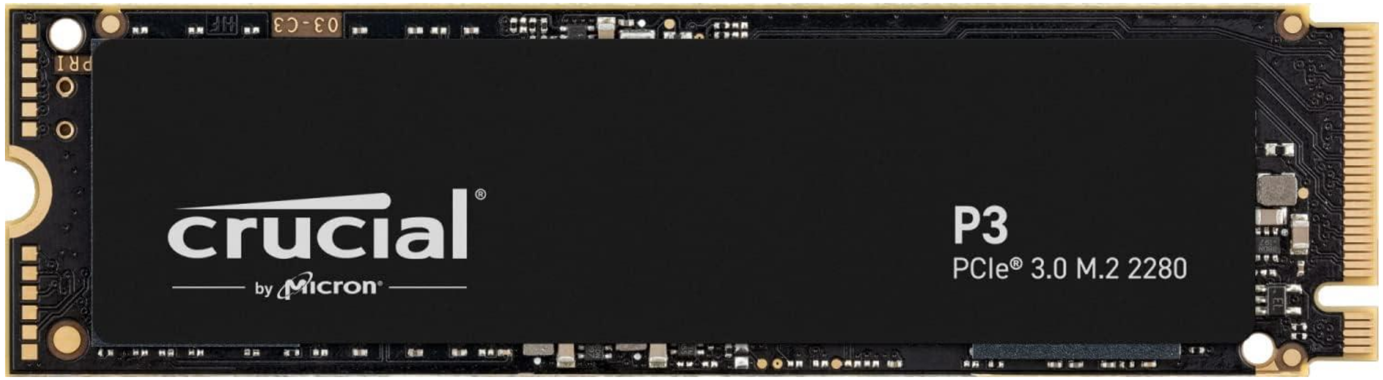
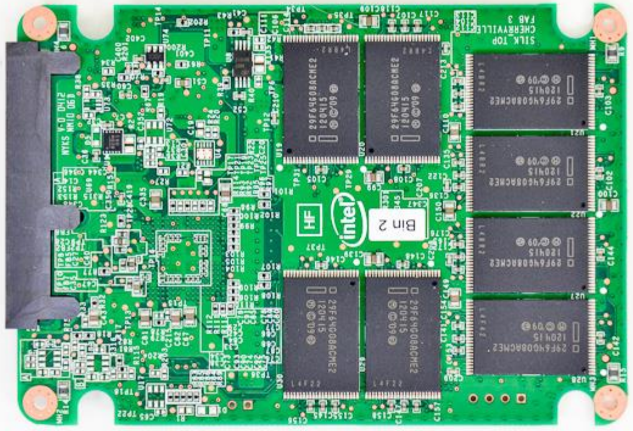
HIGH PERFORMANCE I/O

Hardware and Software interfaces

Storage


crucial
by Micron
P3
PCIe® 3.0 M.2 2280



crucial
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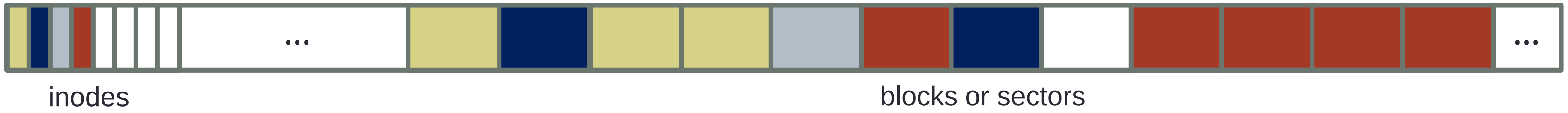
2.5-inch SOLID STATE DRIVE

