SNIA Global Education

# SNIA Tutorial 2
# EVERYTHING YOU WANTED TO KNOW ABOUT STORAGE, BUT WERE TOO PROUD TO ASK:

## Part Vermillion
## What if Programming and Networking Had a Storage Baby?


**J Metz, Cisco - @drjmetz**
**John Kim, Mellanox - @Tier1Storage**



Presented at Flash Memory Summit 2018

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# Welcome to SNIA Education Afternoon at Flash Memory Summit 2018

# Agenda

| | |
|---|---|
| 1:00 pm – 1:50 pm | SNIA Tutorial 1<br>*A Case for Flash Storage*<br>Dejan Kocic, NetApp |
| 1:50 pm – 2:45 pm | SNIA Tutorial 2<br>*What if Programming and Networking Had a Storage Baby Pod?*<br>John Kim, Mellanox Technologies<br>and J Metz, Cisco Systems |
| 2:45 pm – 3:00 pm | Break |
| 3:00 pm – 3:50 pm | SNIA Tutorial 3<br>*Buffers, Queues, and Caches*<br>John Kim, Mellanox Technologies and<br>J Metz, Cisco Systems |
| 4:00 pm – 5:00 pm | SNIA Tutorial 4<br>*Birds-of-a-Feather – Persistent Memory Futures*<br>Jeff Chang, SNIA Persistent Memory and NVDIMM SIG Co-Chair |

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SDC 18
Storage Developer Conference 2018
9/24-9/27 Santa Clara, CA

SDC discount registration cards in FMS bags & at **SNIA booth 820**

SNIA PERSISTENT MEMORY PM SUMMIT
JANUARY 24, 2019 | SANTA CLARA, CA

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# Special Thanks

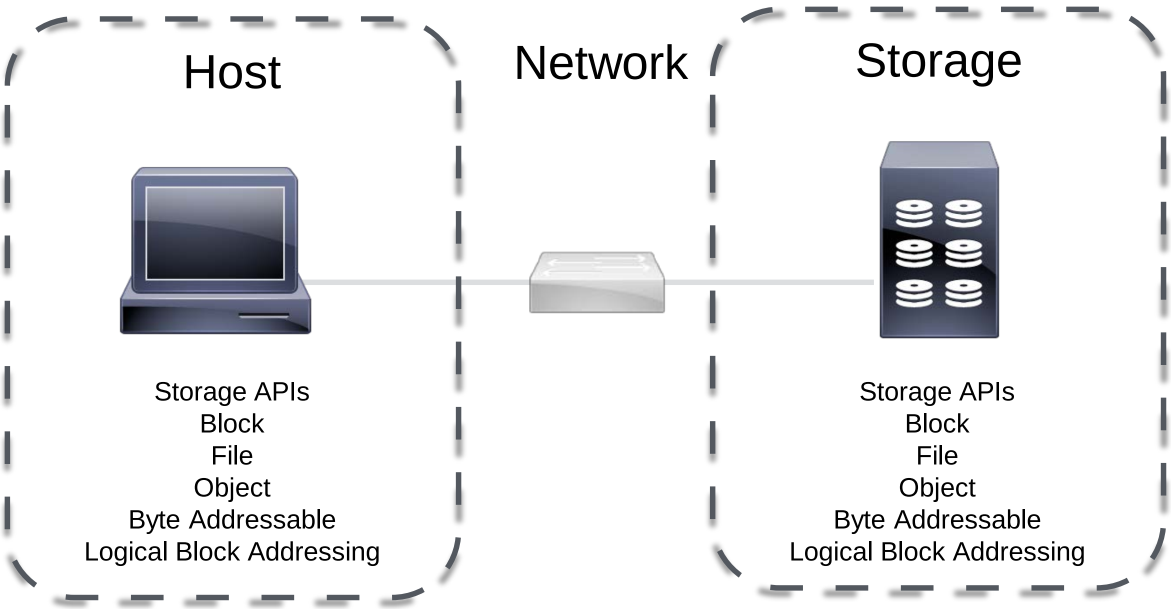
**Alex McDonald**
**NetApp**

**Dror Goldenberg**
**Mellanox**

**Rob Peglar**
**Advanced Computation & Storage, LLC**

# Agenda

- Block vs. File vs. Object
- Byte Addressable vs. Logical Block Addressing
- POSIX and Storage
- Log Structures, Journaling Systems



# Block vs. File vs. Object

# Block, File and Object Storage

- Three types of storage access
  - Block
  - File
  - Object
- Each has distinct characteristics to relationships with hosts
  - Distinct advantages/disadvantages
- These are *not* the same thing as File Systems!

