected to determine system processor consumption—as measured by percent processor utilization—to determine whether SQL Server 2005 uses more system resources than its predecessor.

Figure 5 shows the results of four-way processor utilization. Overall, there is no significant change in CPU consumption between SQL Server 2005 and SQL Server 2000, indicating that the performance gains in SQL Server 2005 do not increase system resource costs.

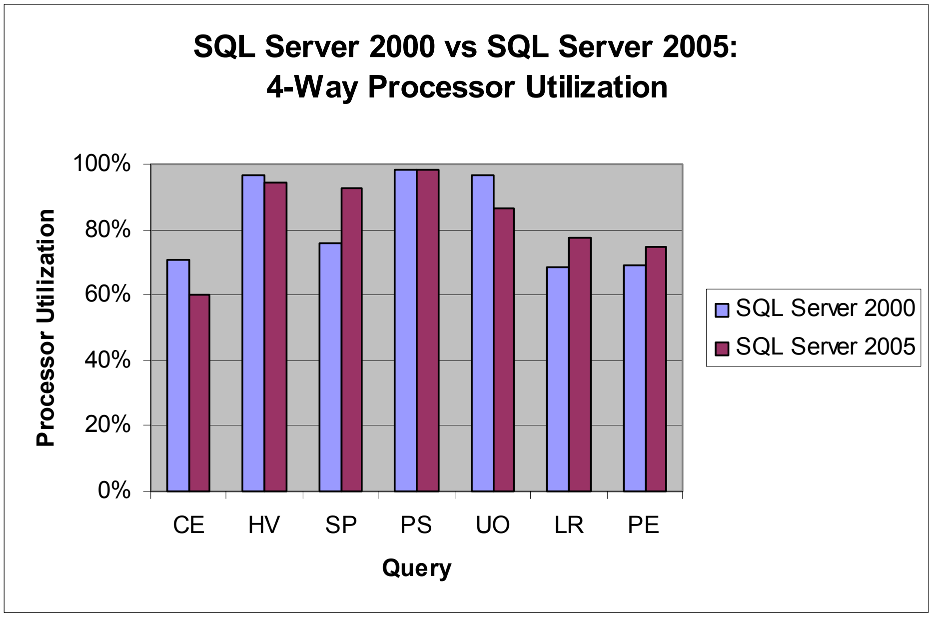

Figure 5) Comparative CPU consumption.

SQL Server 2005 Scaling Testing

In order to determine the performance impact of scaling from four processors to eight, additional SQL Server 2005 tests were run. Note that the eight-processor configuration was performed with storage arrays scaled up from three to six FAS920 storage systems.

Comparative Execution Times

The decrease in response time in Figure 6 and Figure 7 demonstrates that as the resources were doubled, the overall system responded with an almost linear improvement (1.9 times) in system scalability.

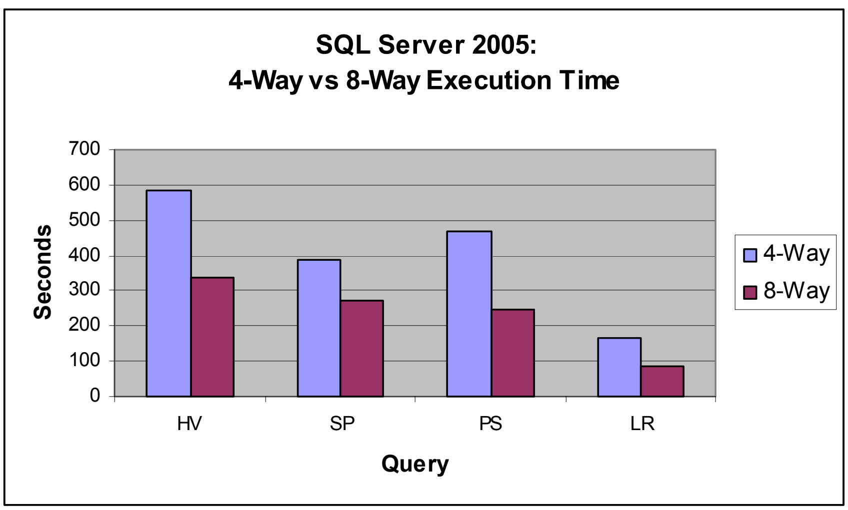

Figure 6) Four-processor/eight-processor execution times for HV, SP, PS, and LR queries.

