OBJECT STORES AND I/O APPROACHES

Hardware and Software interfaces

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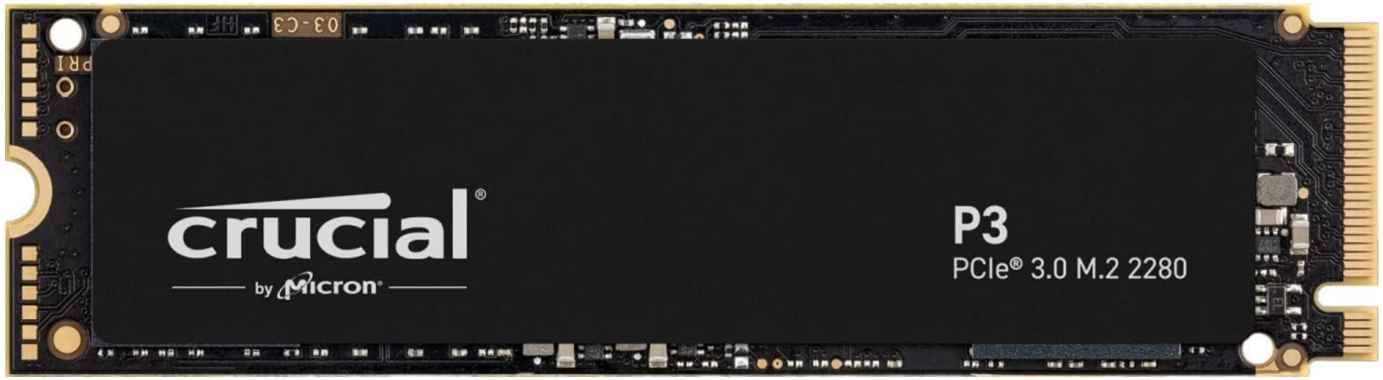
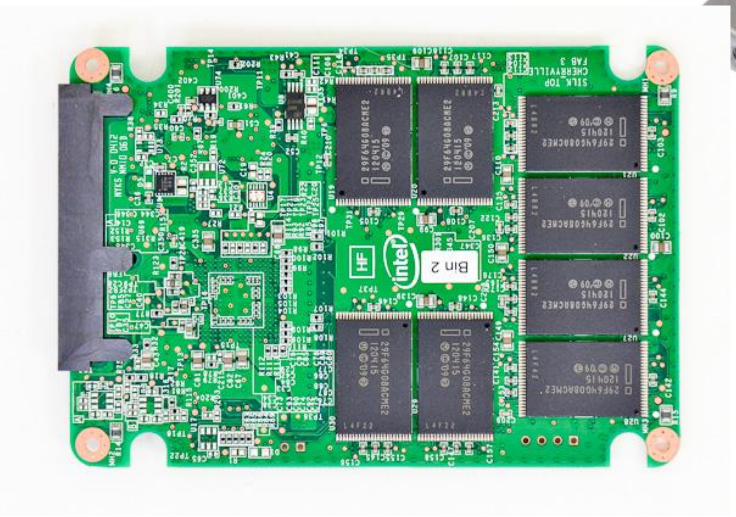
Storage


crucial
by Micron
P3
PCIe® 3.0 M.2 2280




crucial
2.5-inch SOLID STATE DRIVE

Filesystems

- Lots of ways to store data on storage devices
- Filesystems have two components:
    - Data storage
    - Indexing
- Data stored in blocks
    - Chunks of data physically stored on hardware somewhere
- Indexing is used to associate names with blocks

    - File names are the index
    - Files may consist of many blocks
- Variable sized nature of files makes this a hard problem to solve

Filesystems

- Different ways of defining how inodes → blocks, and how directories, filenames, etc… are structured
  - As well as alternative approaches (i.e. log-structured filesystem)
  - Extended functionality (replication, distribution, backup, erasure coding, etc…)
- These are what differentiate filesystems, i.e.:
  - ext*: ext3, ext4
  - xfs
  - zfs
  - btrfs
  - etc…
- Maybe be important for performance or required functionality but the default can be used by most

Parallel filesystems

- Build on local filesystem but provide
  - Aggregated distributed local filesystem
  - Custom approach to define how inodes → blocks, and how directories, filenames, etc... are structured
  - Relaxed consistency (potentially) for concurrent writing
- i.e. Lustre:
  - Open-source parallel file system
  - Three main parts
    - Object Storage Servers (OSS)
      - Store data on one or more Object Storage Targets (OST)
      - The OST handles interaction between client data request and underlying physical storage
      - OSS typically serves 2-8 targets, each target a local disk system
      - Capacity of the file system is the sum of the capacities provided by the targets (roughly)
      - The OSS operate in parallel, independent of one another
    - Metadata Target (MDT)
      - One(ish) per filesystem
      - Storing all metadata: filenames, directories, permissions, file layout
      - Stored on Metadata Server (MDS)
  - Clients
    - Supports standard POSIX access

POSIX I/O

- Standard interface to files
  - Linux approach
  - Based on systems with single filesystem
  - open, close, write, read, etc...
- Does not support parallel or HPC I/O well
  - Designed for one active writer
  - Consistency requirements hamper performance
  - Has a bunch of functions that can impact performance, i.e. locking (flock, etc...)
- Some filesystems/approaches relax POSIX semantics to improve performance
  - Moving beyond filesystems allows other semantics to be targeted

Object storage

- Filesystems use Files
  - container for blocks of data
  - lowest level of metadata granularity (not quite true)
- Object stores use Objects
  - container for data elements
  - lowest level of metadata granularity
- Allows individual pieces of data to be:
  - Stored
  - Indexed
  - Accessed separately
- Allows independent read/write access to “blocks” of data

Object storage

- Generally restricted interface
  - Put: Create a new object
  - Get: Retrieve the object
- Removes the requirements for lots of functionality r.e. POSIX style I/O
- Traditionally objects are immutable
  - Once created cannot be changed
  - This removes the locking requirement seen for file writes
  - Makes updates similar to log-append filesystems, i.e. copy and update
  - Can cause capacity issues (although objects can be deleted)
- Object ID generated when created
  - Used for access
  - Can be used for location purposes in some systems

Object stores

- Often helper services and interfaces
  - Manage metadata
  - Permissions
  - Querying
  - Etc…
- Distribution and redundancy etc… part of the complexity
  - Often eventual consistency
- Lots of complexity in implementations
- Commonly use web interfaces as part of the Put/Get interface

S3 – Simple Storage Service

- AWS storage service/interface
    - Defacto storage interface for a range of object stores
- Uses a container model
    - Buckets contain objects
    - Buckets are the location point for data
    - Defined access control, accounting, logging, etc…
    - Bucket names have to be globally unique
- Buckets can be unlimited in size
    - Maximum object size is 5TB
    - Maximum single upload is 5GB
- A bucket has no object structure/hierarchy
    - User needs to define the logic of storage layout themselves (if there is any)
- Fundamental operations corresponding to HTTP actions:
    - http://bucket.s3.amazonaws.com/object
    - POST a new object or update an existing object.
    - GET an existing object from a bucket.
    - DELETE an object from the bucket
    - LIST keys present in a bucket, with a filter.

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S3

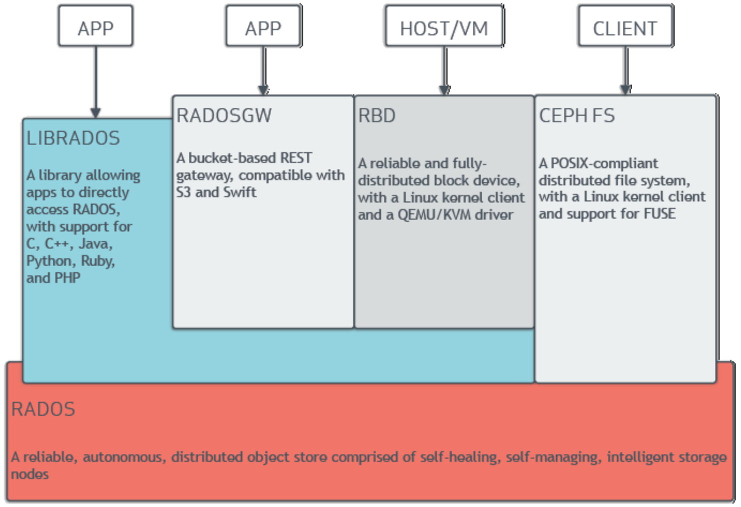
- Objects are combination of data and metadata
- Metadata is name – value pair (key) identifying the object
  - Default has some other information as well:
    - Date last modified
    - HTTP Content-Type
    - Version (if enabled)
    - Access Control List (if configured)
  - Can add custom metadata
- Data
  - An object value can be any sequence of bytes (up to 5TB)
  - Multi-part upload to create/update objects larger than 5GB (recommended over 100MB)