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

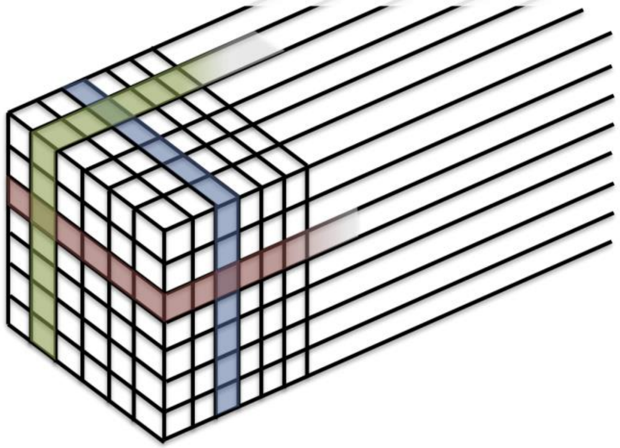
Parallel filesystems

- 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

Object storage

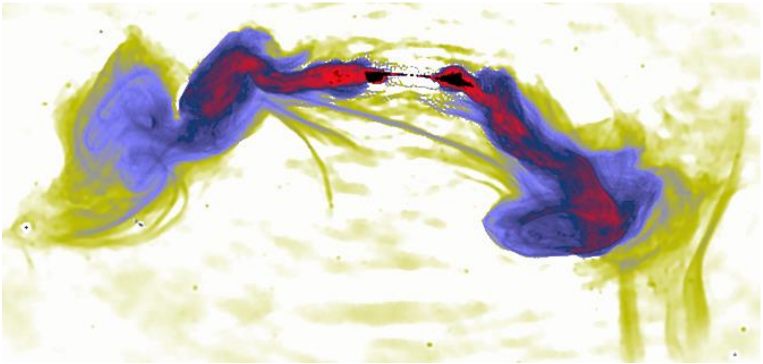
- Filesystems use Files
  - container for blocks of data
  - lowest level of metadata granularity (not quite true)
- Object stores use Objects
  - container for data elements
  - lowest level of metadata granularity
- Allows individual pieces of data to be:
  - Stored
  - Indexed
  - Accessed separately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

Object storage



Clients want to do **different** analytics across **multiple** axis

- Originally designed for unstructured data sets
  - Bunch of data with no specific hierarchy required
- Can also enable efficient/fast access to data in different structures
  - Supports different creation, querying, analysis, and use patterns
- Granular storage with rich metadata
  - Data retrieval leverages metadata
  - **Build structure on the fly**
- Weather/climate
  - Pursuing optimal I/O for applications
    - Weather forecasting workflows
  - End-to-end workflow performance important
  - Simulation (data generation) only one part
    - Consumption workloads different in dimension from production workloads



- Radio astronomy
  - Data collected and stored by antenna (frequency and location) and capture time
  - Reconstruction of images done in time order
  - Evaluation of transients or other phenomenon undertaken across frequency and location

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 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.

S3

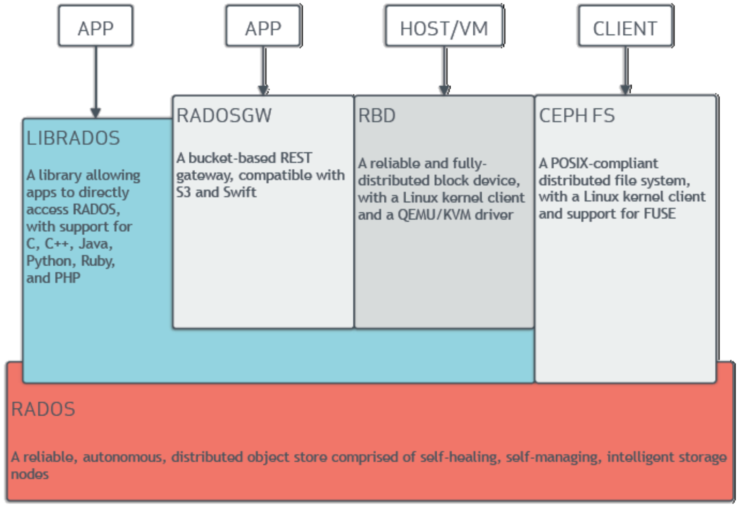
- Objects are combination of data and metadata
- Metadata is name – value pair (key) identifying the object
  - Default has some other information as well:
    - Date last modified
    - HTTP Content-Type
    - Version (if enabled)
    - Access Control List (if configured)
  - Can add custom metadata
- 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)

