SQLskills Immersion Event

IEPTO2: Performance Tuning and Optimization

Module 4: I/O Concepts and I/O Subsystems for DBAs

Jonathan Kehayias

Jonathan@SQLskills.com

Overview

- **Defining storage terminology**
  - IOPS, MB/sec, Latency
- **Magnetic vs. Solid State Drives (SSDs)**
- **RAID configurations**
- **Storage Area Networks**
- **Configuring drives in Windows**
- **Testing with Diskspd and Iometer**

IOPS

- **Number of read or write operations performed per second**
- **Size matters**
  - Smaller block sizes will allow higher I/Os per second than large blocks
  - Watch out for vendor configuration quotes
    - Stated IOPS are typically 4KB block sizes which is rare for databases
- **Important for OLTP workloads where transactions are small and reads/writes are typically single page and highly random**
- **Monitoring in Performance Monitor**
  - Physical Disk: Disk Transfers/Sec
  - Physical Disk: Disk Writes/Sec
  - Physical Disk: Disk Reads/Sec

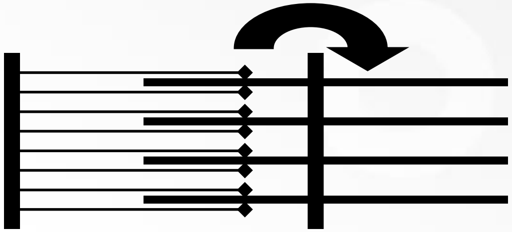
Throughput (Bandwidth) in MB/sec

- **Measurement of the amount of data that can be transferred to or from the disk configuration for a average block size**
  - Rough approximation (number of operations) x (size of operation)
- **Size matters**
  - Larger block sizes will allow higher MB/sec at lower IOPS than small blocks
- **Important for data warehouse and other large scan implementations but generally not as important OLTP databases**
- **Very useful for testing appropriate functionality of multiple paths with SANs (covered in Module 3)**
- **Monitoring in Performance Monitor**
  - Physical Disk: Disk Bytes/Sec
  - Physical Disk: Disk Write Bytes/Sec
  - Physical Disk: Disk Read Bytes/Sec

Latency

- **How long it takes an operation to finish measured in milliseconds**
- **General SQL Server guidelines**
  - < 8ms: excellent
  - < 12ms: good
  - < 20ms: fair
  - > 20ms: poor
- **Reality is “It Depends”**
  - Block size matters, larger block I/O’s take longer to complete
  - Should be workload and SLA-based to meet business requirements
  - Log writes should be as fast as possible (i.e. minimal latency)
- **Monitoring in Performance Monitor**
  - Physical Disk: Avg. Disk Sec/Transfer
  - Physical Disk: Avg. Disk Sec/Read
  - Physical Disk: Avg. Disk Sec/Write

Traditional HDD
Platters



- **Drives have multiple platters with read/write heads above and below each platter**
  - The read/write heads float on a cushion of air created by the rotational speed of the disk platters known as an air bearing
  - "Like a 747 flying 500mph at 1/4 inch above the ground" – Jim Gray
- **Multiple heads still have a fixed articulation point which prevents parallel I/O operations on a single disk**
- **Mechanical limitations affect performance**

Traditional HDD
Performance and Latency

- **The latency or response time in milliseconds it takes for the drive to begin to transfer data**
- **Response time = seek time + rotational latency**
  - Seek time: the time it takes the read/write head to move from the current track to another track on the hard drive.
  - Rotational latency: the time it takes to rotate the disk platter to the correct position for access by the read/write head

HDD Spindle [RPM]	Average rotational latency [ms]
7,200	4.17
10,000	3.00
15,000	2.00

Solid State Drives (SSDs)

- **SSDs have no moving mechanical components**
- **Data is stored in NAND based flash memory that is persistent with bit level addressing for hard disk emulation**
- **Access time depends electrical connections to solid state memory, making it very fast and consistent across cells**
- **General average seek time ranges between 0.08ms and 0.16ms**
- **NAND types**
  - SLC: Single-Level Cell flash stores a single bit value with two states
    - Lower voltages results in longer endurance of 100,000 write cycles
  - MLC: Multi-Level Cell flash stores a double bit value with four states
    - Higher data density per cell at the trade off of higher voltages with reduce cell endurance of 10,000 write cycles
  - TLC: Triple-Level Cell flash stores a triple bit value with eight states
    - Higher data density per cell with reduced cell endurance of 5,000 write cycles
  - 3D MLC/TLC: Layers NAND for higher storage densities (up to 32TB in 2.5")

SSD Concepts (1)

- **Overprovisioning**
  - Reserves a permanent or temporary portion of the SSD capacity as working space for the controller
    - Improves performance and endurance of the NAND cells
- **Wear Leveling**
  - Distributes writes as evenly as possible across the cells to increase endurance and reduce a single cell from wearing out under heavy writes
  - May increase write amplification as static data is moved from a underwritten cell to a heavily written cells
- **Write Amplification**
  - Garbage Collection – data is written in pages but only erased in blocks
    - Used pages within a block are read and rewritten to another block to allow reclamation of the stale pages by erasing the current block

SSD Concepts (2)

- **Flash Translation Layer**
  - Provides logical block mapping and garbage collection capabilities
  - May be prone to *"flying writes"* due to firmware or controller bugs leading to database corruption on write
    - Customer database with GPT (guid partition database) data would show up using DBCC PAGE while investigating corruption reported by DBCC CHECKDB
    - First part of the page was all zeros followed by the GPT information as outlined for the GPT in MSDN
- **OS Error 665 and Defragmentation**
  - OS file fragmentation can affect SQL Server databases stored on SSDs due to NTFS file attribute list limitations
    - Small autogrowths over time can fragment the file hitting the NTFS limitation
    - SQL Server 2014 can run on newer Refs file system without this limit
  - http://bit.ly/ssd-defrag

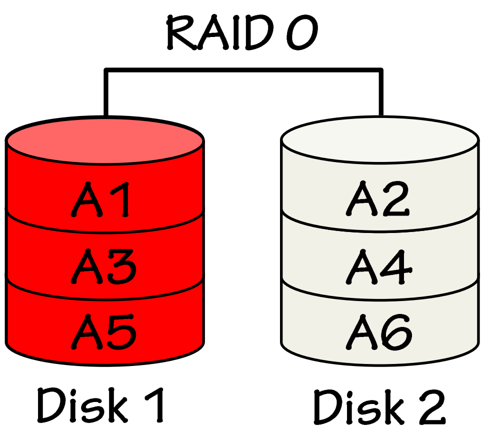
RAID

Redundant Array of Independent/Inexpensive Disks

- **Combines multiple disk drive components into a single logical unit, distributing data across the disks for redundancy and improved performance**
- **Configurations or levels are named by the word RAID and a numeric value specific to the configuration for standardization**
- **Common RAID levels**
  - RAID 0 - Striping
  - RAID 1 – Mirroring
  - RAID 5 – Striping with parity
  - RAID 6 – Striping with double-parity

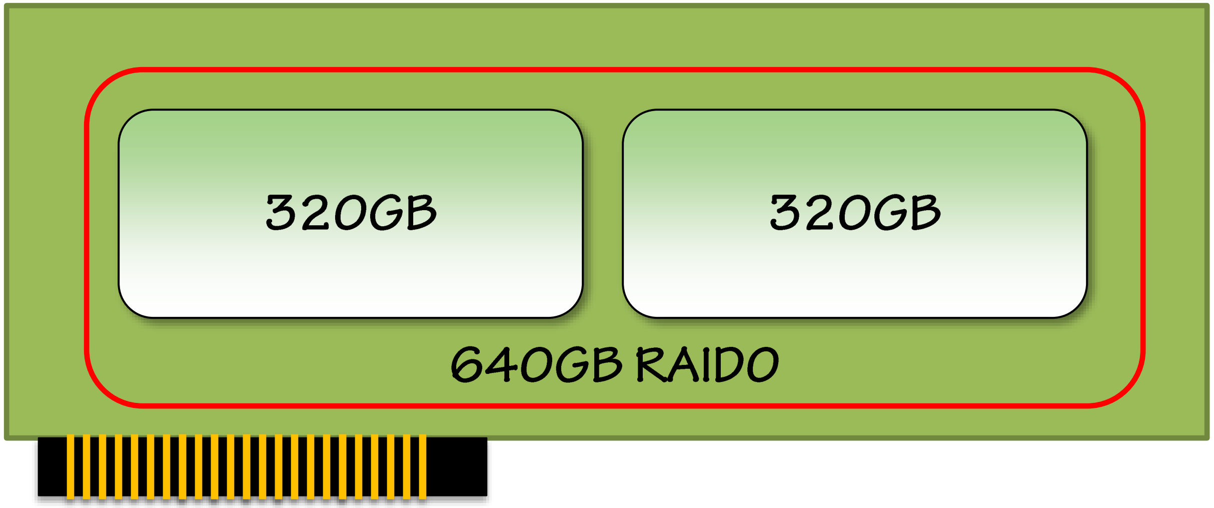
RAID Levels: RAID 0
Striping

- **Usage scenarios:**
  - Data you don’t care about
  - Performance matters more than data loss risk
- **Pros:**
  - Fast read and write performance
- **Cons:**
  - Total loss of data from single disk failure
- **Watch out for this with PCI-Express SSDs and IaaS implementations**