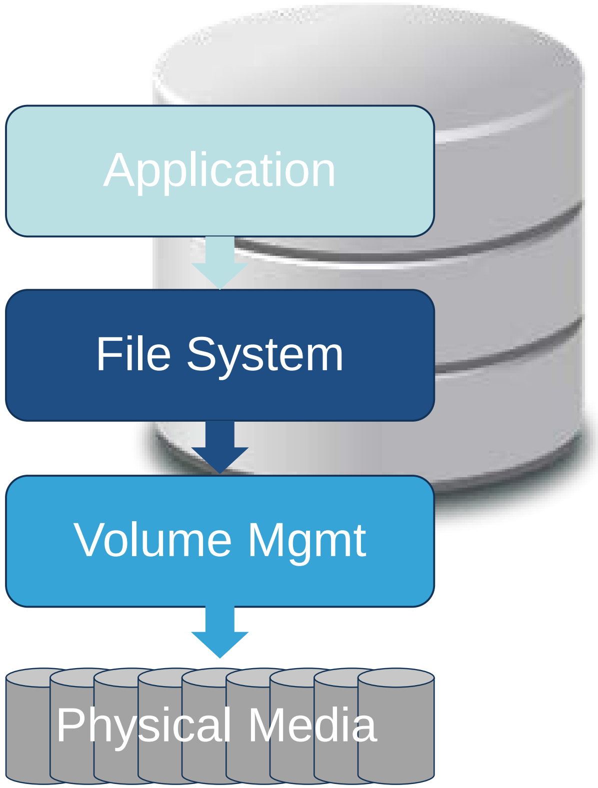
# Block, File and Object Storage

- **Block**
  - The unit in which data is stored and retrieved on disk and tape devices; the atomic unit of data.

Source: SNIA Dictionary

# Block Storage

- What can you do with it?
  - Boot servers/VMs
  - Works very well with databases and transactions
- Pros
  - Host system has direct access to storage memory (drives, disk, NVM)
  - Highest performance capabilities
- Cons
  - Heavy reliance on HA redundancy at every level of the architecture



# Block, File and Object Storage

- **File**
  - An abstract data object made up of (a.) an ordered sequence of data bytes stored on a disk or tape, (b.) a symbolic name by which the object can be uniquely identified, and (c.) a set of properties, such as ownership and access permissions that allow the object to be managed by a file system or backup manager

Source: SNIA Dictionary

# File Storage

- Foundation for Network Attached Storage (NAS)
  - **NFS, SMB**
  - CIFS (deprecated)
- Enterprise
  - Purpose-built, structured and unstructured data over one or more protocols
  - Scalable and higher performance
  - Supports large number of clients
  - Features: tiering, caching, de-duplication, multi-tenancy, replication, multi-protocol support, etc.
  - Suited for large data sets, data sharing
  - Clustered NAS (Scale-up or scale-out)
  - Petabyte scale, 1000s of drives

# Block, File and Object Storage

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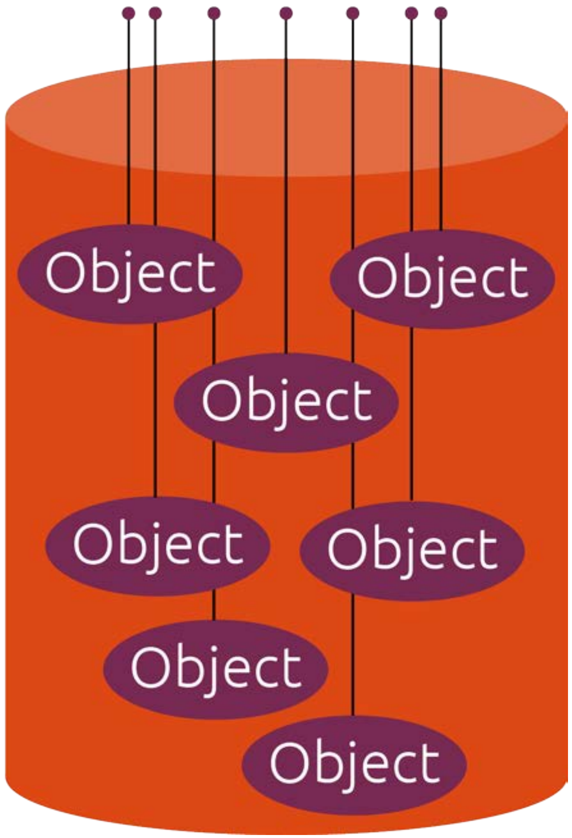
- Object
  - The encapsulation of data and associated metadata

