Toward Scalable and Asynchronous Object-centric Data Management for HPC

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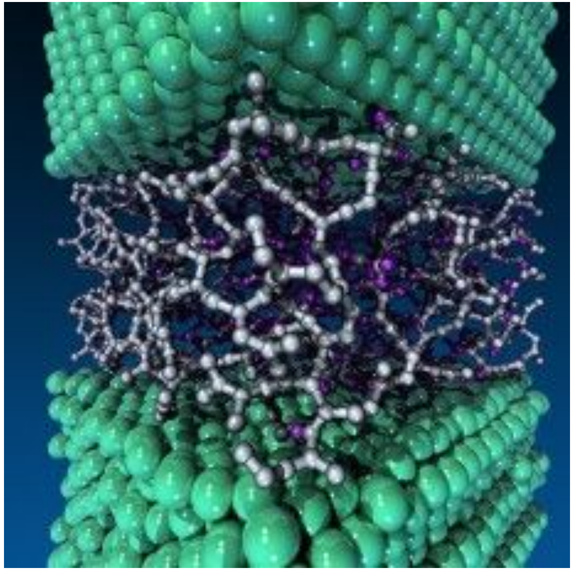
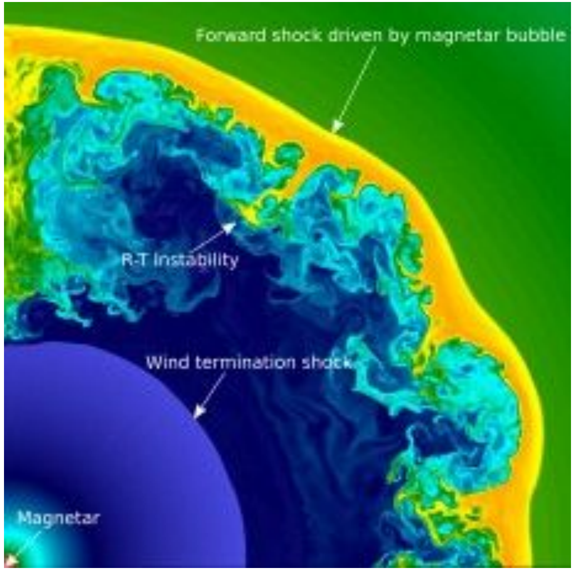
https://sdm.lbl.gov/pdc

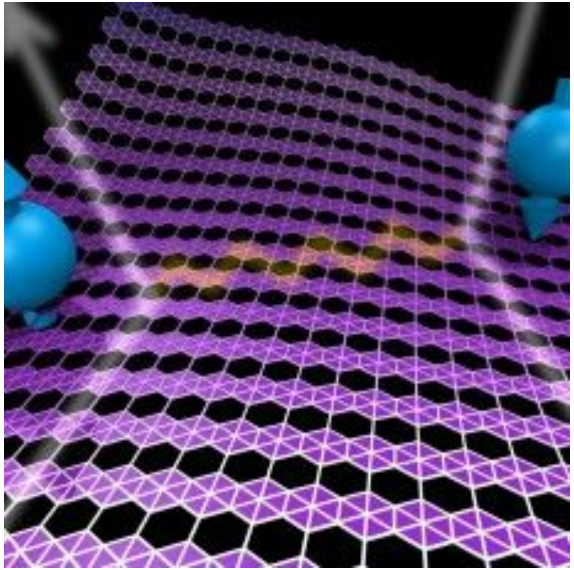
Data-driven Science



Molecular Dynamics Simulations



Superluminous Supernovae



Superconducting

Images from http://www.nersc.gov/news-publications/nersc-news

Storage Systems and I/O: Current status

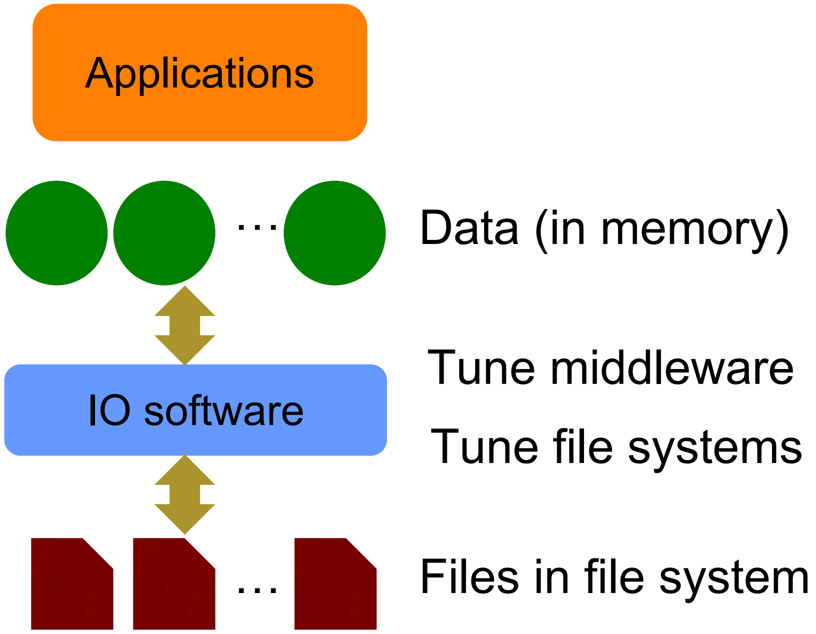
Hardware

- Memory
- Node-local storage
- Shared burst buffer
- Disk-based storage
- Campaign storage
- Archival storage (HPSS tape)

Software

- High-level lib (HDF5, etc.)
- IO middleware (POSIX, MPI-IO)
- IO forwarding
- Parallel file systems