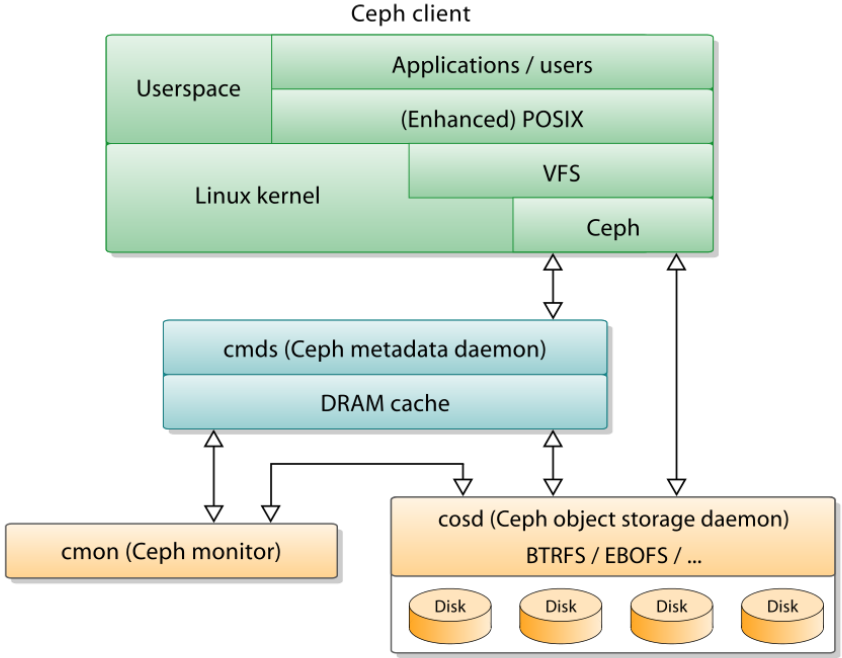
S3 Consistency Model

- Strong RAW (read after write) consistency
  - PUT (new and overwrite) and DELETE operations
  - READ on metadata also strong consistency
  - Across all AWS regions
- Single object updates are atomic
  - GET will either get fully old data or fully new data after update
  - Can’t link (at the S3 level) key updates to make them atomic
- Concurrent writers are *racy*
  - No automatic locking
- Bucket operations are eventually consistent
  - Deleted buckets may still appear after the delete has occurred
  - Versioned buckets may take some time to setup up initially (15 minutes)

Ceph

- Widely used object store from academic storage project
- Designed to support multiple targets
  - Traditional object store: RadosGW → S3 or Swift
  - Block interface: RBD
  - Filesystem: Ceph FS
  - Lower-level object store: LibRados
- Distributed/replicated functionality
  - Scale out by adding more Ceph servers
  - Automatic replication/consistency
    - replication, erasure coding, snapshots and clones
- Supports striping
  - Has to be done manually if using librados
- Supports tiering
- Lacking production RDMA support

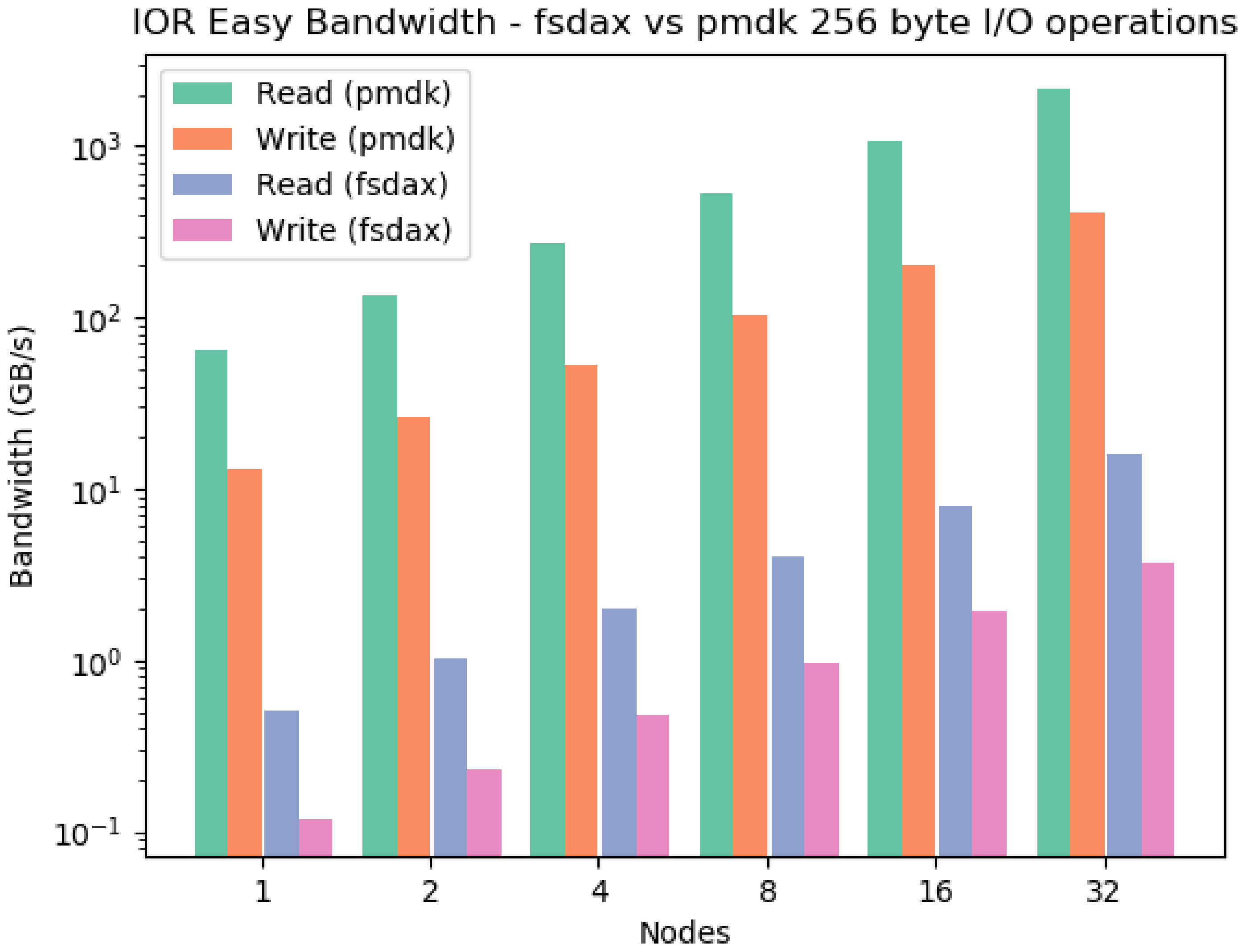




NVRAM

Assembled in Taiwan
NMA1XXD128GPS
128GB
Warranty Void if Label Removed
SN:8089A222100000293D
PN:100—586—613—00

