SQL Server Storage Engine under the hood

How SQL Server performs I/O

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select * from =tg=

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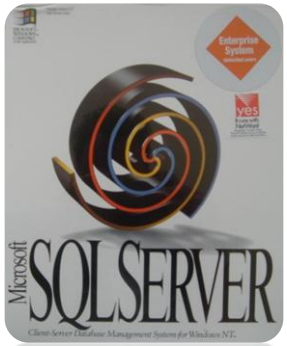
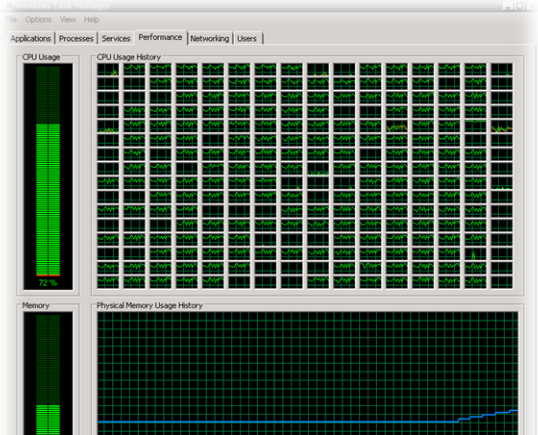
Focus on SQL Server Performance Engineering, Infrastructure and Architecture

Close Relationship with
- SQLCAT (SQL Server Customer Advisory Team)
- SCAN (SQL Server Customer Advisory Network)
- TAP (Technology Adoption Program)
- Product Teams in Redmond

Active PASS member and PASS Summit Speaker

@@Version	Remark
SQL 4.21	First SQL Server ever used (1994)
SQL 6.0	First Log Shipping with failover
SQL 6.5	First SQL Server Cluster (NT4.0 + Wolfpack)
SQL 7.0	2+ billion rows / month in a single Table
SQL 2000	938 days with 100% availability
SQL 2000 IA64	First SQL Server on Itanium IA64
SQL 2005 IA64	First OLTP long distance database mirroring
SQL 2008 IA64	First Replication into mirrored databases
SQL 2008R2 IA64 SQL 2008R2 x64	First 256 CPUs & >500.000 STMT/sec First Scale out > 1.000.000 STMT/sec First time 1.2+ trillion rows in a table
SQL 11 (Denali)	> 220.000 Transactions per second Can't wait to push the limits even further