Usage

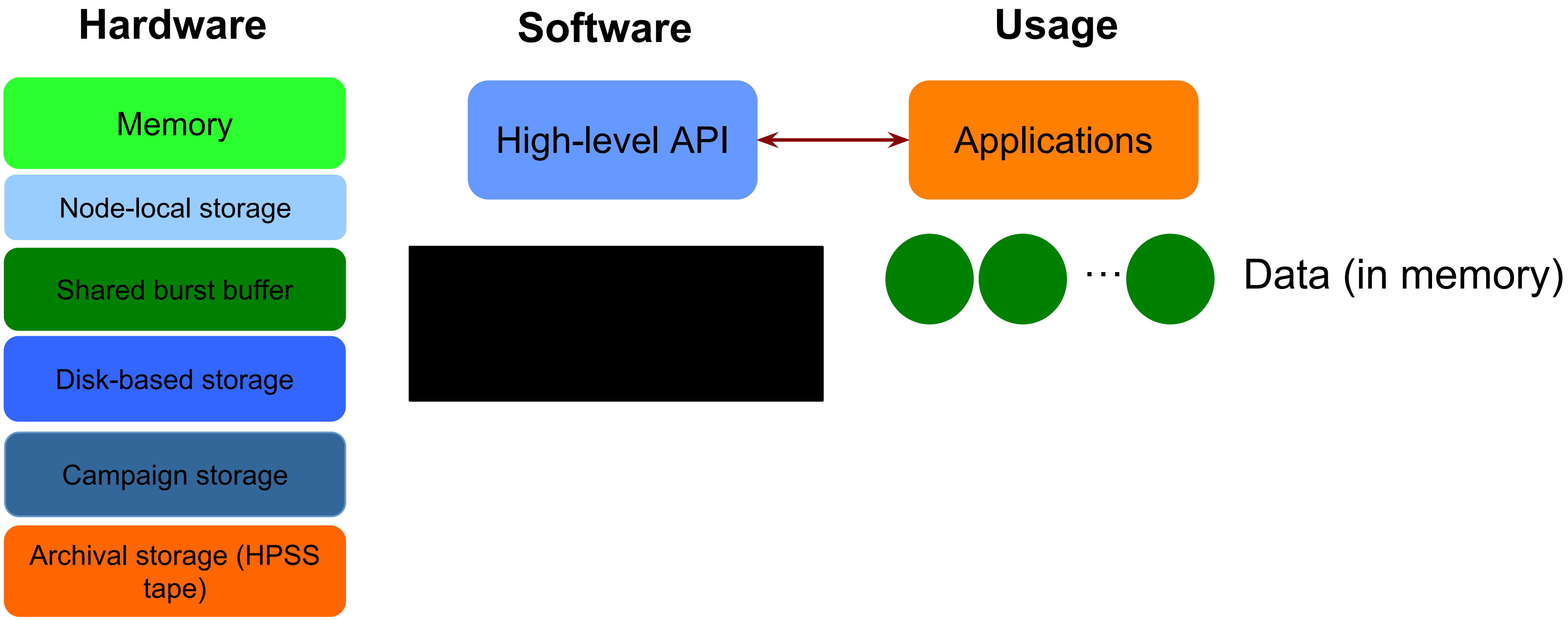


HPC I/O

- **Challenges**:
  - POSIX-IO semantics hinder **scalability** and **performance** of file systems and IO software.
  - **Multi-level hierarchy** complicates data movement, especially if user has to be involved.

- **Requirements**:
  - Simple interfaces and superior performance.
  - Autonomous data management.
  - Information capture and management.

Storage Systems and I/O: Next Generation



Storage Systems and I/O: Next Generation

- Autonomous, proactive data management system beyond POSIX restrictions.

- Transparent data object placement and organization across storage layers with tunable consistency.

- Object-centric storage with rich metadata, accessible through queries.

What is an object?

- Chunks of a file
- Files (images, videos, etc.)
- Array
- Key-value pairs
- File + Metadata

Current parallel file systems

Cloud services (S3, etc.)

HDF5, DAOS, etc.

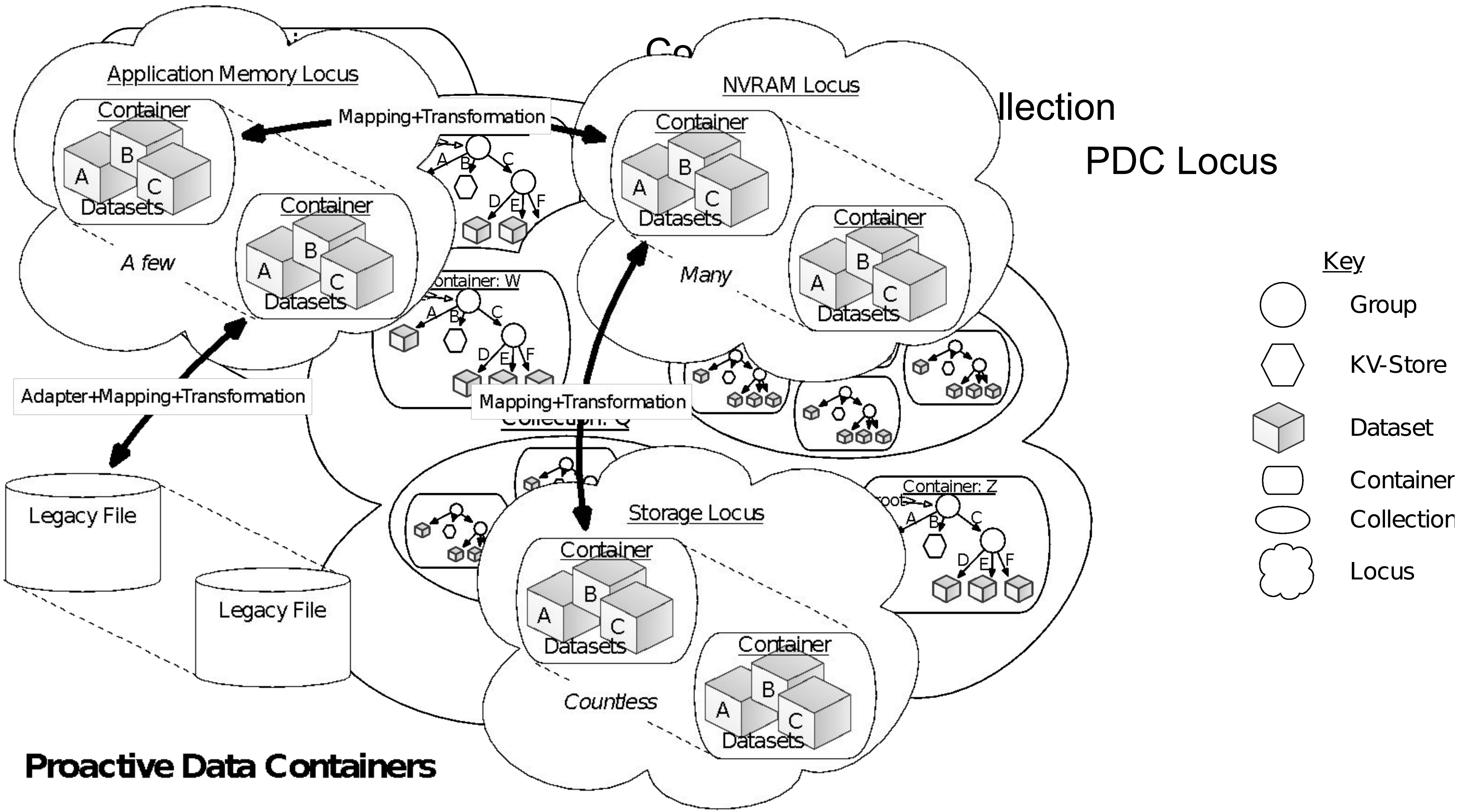
OpenStack Swift, MarFS, Ceph, etc.