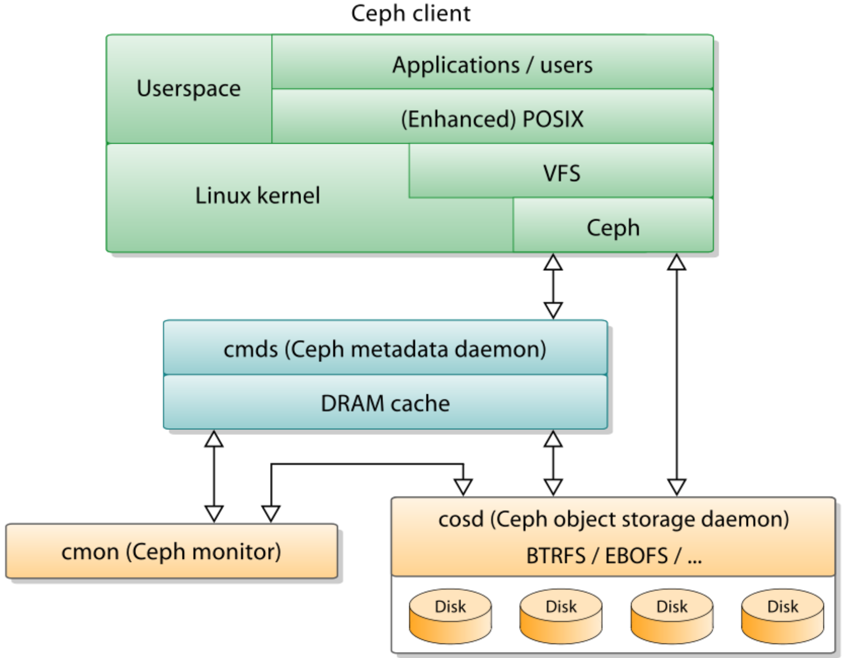
S3 Consistency Model

- 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

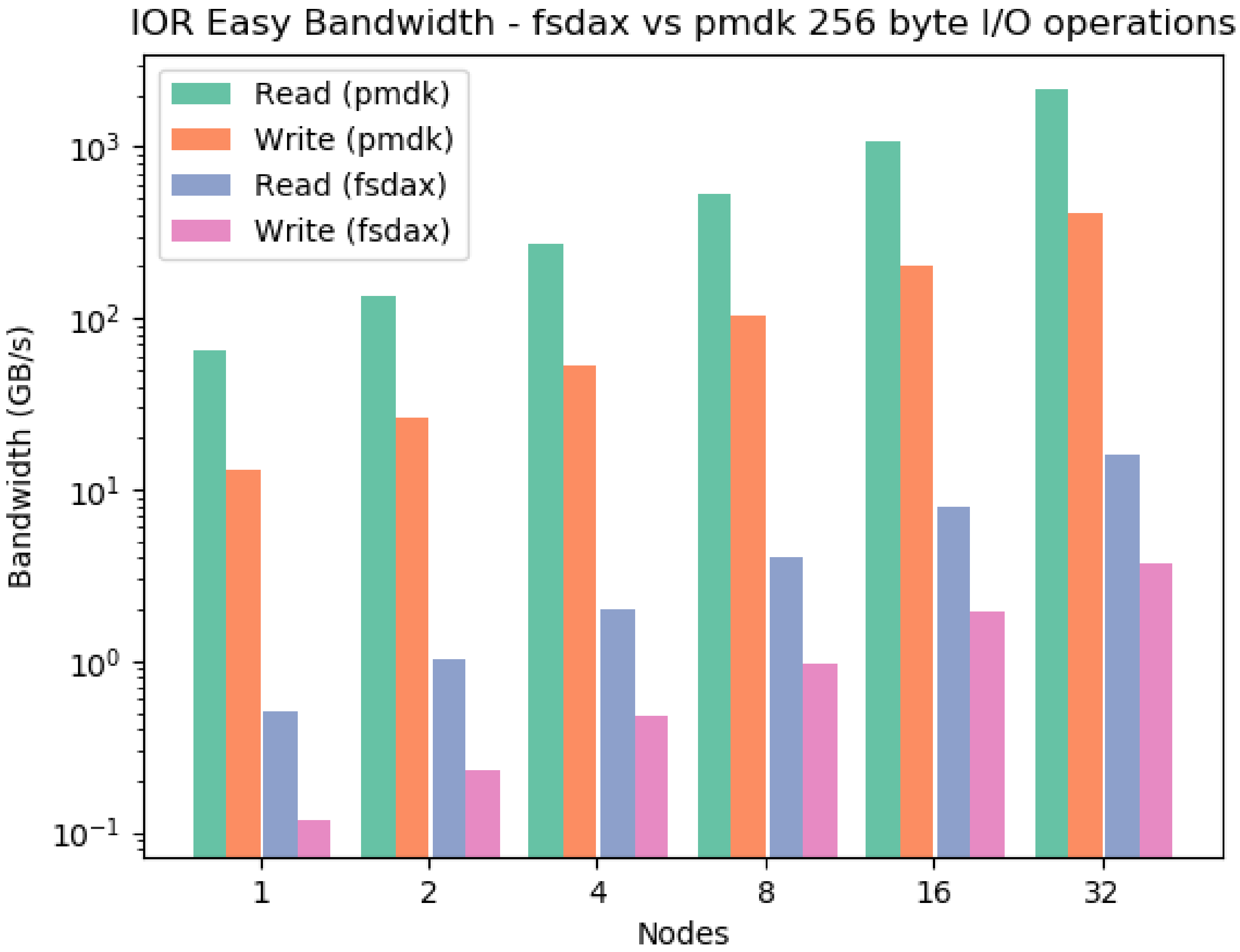

APP
APP
HOST/VM
CLIENT
LIBRADOS
A library allowing apps to directly access RADOS, with support for C, C++, Java, Python, Ruby, and PHP
RADOSGW
A bucket-based REST gateway, compatible with S3 and Swift
RBD
A reliable and fully-distributed block device, with a Linux kernel client and a QEMU/KVM driver
CEPH FS
A POSIX-compliant distributed file system, with a Linux kernel client and support for FUSE
RADOS
A reliable, autonomous, distributed object store comprised of self-healing, self-managing, intelligent storage nodes