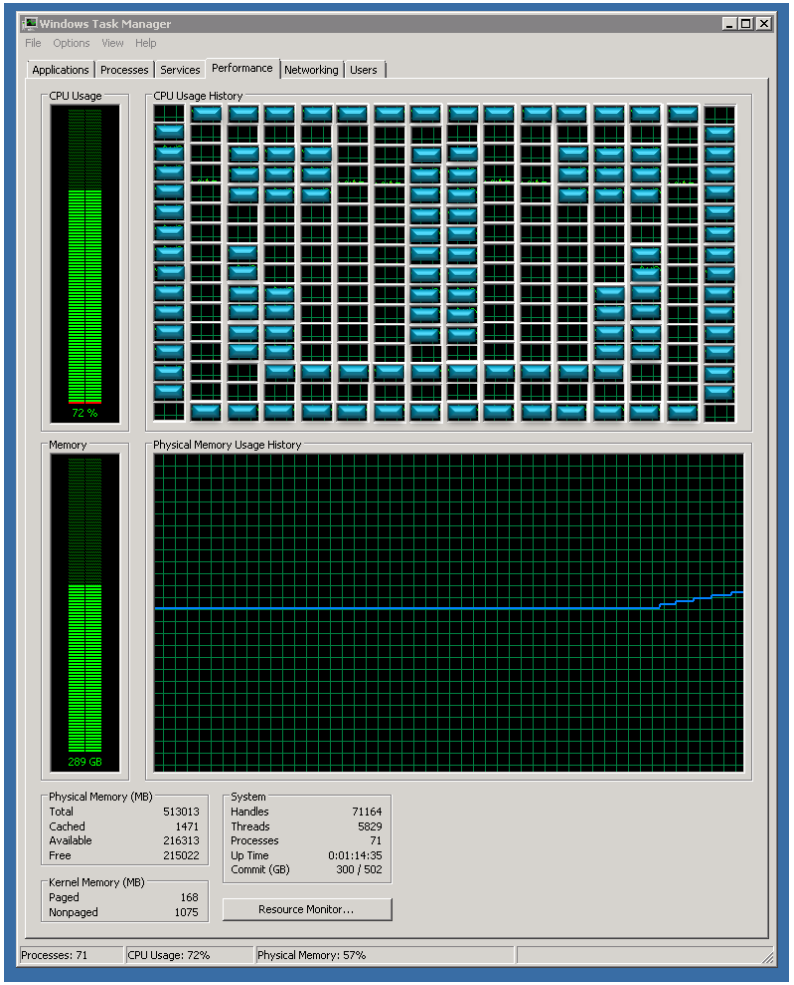


New Book
Expert SQL Server Performance Engineering
coming in 2012 from APress

PASS 2011 SUMMIT

My favorite new SQL2008 R2 feature

CREATE INDEX WITH A SMILE



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Some of the slides and content were originally created and/or the data was collected by

- Thomas Kejser, SQLCAT, Microsoft
- Jürgen Thomas, SQLCAT, Microsoft
- Gunter Zink, Performance Engineering, HP

Thanks to all of them for doing such a great job in discovering, collecting and documenting SQL Server "Know How"

Agenda

I/O Basics

What is an I/O sub system?

Understanding SQL Server I/O Patterns

Storage types

Wrap Up

Q&A

IO Basics

I/O Basics

Random / Sequential

How data is organized in SQL Server

When does IO occur during transactions

Available IO System Technologies

Random / Sequential

Sequential:

- Data is read/written from the IO subsystem in the same order as it is stored on the IO subsystem.

Random:

- Data is read/written from the IO subsystem in a different order as it is stored on the IO subsystem.

Careful: On bad configured/dimensioned/sized systems sequential IO on non RAID 1 may become random IO

How data is organized

SQL Server is an in memory database
All operations are performed in memory
The format on disk and in memory is the same !

8KB pages = 8192 bytes

- 96 bytes of page header
- 8096 bytes of data
  (usage depends of page type [data, index, PFS, …])

8 contiguous pages are combined to a segment
Segment size is 64KB

The query processor just requests the page from the buffer pool the buffer pool knows if its in memory or if it has to pull in from disk

Disk File structure

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Select statement

SELECT * FROM T WHERE ID = 5

Query processor chooses to do an index seek

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Buffer pool

SELECT * FROM T WHERE ID = 5

Page Nr										
Page type										
Data										

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Read root page buffer pool

SELECT * FROM T WHERE ID = 5

Page Nr	8									
Page type	Root									
Data	1:9 12:10									

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Read index page into buffer pool

SELECT * FROM T WHERE ID = 5

Page Nr	8	9								
Page type	Root	Index								
Data	1:9 12:10	1:11 5:12 8:13 10:14								

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Data page into buffer pool

SELECT * FROM T WHERE ID = 5

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Freak							

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Transaction

UPDATE T SET Name = 'Frank' WHERE ID = 6

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Freak							

LOG

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Update Data in memory

UPDATE T SET Name = 'Frank' WHERE ID = 6

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

LOG

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Write to Transaction Log

UPDATE T SET Name = 'Frank' WHERE ID = 6

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Checkpoint: dirty pages are written to disk

CHECKPOINT

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

LOG	ID 6;Old Freak;New Frank									

IO

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Freak	8: Hans	10: Pete	12: Rick 14: Sam		

Checkpoint: Completion persisted in Log

CHECKPOINT

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: And y 2: Bob	5: Eric 6: Frank	8: Hans	10: Pete	12: Rick 14: Sam		