PDC Interpretation of Objects

Data + Metadata + Provenance + Analysis operations + Information (data products)

↓

Proactive Data Containers (PDC)

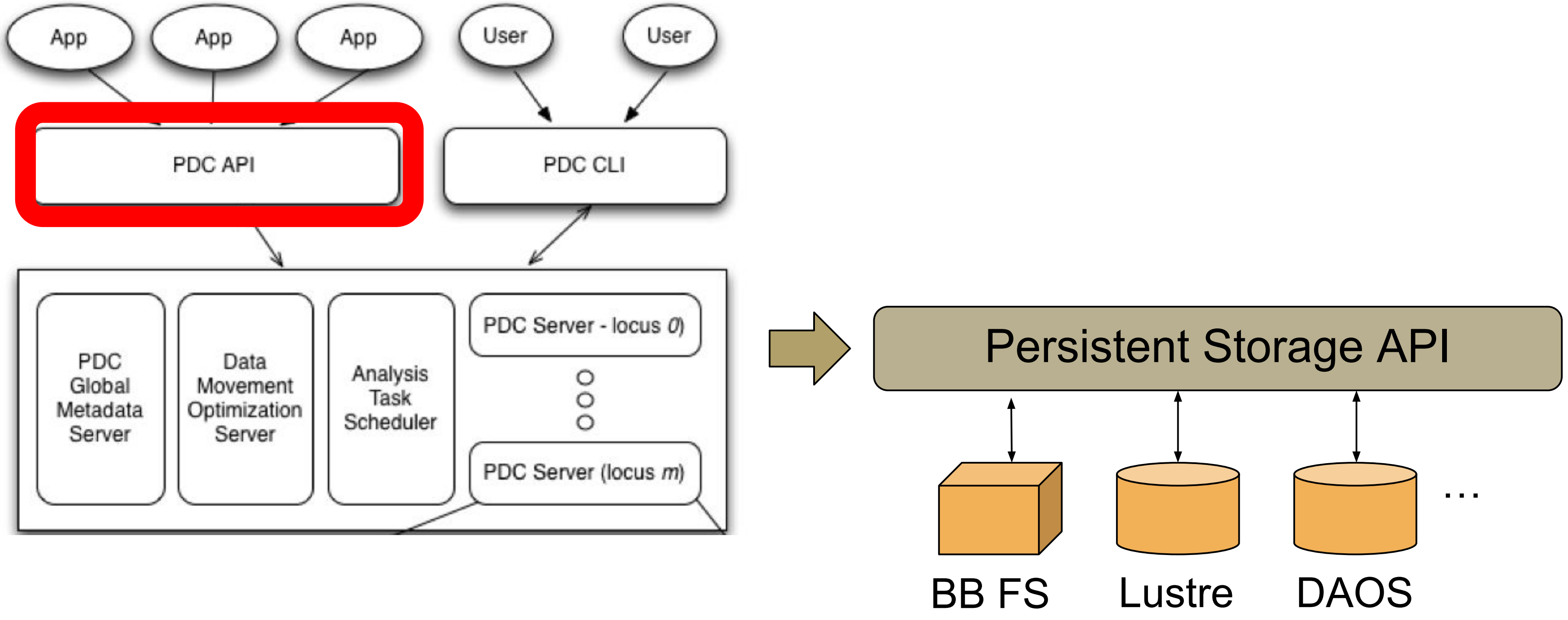


Application Memory Locus
Container
Datasets
A few
Mapping+Transformation
NVRAM Locus
Many
llection
PDC Locus
Container: W
Adapter+Mapping+Transformation
Legacy File
Legacy File
Collection: Q
Storage Locus
Countless
Container: Z
Key
Group
KV-Store
Dataset
Container
Collection
Locus
Proactive Data Containers

PDC System - High-level Architecture

- **Interface**
  - Programming and client-level interfaces
- **Services**
  - Metadata management
  - Autonomous data movement
  - Analysis and transformation task scheduler
- **PDC locus services**
  - Object mapping
  - Local metadata management
  - Locus task execution

PDC System - High-level Architecture



Object-centric API

- **Container and Object management**
  - Create and delete
- **Metadata management**
  - Set / get properties
    - Object name, dimensions, data type,
    - Analysis functions, transformations, relationships, etc.
- **I/O**
  - Put (Write)
  - Get (Read)
- **Query**
  - Metadata query
  - Data query

Metadata Management

Requirements - Efficient Metadata Management

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- **Scalable**
  - Effectively management of a large number of objects.
- **Extensible**
  - Attach more information anytime without a limit
- **Queryable**
  - Find interested objects by specifying a few attributes (exact or partial).

Metadata Object

A collection of ***tags*** (key-value pairs)

Pre-defined Tag	User-defined Tag

• Object ID
• DataObjLocation
• SystemInfo
• ID Attributes
  - Name - Owership
  - AppName - TimeStep
	• (UserTag1, Value1)
	• (UserTag2, Value2)
	• (UserTag3, Value3)
	• ...
	• ...

Capabilities

- Create, update, search, and delete metadata objects.
- All tags are searchable.
- Maintain extended attributes and object relationships.