Optane



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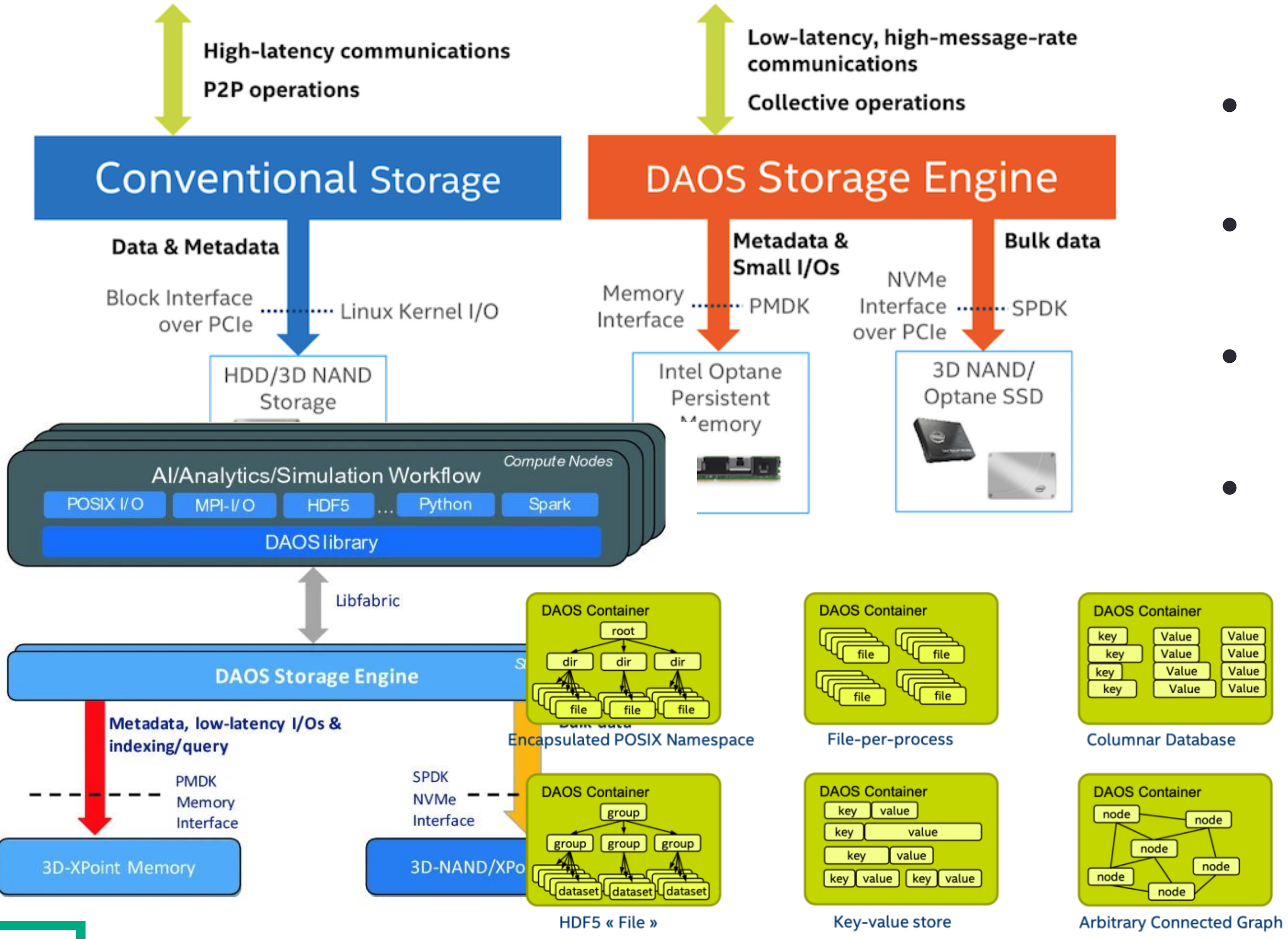
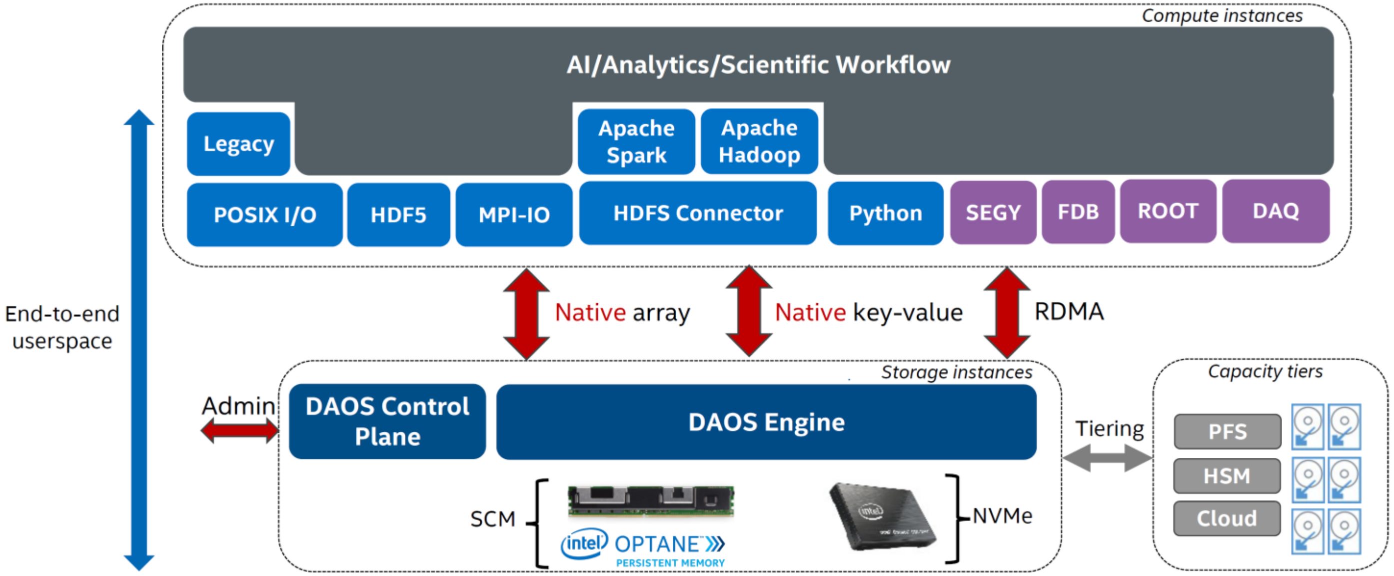


- Native object store on non-volatile memory and NVMe devices and designed for HPC
- Pools
  - Define hardware range of data
- Containers
  - User space and data configuration definitions
- Objects
  - **Multi-level key-array** API is the native object interface with locality
  - **Key-value** API provides a simple key and variable-length value interface. It supports the traditional put, get, remove and list operations.
  - **Array API** implements a one-dimensional array of fixed-size elements addressed by a 64-bit offset. A DAOS array supports arbitrary extent read, write and punch operations.

- Range of storage interfaces
  - Native object store (libdaos)
  - Filesystem (various approaches)
  - Raw block device
  - MPI-I/O (ROMIO)
  - HDF5
  - PyDAOS
  - Spark/Hadoop
  - TensorFlow I/O
- DAOS systems built from DAOS servers
  - One per socket, has own NVMe and NVRAM
  - Scale system by adding more servers (in node or across nodes)
  - Metadata and data entirely distributed/replicated (no metadata centralisation)
  - RAFT-approach used for consensus across servers



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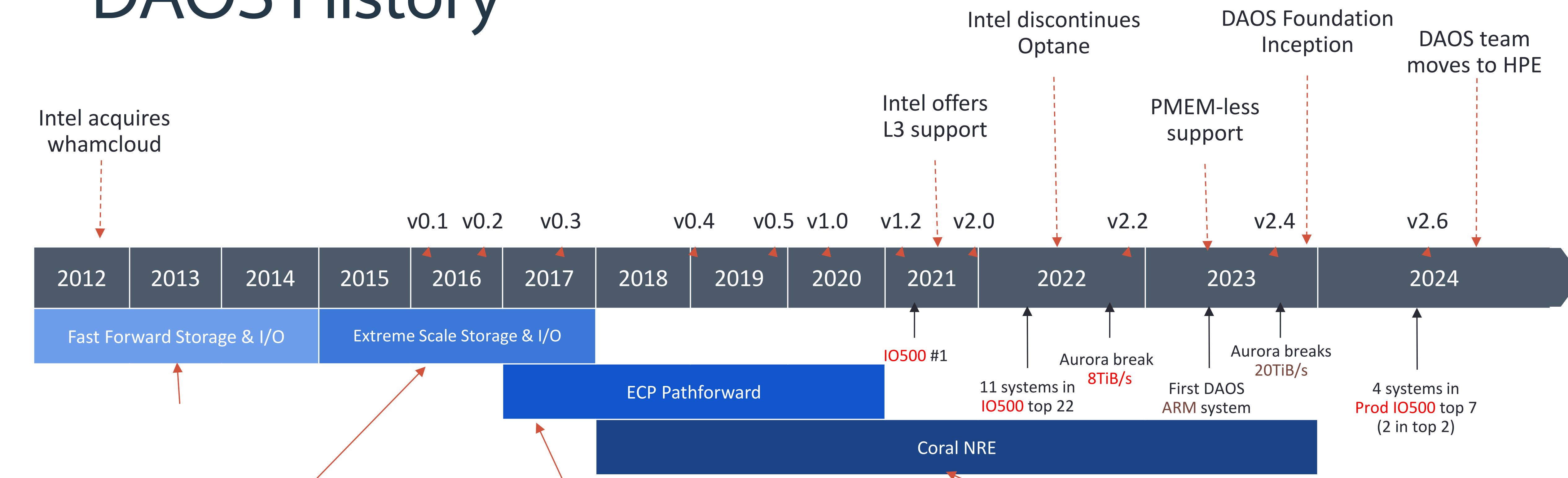
DAOS History