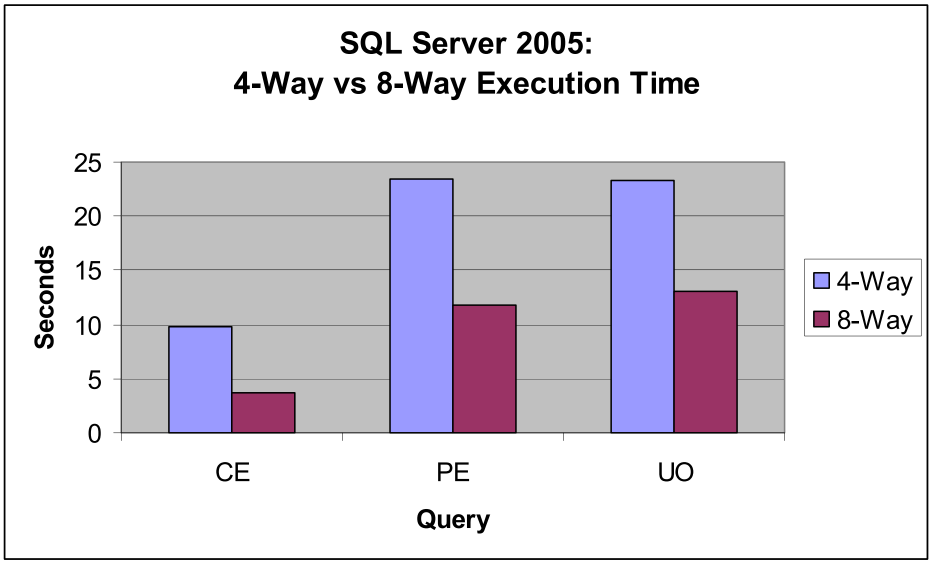

Figure 7) Four-processor/eight-processor execution times for CE, PE, and UO queries.

Disk Read Performance

How is system throughput impacted by scaling from four to eight processors? As seen in Figure 8, storage system throughput, measured as disk reads (megabytes/second), increases as the number of processors increases.

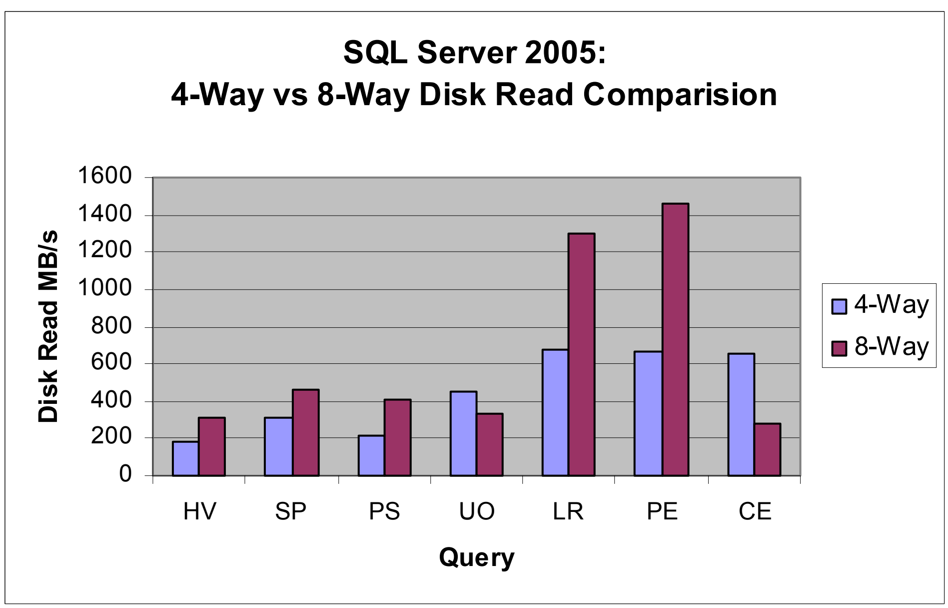

Figure 8) Four-processor/eight-processor disk read scaling.