Source: SNIA Dictionary

# Object Storage

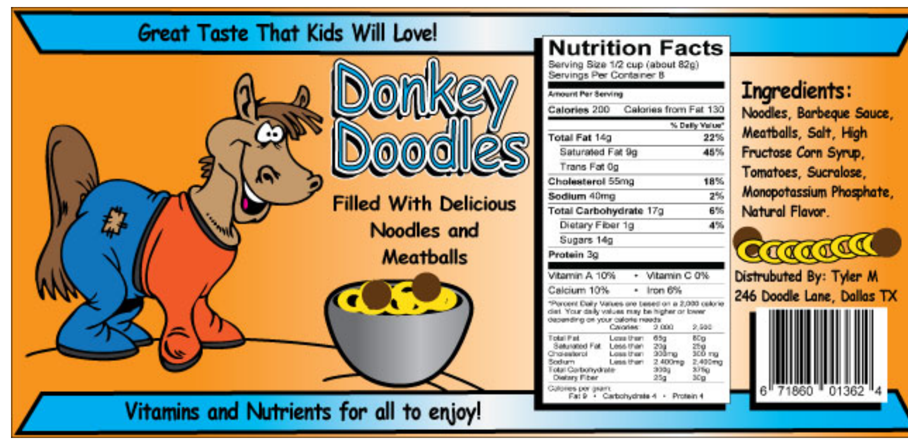
- Instead of a hierarchy, object-storage organizes things in a flat structure. This allows for massive scalability.
- Though it has no file system, like file storage, changes are at the file level.
- Instead of a file system, objects have lots of metadata. These attributes can be built-in or customer-defined.



# Visualizing Object Storage

- Imagine a grocery store with no labels on any of the cans

- Metadata is the information on the label of the cans




- Over time, metadata can be more important than the data itself

Concept borrowed shamelessly from Jeff Lundberg, HDS "The Fundamentals of Object Storage, Part 1", because it was so brilliant.

# Unique Abilities of Object

- Enables the user to find data based upon Regular Expressions
  - You can search in very large datasets on metadata
  - Object storage is ideal for **analytics** applications
- Allows you to treat the Cloud not as a large "Object Store" but as a database
- As the size of the Cloud grows, so does your ability to find data
  - The better your metadata is, the better your queries can be
- Examples of using complex queries:
  - Find objects of a certain age and containing specific meta-data
  - Find objects belonging to a person or application that can be removed but including other criteria for exclusion
  - Find similar objects and classify them
- Recall: SCSI doesn't have the ability to "find objects"

# Use Cases

### Block

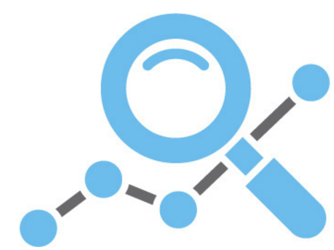
- Databases
- Transactional Processing
- Enterprise-wide Applications
- Dedicated Network/High Performance

### File

- Departmental Applications
- End User Data/Files
- Shared/Clustered Systems

### Object

- Analytics
- Unstructured Data Applications
- Cost effective
- Extremely scalable



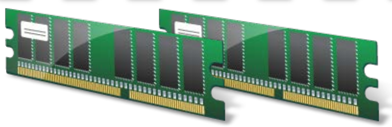
# Side x Side Comparison

| | Block | File | Object |
|---|---|---|---|
| Transaction Units | Blocks | Files | Objects, that is, files w/ custom metadata |
| Supported Update Types | Supports in-place updates | Supports in-place updates | No in-place update support; updates create new object versions |
| Protocols | SCSI, Fibre Channel, SATA. NVMe | SMB and NFS | REST and SOAP over HTTP |
| Metadata Support | Fixed system attributes | Fixed file-system attributes | Supports custom metadata |
| Best suited for | Transactional, and frequently-changing data | Shared file data | Relatively static file data and cloud storage |
| Biggest Strength | High performance | Simplified access and management of shared files | Scalability and distributed access |
| Limitations | Difficult to extend beyond the Data Center | Difficult to extend beyond the Data Center | Ill-suited for frequently changing transactional data, doesn't provide a sharing protocol with a locking mechanism |