PCI-Express SSDs

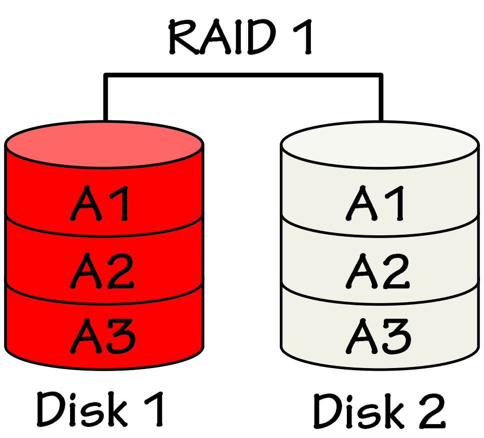
- Some PCI-Express SSDs like the FusionIO ioDrive Duo 640 present two physical disks to Windows



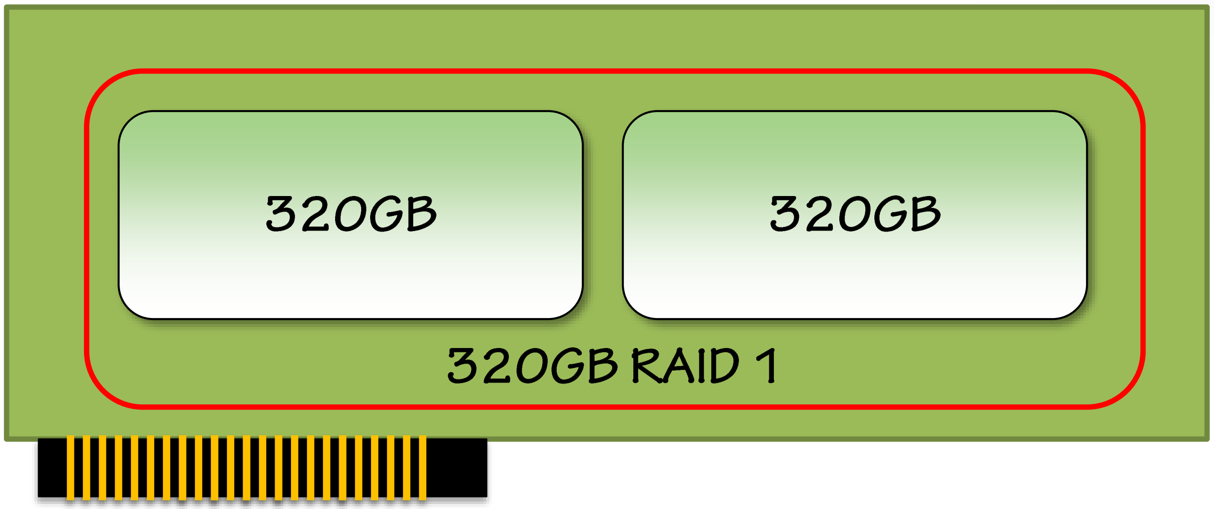
- To get full capacity from the card requires Windows RAID 0

RAID Levels: RAID 1
Mirroring

- **Usage scenarios:**
  - Important data that requires redundancy to protect from disk failures
- **Pros:**
  - Mirrored storage protects from single disk loss
- **Cons:**
  - Only provides half the storage
  - Write performance equal to one disk

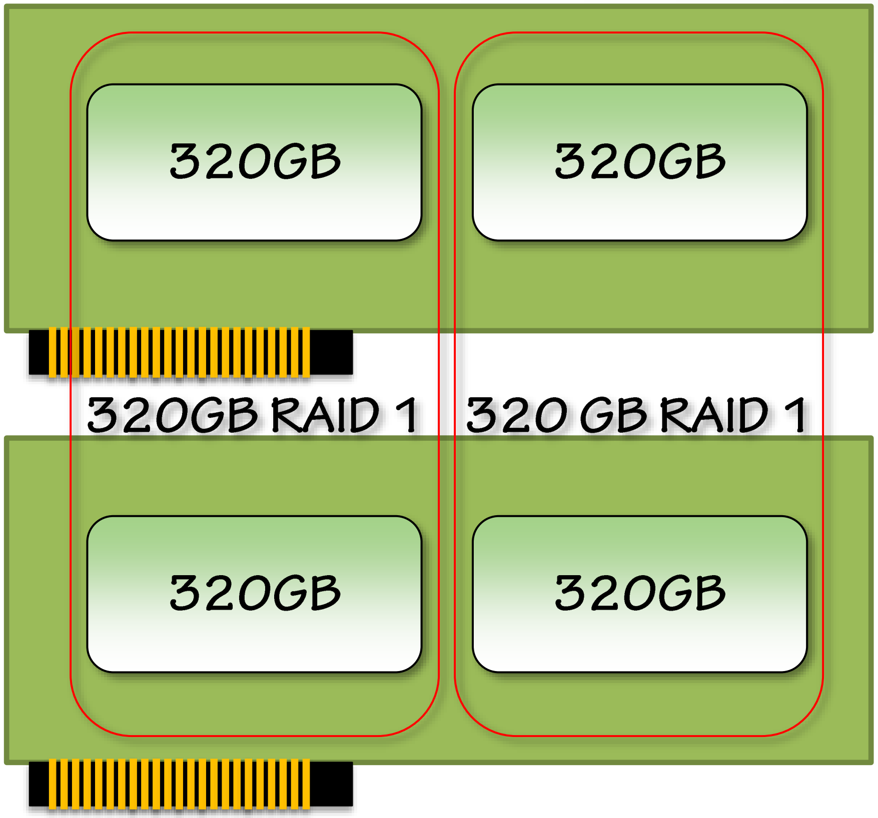


PCI-Express SSDs and RAID 1



- RAID 1 using a single card still does not provide redundancy against a controller failure on the card or PCIe slot failures

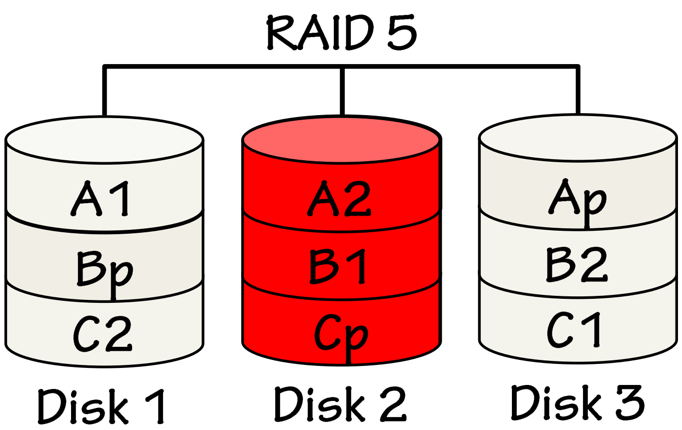
PCI-Express SSDs



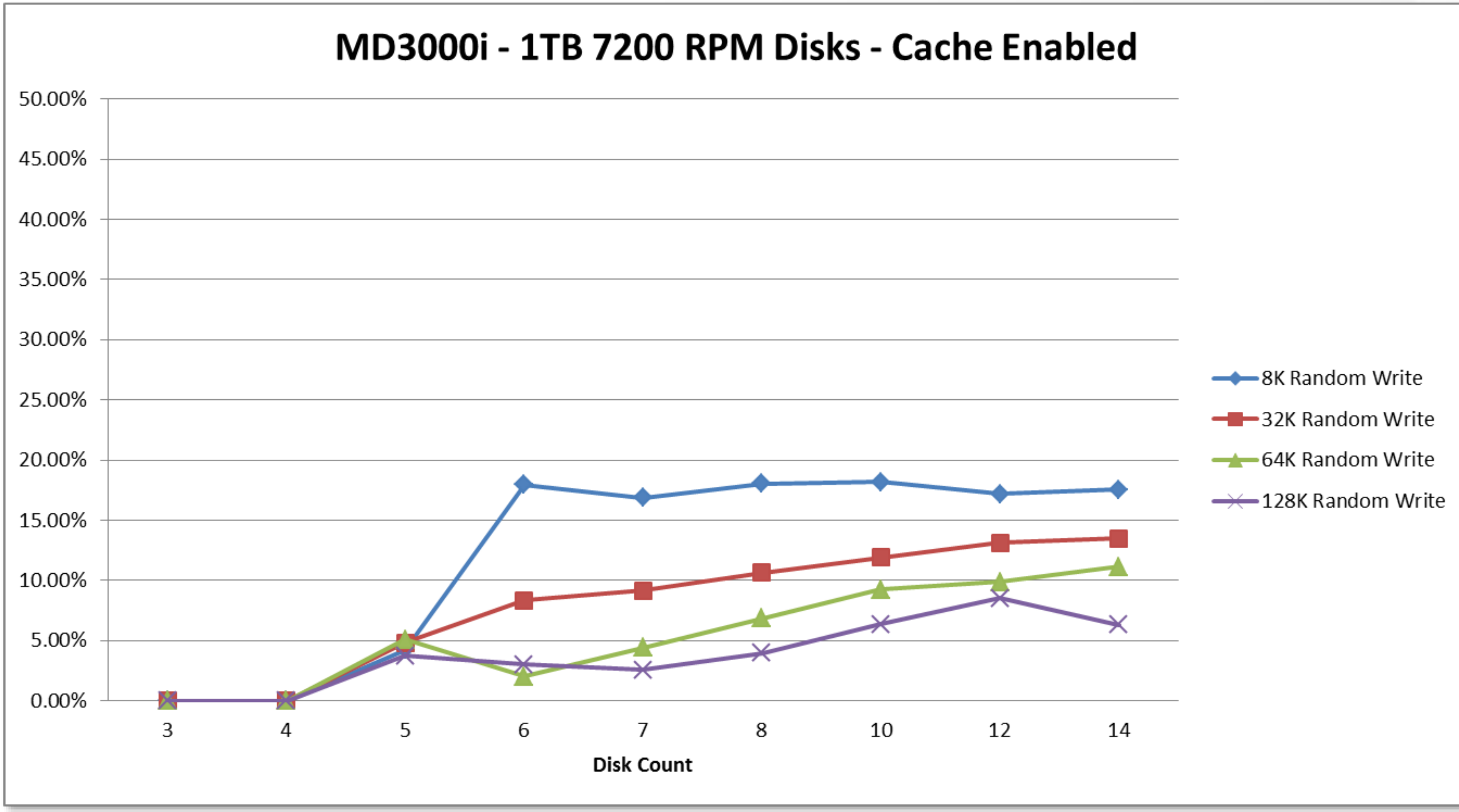
- **640GB capacity with full redundancy requires two cards and RAID 1 across the cards**