NVRAM

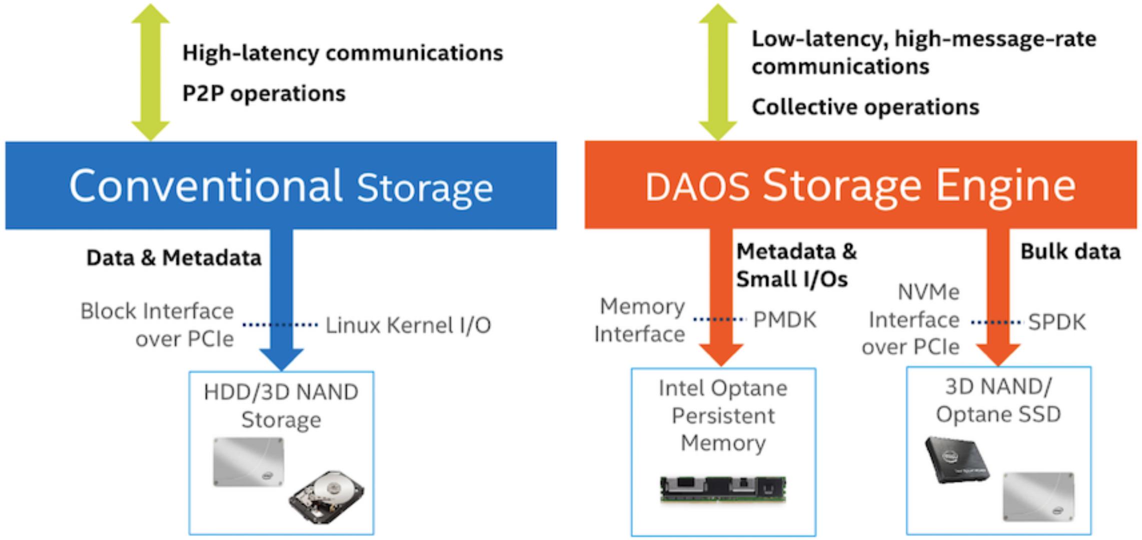
OPTANE
PERSISTENT MEMORY
Assembled in Taiwan
8089-A2-2210-0000293D
NMA1XXD128GPS
128GB
9424010
K18849-901
Warranty Void if Label Removed
SN:8089A222100000293D
PN:100-586-613-00
H42898-004 FXC211110

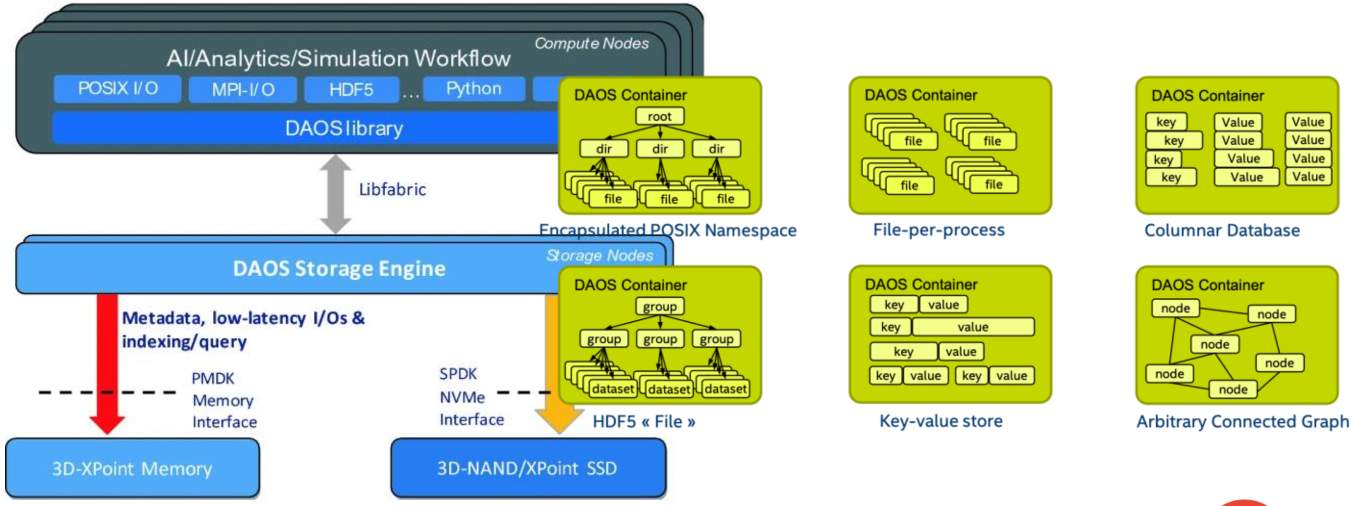
Optane



IOR Easy Bandwidth - fsdax vs pmdk 256 byte I/O operations
Read (pmdk)
Write (pmdk)
Read (fsdax)
Write (fsdax)
Bandwidth (GB/s)
10^3
10^2
10^1
10^0
10^{-1}
1
2
4
8
16
32
Nodes

DAOS





- 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.