Transaction Log Backup

BACKUP LOG …

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Frank	8: Hans	10: Pete	12: Rick 14: Sam		

Transaction log is cleared
after the LOG Backup is completed

Page Nr	8	9	12							
Page type	Root	Index	Data							
Data	1:9 12:10	1:11 5:12 8:13 10:14	5: Eric 6: Frank							

Page Nr	…	8	9	10	11	12	13	14	15	16	…
Page type		Root	Index	Index	Data	Data	Data	Data	Data	Empty	
Data		1:9 12:10	1:11 5:12 8:13 10:14	12:15	1: Andy 2: Bob	5: Eric 6: Frank	8: Hans	10: Pete	12: Rick 14: Sam		

What is an I/O Subsystem?

Available IO System Technologies

SAN Storage Area Network

DAS Direct Attached Storage

- Typically SCSI disks where the controller is in the server and the disk in an external chassis

SSD Solid State Device

- The disk **is** the controller
- Do not confuse with Solid State Disk that can be used in DAS or SAN environments

Measuring I/O

An I/O subsystem has three characteristics

1. **Capacity**
   - Measured in GB/TB

The easy one!

2. **Throughput**
   - Measured in MB/sec or IOPs
   - Performance Monitor: Logical Disk
     - Disk Read Bytes / Sec
     - Disk Write Bytes / Sec
     - Disk Read / Sec
     - Disk Writes / Sec

3. **Latency**
   - Measured in milliseconds (ms)
   - Performance Monitor: Logical Disk
     - Avg. Disk Sec / read
     - Avg. Disk Sec / write
   - Consistent high values (>15ms) indicate I/O bottleneck

The hard one!

Specifying I/O

When building an I/O system, it is important to understand both limitations and growth options

- Maximum Throughput
  - Depends on:
    - Block sizes requested
    - Sequential vs. Random
    - Read or write pattern
- Minimum latency
  - The lower limit for latency
  - Important for real time systems
- Capacity

Understand how to grow the three factors

It takes a **LOT** of I/O to saturate SQL Server

- DW workload typically more I/O intensive than OLTP
- Not unusual to see machine dedicated SAN for large DW installations

Basic requirements of storage

Stable and Durable

- Storage must survive system restart or common failure
  - Power loss
  - Drive failure
  - Controller failure

Write Ordering

- Preserving order of I/O operations

RAID levels

Both a stability and a performance technology

Characteristics depend on RAID level

- Abilities depend on storage vendor implementation
- RAID 1/0 is typically the fastest option

The more cache the controllers/arrays have the less the RAID level matters.

- Except while in degraded state!
  - RAID 5 and RAID 6 much slower when degraded
  - Rebuild takes forever

Best Practice: Benchmark and compare the different RAID levels before deploying

SQL Server I/O Characteristics

Understanding I/O patterns

The I/O pattern generated by SQL Server varies by the workload

Relational Database Workloads

- Log Writes
- Checkpoint / Lazy Writer
- Index Seeks
- Table / Range Scans
- Bulk Load

Log Writes - Workload Description

Threads fill log buffers & requests log manager to flush all records up to certain LSN

- log manager thread writes the buffers to disk

Log manager throughput considerations

- SQL Server 2000 SP4 & SQL Server 2005 RTM
  - Limit log writes to 8 outstanding (per database)
- SQL Server 2005 SP1 or later
  - Limit of 8 (32-bit) or 32 (64-bit) outstanding log writes
  - No more than 480K "in-flight" for either
- SQL Server 2008 increases "in-flight" per log to 3840K (factor of 8)

Log Writes - Pattern / Monitoring

Sequential I/O

Write size varies

- Dependent on nature of transaction
- Transaction "Commit" forces log buffer to be flushed to disk
- Up to 60KB

SQL Server Wait Stats

- WRITELOG
- LOGBUFFER

Performance Monitor:

- MSSQL: Databases
  - Log Bytes Flushed/sec
  - Log Flushes/sec
  - Avg. Bytes per Flush = (Log Bytes Flushed/sec) / (Log Flushes/sec)
  - Wait per Flush = (Log Flush Wait Time) / (Log Flushes / sec)

Checkpoint / Lazy Writer

Workload Description / Types of Checkpoints

- Background/automatic checkpoints: Triggered by log volume or recovery interval and performed by the checkpoint thread
- User-initiated checkpoints: Initiated by the T-SQL CHECKPOINT command.
- Reflexive checkpoints: Automatically performed as part of some larger operation, such as recovery, restore, snapshot creation, etc.