RAID Levels: RAID 5
Striping with Parity

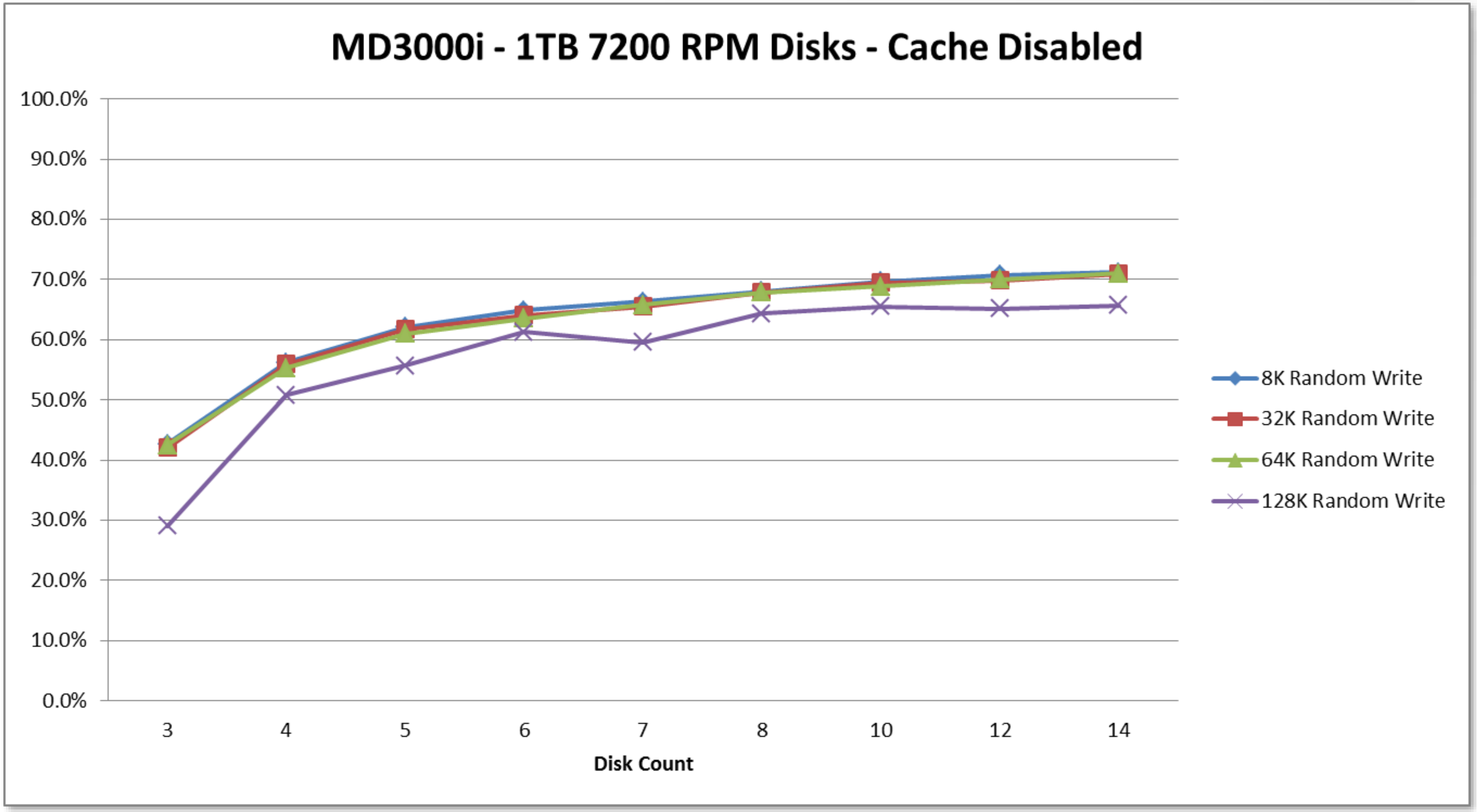
- **Usage scenarios:**
  - Where reads exceed writes, data files
- **Pros:**
  - Maximize available capacity from minimal number of disks with redundancy
- **Cons:**
  - Protection from single disk failure only as loss of two disks results in total data loss
  - Write penalty for parity calculation
  - Significant performance impact occurs when degraded



RAID 5 Degraded Performance



RAID 5 Degraded Performance



Nested RAID Levels

- Implement one level of RAID on top of another level of RAID
- Can be used to create better redundancy as well as higher levels of performance
- Common nested RAID levels are
  - 10 or 1+0: striping over mirrored pairs
  - 01 or 0+1: mirroring over striping
  - 50 or 5+0: striping over single-parity striping
  - 60 or 6+0: striping of double-parity striping
  - 100 or 10+0 or 1+0+0: striping over a striped set of mirrored pairs

Nested RAID Levels: RAID 10 or 1+0

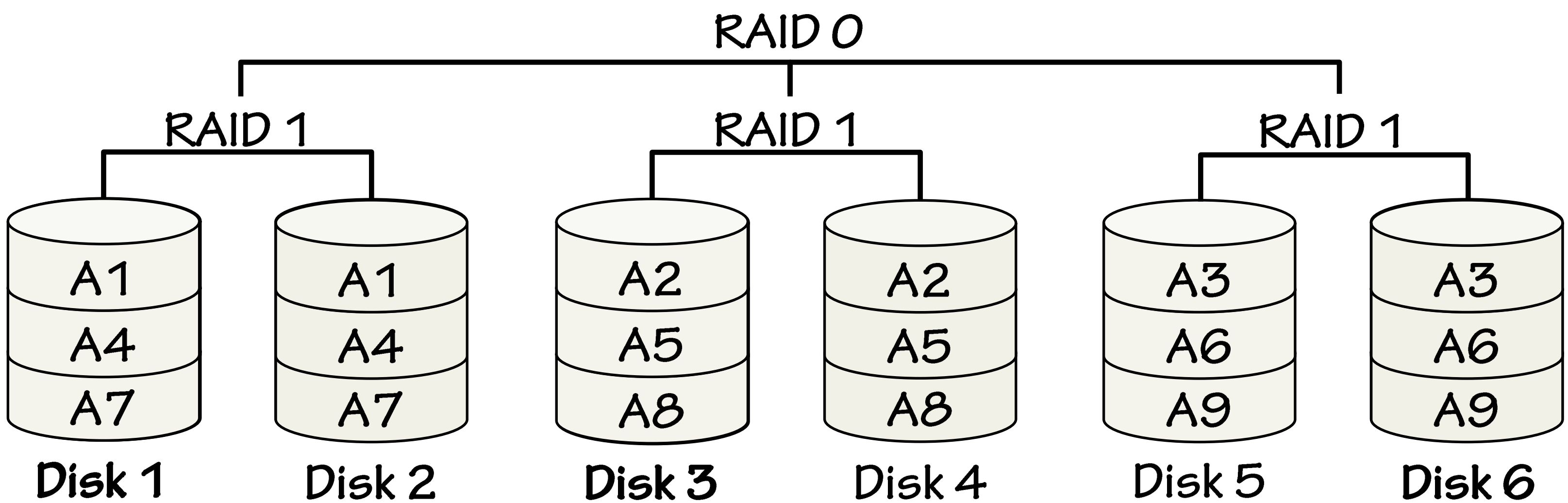
Striping Over Mirrored Pairs

- **Usage scenarios:**
  - Transaction log files, heavy write data files
  - Redundancy is more important than cost
- **Pros:**
  - Fast read and write performance
  - Supports multiple disk failures as long as two of the failed disks aren't in the same RAID 1 pair
- **Cons:**
  - Doubles the cost of storage