Prototype over Lustre

- Build over ZFS OSD
- DAOS API over Lustre

Standalone prototype

- OS-bypass
- Persistent memory via PMDK
- Replication & self healing

DAOS embedded on FPGA

- Disaggregated I/O
- Monitoring
- NVMe SSD support via SPDK

DAOS Productization for Aurora

- Hardening
- 10+ new features
- Support for extra AI/Big data frameworks

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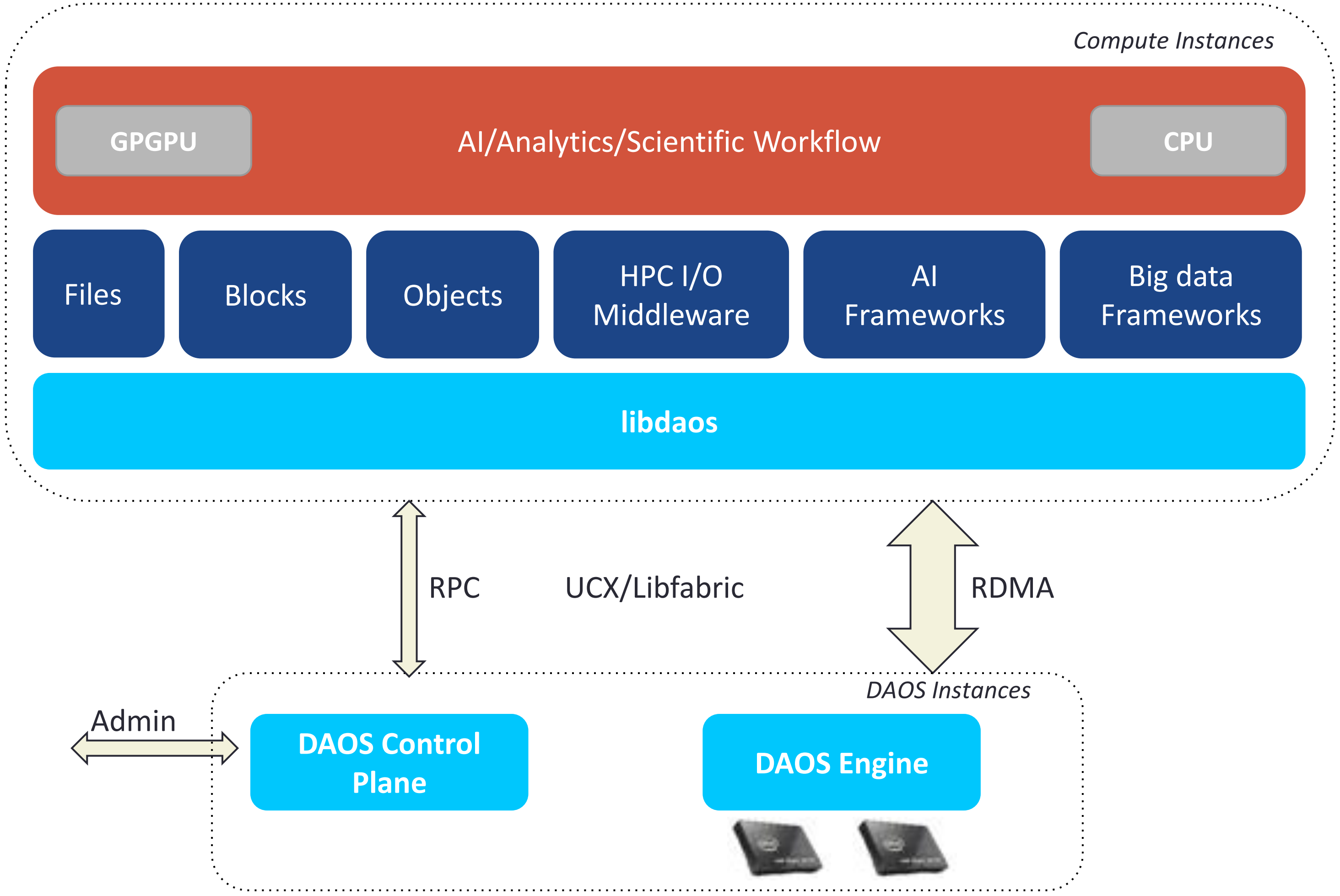
DAOS: Nextgen Open Storage Platform

- Platform for innovation
- Files, blocks, objects and more
- Full end-to-end userspace
- Flexible built-in data protection
    - EC/replication with self-healing
- Flexible network layer
- Efficient single server
    - O(100)GB/s and O(1M) IOPS per server
- Highly scalable
    - TB/s and billions IOPS of aggregated performance
    - O(1M) client processes
- Time to first byte in O(10) µs



DAOS Design Fundamentals

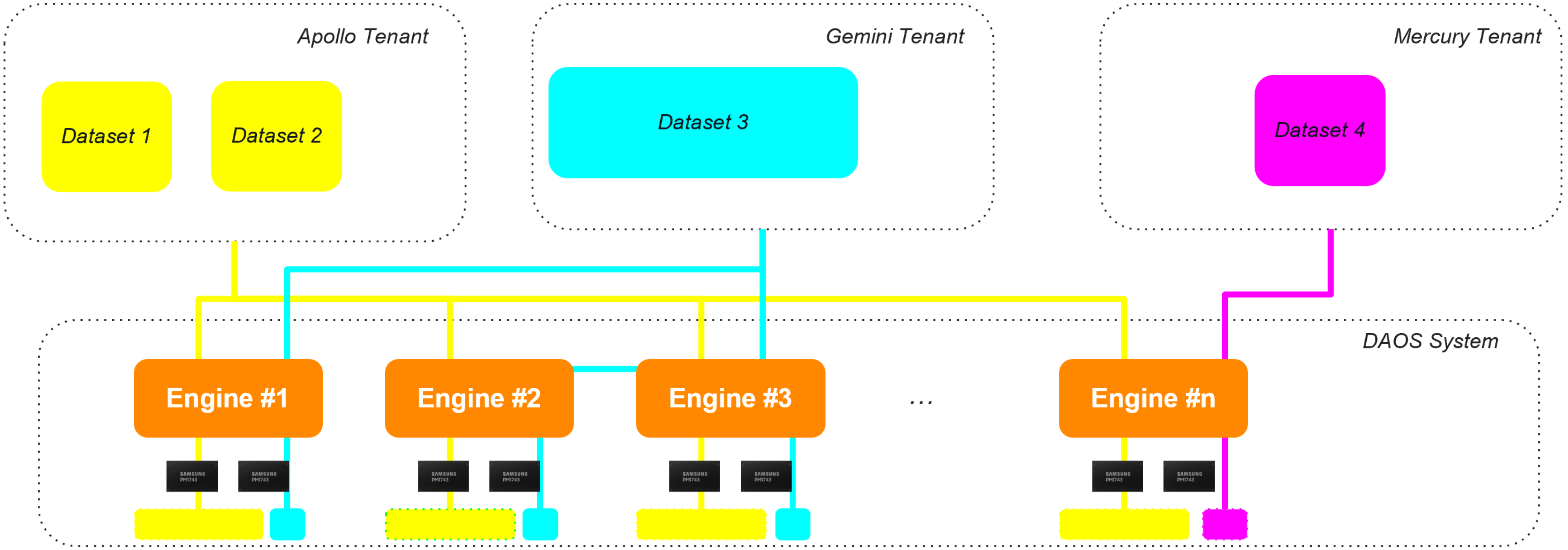
- No read-modify-write on I/O path (use versioning)
- No locking/DLM
- No client tracking or client recovery
- No centralized (meta)data server
- No global object table
- Non-blocking I/O processing (futures & promises)
- Serializable distributed transactions
- Built-in multi-tenancy
- User snapshot

Scalability & Performance

High IOPS

Unique Capabilities

Flexibility in data space creation and operation



Pool 1	Apollo Tenant	100PB	20TB/s	200M IOPS
Pool 2	Gemini Tenant	10PB	2TB/s	20M IOPS
Pool 3	Mercury Tenant	30TB	80GB/s	2M IOPS