Processor Utilization

Although query response time decreases as more system resources are added, how effective is SQL Server 2005 in making use of the overall system configuration? Figure 9 shows that CPU utilization of the four-processor and eight-processor systems are very similar, indicating that SQL Server 2005 uses system resources effectively.

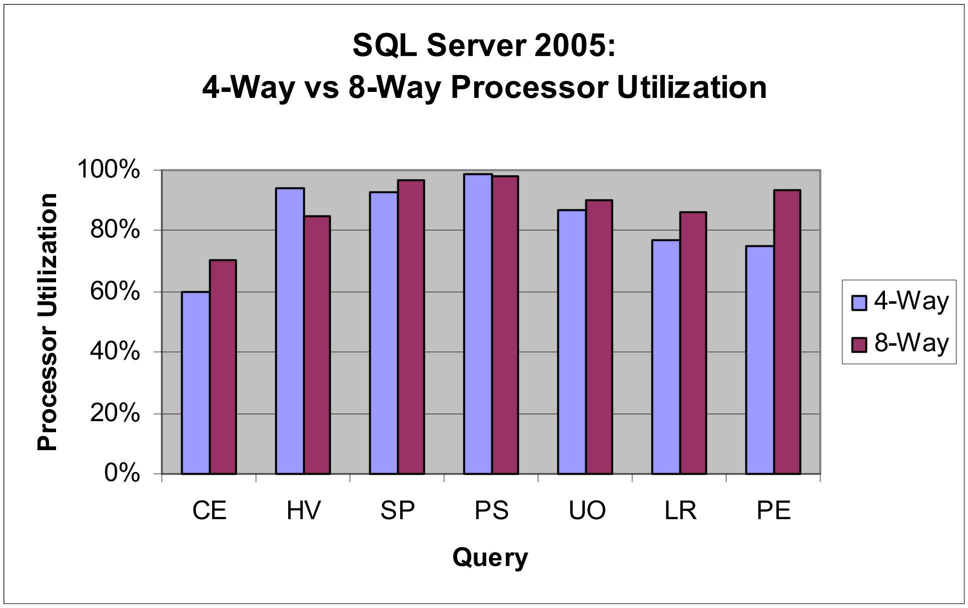

Figure 9) Four-processor/eight-processor comparative CPU usage.

Summary

This paper details a number of improvements in SQL Server 2005 that enhance the performance and scalability of decision support system queries.

A series of DSS queries were run against SQL Server 2000 and SQL Server 2005 to determine the effects of these changes on performance and resource utilization. Among the key results are the following:

- SQL Server 2005 has significantly improved the response time for certain DSS queries compared with SQL Server 2000.
- SQL Server 2005 and SQL Server 2000 consume equivalent amounts of CPU for the same types of queries.
- SQL Server 2005 generates equivalent or faster disk read throughput for the given queries than SQL Server 2000.

A second series of tests using the same set of DSS queries compared the scalability of SQL Server 2005 with four and eight processors. Among the key results were the following:

- The speed with which query results are returned increases almost linearly with additional CPU.
- Overall, disk reads are faster when scaling from four to eight processors.
- System resource usage is very similar for both four- and eight-processor configurations.

The tests carried out for SQL Server 2000 and 2005 showed that during the test runs the FAS920 storage system

- was able to sustain rates of 250MB/sec I/O each, during periods of large sequential table scans
- was able to deliver response times of less than 5 msec, during periods when queries used small random access
- had disk utilization between 20% and 45%

Based on these performance tests, the results indicate that for complex DSS queries, SQL Server 2005 performance and scalability exceeds that of SQL Server 2000. These results also demonstrate that SQL Server 2005 can make effective use of industry-leading block-based storage technologies like the Network Appliance FAS920 storage system.

Appendix

Storage System Layout

The following figures show the physical and logical layouts of the storage systems for hosting the SQL Server database files. All storage was provided by Network Appliance, as detailed in Table 6.