Nested RAID Levels: RAID 10 or 1+0

Striping Over Mirrored Pairs

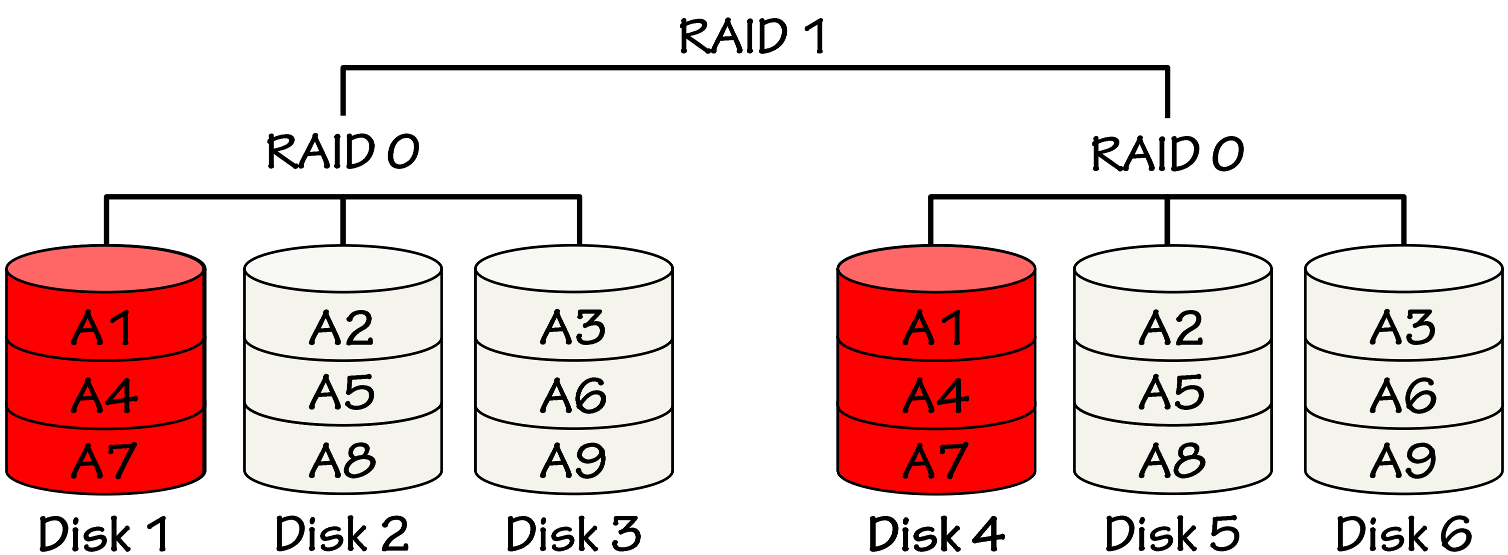
- Single disk loss keeps array available
- Multiple disk losses in different RAID 1 keeps array available
- Double disk loss in same RAID 1 results in array failure



Nested RAID Levels: RAID 01 or 0+1

Mirroring Over Striping

- IS NOT THE SAME AS RAID 10/1+0
- Single disk loss keeps array available
- Double disk loss in different RAID 0 results in array failure



Other RAID Configurations

- **RAID 6**
  - Similar to RAID 5 but provides double parity disks allowing for up to two disks to fail and the array remains available
  - Common recommendation for some SAN vendors
- **RAID 50, RAID 100, etc**
  - Specialized RAID configurations that stripe other RAID levels to increase performance

DAS Benefits

- Inexpensive to implement and achieve high performance configurations for SQL Server
- Ease of configuration requires minimal knowledge of underlying storage specifics
- Storage dedicated to SQL Server simplifying monitoring and troubleshooting of performance

DAS Disadvantages

- **Does not support clustering before SQL Server 2012**
  - Some exceptions exist where a single array may be connected by serially-attached SCSI (SAS) to two servers redundantly
    - MD3200
- **Requires appropriate IOPS, MB/sec, and storage size considerations up front**
  - LUN configurations cannot be dynamically reconfigured once set up (some exceptions exist)
  - Beware of controller and interface bottlenecks that limit the available throughput from the disks in the array

Storage Area Networks (SANs)

- **“A storage area network (SAN) is any high-performance network whose primary purpose is to enable storage devices to communicate with computer systems and with each other” (Storage Networking Industry Association)**
  - Does not specify interconnect technology
  - Does not specify types of storage devices

What Do You Think of as a SAN?

Scale out Compellent

OR

Equallogic PS6210XS

- **Reality is: both are SANs and have very different capabilities!**

SAN Advantages

- **Shared storage**
  - Increases disk utilization
  - Reduces management by making it easier to create new volumes and dynamically allocate storage
  - Create diskless servers that boot from SAN only
- **Advanced features**
  - Mirroring, snapshots, continuous data protection, clustering and geo-clustering only offered by SANs
- **Performance**
  - Almost unlimited number of spindles, controllers, and cache can be put together to meet the requirements

SAN Disadvantages

- **Unpredictable performance**
  - When you share your disks, controllers, and fiber switches between dozens of servers it is very difficult to have predictable performance
- **Higher latency**
  - Distance the I/Os have to travel; added layers of switches, cabling and ports
  - PCI Bus → HBA → FC switches → FC ports → array processors → disks
- **Limited bandwidth**
  - FC now 16Gb/s max
  - iSCSI 10Gb/s max
  - Note: 1Gb/s = 128MB/s
- **Cost**

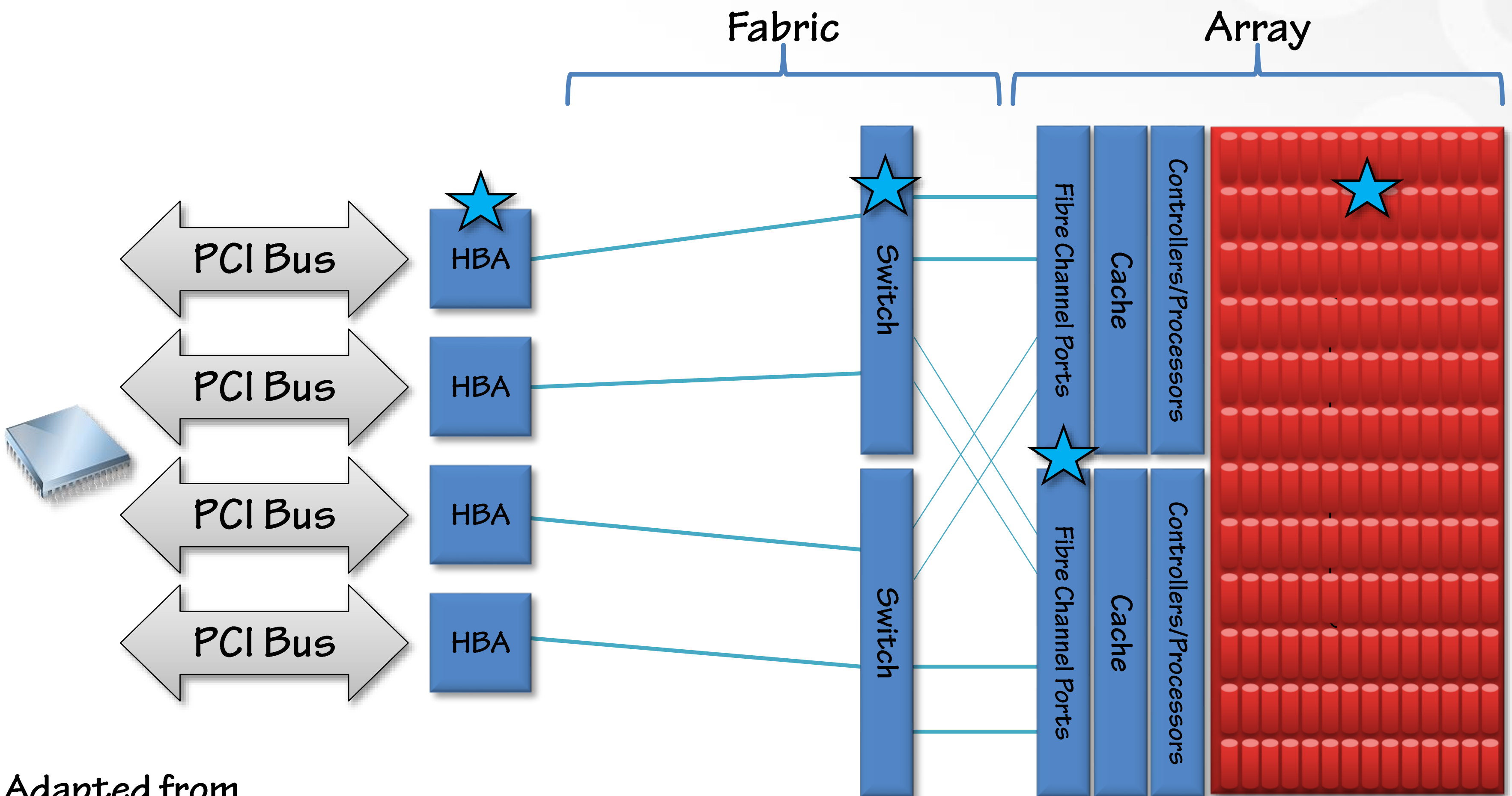
SAN Components
Basics

- **Drives**
  - Physical interface, size, rotation speed, and RAID configuration level
- **SAN storage controllers**
  - FA port/iSCSI port count and speeds
  - Cache size and configuration
- **SAN fabric**
  - Number of switches, their port speeds and path configurations
- **Host bus adapter**
  - Queue depth, port speeds, pathing/multipathing

Multipathing

- **Primary purpose of multipathing configurations is to provide redundancy and protection**
- **Secondary to redundancy is to improve performance**
  - Just having multiple paths doesn't guarantee a performance improvement
  - Some SANs only allow one path per LUN
  - iSCSI allows one connection per target
  - Achieving performance improvements may require changes to the physical database layout

Path to the Drives: SAN



Adapted from slide deck by Thomas Kejser (with permission)

Denotes possible bottleneck point

Slowest point in the configuration is the limiting factor

Understanding SAN I/O Capacity

- **The available bandwidth of a SAN is limited to the lowest available bandwidth bottleneck in the configuration**
- **Example scenario**
  - HBAs: 2 x 8Gb/s = ~1,600MB/s (max)
  - Switch: 2 x 8Gb/s = ~1,600MB/s (max)
  - SAN has 4 x 2Gb/s FA Ports = ~800MB/s (max)