Data Movement Management

Requirement - Efficient Data Management

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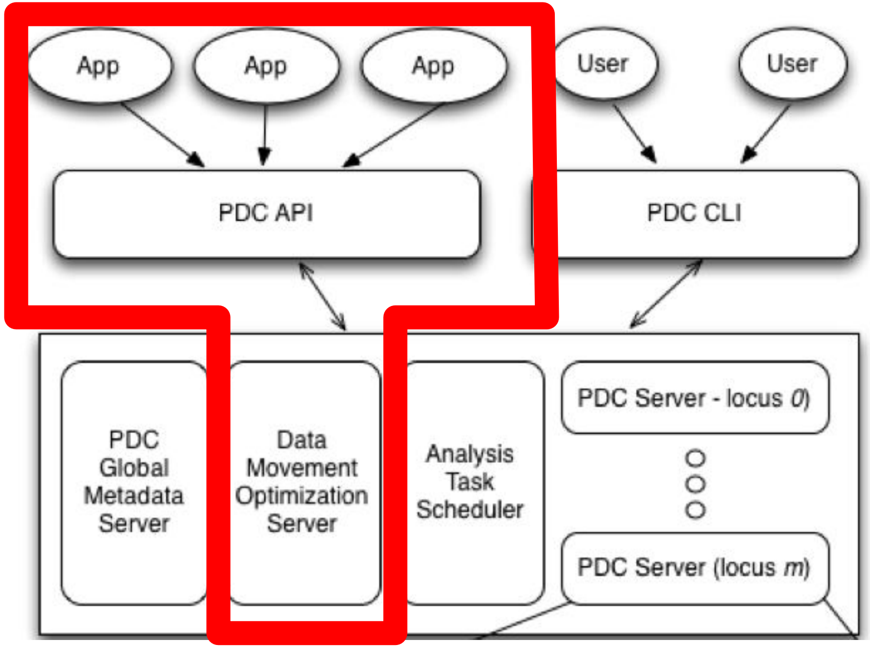
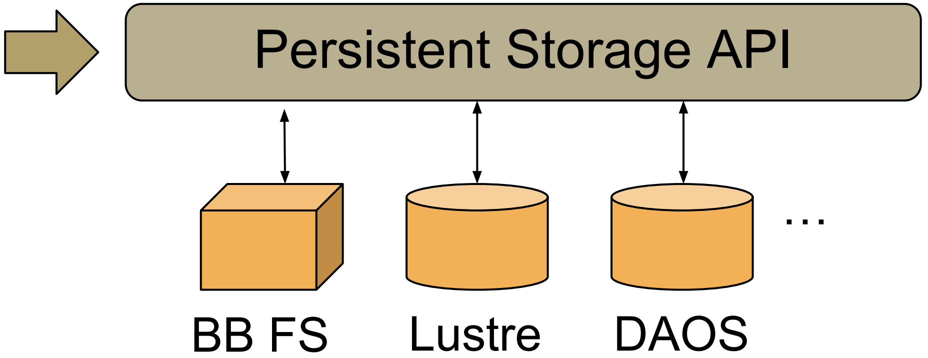
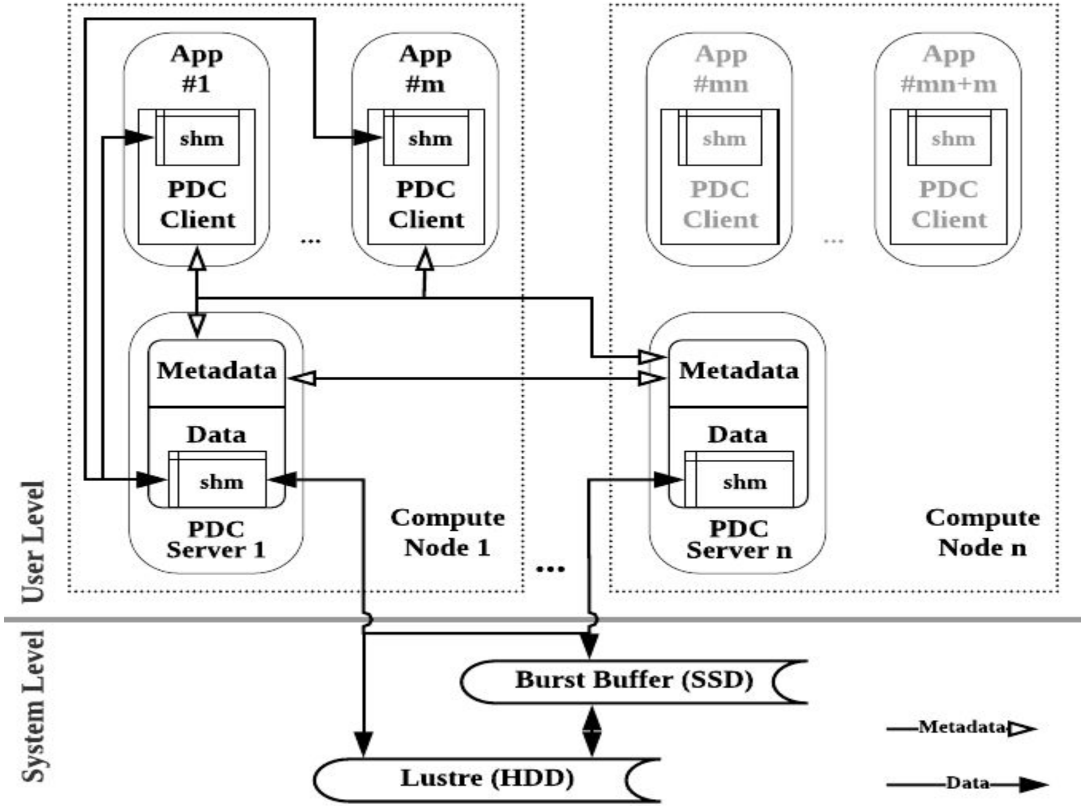
- **Scalable and asynchronous I/O**
  - Client does not stay idle to wait for I/O completion.
- **Transparent Movement between multiple storage layers.**
  - Node-local Memory/NVRAM, Burst Buffer, Lustre, etc.
- **Object-centric interface.**
  - Access data objects conveniently.
- **Direct support of multi-dimensional array and sub-region selection.**

PDC System - High-level Architecture



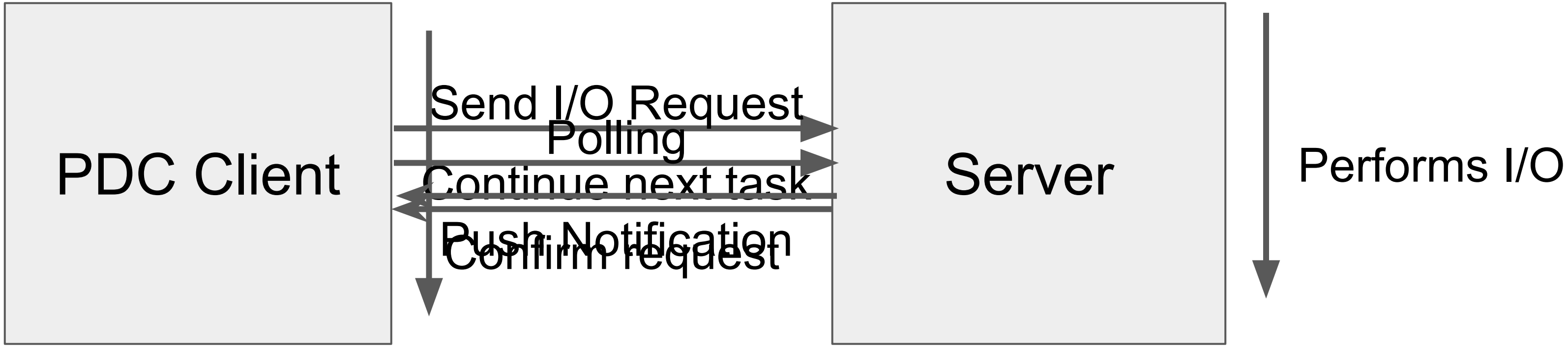


PDC System



App
#1
shm
PDC
Client
App
#m
shm
PDC
Client
App
#mn
shm
PDC
Client
App
#mn+m
shm
PDC
Client
Metadata
Data
shm
PDC
Server 1
Compute
Node 1
Metadata
Data
shm
PDC
Server n
Compute
Node n
User Level
System Level
Burst Buffer (SSD)
Lustre (HDD)
Metadata
Data

Asynchronous I/O



Storage Hierarchy-Aware Data Management

- **Memory**
  - Fastest.
  - Temporary and limited storage space.
- **Burst Buffer**
  - Fast.
  - Temporary and limited storage space.
- **Lustre**
  - Slower and requires expertise in performance tuning
  - Long term storage with enough storage space.