# Byte Addressable vs. Logical Block Addressing

# System Architecture

DRAM

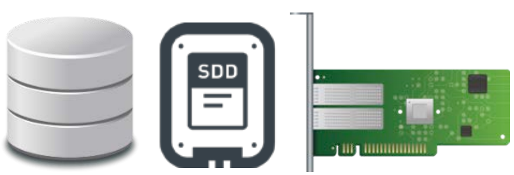


Memory Bus

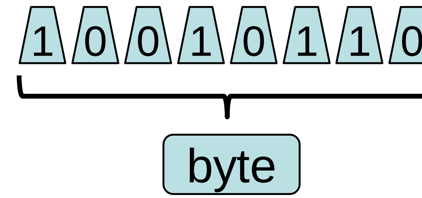
CPU

PCIe Bus

Peripherals: Storage & Network

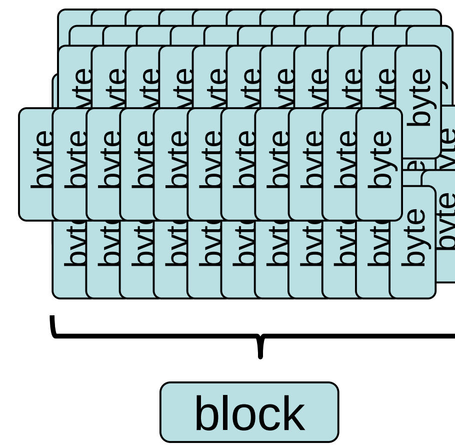



Bit=1 or 0


Byte = 8 bits

Block = 512 bytes, or 1024, 4096, 32K, 4 million bytes, etc.



# Addressing


Address - describes the location

What is byte/block addressing?

# Byte and Block Addressing

- Byte Addressable: Access one byte at a time
  - 1 byte = 8 bits
  - Traditionally used for memory (volatile)
- Logical Block Addressable
  - Access an entire block (many bytes) at a time
  - Traditionally used for storage (persistent)
  - Typical access is 512 bytes (sector)

# Comparing Byte vs. Logical Block

- Byte Addressable
  - Fine grained access
  - 8 bits at a time
  - Load/store commands
  - 32-bit address → 4GB of memory
  - Traditional on memory bus
- LBA
  - Coarse access
  - Often 512-byte blocks
  - I/O commands
  - 32-bit address → 2TB of storage.
  - Traditional on storage dev

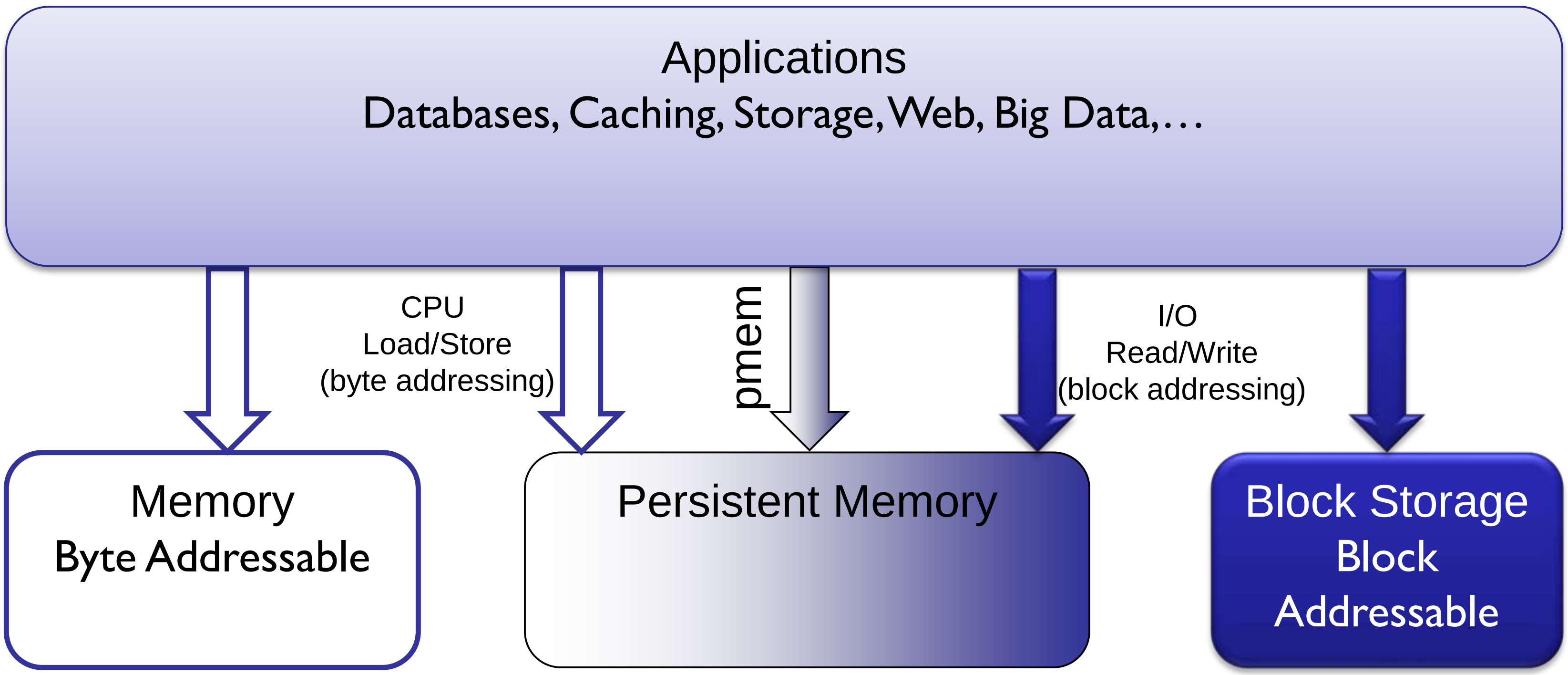
# What About Persistent Memory?