Understanding SAN I/O Capacity
Scenario 1

- HBAs: 2 x 8Gb/s = ~1,600MB/s (max)
- Switch: 2 x 8Gb/s = ~1,600MB/s (max)
- SAN ports: 4 x 2Gb/s FA ports = ~800MB/s (max)
- Cache: 1 x 1,600MB/s = ~1,600MB/s (max)
- Disks: 80 x 20MB/s = ~1,600MB/s (max)

- Maximum bandwidth is limited by the SAN ports

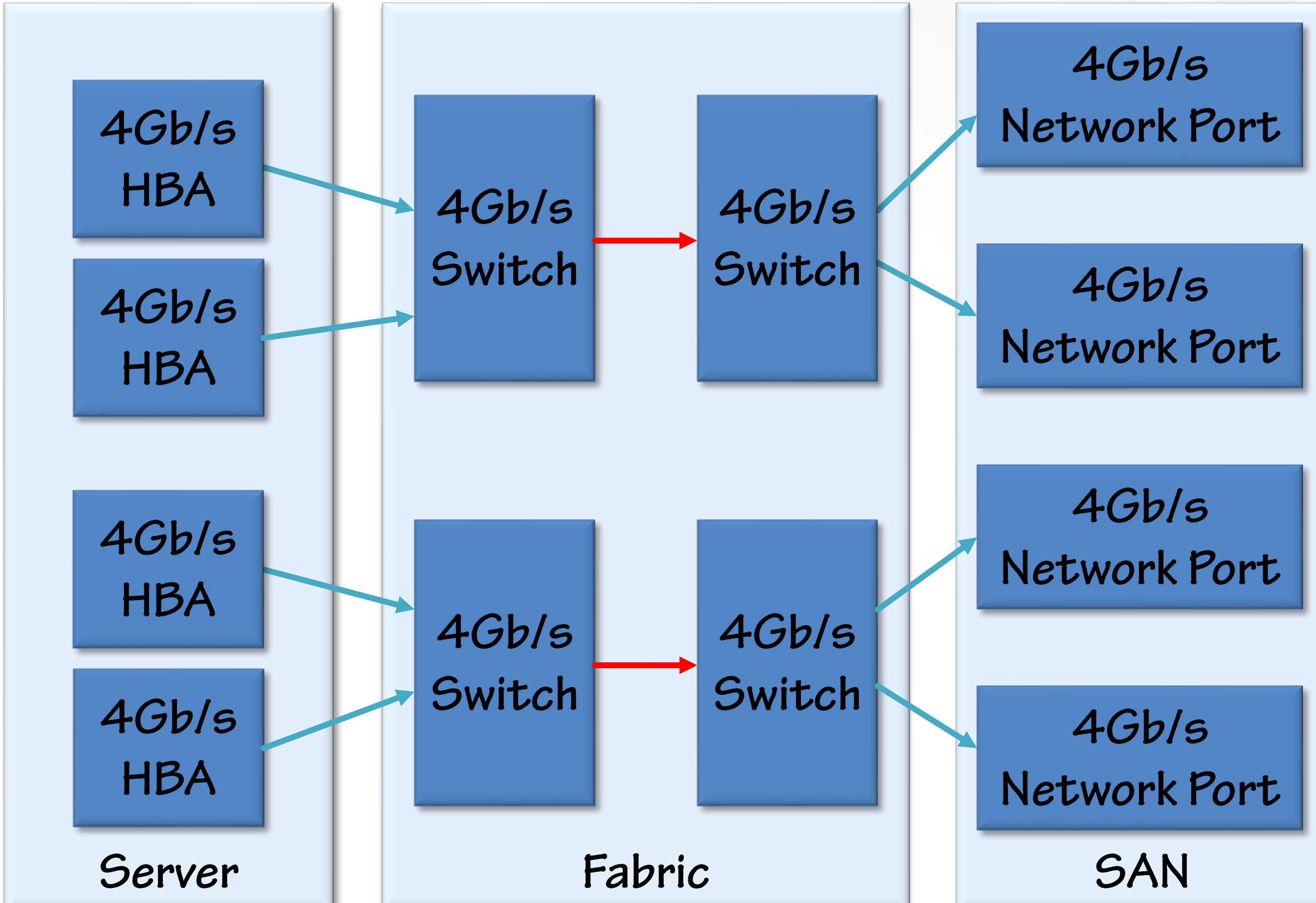
Understanding SAN I/O Capacity

Scenario 2

- HBAs: 2 x 8Gb/s = ~1,600MB/s (max)
- Switch: 2 x 8Gb/s = ~1,600MB/s (max)
- SAN ports: 4 x 8Gb/s FA ports = ~3,200MB/s (max)
- Cache: 1 x 1,600MB/s = ~1,600MB/s (max)
- Disks: 40 x 20MB/s = ~800MB/s (max)

- Maximum bandwidth is limited by the disks

Understand Bottlenecks Completely



iSCSI vs. Fibre Channel

Best Practices

- **Use the fastest interface you can:**
  - 16Gb/s FC, 10Gb/s iSCSI, 8Gb/s FC, 4Gb/s FC, 2Gb/s FC, 1Gb/s iSCSI or FC
- **The slower the interface the more important appropriate multipathing becomes to achieving the needed throughput**
- **Know the limitations of the controller's connections**
  - You can probably connect more than you are currently using

iSCSI Considerations

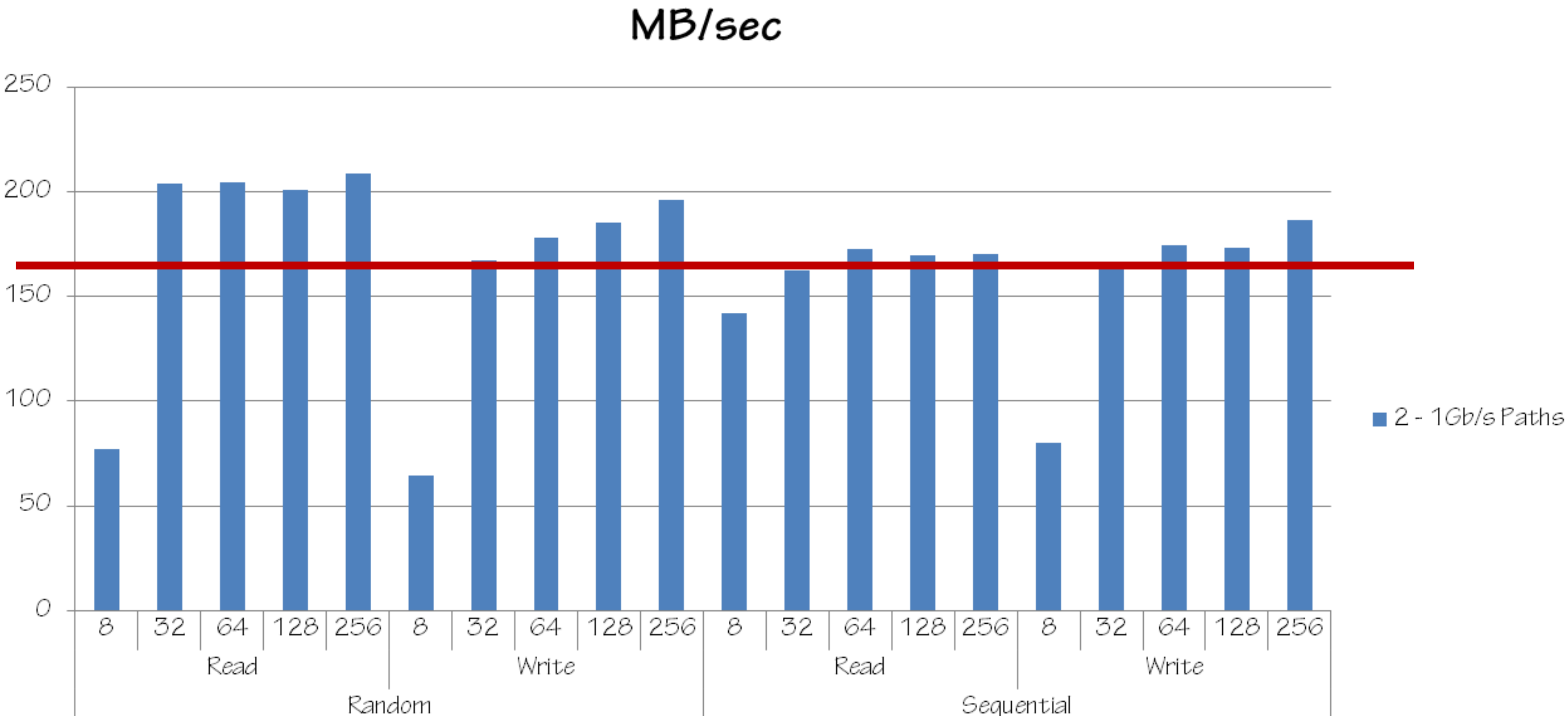
- **Network design**
  - Dedicated hardware including HBAs, switches, and cabling
  - TCP Offload Engine (TCOE) enabled NICs or iSCSI HBAs for servers
  - Use Jumbo Frames end-to-end on iSCSI network to improve throughput for larger packet sizes
- **Single path per target may require considerations for LUN and database file layout to achieve the optimal I/O configuration**
- **May require intervention to bring multiple paths back online after failure**

iSCSI Performance Characteristics

- **Equallogic PS-6100XS**
  - 7 x 400GB SSD + 17 x 600GB 10K RPM
  - RAID 6
  - Two controllers – 4GB cache, 4 x 1Gb/sec per controller