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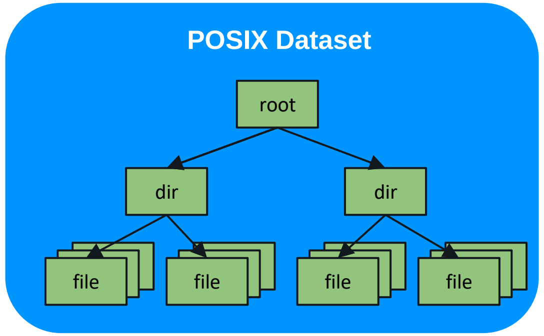
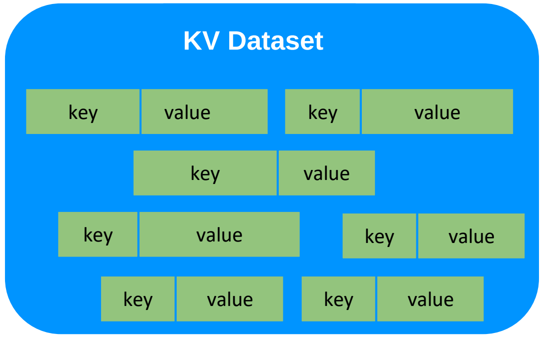
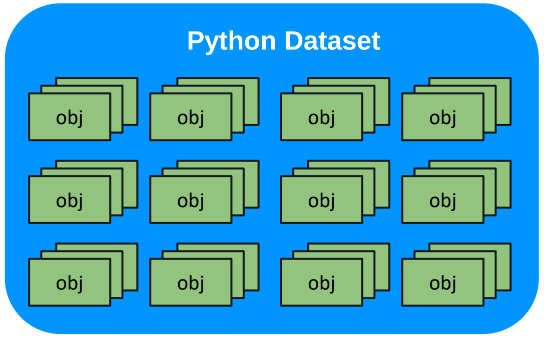
Beyond files

- New data model not based on files and file based approaches
- Introduce notion of dataset
- Basic unit of storage
- Datasets have a type
- POSIX datasets can include trillions of files/directories
- Advanced dataset query capabilities
- Unit of snapshots
- ACLs/IAM per dataset