Storage Layout for Four-processor Testing

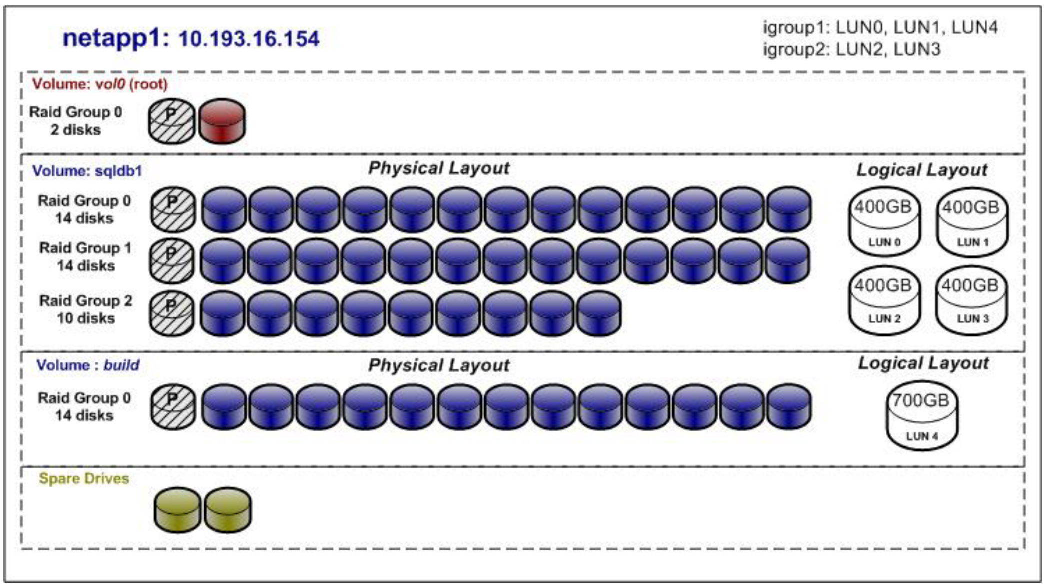

Figure 10) FAS920-1 disk layout.

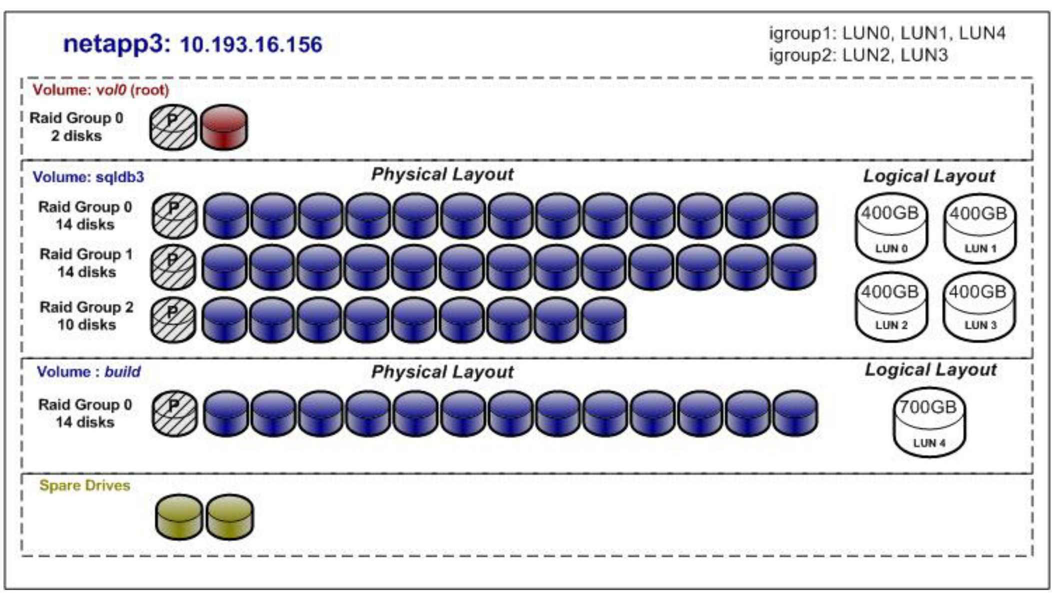

Figure 11) FAS920-3 disk layout.