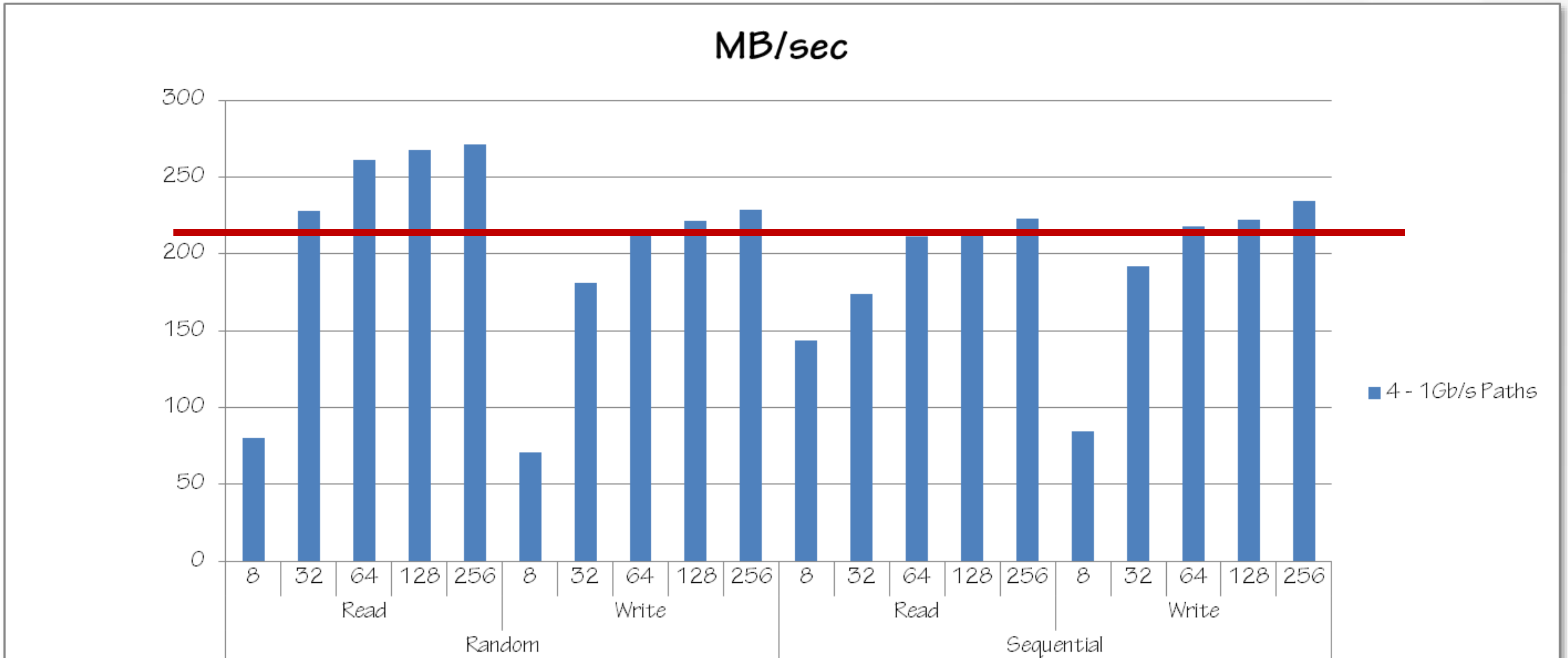
- **Equallogic PS-6110XS**
  - 7 x 400GB SSD + 17 x 600GB 10K RPM
  - RAID 6
  - Two controllers – 4GB cache, 4 x 10Gb/sec per controller

PS-6100XS – Two 1Gb/s Paths



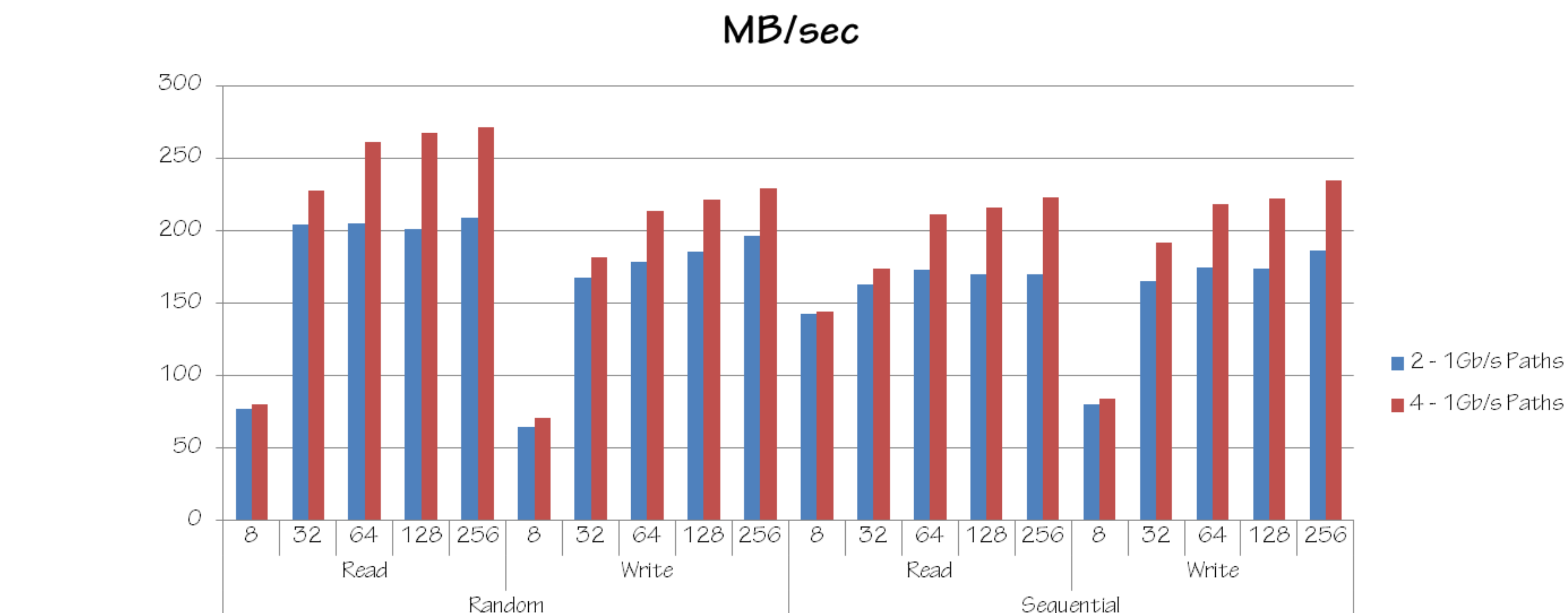
	Random Read 8	Random Read 32	Random Read 64	Random Read 128	Random Read 256	Random Write 8	Random Write 32	Random Write 64	Random Write 128	Random Write 256	Sequential Read 8	Sequential Read 32	Sequential Read 64	Sequential Read 128	Sequential Read 256	Sequential Write 8	Sequential Write 32	Sequential Write 64	Sequential Write 128	Sequential Write 256
2 - 1Gb/s Paths	76.9	204	205	201	208	64.5	167	178	185	196	142	163	172	170	170	79.8	165	174	173	186

PS-6100XS – Four 1Gb/s Paths



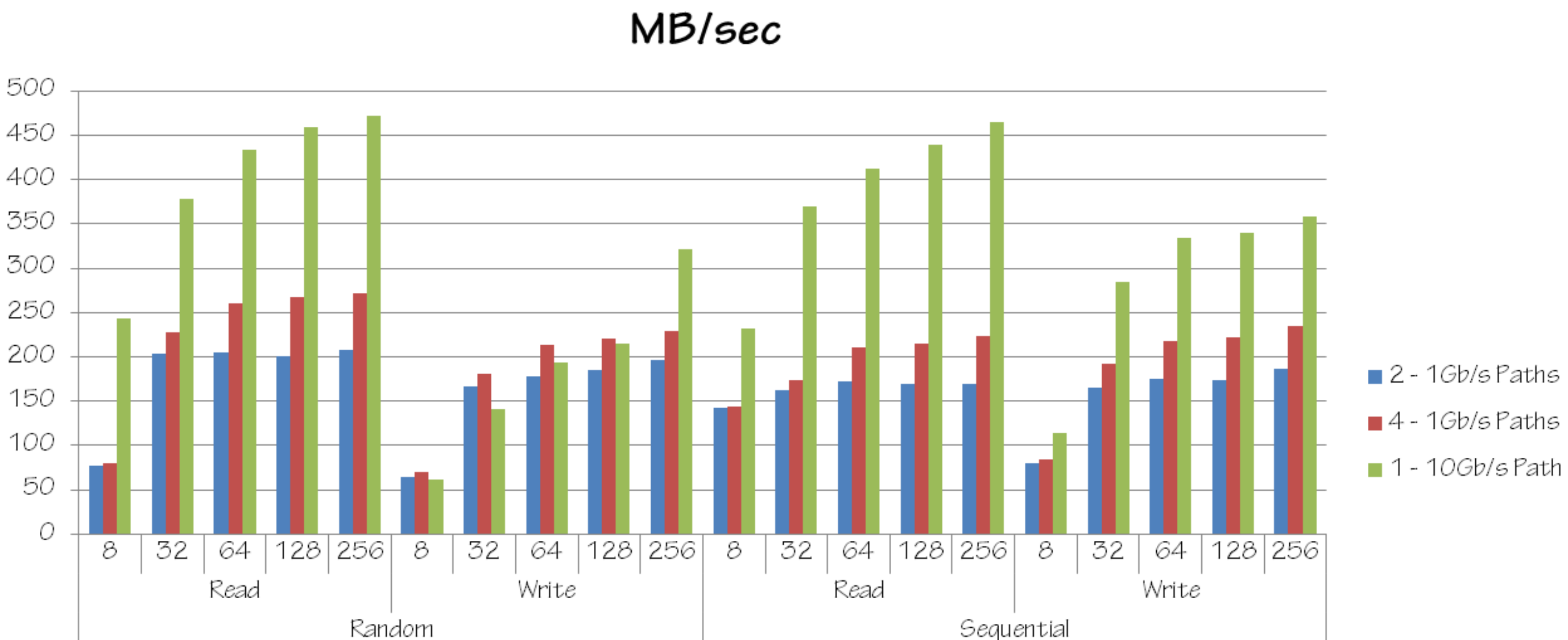
	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256
4 - 1Gb/s Paths	80.1	228	261	268	271	70.7	181	213	221	229	144	174	211	215	223	84.2	192	218	222	234

