Life of a Storage Packet (Walk)

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Why a Packet Walk?

- It’s not a question of smarts, it’s a question of scope
- A lot of focus on the details, but not enough on the relationships between details
What Is It?

Putting many little pieces together may not give you the right big picture.

Who is this for?

- People who want an introduction to storage systems (i.e., beginners)
- Experts in one field, but not all
- People who want to know more about the basics (but were afraid to ask)
Avoiding Bad Things

- Ignorance in storage can be a Very Bad Thing
- Can cause “religious” differences based upon what people are comfortable with, rather than technological merits
- Can lead to incompatible solutions and unintended consequences
Agenda

- Introduction/What this Presentation Is
- Understanding the Parts (pieces of the puzzle)
- Understanding What the Application Sees
- Understanding What the Storage Sees
- Understanding What the Network Sees
- Putting It All Together
- Additional Resources
- Conclusion
What This Presentation Is

- Focus on the holistic storage problem
- Emphasis on the relationships between storage elements
- Visualizing the concepts in a different way
- Keeping it Simple and Sane
- Keeping a level head and a balanced view
What This Presentation Is NOT

- Virtualized Storage
- Software Defined Storage
- BC/DR/Storage-over-Distance
- Security
- Comprehensive

- Many of the nuances will be missing!
The Common Parts
Three main conceptual areas: Host/Application, Storage Media, and Storage Network
Three main conceptual areas: Application, Storage Media, and Storage Network
“Here is a bit of data. Hold onto it. Give that same bit back to me when I ask for it.”
Understanding What the Application Sees
Applications

- Each system has a CPU with many applications running
- These applications think they have all the available memory
Compute systems have a Memory Management Unit (MMU)

The MMU communicates with the DRAM Memory directly, gets a list of free pages available
Memory Management Module

**Multi-tenancy**

- Memory owned by one process (e.g., application) can’t be overwritten by another process

**Addressing**

- Translating CPU’s physical address into particular DRAM or row of DRAMs
Accessing Memory

Applications get memory when they try to access it.
Assigning Memory

- Pages can be anywhere in memory
- MMU initializes memory before giving it to application
- MMU returns memory to pool when no longer needed
Rule of Thumb: Always put storage/memory as close to the CPU as possible

Improving time constraints will be a constant theme in storage

Accessing DRAM takes anywhere from 60-100ns

Need to get closer to “zero”
Magic of Caching

- A Level 1 (L1) cache directly connects to a CPU core, taking ~1ns
- Level 2 (L2) cache takes about 3-6 ns
No More Room = Accessing Disk

- When you have no more room at the DRAM, you need to go to more permanent storage (e.g.,) disk
- Going to disk is expensive (time-wise)
- Do you want to drive:
  - 1km for your pizza?
  - 5 km for your pizza?
  - 100 km for your pizza?
  - 8 million km for your pizza? (i.e., more than 10 round trips to the moon!)
Best Practice:
- Always keep storage as close to the application as possible
- The storage drive is a different part of the process, and has some additional pieces
- Unlike RAM, storage devices don’t “speak CPU” natively
  - Need some additional parts to get them to talk
Understanding What the Storage Sees
Storage Media
Block I/O Stream

- CPU and memory are connected to storage via the PCI bus (usually PCIe nowadays)
- Applications ask for a location and a length (range) of data storage
- The system needs to translate both the address and the location of where that range of data exists
- The system needs help with that translation in the form of a protocol
Commands from the CPU need to be adapted/translated to speak to storage devices (e.g., SCSI, IDE/ATA)
A Little Bit About SCSI

- **SCSI is ubiquitous**
  - Hard Drives, SSDs, Tape Drives, etc.
- **Backwards Compatible**
- **Common SCSI Components**
  - **Initiator** - Issues requests for service by SCSI devices, can be on-board or part of an adapter
  - **Target** - Physical storage device, can be single disk or array
  - **Service Delivery Subsystem** - Communication mechanisms (usually over a wire) between initiators and targets
More About Blocks