Checkpoint / Lazy Writer

Pattern / Monitoring

- Random, but SQL Server will attempt to find adjacent pages
- Up to 256KB in a single I/O request
- Performance Monitor
  - MSSQL:Buffer Manager
    - Checkpoint pages / sec
    - Lazy Writes / sec

Checkpoint (continued)

Checkpoint Throttling

- Checkpoint measures I/O latency impact and automatically adjusts checkpoint I/O to keep the overall latency from being unduly affected
- CHECKPOINT [checkpoint_duration]
  - CHECKPOINT now allows an optional numeric argument, which specifies the number of seconds the checkpoint should take
  - Checkpoint makes a "best effort" to perform in the time specified
  - If specified time is too low it runs at full speed

NUMA systems spread the checkpoints to lazy writers on each node

Index Seeks - Workload Description

Query plans performing loop joins will typically do many index seeks

Single row lookups in index

Traverse the B-Tree of the index, retrieve single page / row

OLTP workloads typically heavy on these

SQL Server may perform read-ahead

- Single page request bring in entire 8-page (64KB) extent
- Helps server come up to speed quicker

Index Seeks - Pattern / Monitoring

Random I/O

8 KB Block Sizes

- 64KB when doing read ahead and during startup

SQL Server Wait Stats

- PAGEIOLATCH_<X>

dm_db_index_usage_stats

- user_seeks
- user_lookups

Performance Monitor:

- MSSQL:Access Methods
  - Index Seeks / Sec
- MSSQL:Buffer Manager
  - Readahead Pages / sec

Table / Range Scan - Workload Description

Query plans doing hash and merge joining

Aggregation Queries

Typical for DW workloads

SQL Server may perform read-ahead

- Dynamically adjust read-ahead size by table
- Standard Edition: Up to 128 pages
- Enterprise Edition: Up to 512 pages

Table / Range Scan - Pattern / Monitoring

Sequential I/O

- 64-512KB Block Sizes

SQL Server Wait Stats

- PAGEIOLATCH_<X>

dm_db_index_usage_stats

- user_scans

Performance Monitor:

- MSSQL:Access Methods
  - Range Scans / Sec
  - Table Scans / Sec
- MSSQL:Buffer Manager
  - Readahead Pages / sec

Bulk Load - Workload Description

Occurs when a bulk load operation is performed

Typical for DW workloads

I/O Depends on Data recovery mode

- SIMPLE / BULK LOGGED mode writes to database
- FULL writes to transaction log and flush to database

Bulk Load - Pattern / Monitoring

Sequential I/O

64KB-256 KB

- Block sizes depend on database file layout

SQL Server Wait Stats

- WRITELOG / LOGBUFFER
- PAGEIOLATCH_EX
- PAGELATCH_UP
  - PFS Contention, not I/O related

SQL Server I/O Characteristics- Summary

Workload	Type	Block Size
Log writes	Sequential	Up to 60KB
Checkpoint / Lazy Write	Random	Up to 256KB
Index Seeks	Random	8KB 64KB (read Ahead)
Table / Range Scan	Sequential	64KB-512KB
Bulk Load	Sequential	64KB-256KB
Backup Operations	Sequential	64KB-4MB

Typical I/O Workloads

OLTP (Online Transaction Processing)

- Typically, heavy on 8KB random read / writes
- Some amount of read-ahead
  - Size varies – multiples of 8K (see read-ahead slide)
  - Many "mixed" workloads observed in customer deployments
- **Rule of Thumb**: Optimize for Random I/O