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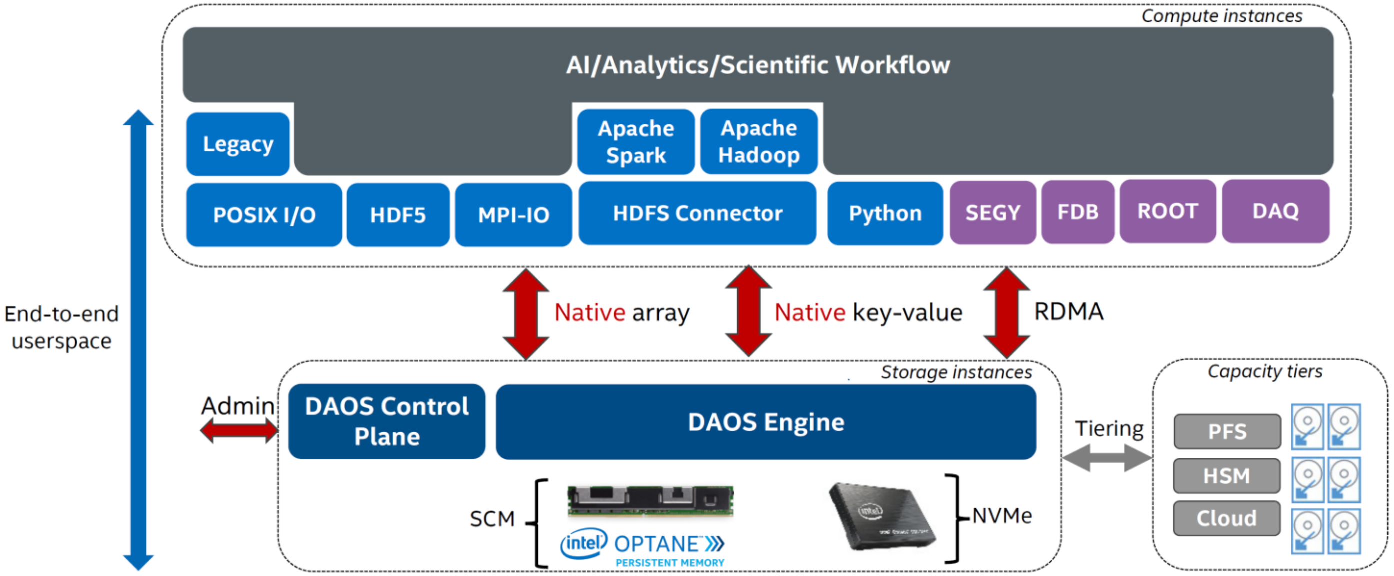
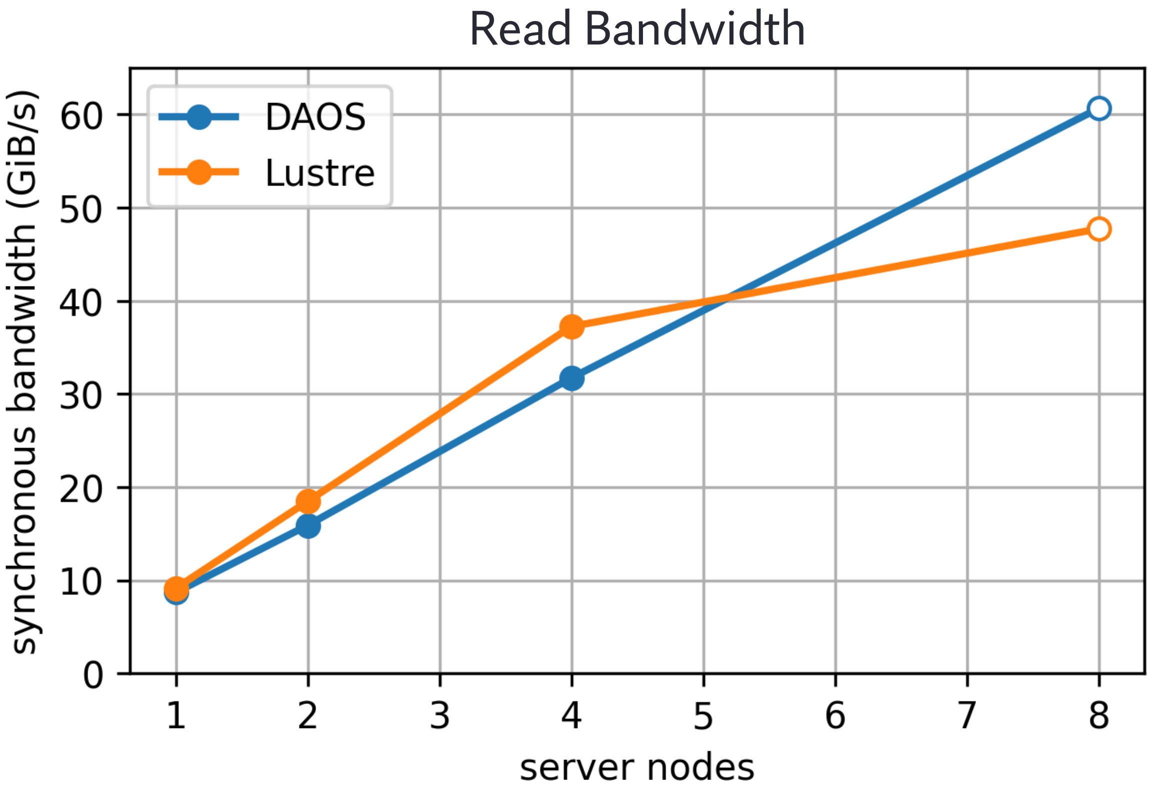
DAOS