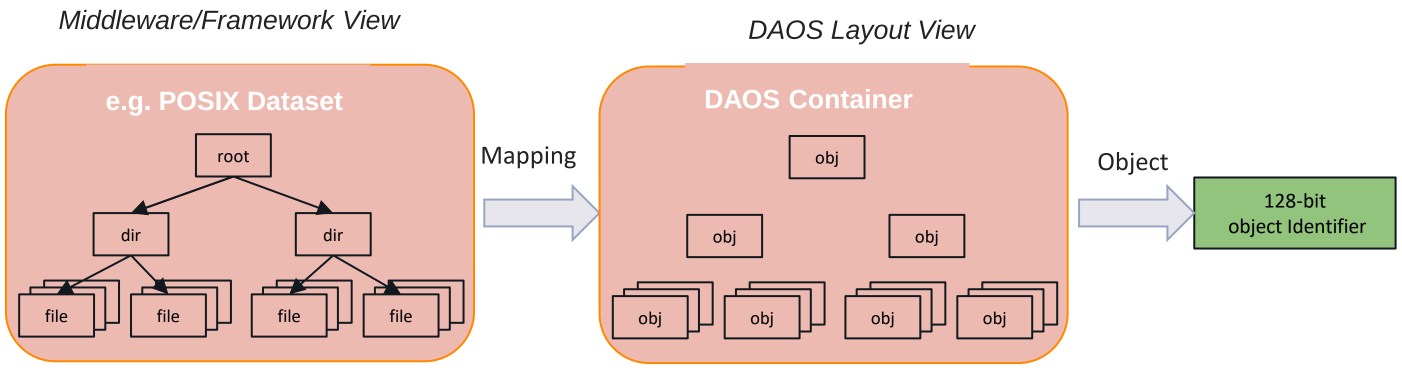


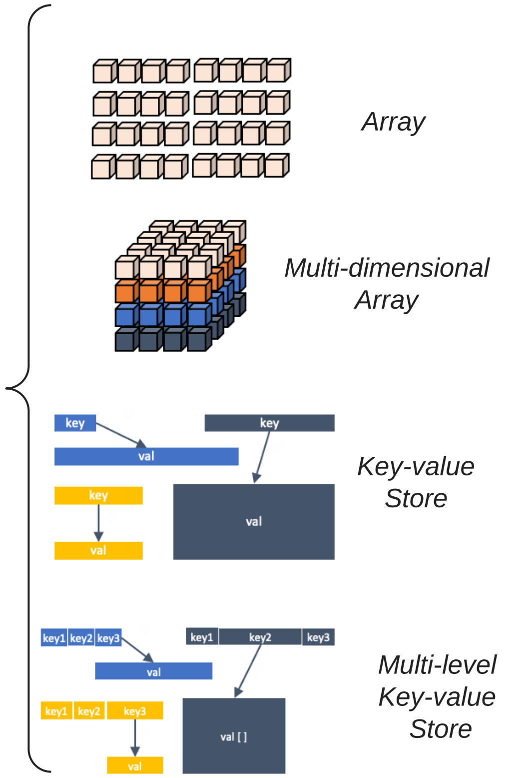




Objects

- Objects are the final level of storage for DAOS

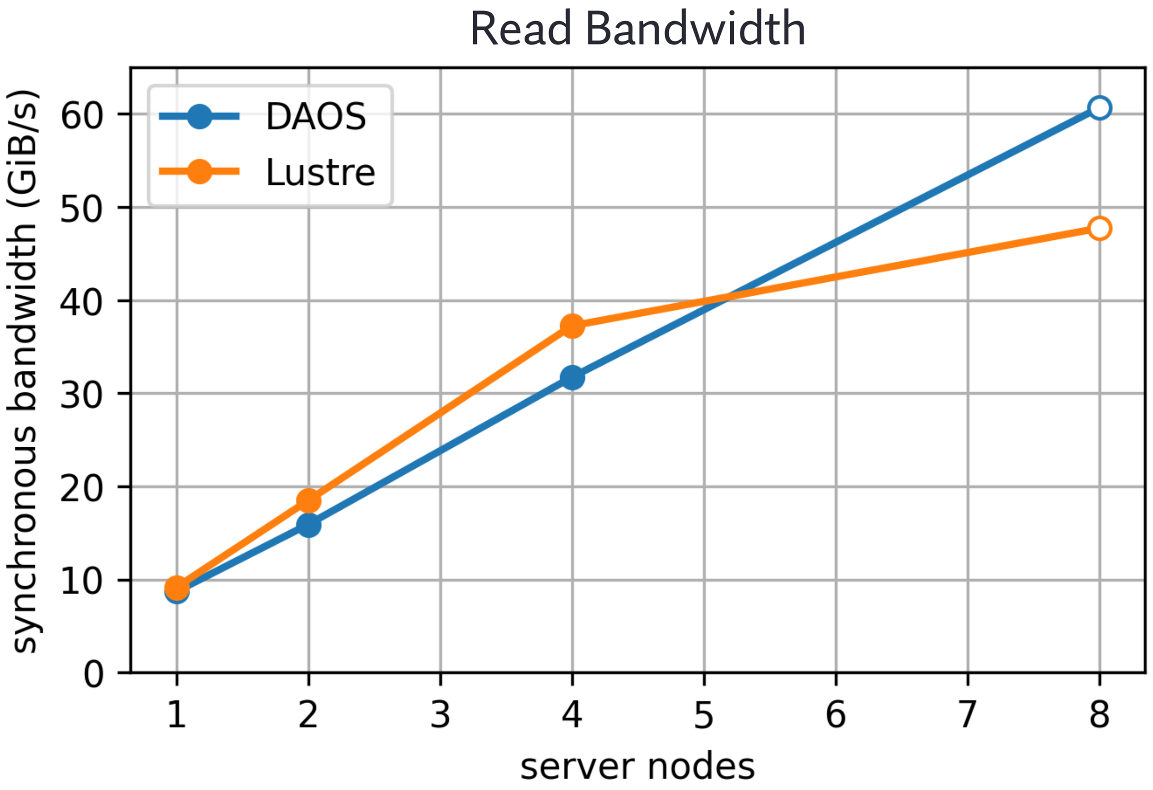


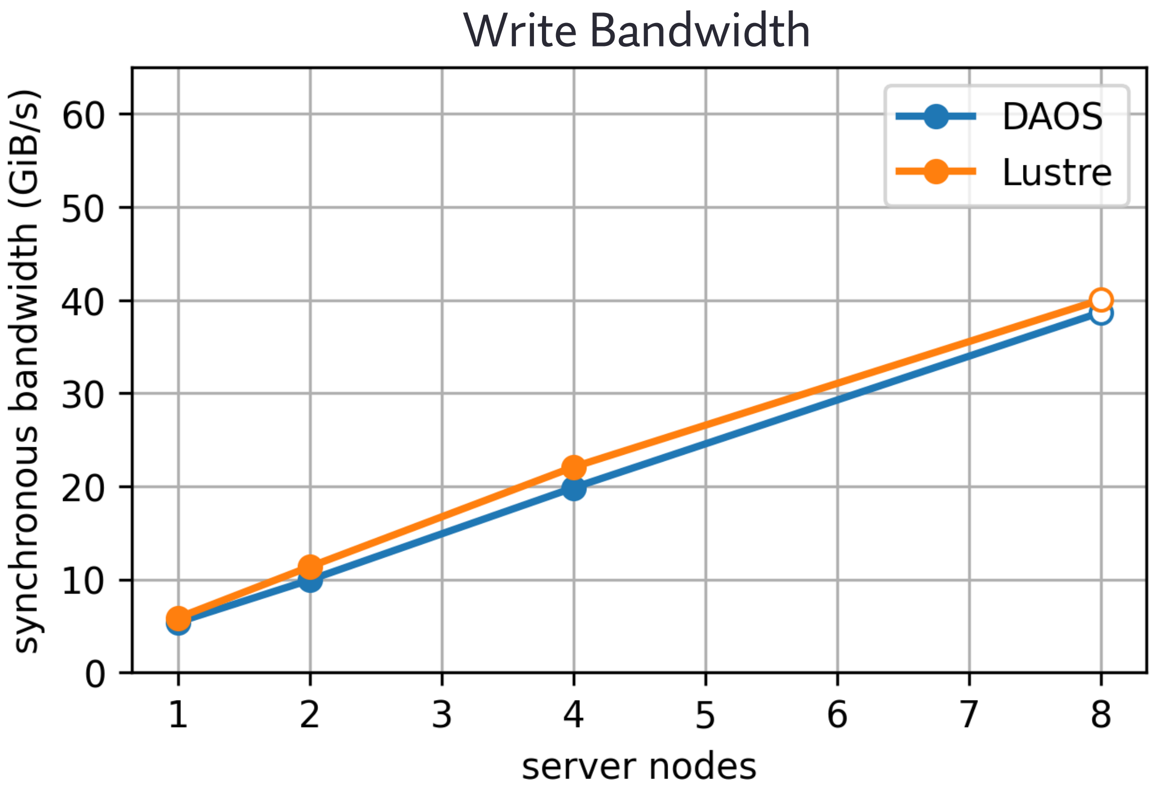


- Metadata operations are with the container
  - No size, permission/ACLs or attributes
- Sharded and erasure-coded/replicated
- Algorithmic object placement
- Very short Time To First Byte (TTFB)

DAOS Performance

- Comparing Lustre and DAOS on the same hardware
  - IOR bulk synchronous I/O





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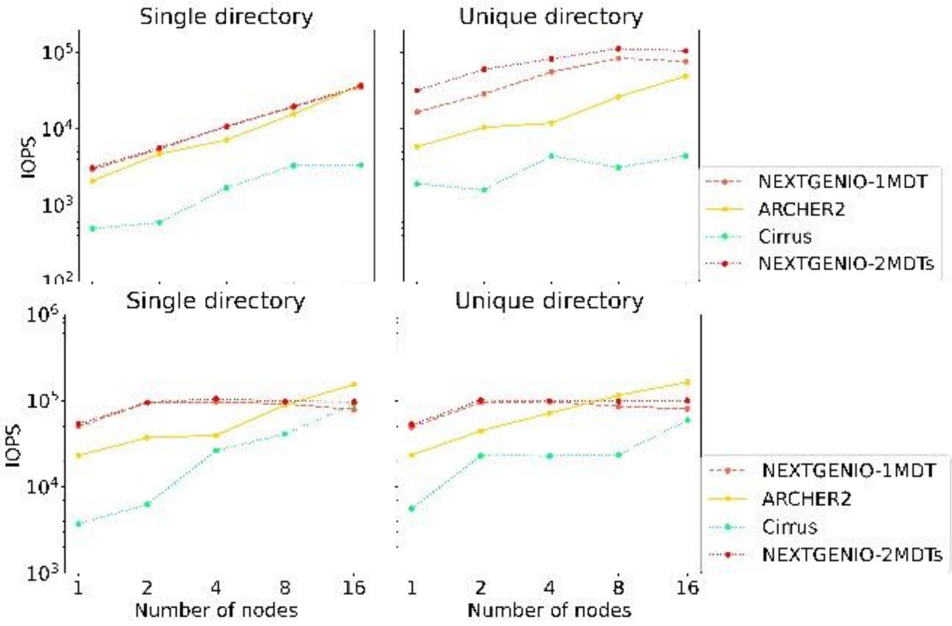
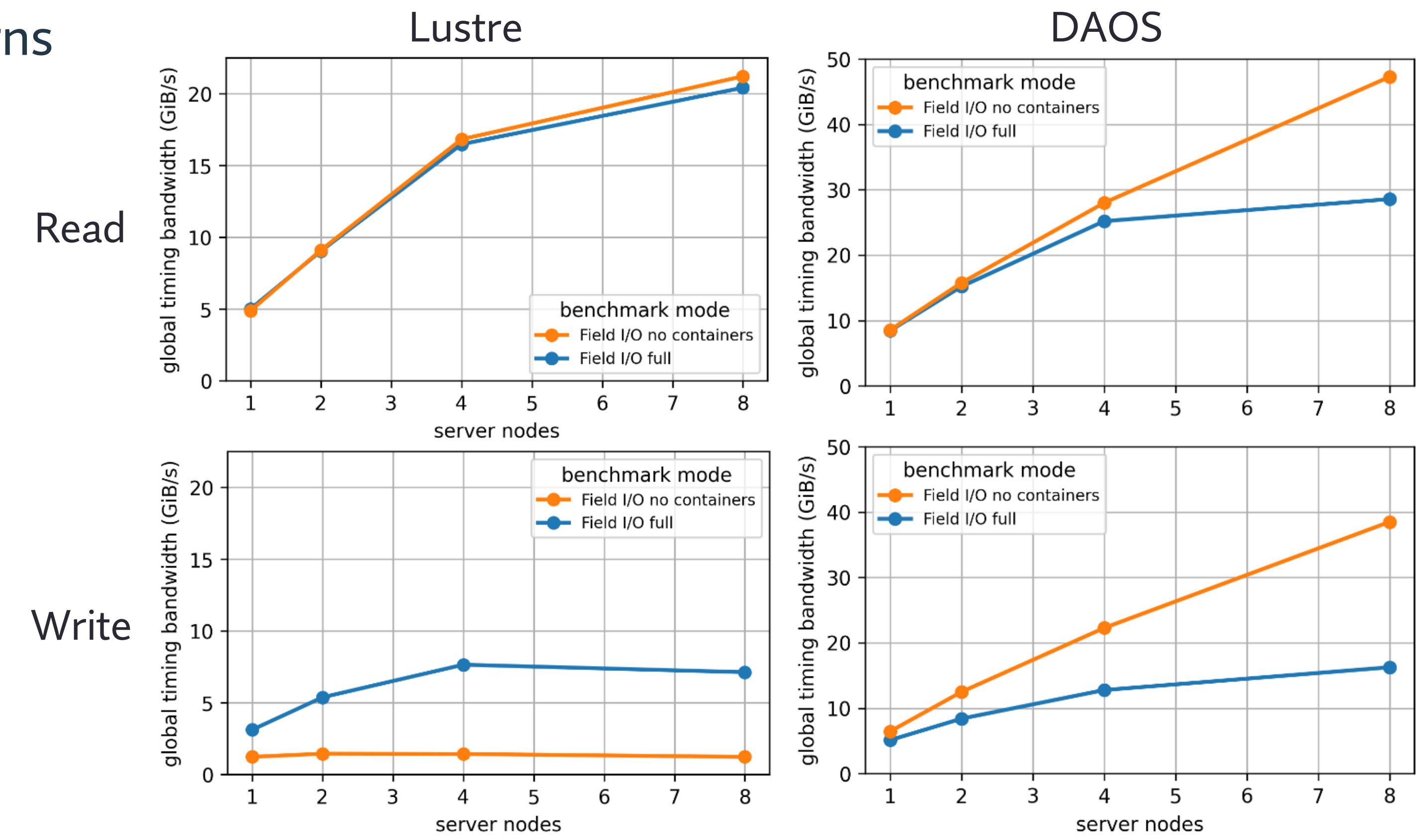
DAOS performance

- Separate read and write steps
  - More “object like” access patterns
  - Weather field -> Object or file