RDW (Relational Data Warehousing)

- Typical 64-256KB sequential reads (table and range scan)
- 128-256KB sequential writes (bulk load)
- **Rule of Thumb**: Optimize for Sequential I/O

SQL Server View of I/O

Tool	Monitors	Granularity
sys.dm_io_virtual_file_stats	Latency, Number of IO's	Database files
sys.dm_exec_query_stats	Number of … Reads (Logical Physical) Number of writes	Query or Batch
sys.dm_db_index_usage_stats	Number of IO's and type of access (seek, scan, lookup, write)	Index or Table
sys.dm_db_index_operational_stats	IO latch wait time, Page splits	Index or Table
sys.dm_os_wait_stats	PAGEIOLATCH waits	SQL Server Instance level (cumulative since last start – most useful to analyze over time periods).
Xevents	PAGEIOLATCH waits	Query and Database file

Windows View of I/O

Counter	Description
Disk Reads/Writes per Second	Measures the Number of I/O's per second Discuss with vendor sizing of spindles of different type and rotational speeds Impacted by disk head movement (i.e. short stroking the disk will provide more I/O per second capacity)
Average Disk/sec Read & Write	Measures disk latency. Numbers will vary, optimal values for averages over time: 1 - 5 ms for Log (Ideally 1ms or better) 5 - 20 ms for Data (OLTP) (Ideally 10ms or better) <=25-30 ms for Data (DSS)
Average Disk Bytes/Read & Write	Measures the size of I/O's being issued. Larger I/O tend to have higher latency (example: BACKUP/RESTORE)
Current Disk Queue Length	Hard to interpret due to virtualization of storage. Not of much use!
Disk Read & Write Bytes/sec	Measure of total disk throughput. Ideally larger block scans should be able to heavily utilize connection bandwidth.

Storage Types

Storage Selection - General

Understanding the I/O characteristics and availability requirements is key

Engage the engineers from all sides, early on

Number of spindles matter

- More spindles typically yield better speed
  - True for both SAN and DAS
  - New game on SSD

There is no one single "right" way to configure storage for SQL Server

- Physical isolation practices become more important at the high end

Best Practice: Validate and compare configurations prior to deployment

Storage Selection-Common Pitfalls

There are barriers between DBA's and storage administrators

- Each needs to understand the others "world"

Sizing only on "capacity" is a common problem

- Must take latency and throughput into consideration

One size fits all type configurations

- Storage vendor should have knowledge of SQL Server and Windows best practices when array is configured
  - Especially when advanced features are used (snapshots, replication, etc…)