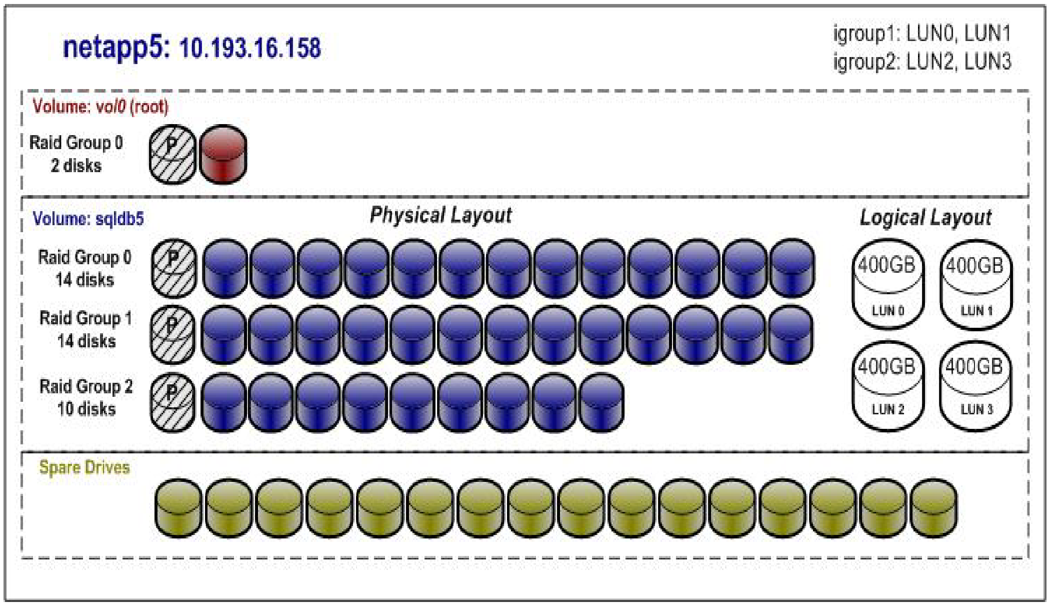

Figure 12) FAS920-5 disk layout.

Storage Layout for four-processor Testing

These systems are additional to that for the four-processor testing configuration, making a total of six FAS920s for the eight-processor tests.

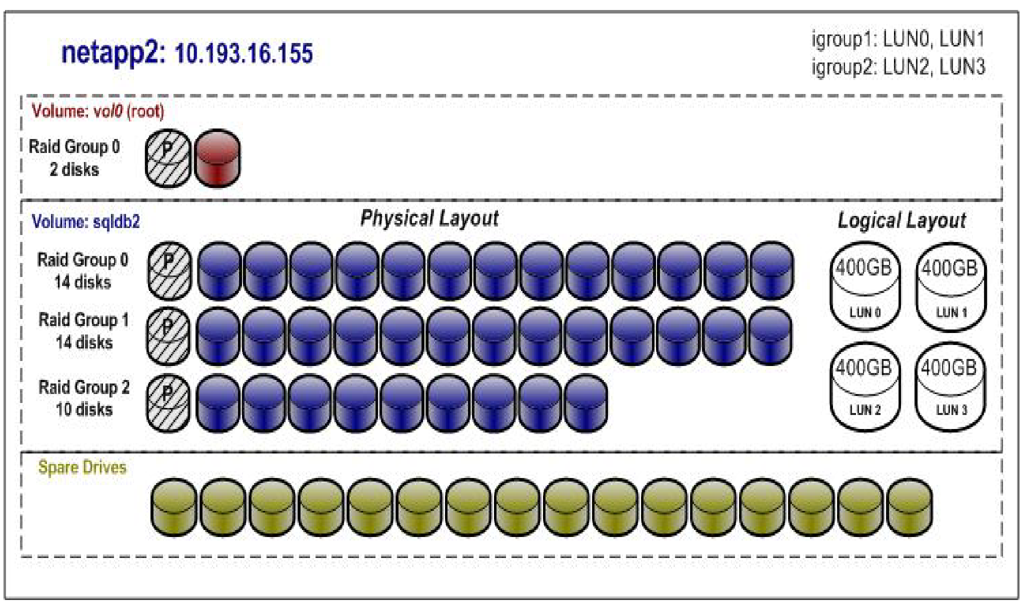

Figure 13) FAS920-2 disk layout.