- Blocks are logical and physical units that are located on storage media.
- It is the smallest unit writable by a disk or file system.
- All storage - including file storage and object storage, eventually winds up talking to blocks.
Anatomy of a Disk Drive

Components:
- Platter
- Track
- Sector

Location of data greatly affects performance
Blocks and Sectors

- Blocks are made up of sectors on a drive.
- Each block is given a unique number.
- Everything that a file system does with storage media is composed of operations on blocks.
Files and Blocks

- Applications (including OS) think in terms of files
- Storage thinks in terms of blocks
- Need to match these up somehow
Understanding Files and Blocks
File Systems

- Every operating system (OS) has a file system (FS) as part of its kernel.
- FS maintains a list of file names on the disk and their corresponding storage media.
Enter the File System

- Drives are managed by a drive controller
  - Takes I/O commands from the file system
  - Done through I/O module using a protocol (such as SCSI)

- In-between the file system and the drive controller is a Volume Manager*
  - Aggregates and creates “fake disks” that the File System uses

* SIMPLIFIED FOR EXPLANATORY PURPOSES AND CLARITY
Volume Manager

- Creates a virtual volume layer

* SIMPLIFIED FOR EXPLANATORY PURPOSES AND CLARITY
File System and Drives

- Translates and manages the virtual addresses that the application sees to the block address on a drive
- Not all blocks are created equal
Inodes, Files, and Directories

Inodes are metadata
- Mapping of files to blocks is handled through Inodes
- Each Inode describes one file
  - Every file or folder will have a corresponding Inode
- Each Inode contains a list of the disk block numbers in the file it describes
- Names of files live in Directory Structures
  - Directory Structure maps names to Inode numbers
- Directory Inodes
  - Will have Data Blocks that contain file names and inodes of the files
- File Inodes
  - Will have data blocks that contain the actual data of the file

<table>
<thead>
<tr>
<th>Inode Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>Owner</td>
</tr>
<tr>
<td>Mode</td>
</tr>
<tr>
<td>Timestamp</td>
</tr>
<tr>
<td>Address</td>
</tr>
<tr>
<td>Data Block</td>
</tr>
<tr>
<td>[some other stuff*]</td>
</tr>
</tbody>
</table>

---

*SIMPLIFIED FOR EXPLANATORY PURPOSES AND CLARITY*
Kernel starts at root of the file system: “/”
Looks for directory called “home”
Goes to that Inode, sees its a directory structure, looks up entry for “foo.txt”
Goes to that Inode for “foo.txt” and holds list of disk block numbers
  Step that converts from FS into real disk block numbers
Goes to SCSI controller, which puts those block numbers into a SCSI command (e.g., “read”)

*Simplified for explanatory purposes and clarity*
Storage Packet Walk
Operating System checks main memory (and associated caches) first
If not there, it needs to use the file system’s ability to retrieve from disk
Packet Walk

- File system checks Unified Buffer Cache (UBC) to see if file has been previously accessed.
- If not, then it needs to check its directory structure to see how the file name is associated with a disk block (i.e., Inode).
Packet Walk

- **SCSI controller returns the contents of the Inode**
- **The response is a directory (“home”), which has its own Inode pointer**
Packet Walk

- The data is put into the Unified Buffer Cache (i.e., specifically an Inode cache)
- Process continues until we get to actual data blocks
Packet Walk

- The contents of the data block is collected by the Drive controller, and sent to the SCSI controller.
- SCSI controller translates the format back to the File System can understand.