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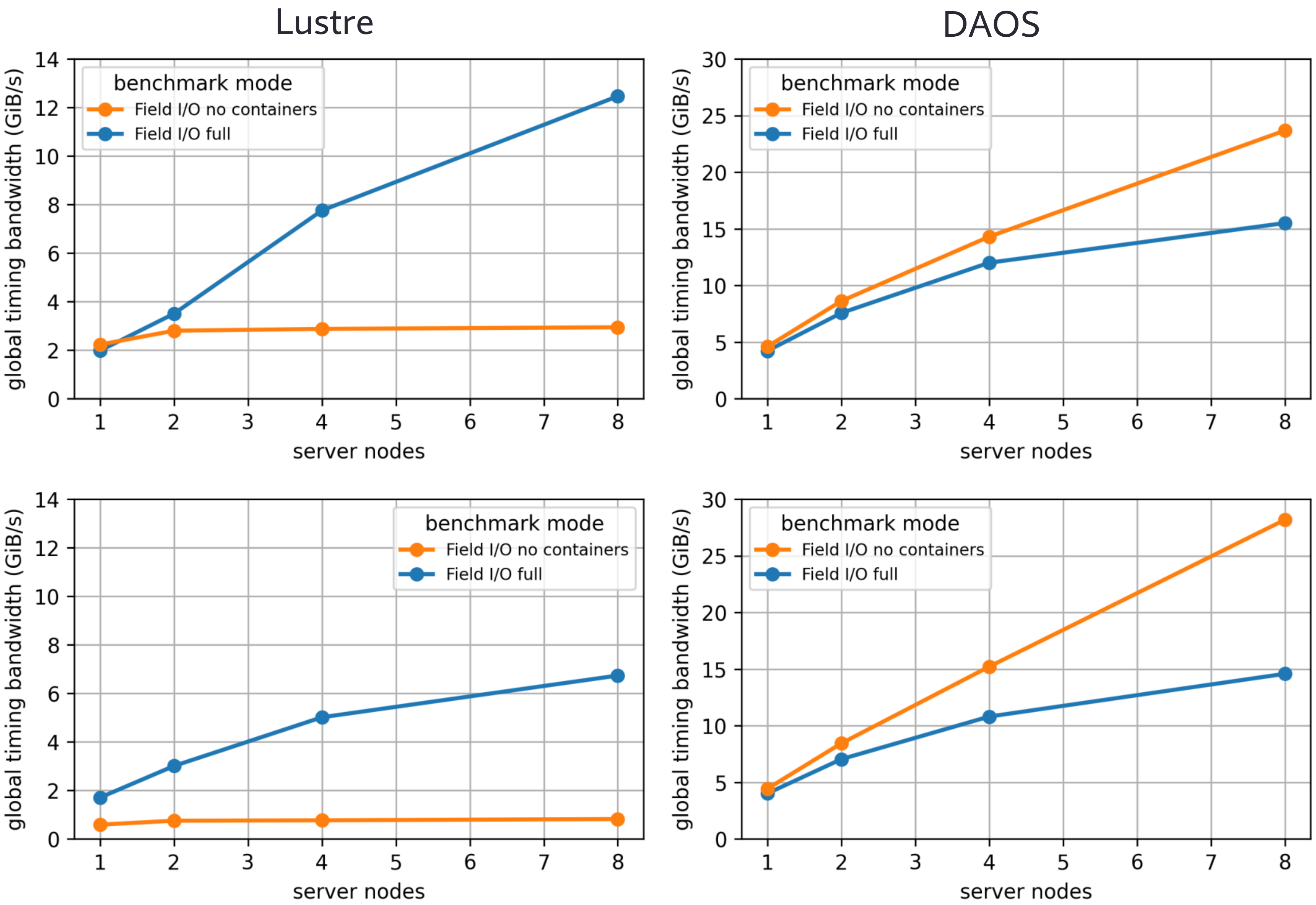
DAOS performance

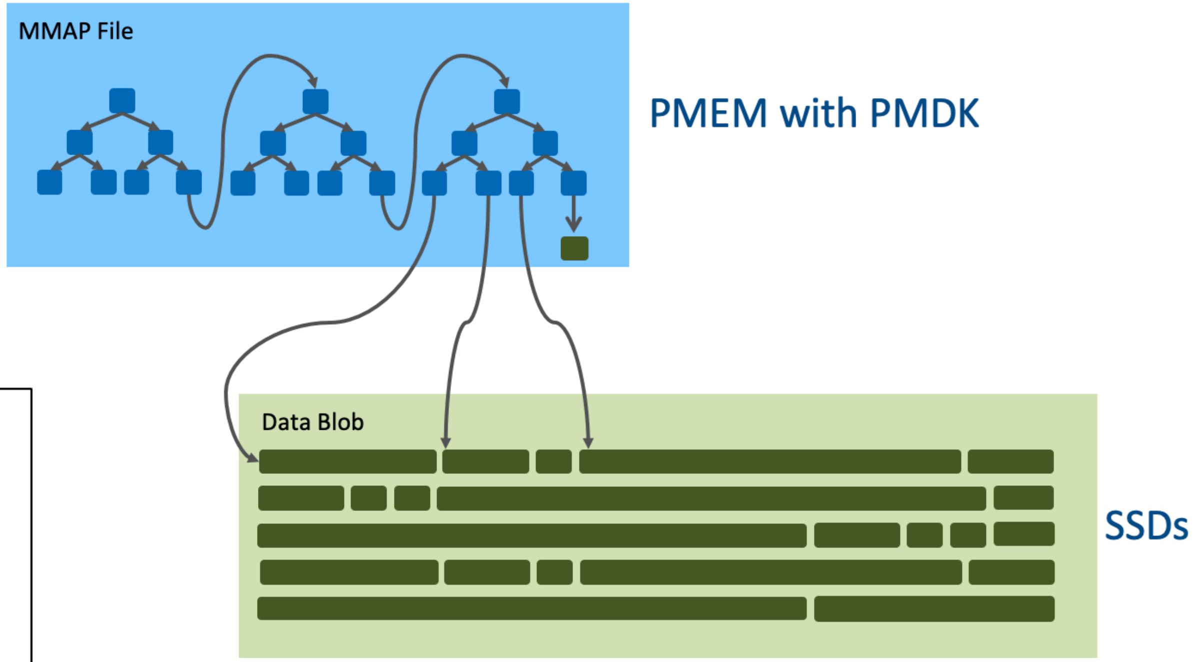
Read

Write



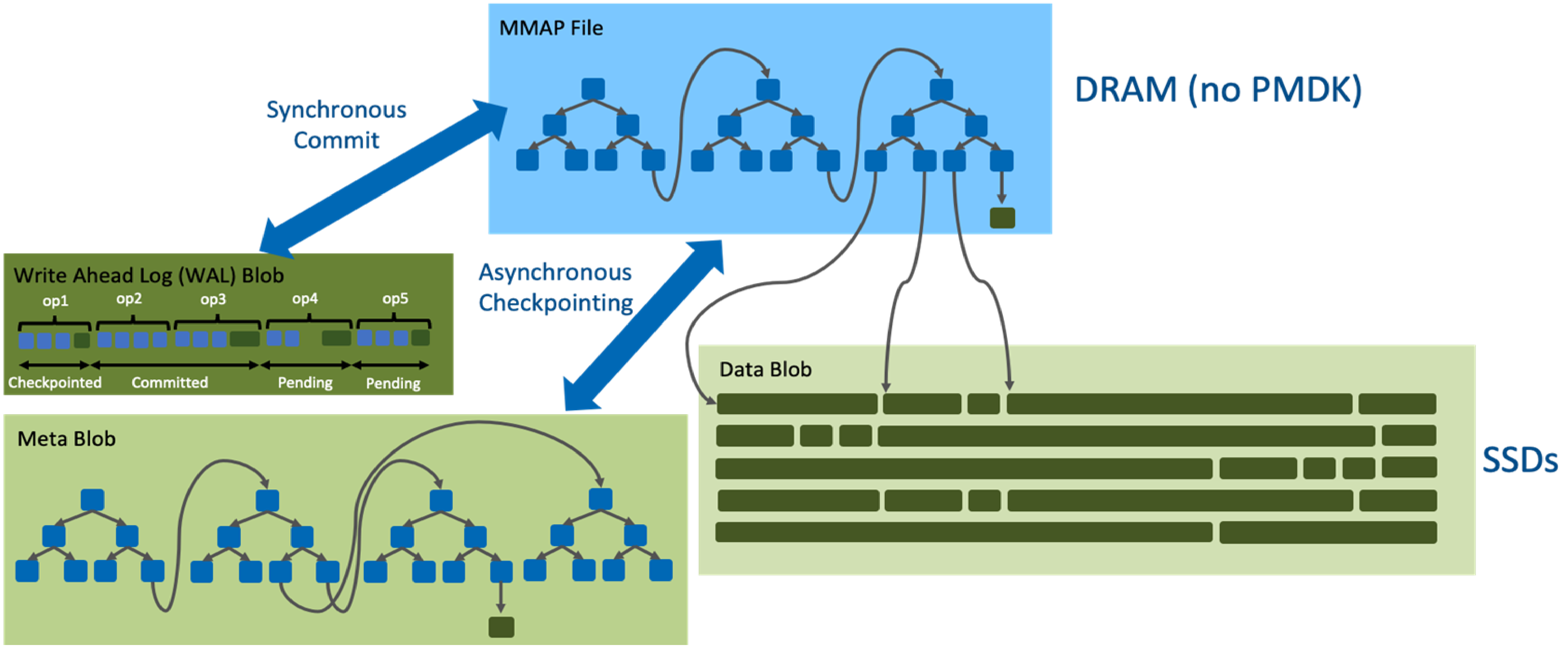
- Contending read and write workers
    - Containers represent filesystem or object store structure