Data Management Optimizations

- **Node-local data aggregation**
  - Each server aggregates I/O requests from node local clients.
  - Effective use of shared memory to transfer data.
  - Log-structured write.

- **Automatic Lustre Tuning**
  - Automatically setting stripe count, size, OST index.

Metadata Optimizations

- **Collective Metadata querying.**
  - Aggregate the requests and retrieve corresponding metadata.
  - Reduce communication cost.

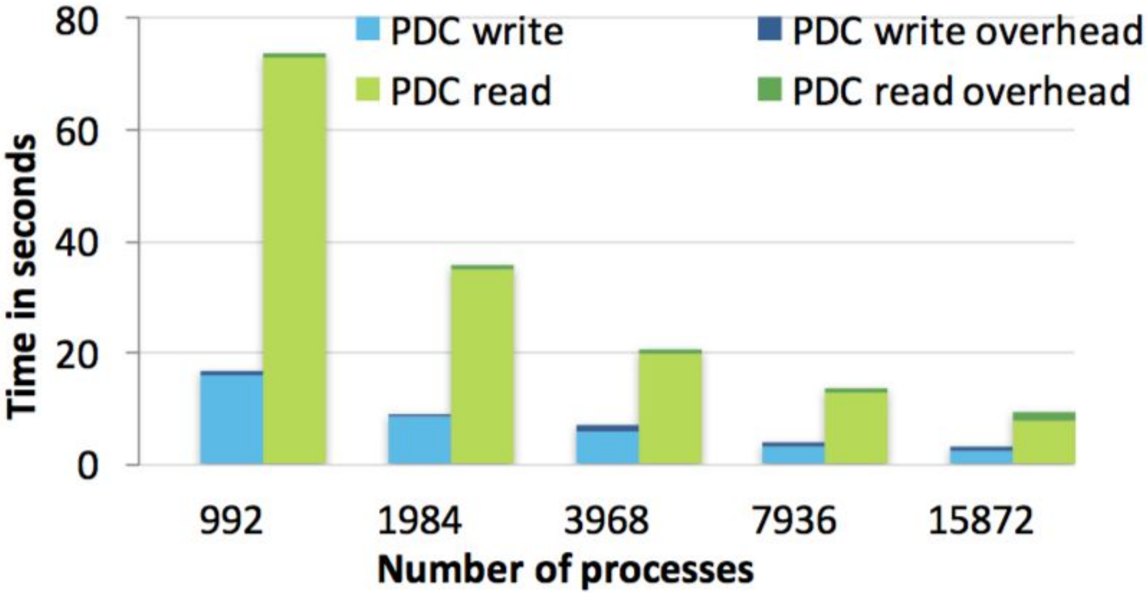
- **Relaxed metadata consistency.**
  - Delay some metadata updates and bundle with others.
  - Reduce communication cost.

Performance Evaluation

Experimental Setup

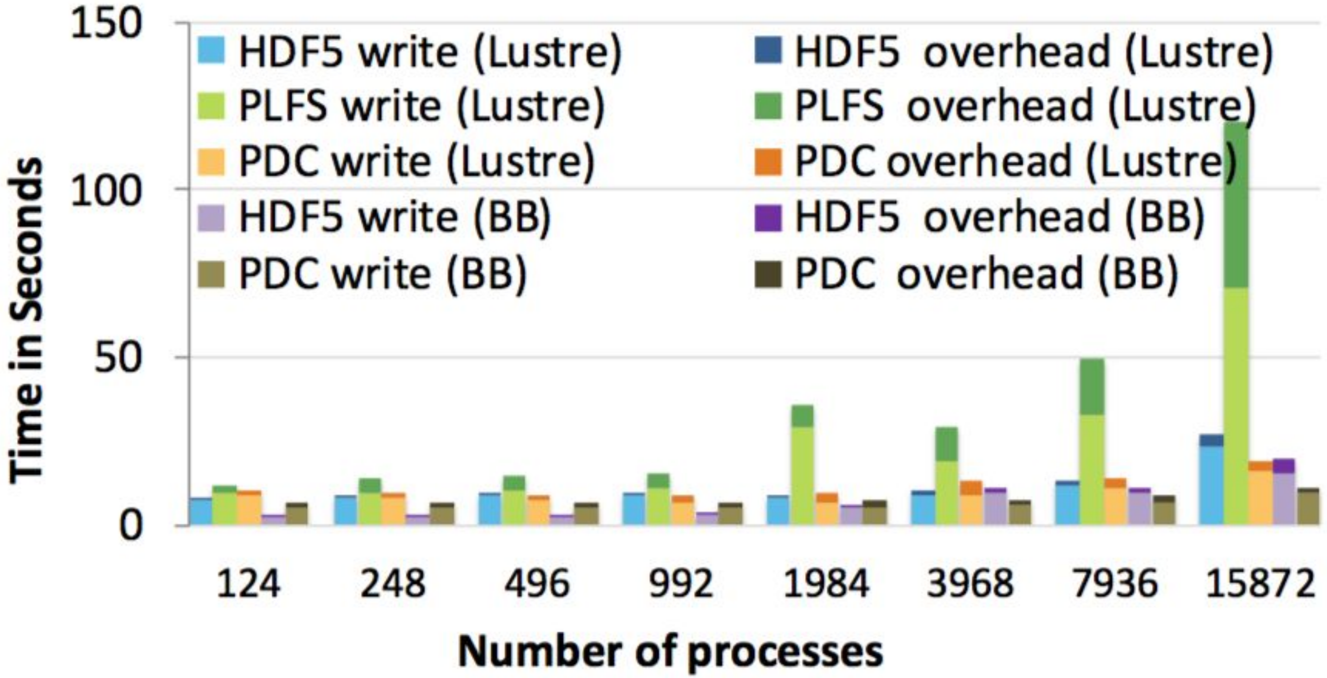
HPC Systems	Cori (NERSC), Cooley (Argonne)
Comparison	PDC, HDF5, and PLFS
Workloads	Benchmarks IO Kernels (VPIC-IO, BDCATS-IO)
Operations	Write, read with single and multiple time steps. Strong and weak scaling
Storage	Main Memory SSD-based Burst Buffer Hard disk drive (Lustre and GPFS)