- Traditionally…
  - Memory is fast and volatile on memory bus
  - Storage is slow and persistent on peripheral bus
- New persistent memory breaks the rules
  - Fast like memory, persistent like storage
  - Fast storage on PCIe bus, or…
  - Persistent memory on memory bus
- New access and programming models

# NVM Programmable Models

- Access options
  - Place on DRAM bus but use LBA like storage
  - Place on DRAM bus and address like memory
  - Place on DRAM bus and address like storage class memory
- Need to deal with persistency
- See SNIA NVM Programming Model
  - https://www.snia.org/tech_activities/standards/curr_standards/npm

# Summary

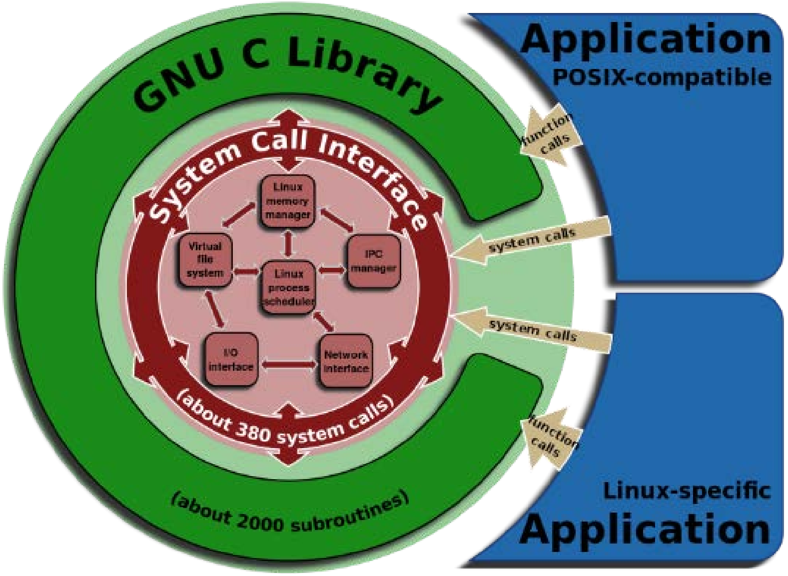


Applications
Databases, Caching, Storage, Web, Big Data,…
CPU
Load/Store
(byte addressing)
pmem
I/O
Read/Write
(block addressing)
Memory
Byte Addressable
Persistent Memory
Block Storage
Block
Addressable

# POSIX and Storage

# POSIX & Storage

- POSIX
  - "Portable Operating System Interface for uniX"
  - Goal; provide portability for applications across multiple OSes
  - Family of standards, specified by the IEEE
    - Late 1980s thru 1997; see http://standards.ieee.org/develop/wg/POSIX.html
    - Includes C programming language standard
  - Specifies API level interfaces for a wide variety of operating system interfaces



# POSIX & Storage

- Storage related parts
- POSIX layer lives above device driver (or block level)
  - Provides directories and files
  - Data as stream of bytes
- Sets of I/O operations
  - open, close, read, write, lseek, ioctl
  - Plus a large number of ancillary calls and CLI cmds in support

- open
- read
- write
- close
- lseek
- llseek
- _llseek
- lseek64
- stat
- fstat
- stat64
- chmod
- fchmod
- access
- rename
- mkdir
- getdents
- fcntl
- unlink
- fseek
- rewind
- ftell
- fgetpos
- fsetpos
- fclose
- fsync
- creat
- readdir
- opendir
- fopendir
- rewinddir
- scandir
- seekdir
- telldir
- flock
- lockf
- lseekm
- lstat
- fstatat
- fopen
- fdopen
- freopen
- remove
- chown
- fchown
- fchmodat
- fchownat
- faccessat
- utime
- futimes
- lutimes
- futimesat
- link
- linkat
- unlinkat
- symlink
- symlinkat
- rmdir
- mkdirat
- getxattr
- lgetxattr
- fgetxattr
- xetxattr
- lsetxattr
- fsetxattr
- listxattr
- llistxattr
- flistxattr
- removexattr

# POSIX & Storage

- Benefits of POSIX
  - Simplicity & broad application
    - Data as a stream of bytes matches capabilities of wide range of devices