DAOS beyond NVRAM/Optane/PMem

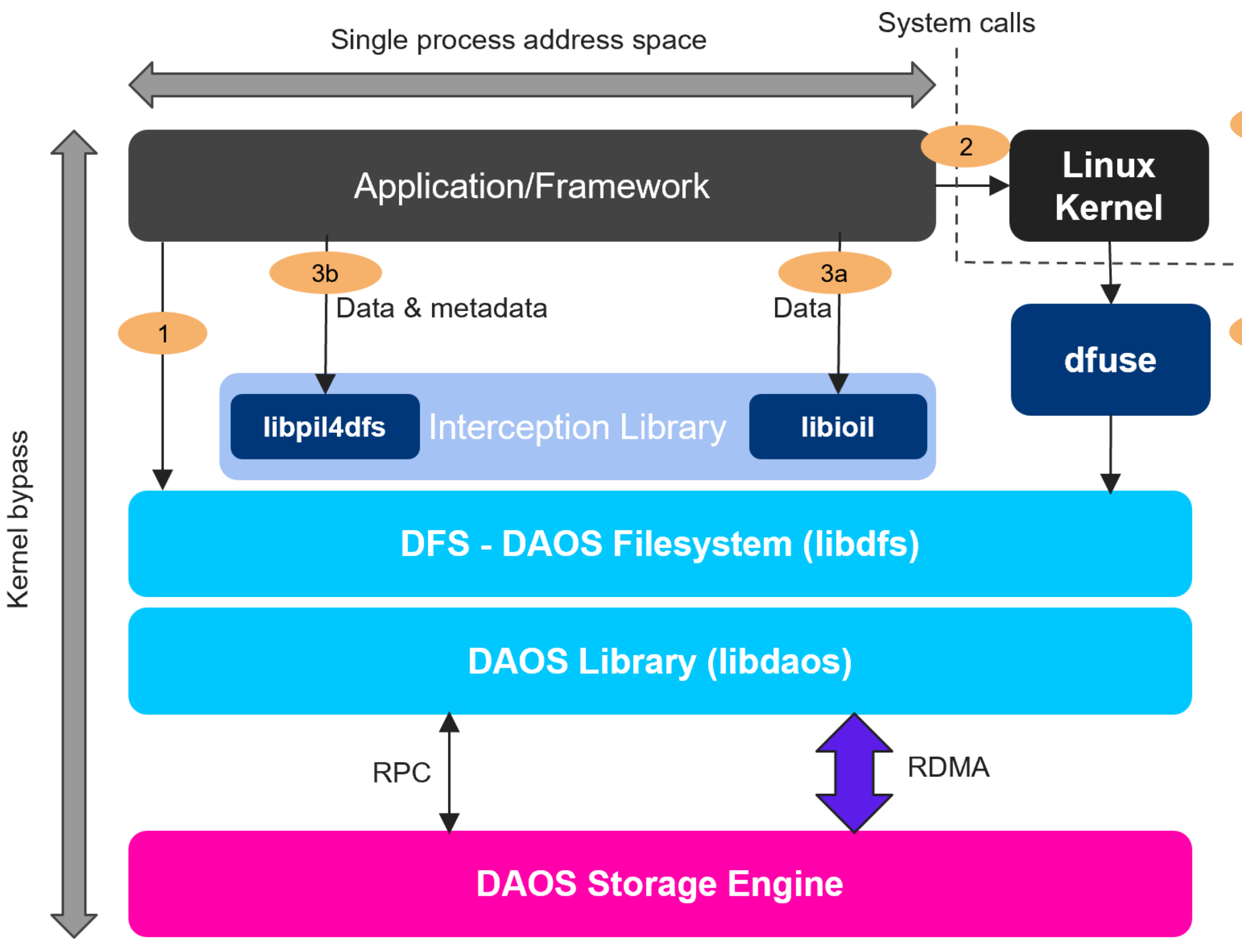


- Persistent metadata
- Require Intel Optane PMEM (or NVDIMM-N)
- App Direct mode
- Mode used on Aurora

DAOS beyond NVRAM/Optane/PMem



DAOS access approaches



1 1. Userspace DFS library with API like POSIX
   - **Require** application changes
   - Low latency & high concurrency
   - No caching

2 2. DFUSE daemon to support POSIX API
   - **No** application changes
   - VFS mount point & high latency
   - Caching by Linux kernel

3. DFUSE + Interception library
   - **No** application changes
   - 2 flavours using LD_PRELOAD
   - 3a libioil
     - (f)read/write interception
     - Metadata via dfuse
   - 3b libpil4dfs
     - Data & metadata interception
     - Aim at delivering same performance as #1 w/o any application change
     - mmap & binary execution via fuse

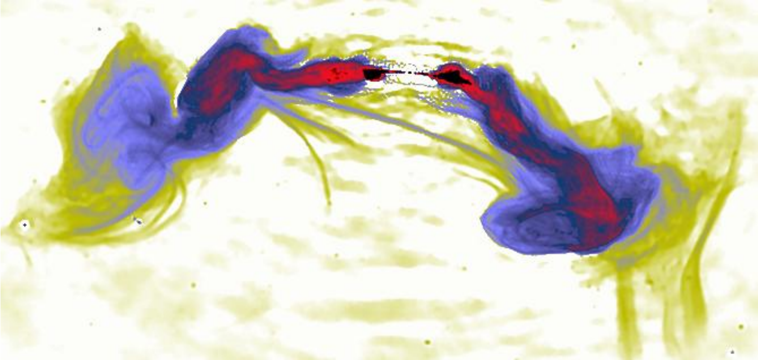
Object stores

- High performance object stores offer:
  - Server-side consistency by default
    - reducing round trip messaging for some operations
  - Distributed metadata functionality
    - no single performance bottleneck
  - Small object size performance
    - non-kernel space I/O operations so don't have interrupt/context switch performance issues
    - designed for faster hardware and for large scale operation
  - Decoupled metadata from data
  - In-built redundancy control/configuration
  - Multi-versioning and transactions to reduce contention/provide consistency tools
  - Scaling across storage resources
  - Searching/discovery across varying data dimensions

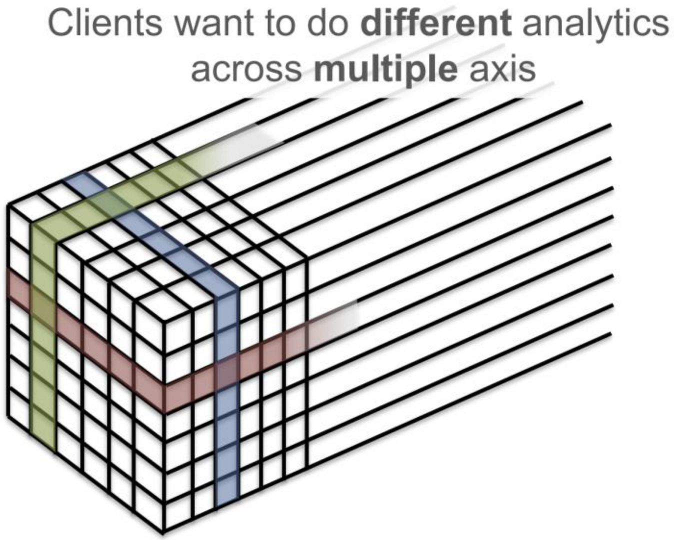
Object stores

- Object can have as much or as little complexity as you want
  - Single array
  - Single key-value
  - Nested object containing table of entries
  - etc..
- High performance object stores can't....
  - Beat filesystems for bulk I/O with low metadata overheads
  - Support high performance alternative functionality without porting effort
  - Eliminate server side contention
  - Fix poor storage design
  - Create your data layout and indexing for you
  - Fix configuration/resource issues

- Object Stores can unlock previously expensive I/O patterns



- Enable discovery as well as storage



Practical Setup

- https://github.com/adrianjhpc/ObjectStoreTutorial/Exercises/exercisesheet.pdf
- Take IOR source code
- Run on the EPCC system
- SSH to
- You will get a username
    - ngguestXX
    - And a password

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