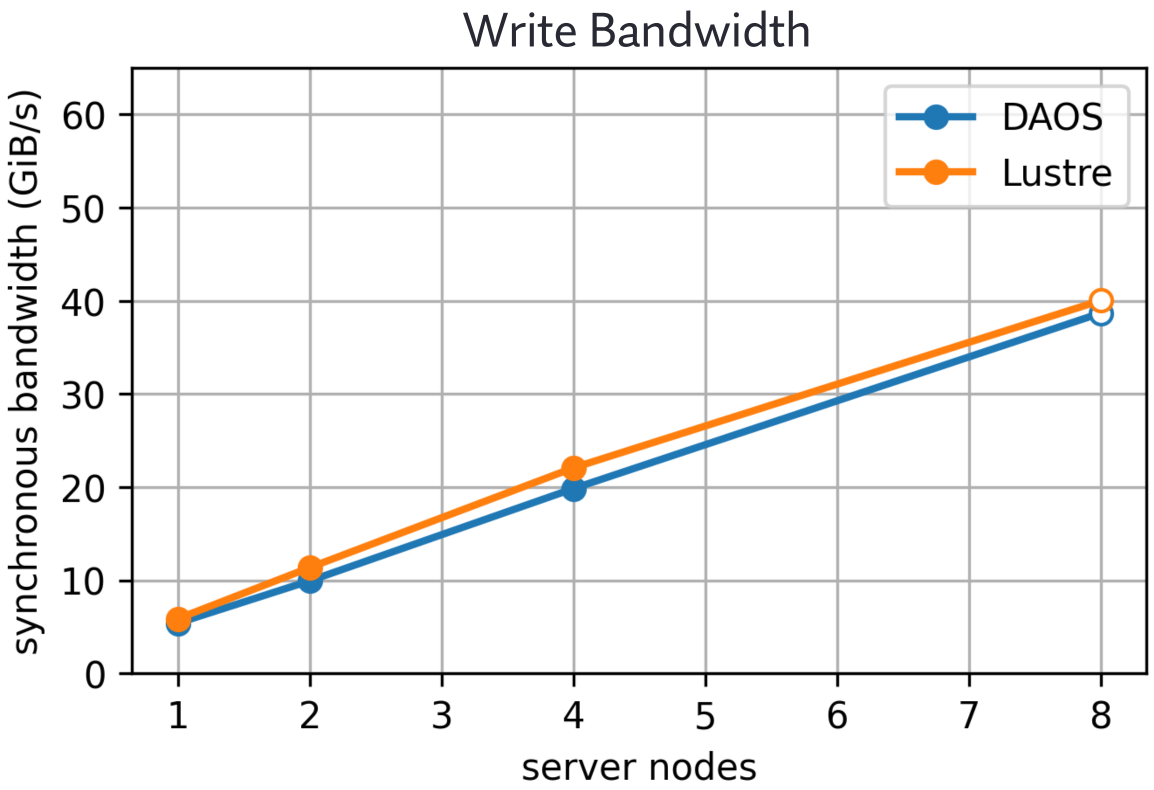


- Range of storage interfaces
  - Native object store (libdaos)
  - Filesystem (various approaches)
  - Raw block device
  - MPI-I/O (ROMIO)
  - HDF5
  - PyDAOS
  - Spark/Hadoop
  - TensorFlow I/O
- DAOS systems built from DAOS servers
  - One per socket, has own NVMe and NVRAM
  - Scale system by adding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