PS-6100XS – Side-by-Side Comparison



	Random										Sequential									
	Read					Write					Read					Write				
	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256
2 - 1Gb/s Paths	76.9	204	205	201	208	64.5	167	178	185	196	142	163	172	170	170	79.8	165	174	173	186
4 - 1Gb/s Paths	80.1	228	261	268	271	70.7	181	213	221	229	144	174	211	215	223	84.2	192	218	222	234

Comparison to PS-6110XS – 10Gb/s iSCSI



	Random										Sequential									
	Read					Write					Read					Write				
	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256	8	32	64	128	256
2 - 1Gb/s Paths	76.9	204	205	201	208	64.5	167	178	185	196	142	163	172	170	170	79.8	165	174	173	186
4 - 1Gb/s Paths	80.1	228	261	268	271	70.7	181	213	221	229	144	174	211	215	223	84.2	192	218	222	234
1 - 10Gb/s Path	244	379	434	459	472	61.6	141	193	215	322	232	370	413	440	464	114	285	334	340	359

Real World Customer Example

- **EMC CX4-240 SAN with 240 15K RPM disks**
  - Each shelf of drives contains 16 15K RPM 300GB disks – total of 15 shelves
  - Three shelves of drives (total 48) dedicated to SQL Server
    - 4 disk RAID 10 for system database data files
    - 4 disk RAID 10 for system database log files
    - 8 disk RAID 10 for main database data files
    - 4 disk RAID 10 for main database log files
    - 8 disk RAID 10 for tempdb data files
    - 4 disk RAID 10 for tempdb log file and secondary database log file
    - 6 disk RAID 10 for second database data file
    - 7 disk RAID 5 for backups
    - 3 hot spares (one per shelf)
  - Avg. Latency for writes 70-200ms
  - Avg. Latency for reads 140-260ms

Real World Customer Example (2)

- **Same EMC CX4-240 SAN with 240 15K RPM disks**
  - Each shelf of drives contains 16 15K RPM 300GB disks – total of 15 shelves
  - Three shelves of drives (total 48) dedicated to SQL Server
    - 3 hot spares (one per shelf)
    - 28 disk RAID 5+0 (EMC internal striping of 4 disk RAID 5) for database data files
    - 10 disk RAID 10 for log files
    - 7 disk RAID 5 for backups
  - Avg. Latency for writes 20-40ms
  - Avg. Latency for reads 20-50ms

- **Identical workloads and the same total number of disks but striped so that performance is significantly improved**
- **This also is EMC's recommended configuration for SQL Server**

SQLskills immerse yourself in sql server

Storage Spaces Direct (S2D) Windows Server 2016

- **Storage Spaces Direct uses local-attached drives to create a converged or hyper-converged environment that supports failover clustering and shared volumes across independent servers**
  - Converged = SMB3
  - Hyper-converged = CSVs
- **Hyper-converged configurations require 4GB RAM per TB of drive capacity for cache and S2D internal usage**
- **Requires Windows Server 2016 Datacenter and a minimum of 2 nodes with a maximum of 16 nodes**
  - All servers must have the same drive types
  - 2 drive minimum for cache per server if using caching
  - 4 drive minimum for capacity per server (2 for virtual machines)

Cloud Storage (Azure and AWS)

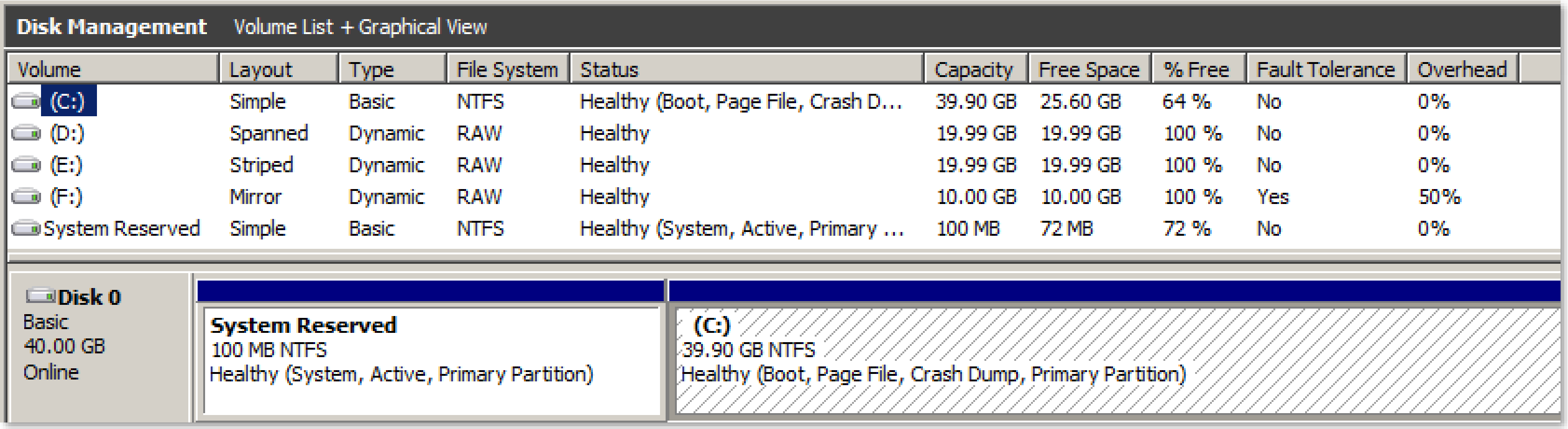
- **Cloud infrastructure performance is based entirely on the configuration appropriately being sized to requirements**
- **Maximum IOPS limits per VM and per disk volume are independent of each other**
  - AWS EC2 instance type maximum I/O throughput limits (https://sqlskills.com/help/aws-ebs)
  - Azure VM size and type IOPS limits (https://sqlskills.com/help/azvmio)
- **Achieving appropriate storage throughput usually requires striping multiple volumes together using Windows Storage Spaces (not S2D)**
  - Must use PowerShell for configuration to set column count (# disks to stripe data across) – THIS IS INCREDIBLY IMPORTANT!!! Column count cannot be changed after VDISK creation.

Storage Design
Shared vs. Dedicated Spindles

- **Shared spindles allows for higher utilization of the underlying storage capacity**
  - Requires significant consideration up front to minimize the performance impact of sharing spindles
  - One application (often SQL Server, Exchange, or other OLTP solution) can cause the majority of I/O demand
  - I/O demanding applications should never share the same physical spindles
- **Dedicated spindles have lower utilization of storage capacity but predictable performance**
  - Some SANs only offer shared storage configurations
- **Virtualization**
  - Underlying VHD/VMDK appears dedicated but may be on shared LUN physically

Windows Disk Types
Basic

- **Default and most common disk type to use in Windows for SQL Server**
- **Can use master boot record (MBR) or GUID-partition table (GPT) partition types**
  - MBR limit to 2TB in size
- **Volumes can be extended if contiguous free space exists physically**