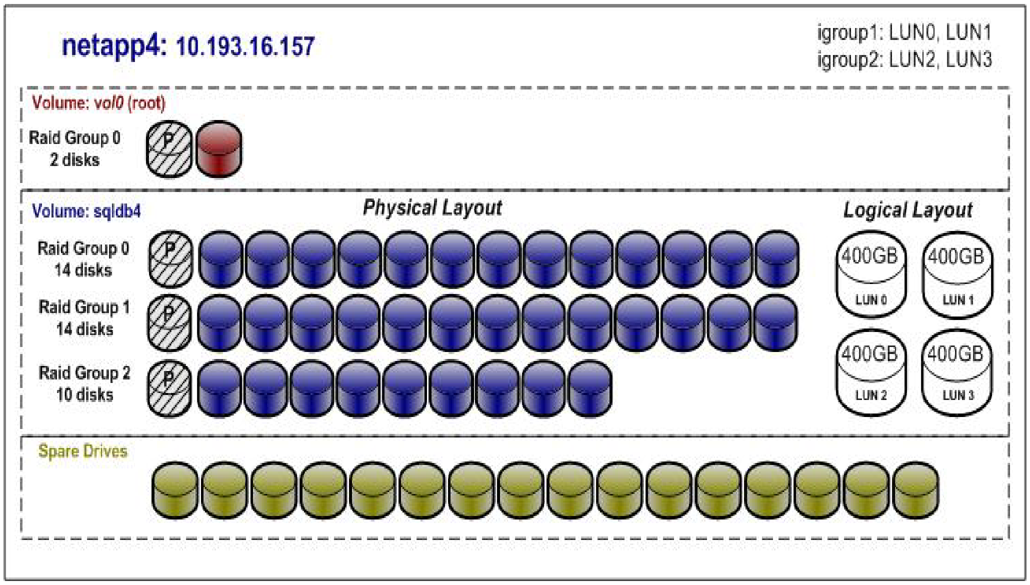

Figure 14) FAS920-4 disk layout.

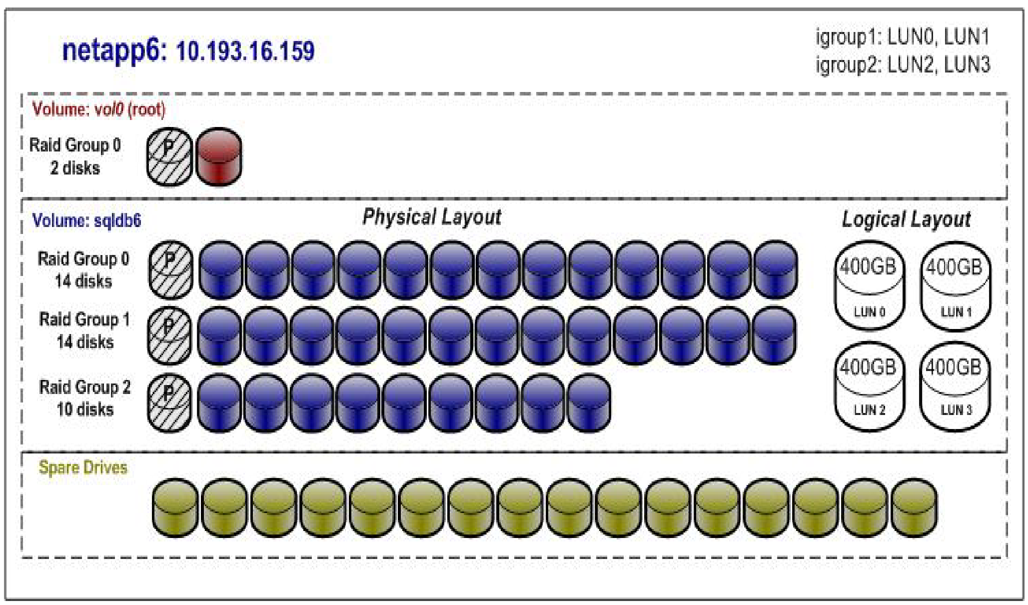

Figure 15) FAS920-6 disk layout.

Related Links

See the following resources for further information:

NetApp storage systems information at http://www.netapp.com/products/filer/index.html

NetApp SnapManager for SQL Server at http://www.netapp.com/products/software/snapmanager-sql.html

10 reasons to choose NetApp storage consolidation for SQL Server at http://www.netapp.com/ftp/sc-sql-10reasons.pdf

For the latest information about SQL Server 2005, see the Microsoft SQL Server site at www.microsoft.com/sql/2005/

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