I/O Strong Scaling



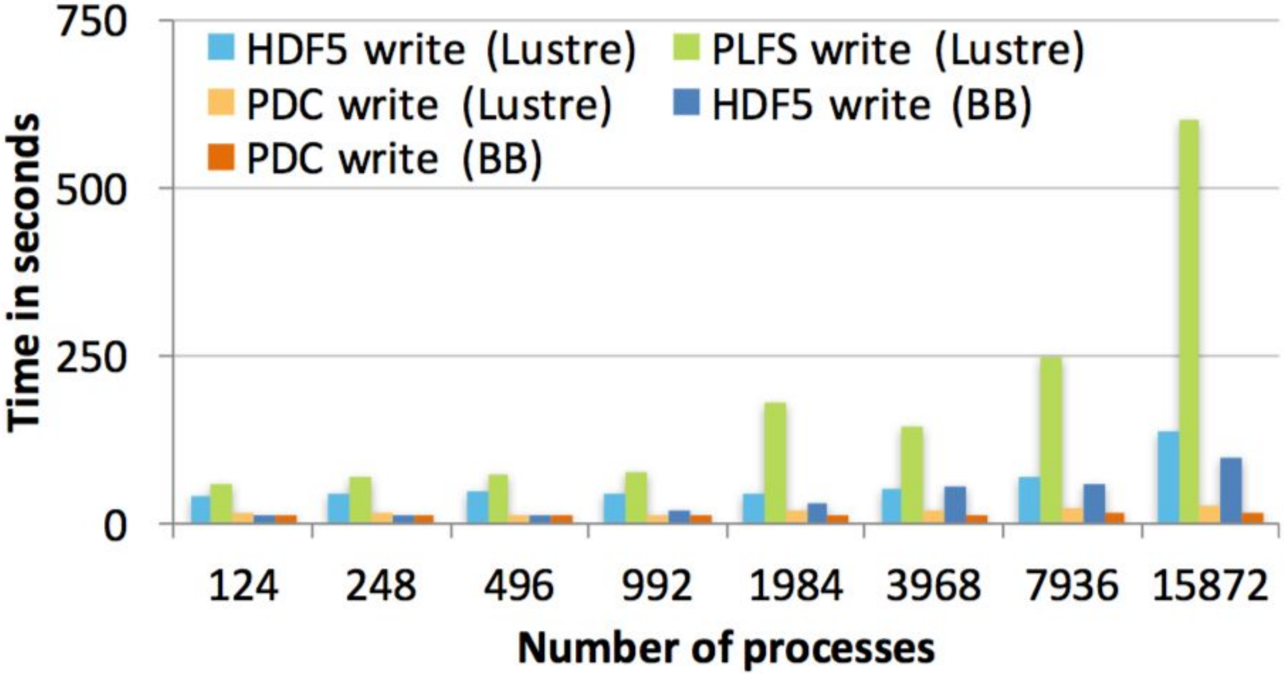
PDC strong scaling performance for writing and reading 512GB data on Lustre.

VPIC-IO (Weak Scaling) Single-timestep Write



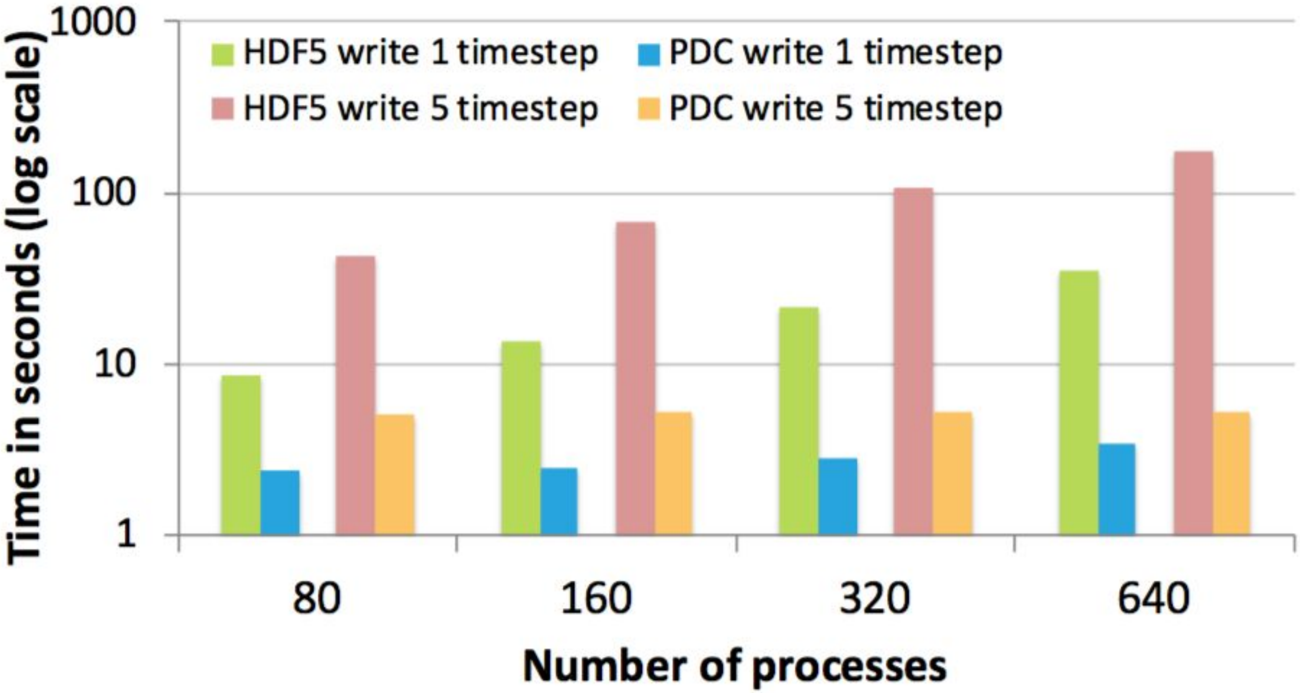
Total time for writing 1 timestep to Lustre and Burst Buffer using HDF5, PLFS, and PDC on Cori. PDC is up to **1.7x** faster than HDF5 and **9.2x** over PLFS