DAOS Performance

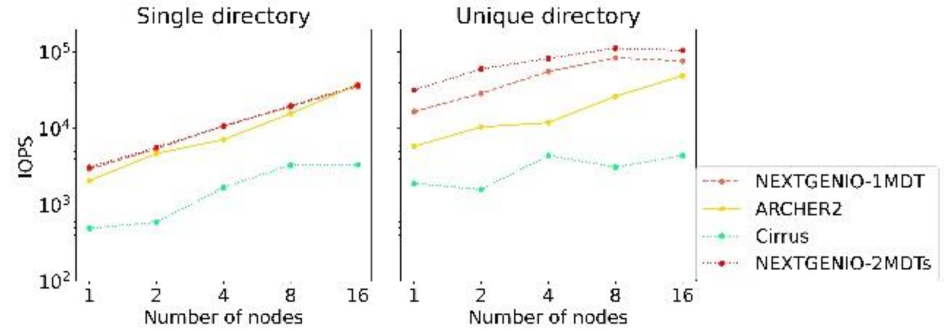
- Comparing Lustre and DAOS on the same hardware
  - IOR bulk synchronous I/O

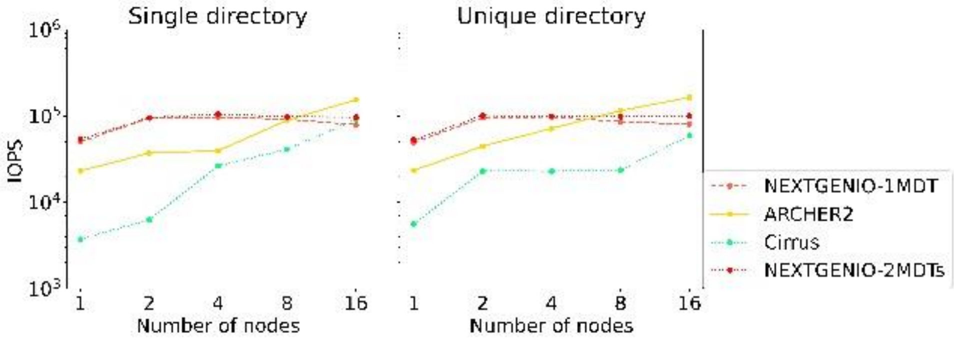

Read Bandwidth

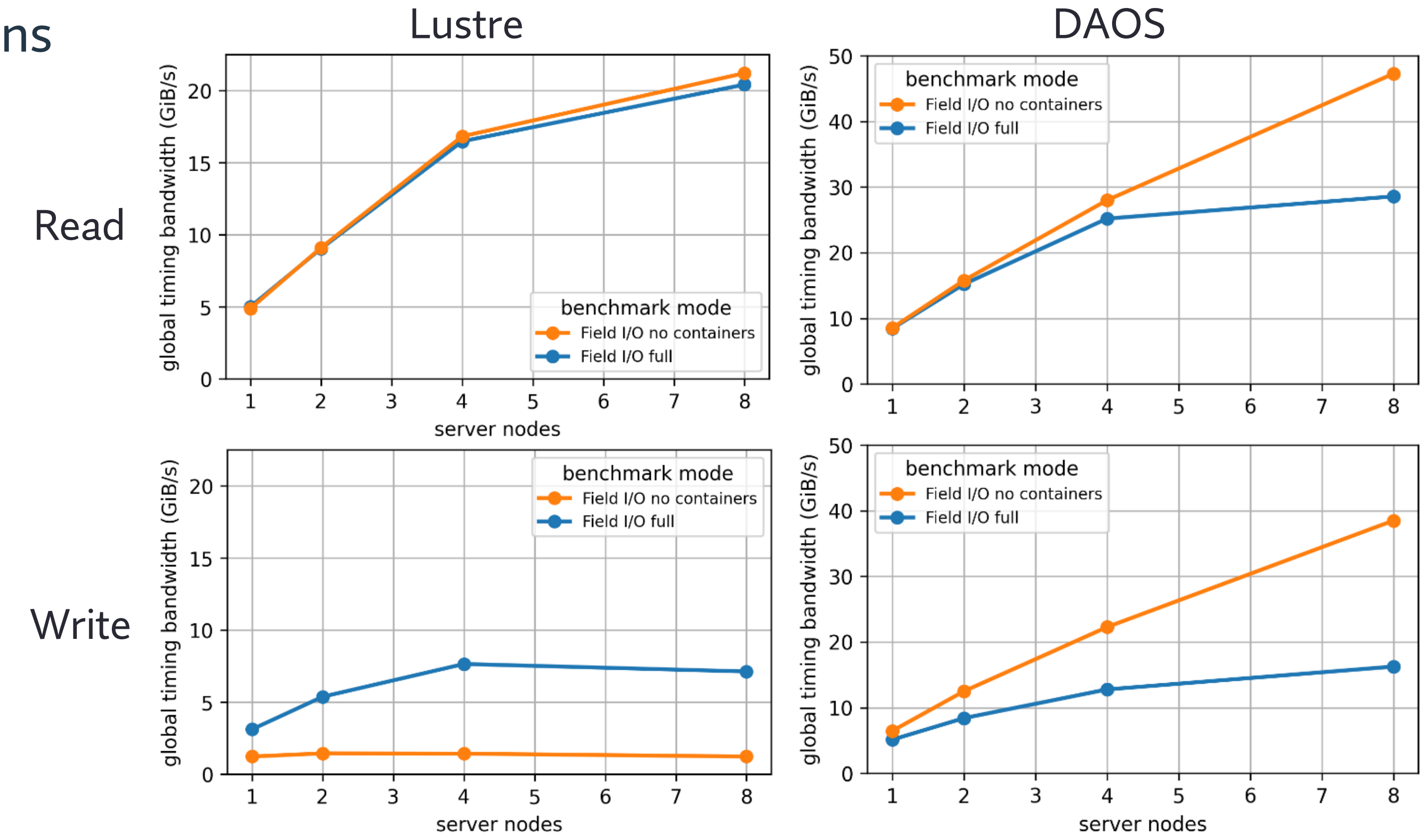

Write Bandwidth

DAOS performance

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