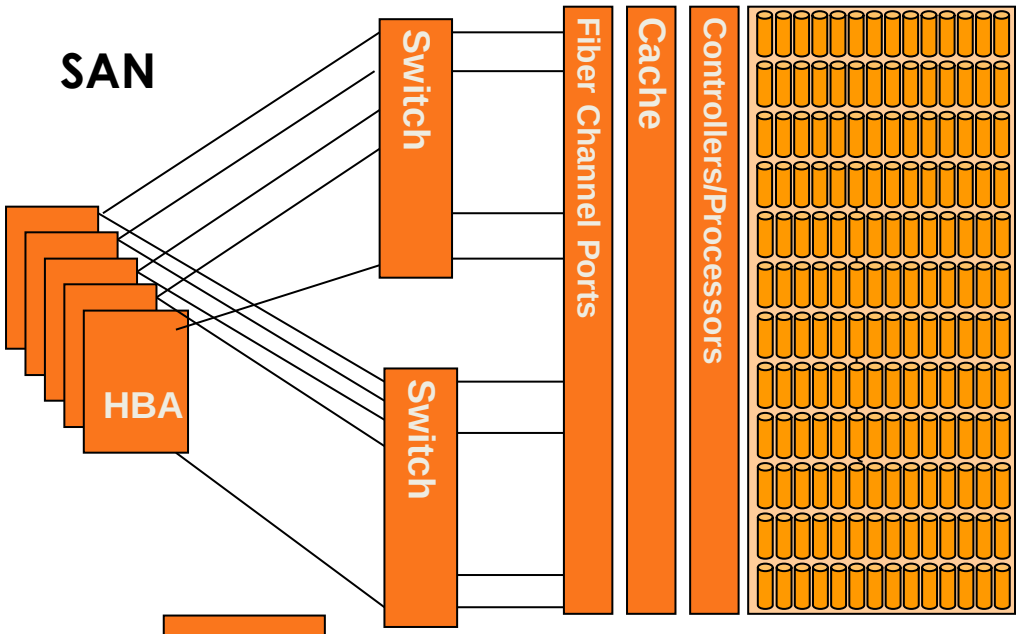
SAN is complex

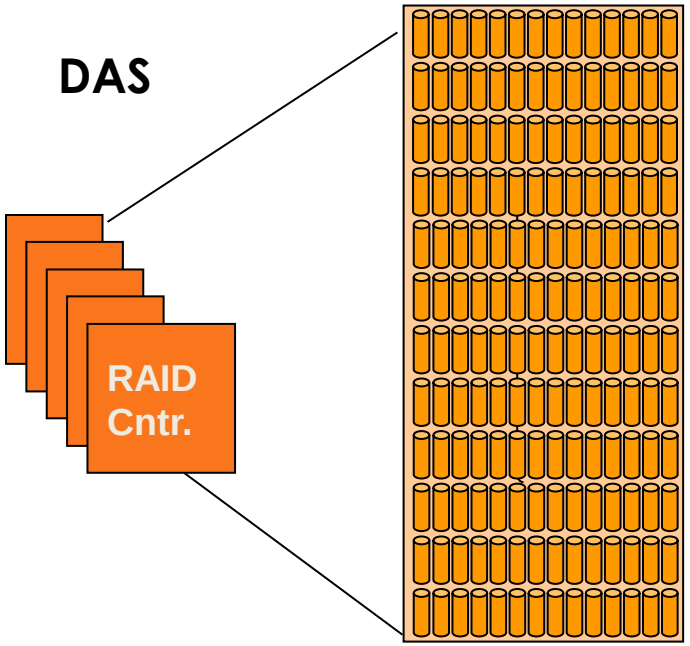
- Generally involves multiple organizations to put a configuration in place

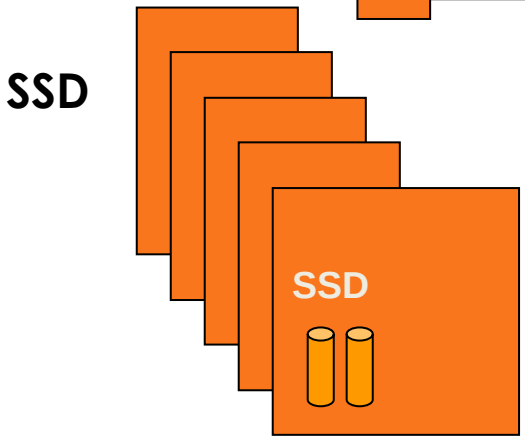
Feature	SAN	DAS	SSD
Cost	High - but may be offset by better utilization	Low - But may waste space	Very High
Flexibility	Virtualization allows online configuration changes	Better get it right the first time	Low
Skills required	Steep learning curve	Simple and well understood	New Technology
Additional Features	Snapshots Storage R		None
Performance	Contrary belief, SA performan technology	ce for	Very High
Reliability	Very high reliability	Typically le liable. - May be offse higher redunda on RAID levels	Wear down time is relatively short
Clustering Support	Yes	No	No

SQL Server Codename Denali will change that

Understand the path to the drives







SQL Server on SAN – Common Pitfalls

Non-disk related bottlenecks

- Many shared components (fiber ports / switches, array cache, service processors, etc…) in SAN
- Disks may not be the bottleneck – understand the full path to the drives

Physical design matters!