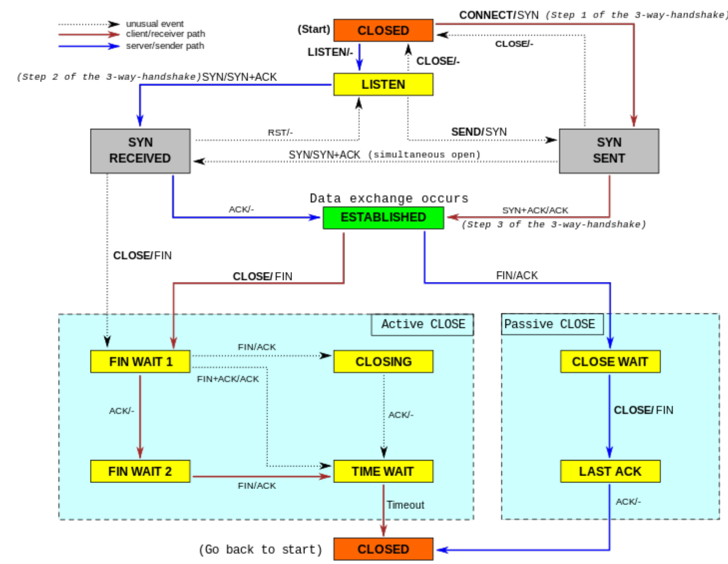

  - Consistency & locking
    - Last writer wins, read gets latest written, file & byte range locking
  - Easy[1] to port apps across POSIX compliant systems
  - Provides state through an opaque[2] file handle
  - File systems are ubiquitous (and there a huge variety of them) but most have similar to identical POSIX interfaces

[1] For some definition of "easy" that doesn't include "impossible"
[2] Or transparent depending on your view of the semantics of these words

# POSIX & Storage

## Downsides of POSIX

- Definitions are implemented as a C language API
- Stateful
  - Not RESTful
  - Compare: HTTP provides POST, GET, PUT, DELETE; no handle, just resource IDs in the form of URLs, and is idempotent with no locking
- Network unfriendly
  - Chatty; network latency an issue; every operation requires client to server acknowledgements; locking
  - Difficult & complex recovery in the face of bad network connectivity
- Metadata, operation ordering & cache coherence…



# POSIX & Storage

- Positive future for POSIX
  - File system protocols are maturing & becoming more capable
    - Protocols allow talking to file systems over a network
    - NFSv4.x, SMB3.x (“POSIX-like” semantics)
  - Interesting file system developments
    - High-performance clustered file systems; Btrfs, Ceph, GlusterFS and more
    - File systems in IoT edge devices
  - Cloud & object type stores can’t (yet) replace all the functionality apps require
    - Transactional systems
    - Stream oriented data increasingly important

# Log Structuring and Journaling

## and other fun stuff

# Log Structured Systems

## Log Structured Systems

- Definition – a system where all incoming metadata and data are written sequentially to a circular buffer, called a log
  - First proposed in 1988 (Ousterhout and Douglis)
  - First implemented in Sprite (Unix-like distributed OS) by Ousterhout and Rosenblum in 1992
- Non-log systems write randomly, overwrite-in-place
- Log systems 'batch up' updates and write sequentially
  - Not overwrite-in-place
  - Log enables crash recovery (end of log), checkpoints (last known good persist), roll-forward