VPIC-IO (Weak Scaling) Multi-timestep Write



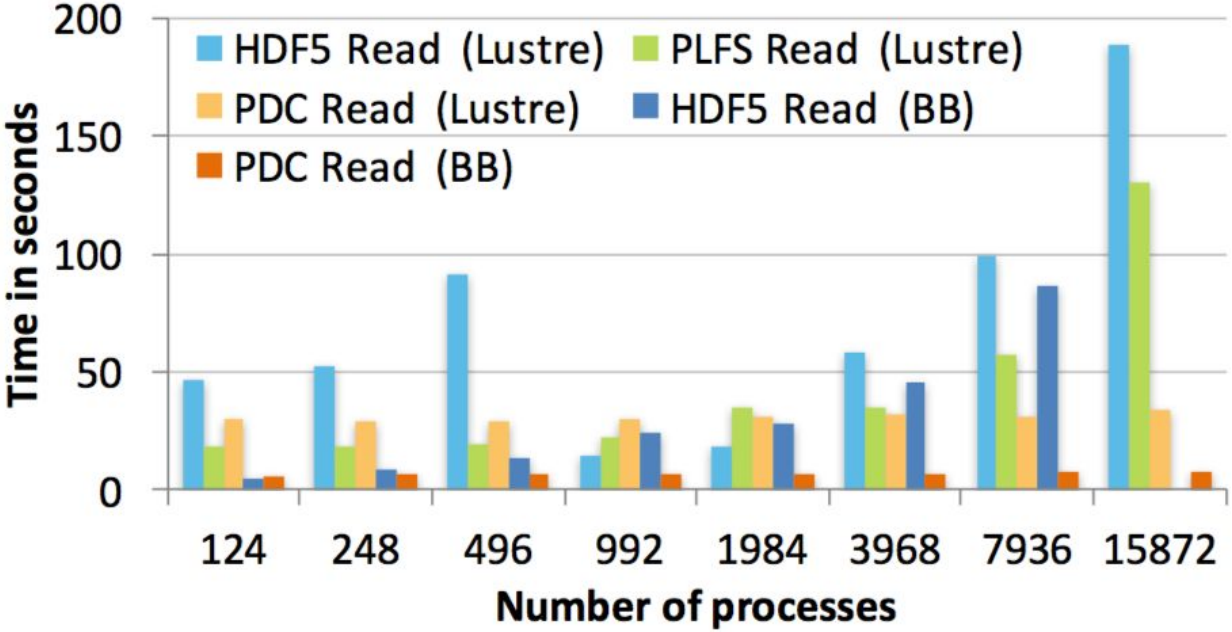
Total time to write 5 timesteps from the VPIC-IO kernel to Lustre and Burst Buffer on Cori. PDC is up to **5x** faster than HDF5 and **23x** over PLFS.

VPIC-IO Write on Cooley



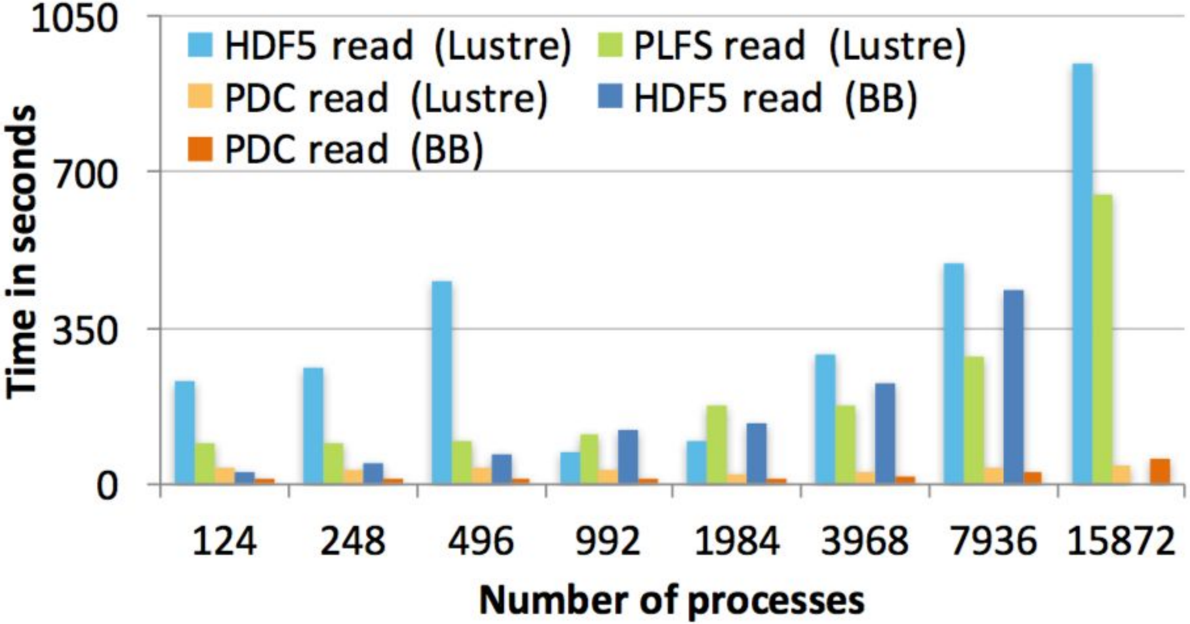
Total time to write 1 and 5 timesteps from the VPIC-IO kernel to the GPFS file system on Cooley. PDC is up to **7x** and **35x** than HDF5 to write 1 and 5 timesteps data.

BD-CATS-IO (Weak scaling) Single-timestep Read



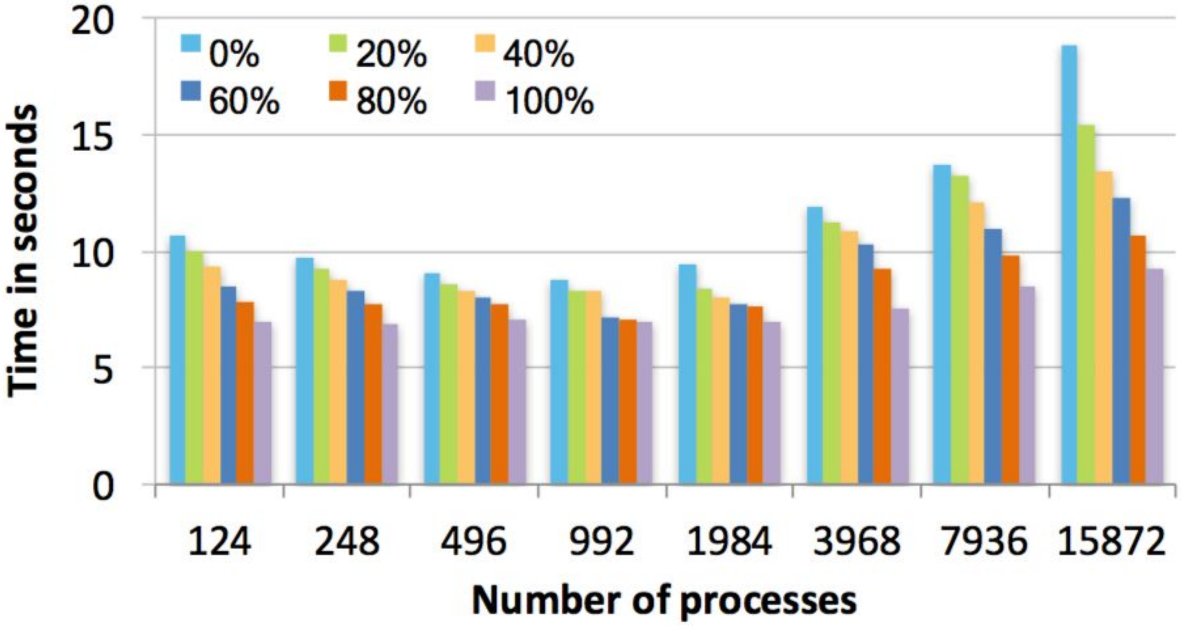
Total time for reading 1 timestep data using the BD-CATS-IO kernel using HDF5, PLFS, and PDC. PDC is up to **5x** and **4x** faster than HDF5 and PLFS.