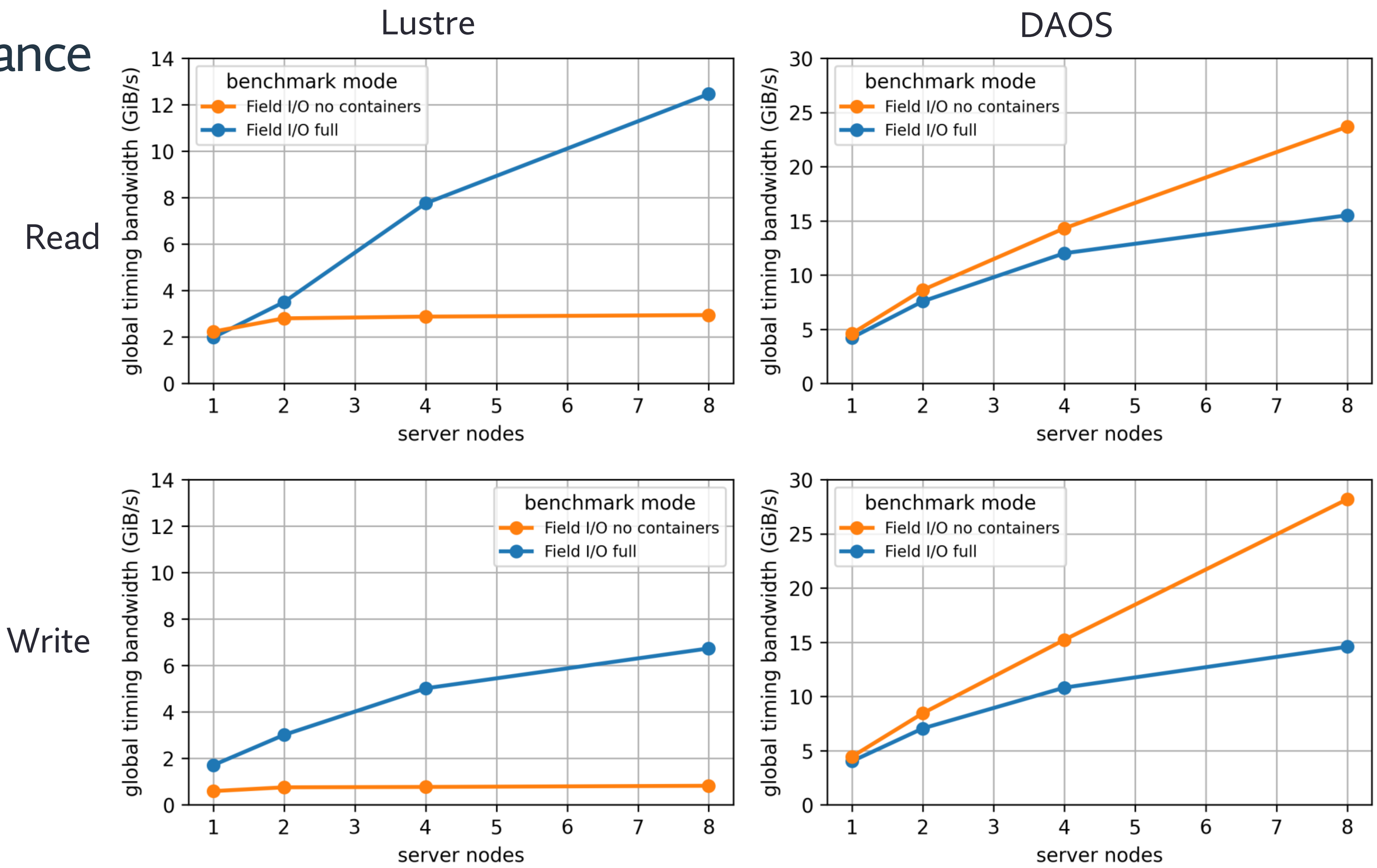






DAOS performance

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



Practical Setup

- https://github.com/ObjectStoreTutorial
- Take IOR source code
- Run on the GCP system

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