- Think about splitting workloads with very different I/O configurations at the physical (disk) level
- Provides predicable performance
- Sharing disks between servers may be a very *bad* idea

SAN Cache does *not* solve all performance problems

- Limited benefit for random read and for read-ahead operations within SQL Server
- Best to tune for writes; supporting low log latency and absorbing checkpoint operations
- Cache trashing may occur, especially with heavy DW workload.

Configuration Issues

- Queue depth set too low, multi-pathing improperly configured
- Get the right drivers
- HBA placement: Avoid overloading single PCI bus with HBA traffic

SQL Server on DAS - Common Pitfalls

Beware of non disk related bottlenecks

- SCSI controller may not have bandwidth to support disks
- PCI-X bus should be fast enough
- Example: Need PCIe 8x to consume 1GB/sec

Can use Dynamic Disks to stripe LUN's together

- Bigger, more manageable partitions

Cannot grow storage dynamically

- Buy enough
- … or plan database layout to support growth

Inexpensive way to create very high performance I/O system

No SAN = No Cluster!

Solid State Devices

Emerging technology
Storage device based on DRAM and NAND flash (SLC & MLC)
Fits into PCI slot

- Drivers required

Advantages

- Performance, weight, power consumption, more durable
- Random = Sequential !

Disadvantages

- Cost per GB
- Limited experience for enterprise use

Most appealing for

- IOPs intensive "Tier 0" storage (LOG files, TempDB)
- Mobile devices
- Very random reads

Solid State Disks

Emerging technology
Storage device based on NAND flash (MLC & SLC)
Fits into regular HDD slot

- Utilizes the same command set and interface
- Can be used both in SAN and DAS

Advantages

- Performance, weight, power consumption, more durable
- Random = Sequential !

Disadvantages

- Controller is the limit
- Cost per GB, shifting bottleneck
- Writes are expensive relative to reads

Most appealing for

- IOPs intensive "Tier 0" storage RANDOM READS
- Mobile devices

Tools

SQLStress

- SQLStress is the tool to stress test a Microsoft SQL Server installation. It can also be used for hardware sizing, system tuning, benchmarking or verifying "High Availability Features" like clustering and database mirroring.
- http://www.sqlstress.com/

Diskpar.exe

- Windows 2000 Companion CD
- http://www.microsoft.com/windows2000/techinfo/reskit/en-us/default.asp?url=/windows2000/techinfo/reskit/en-us/prork/pree_exa_oori.asp

SQLIO

- Used to stress an I/O subsystem – Test a configuration's performance
- http://www.microsoft.com/downloads/details.aspx?FamilyId=9A8B005B-84E4-4F24-8D65-CB53442D9E19&displaylang=en

SQLIOSim

- Simulates SQL Server I/O – Used to isolate hardware issues
- 231619 HOW TO: Use the SQLIOStress Utility to Stress a Disk Subsystem http://support.microsoft.com/?id=231619

Fiber Channel Information Tool

- Command line tool which provides configuration information (Host/HBA)
- http://www.microsoft.com/downloads/details.aspx?FamilyID=73d7b879-55b2-4629-8734-b0698096d3b1&displaylang=en

KB Articles

KB 824190 Troubleshooting Storage Area Network (SAN) Issues
- http://support.microsoft.com/?id=824190

KB 304415: Support for Multiple Clusters Attached to the Same SAN Device
- http://support.microsoft.com/?id=304415

KB 280297: How to Configure Volume Mount Points on a Clustered Server
- http://support.microsoft.com/?id=280297

KB 819546: SQL Server support for mounted volumes
- http://support.microsoft.com/?id=819546

KB 304736: How to Extend the Partition of a Cluster Shared Disk
- http://support.microsoft.com/?id=304736

KB 325590: How to Use Diskpart.exe to Extend a Data Volume
- http://support.microsoft.com/?id=325590

KB 328551: Concurrency enhancements for the tempdb database
- http://support.microsoft.com/?id=328551

KB 304261: Support for Network Database Files
- http://support.microsoft.com/?id=304261