- File system copies data to its own buffer cache.
- Sends data back to application, storing copies in cache in main memory.
Packet Walk

- Each time we access blocks we have to wait for the platters to move to the correct address for the read/write head to access the contents.
- If the blocks are not stored on the drive in sequence, we have to wait even longer.
Anatomy of a Flash Drive

- No spinning media
  - All data is randomly accessed
- Cells contain bits
  - SLC - 1 bit per cell
  - MLC - 2 bits per cell
  - TLC - 3 bits per cell
- Pages are the smallest unit that can be programmed
  - Made up of cells
  - Can come in 2k, 4k, 8k, 16k
- Blocks are the smallest unit that can be erased
  - Made up of pages
  - Most blocks have 128 or 256 pages
- Managed by a Flash Translation Layer (FTL)
Once More, With Flash

- Process is functionally identical
- No moving parts; reduced time
Back to the Pizza Delivery

1 ns = 1 km
Understanding What the Network Sees

HOWDY.
Networks
Impact of the Network

[Diagram showing Direct-Attached Storage (DAS), Network-Attached Storage (NAS), and Storage-Area Network (SAN)]
Translation Layer Extravaganza
Where does the network go?
Another Way To Think About It

- Do you want a network to understand the applications better?
- Do you want a network to understand the storage better?
- Typical Trade-Off: Flexibility versus Performance

* OBJECT-BASED STORAGE CAN BE SEEN AS A SPECIAL CLASS OF FILE-BASED STORAGE, BUT OUTSIDE THE SCOPE OF THIS PRESENTATION BEYOND WHAT IS SHOWN HERE.

** NVMeOFS IS A BLOCK-BASED PROTOCOL BASED ON NON-VOLATILE MEMORY EXPRESS, NOT SCSI, BUT ALSO FALLS OUTSIDE THE SCOPE OF THIS PRESENTATION.
File System Inode Process to a SAN*

- SANs insert SCSI communication networks
- Permit consolidation of storage for multiple hosts over a storage network
- Each host controls (i.e., “owns” its assigned storage)
  - “Blue” owns blue logical drive, “Green” owns green logical drive, etc.

* Simplified for explanatory purposes and clarity
SCSI Network Communication Options

Many different ways to have SCSI communicate over a network
File System Inode Process To Network-Attached Storage

$ CAT /HOME/FOO.TXT

<table>
<thead>
<tr>
<th>File Name</th>
<th>Inode Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>home</td>
<td>{network mount} Inode 3</td>
</tr>
</tbody>
</table>

**NETWORK-ATTACHED DEVICE**

<table>
<thead>
<tr>
<th>File Name</th>
<th>Inode Block</th>
</tr>
</thead>
<tbody>
<tr>
<td>home</td>
<td>38</td>
</tr>
</tbody>
</table>

SCSI Bus

SCSI Drives

Inode Block 3

Inode Block 4

Inode Block 5

Inode Block 6

Data Block 10

Data Block 11

Data Block 12

Data Block 13

Inode Block 38

Inode Block 39

Inode Block 40

Inode Block 41

Data Block 100

Data Block 101

Data Block 102

Data Block 103
Summary
The Big Picture
Summary Points

- These were just the basics, the bare-bones minimum
- The storage process is more involved than simply having a favorite storage medium, network, or file system
- Understand the process, understand the trade-offs
- Watch more SNIA-ESF webinars to fill in the details!
Additional Info

- **“Anatomy of a File System”** by Benno Joy
  - [https://youtu.be/0Yf-W7Ps6u4](https://youtu.be/0Yf-W7Ps6u4)
  - Excellent video on SCSI, drives, and file systems

- **Operating Systems Course by John Bell, U of Illinois (Chicago)**
  - Great overview of memory and I/O for OSes
  - [https://www2.cs.uic.edu/~jbell/CourseNotes/OperatingSystems/](https://www2.cs.uic.edu/~jbell/CourseNotes/OperatingSystems/)

- **Schulz, Greg. Cloud and Virtual Data Storage Networking. CRC Press. 2012.**
  - Excellent foundation book for storage as a holistic concept (not just the networking piece).
  - [http://storageio.com](http://storageio.com)

- **SNIA’s website**
  - [http://snia.org](http://snia.org)
After This Webcast

This webcast and a PDF of the slides will be posted to the SNIA Ethernet Storage Forum (ESF) website and available on-demand

http://www.snia.org/forums/esf/knowledge/webcasts

A full Q&A from this webcast, including answers to questions we couldn't get to today, will be posted to the SNIA-ESF blog

http://sniaesfblog.org/

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THANK YOU!

BYE BYE!