# Basic Operation

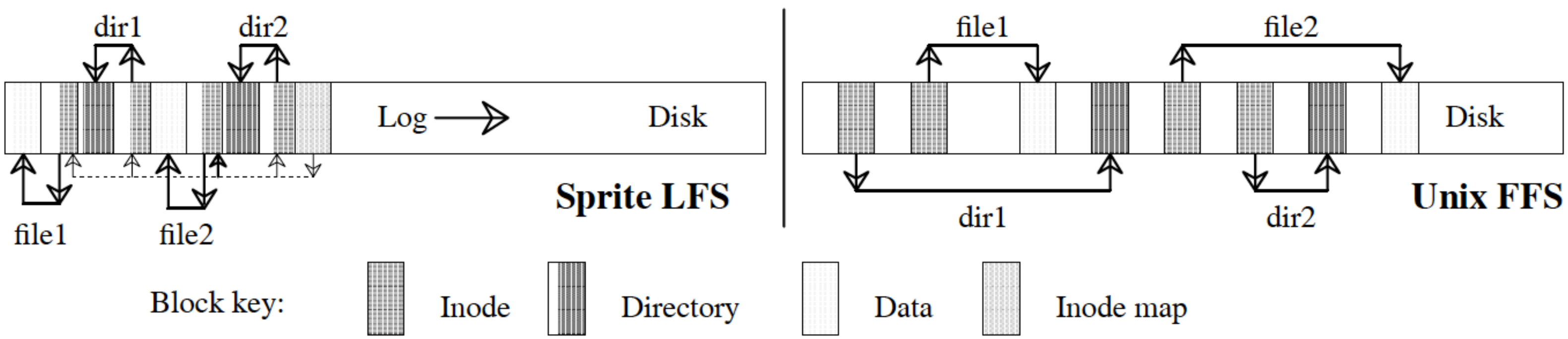
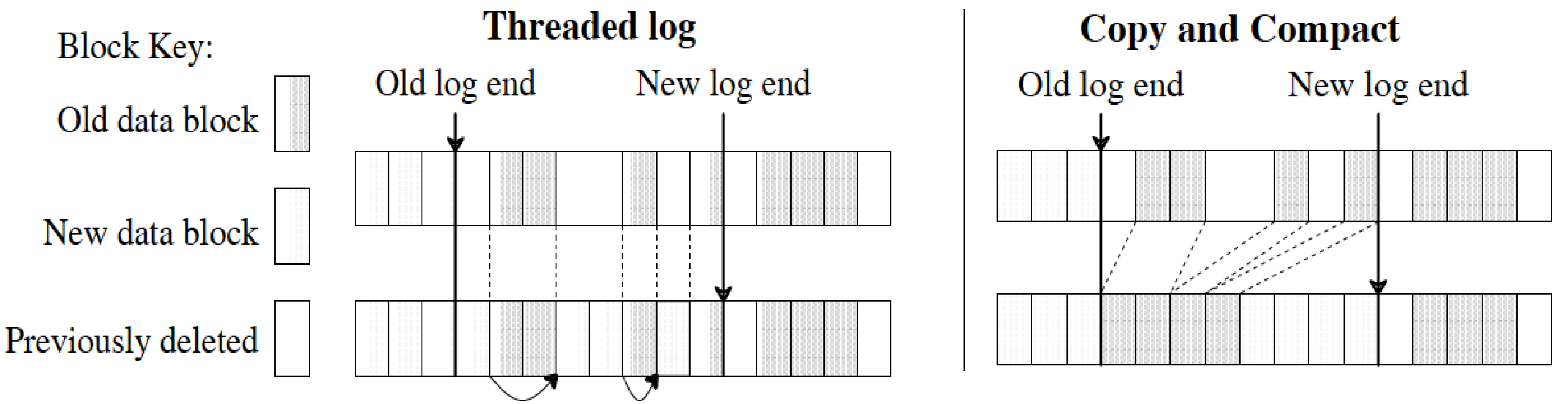



**Figure 1 — A comparison between Sprite LFS and Unix FFS.**
This example shows the modified disk blocks written by Sprite LFS and Unix FFS when creating two single-block files named `dir1/file1` and `dir2/file2`. Each system must write new data blocks and inodes for `file1` and `file2`, plus new data blocks and inodes for the containing directories. Unix FFS requires ten non-sequential writes for the new information (the inodes for the new files are each written twice to ease recovery from crashes), while Sprite LFS performs the operations in a single large write. The same number of disk accesses will be required to read the files in the two systems. Sprite LFS also writes out new inode map blocks to record the new inode locations.

Attribution: "The Design and Implementation of a Log-Structured File System" Ousterhout and Rosenblum, July 1991