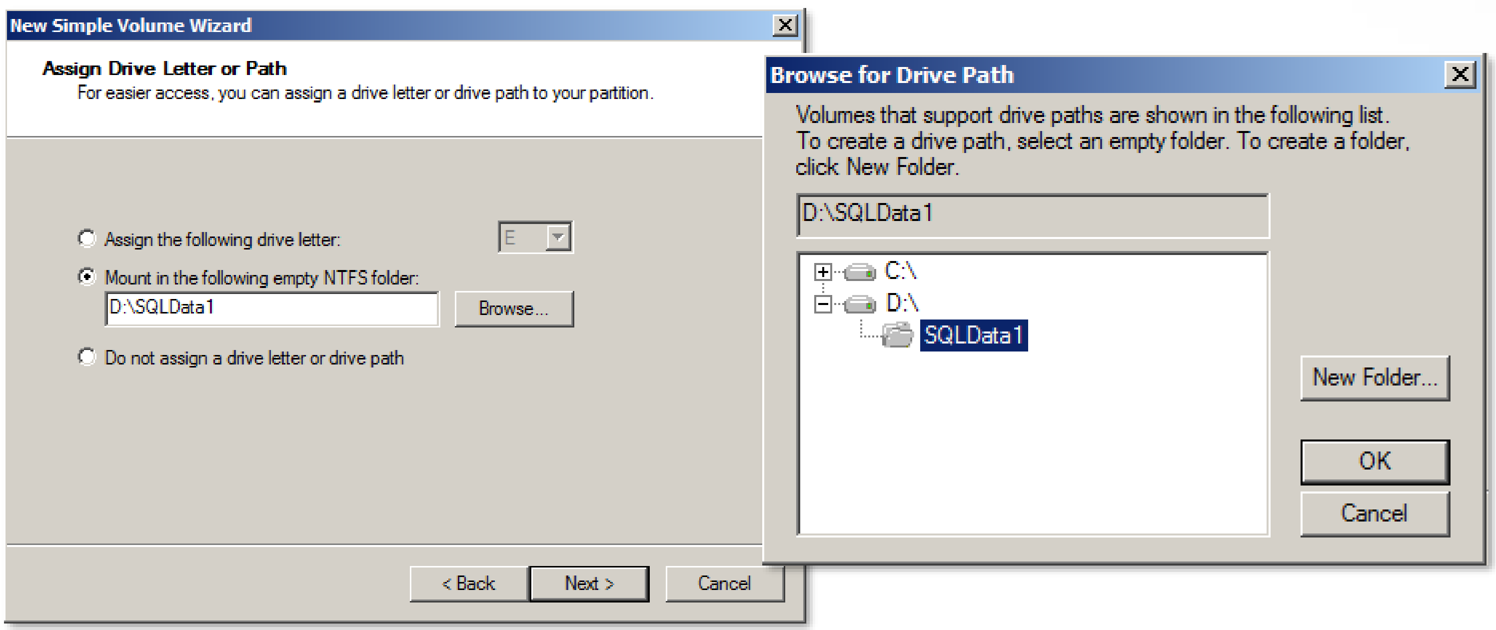
Volume	Layout	Type	File System	Status	Capacity	Free Space	% Free	Fault Tolerance	Overhead
(C:)	Simple	Basic	NTFS	Healthy (Boot, Page File, Crash D...	39.90 GB	25.60 GB	64 %	No	0%
(D:)	Spanned	Dynamic	RAW	Healthy	19.99 GB	19.99 GB	100 %	No	0%
(E:)	Striped	Dynamic	RAW	Healthy	19.99 GB	19.99 GB	100 %	No	0%
(F:)	Mirror	Dynamic	RAW	Healthy	10.00 GB	10.00 GB	100 %	Yes	50%
System Reserved	Simple	Basic	NTFS	Healthy (System, Active, Primary ...	100 MB	72 MB	72 %	No	0%

Windows Disk Types
Dynamic

- **Software RAID**
  - Create RAID 0, RAID 1, and RAID 5 volumes
- **Use with SQL:**
  - Mirrored (RAID 1)
    - Use with Fusion-io or other PCI-X SSDs to provide redundancy across multiple cards
- **Do not use:**
  - Striped (RAID 0)
    - No redundancy
  - Spanned
    - Data written to disks sequentially filling each disk before writing to the next disk in the span
  - Striping with parity (RAID 5)
    - High CPU overhead for software-parity calculations

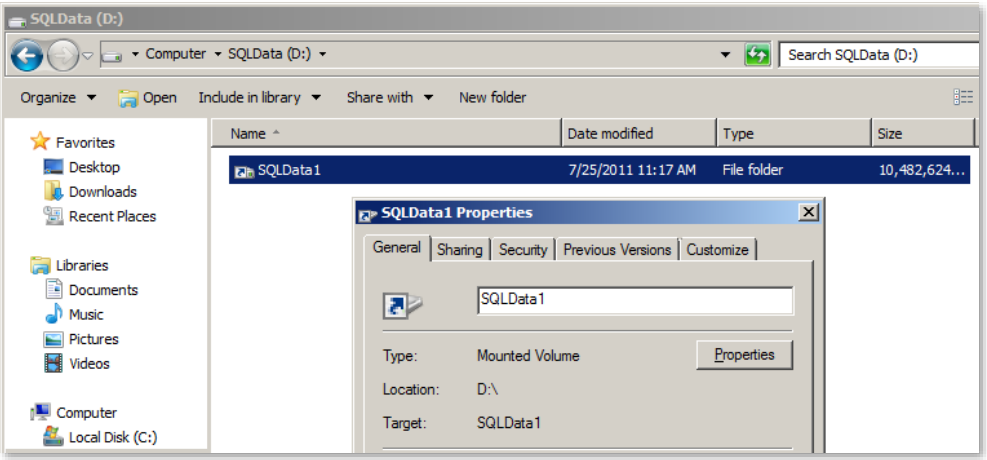
Mount Points

- **Provide a mechanism to exceed 26 volume limit based on available drive letters**
  - Additional volumes can be mounted as folders under an existing volume
- **May be required for large multi-instance clusters**



Mount Points
Monitoring Complications

- Mount point support is not built into most monitoring tools requiring custom solutions to monitor space usage of the mounted volumes
- Mount points properties provide the target volume information for matching to Disk Management
- sys.dm_os_volume_stats DMF in SQL Server 2008 R2 onwards will return mounted volume information per database file



Partition Alignment
Background

- **Disks report the first 63 sectors as hidden**
  - This reserved portion is where the master boot record is stored
  - Equates to 31.5KB of disk space: (512 bytes per sector) x (63 sectors)
- **Prior to Windows Server 2008, partitions were offset by 31.5KB resulting in misalignment of the partition with stripe units, disk controller, and cache segment lines**
  - Misalignment can reduce performance by 30% or more depending on the array stripe size and allocation unit size
  - Plenty of evidence from many, many customers

Partition Alignment
Determining Offset

- **(partition offset) divided by (stripe unit size)**
  - Should result in a whole number
  - Common stripe sizes are 64KB, 128KB, 256KB and 512KB
  - 32,256 bytes (31.5 KB) / 65,536 bytes (64 KB) = 0.4921875
    - Misaligned
  - 131,072 bytes (128 KB) / 65,536 bytes (64 KB) = 2
    - Properly aligned
- **Windows Server 2008**
  - Uses 1,024 KB (2,048 sectors) alignment for new partitions
  - Previously created partitions may be misaligned
  - Even on Windows Server 2008, always check and validate
    - Command Line: wmic partition get StartingOffset, Name
  - Manually create partitions using DiskPart to set offset when necessary
    - Uncommon stripe sizes

NTFS Allocation Unit Size

- **Also known as 'NTFS cluster size'**
- **Sets the smallest unit of consumption on NTFS volume for files**
- **Can only be set when the volume is formatted**
- **Default size: 4KB**
  - Optimized for storage of lots of small files
- **For SQL Server a 64KB allocation unit size should be used to match the size of a single extent**
  - Improves read-ahead performance
  - Reduces the number of split I/Os
  - Does not allow the disk to use NTFS compression
  - Plenty of empirical evidence to prove this
- **This is not as critical as partition alignment for performance!!**

Benchmarking Storage
Diskspd and IOMeter

- **Use test files that are at least twice the size of the installed cache size**
  - Small files against a large cache = cached I/O
  - Disabling cache = not reality during production
  - Exceeding cache size forces physical disk I/Os
- **Test different I/O sizes (4KB, 8KB, 64KB, 256KB)**
- **Test different workload types (read/write, sequential/random)**
- **Test impact of thread count and outstanding I/Os**

Considerations During Testing

- **Test normal configuration and impact of degraded RAID**
  - Degraded performance can be significantly worse than normal configuration and may not meet SLA
- **If testing a shared SAN, ensure that the SAN is under its normal workload during the tests**
- **“Pull-the-plug” tests**
  - Ensure that multipathing works as expected when one of the paths is removed
  - Test for path stickiness after restoration of a failed path to determine if the path resumes normal operation or not
  - Ensure that write caching is battery backed and doesn’t lead to lost write or data corruption issues

Key Takeaways

- **Configure storage based on performance and redundancy requirements, not strictly on capacity**
- **The type of workload and data being stored on a disk array should dictate the RAID level being used**
  - Don’t use RAID 5 for heavy writes (e.g. transaction logs, tempdb), use RAID 10 instead to provide better redundancy and eliminate parity overhead
- **PCI-Express SSDs require extra cards with RAID 1 across the cards for true redundancy**

Key Takeaways

- **Follow the SAN vendor's recommended best practices for SQL Server**
- **Don't assume SAN-based storage performance problems are automatically a problem with the SAN itself, remember there are a lot of components between the server and the actual storage**
  - Watch out for the "I can ping it" network guy, the SAN admin hates him too
- **Collect performance metrics in Performance Monitor and bring your latency numbers to the SAN admin to show where performance is affecting SQL Servers workload to troubleshoot**
- **Don't over-think SAN storage configuration and try to slice the storage up following "best practices" for isolation, it might be better to use a larger pool of disks, dedicated to SQL Server, than to have smaller isolated groups**

Additional Resources

- Storage Area Network Essentials http://amzn.to/1sLlEJy
- SQL Server Best Practices for I/O Whitepaper http://bit.ly/1rwtbYN
- Storage Top 10 Best Practices http://bit.ly/YHxhmJ
- SQL Server SAN Best Practices http://bit.ly/1nARo27

Additional Resources

- NAND Basics: Understanding the Technology Behind Your SSD http://bit.ly/1sLlKRl
- SLC, MLC or TLC NAND for Solid State Drives http://bit.ly/YD88tz
- The SSD Endurance Experiment http://bit.ly/1pmthPy
- Disk Partition Alignment Best Practices for SQL Server http://bit.ly/1uWKaE2

Review

- Defining storage terminology
  - IOPS, MB/sec, Latency
- Magnetic vs. Solid State Drives (SSDs)
- RAID configurations
- Storage Area Networks
- Configuring drives in Windows
- Testing with Diskspd and Iometer

Questions?

SQLskills
immerse yourself in sql server