General Storage References

Microsoft Windows Clustering: Storage Area Networks

- http://www.microsoft.com/windowsserver2003/techinfo/overview/san.mspx

StorPort in Windows Server 2003: Improving Manageability and Performance in Hardware RAID and Storage Area Networks

- http://www.microsoft.com/windowsserversystem/wss2003/techinfo/plandeploy/storportwp.mspx

Virtual Device Interface Specification

- http://www.microsoft.com/downloads/details.aspx?FamilyID=416f8a51-65a3-4e8e-a4c8-adfe15e850fc&DisplayLang=en

Windows Server System Storage Home

- http://www.microsoft.com/windowsserversystem/storage/default.mspx

Microsoft Storage Technologies – Multipath I/O

- http://www.microsoft.com/windowsserversystem/storage/technologies/mpio/default.mspx

Storage Top 10 Best Practices

- http://sqlcat.com/top10lists/archive/2007/11/21/storage-top-10-best-practices.aspx

SQL Server Storage References

SQL Server Consolidation on the 64-Bit Platform
- http://www.microsoft.com/technet/prodtechnol/sql/2000/deploy/64bitconsolidation.mspx

SQL Server Consolidation on the 32-Bit Platform using a Clustered Environment
- http://www.microsoft.com/technet/prodtechnol/sql/2000/deploy/32bitconsolidation.mspx

SQL Server 2000/2005 I/O Basics on TechNet
- http://www.microsoft.com/technet/prodtechnol/sql/2000/maintain/sqlIObasics.mspx
- http://www.microsoft.com/technet/prodtechnol/sql/2005/iobasics.mspx

Microsoft SQL Server I/O subsystem requirements for the tempdb database
- http://support.microsoft.com/kb/917047

SQL Server AlwaysOn Partner program
- http://www.microsoft.com/sql/alwayson/default.mspx

SQL Server PreDeployment Best Practices
- http://www.microsoft.com/technet/prodtechnol/sql/bestpractice/pdpliobp.mspx

Scalability and VLDB Resources on Microsoft.com
- http://www.microsoft.com/sql/techinfo/administration/2000/scalability.asp

Case Studies

ICE Reference case

- http://msevents.microsoft.com/CUI/EventDetail.aspx?EventID=1032341825&Culture=en-US

SQL Server Case Studies

- http://www.microsoft.com/sql/casestudies/default.mspx

References – Vendor Specific

Microsoft SQL Server OLTP Applications for the Adaptable Modular Storage 1000

- http://www.hds.com/related-information/best-practices-for-microsoft-sql-server-oltp-applications.html?WT.ac=hp_sp2_r0_oltp_072508

Hitachi Adaptable Modular Storage 2000 Family Best Practices with Microsoft® SQL Server

- http://www.hds.com/assets/pdf/hitachi-adaptable-modular-storage-2000-family-bp-guide-for-sql-server.pdf

Hitachi Dynamic Provisioning Software Best Practices Guide - Guidelines for the Use of Hitachi Dynamic Provisioning Software with the Microsoft® Windows Operating System and Microsoft SQL Server 2005, Microsoft Exchange 2003 and Microsoft Exchange 2007

- http://www.hds.com/assets/pdf/hitachi-dynamic-provisioning-software-best-practices-guide-microsoft.pdf

Tuning Microsoft SQL Server 2005 Performance

- http://www.hds.com/assets/pdf/tuning-microsoft-sql-server-2005-performance-wp.pdf

Hitachi HiCommand® QoS for Microsoft SQL Server

- http://www.hds.com/assets/pdf/br_hicommand_qos_ms_sql_server_568.pdf

Microsoft® SQL Server "Always On" Technologies Hitachi Data Systems Contributes "Always On" Storage Solutions

- http://www.hds.com/assets/pdf/microsoft-sql-server-always-on-technologies.pdf

Solutions : Microsoft SQL Server

- http://www.hds.com/solutions/applications/microsoft/ms-sql-server.html

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