# Segment Cleaning (aka GC)




Skip over active blocks, overwrite deleted/overwritten blocks

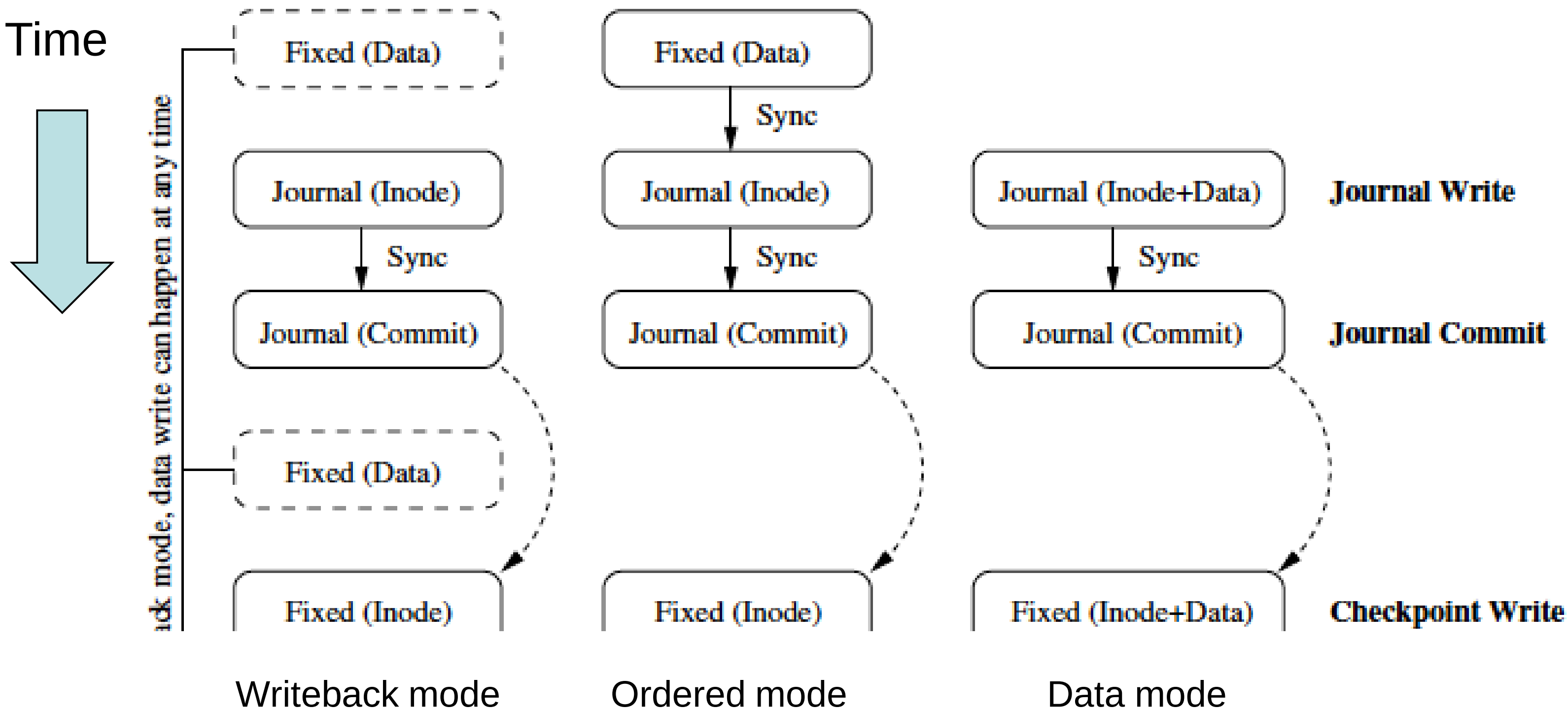
Rewrite active blocks into new space, move end

Attribution: “The Design and Implementation of a Log-Structured File System”
Ousterhout and Rosenblum, July 1991

# Journaling Systems

- Journaling Systems
  - Definition – a system where intended metadata for writes (updates) are recorded in a journal - but not necessarily data
    - Very popular – first implemented in 1990 (JFS)
    - Many systems today – NTFS, ext3, ext4, ReiserFS, etc., including split-journal
  - Record pending persistence – then commit (aka 2-phase, write twice)
  - Provides for true atomicity – known persist success (or failure)
  - Comparison:
    - Log-Structured –is- the filesystem; journal is only ½ the filesystem
      - Journal has crash recovery (journal replay), assured last-known-good, optional barriers

# Basic Operation (ext3 example)




Attribution: “Analysis and Evolution of Journaling File Systems” Prabhakaran and Arpaci-Dusseau, USENIX 2005

# Log Structuring and Journaling

## Wasn't that fun?

# Overall Summary

- **Block/File/Object**
  - Fundamental storage types in Data Center applications, each requiring performance/flexibility trade-offs
- **Byte Addressable v. Logical Block Addressable**
  - Traditional ways to access memory and storage respective, whose use is changing with the adoption of persistent memory
- **POSIX and APIs**
  - POSIX a standard that enables storage to be viewed as both a random access and a stream oriented source of data
- **Log Structuring and Journaling**
  - Two related techniques, that enhance consistency and recovery aspects of systems which persist data, especially filesystems

# Other Storage Terms Got Your Pride? This is a Series!

- Check out previously recorded webcasts:
  - http://sniaesfblog.org/everything-you-wanted-to-know-about-storage-but-were-too-proud-to-ask/
- **Teal** – Buffers, Queues and Caches
- **Rosé** - All things iSCSI
- **Chartreuse** – The Basics: Initiator, Target, Storage Controller, RAID, Volume Manager and more
- **Mauve** – Architecture: Channel vs. Bus, Control Plane vs. Data Plane, Fabric vs. Network
- **Sepia** – Getting from Here to There
- **Turquoise** – Where Does My Data Go?
- **Cyan** – Storage Management
- **Aqua** – Storage Controllers

# Speaking of Series…Check out Storage Performance Benchmarking

- Storage Performance Benchmarking:
  1. Introduction and Fundamentals
  2. Solution under Test
  3. Block Components
  4. File Components

Watch them all on-demand at:
http://www.snia.org/forums/esf/knowledge/webcasts-topics

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