BD-CATS-IO (Weak scaling) Multi-timestep Read



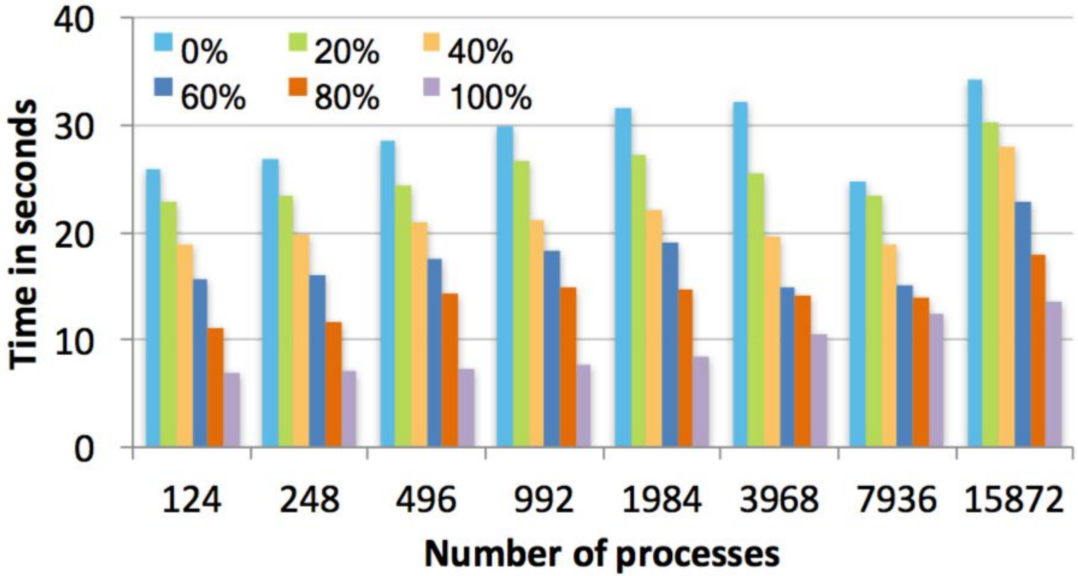
Total time for reading data of 5 timesteps from the BD-CATS-IO kernel from the Lustre and from the burst buffer. PDC is up to **11X** faster than PLFS and HDF5.

Multi-level Storage Write



Write time with part of the data written to faster burst buffer and the remaining to slower Lustre file system on Cori.

Multi-level Storage Read



Read time with part of the data written to faster burst buffer and the remaining to slower Lustre file system on Cori.

Spatial-selection Data Read from Lustre

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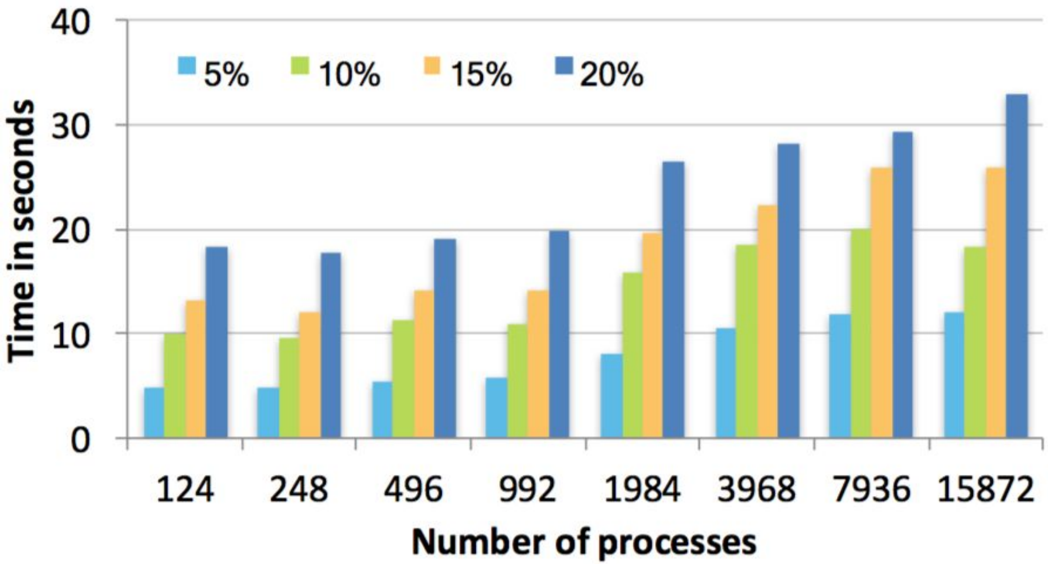
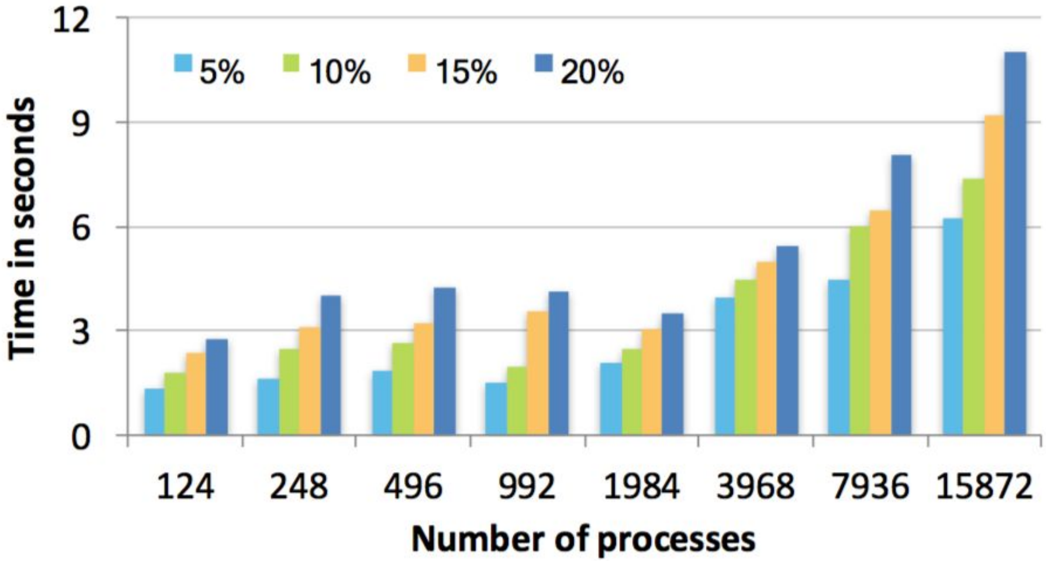


Time to read various selected object regions specified by the client processes from Lustre on Cori.

Spatial-selection Data Read from Burst Buffer



Time to read various selected object regions specified by the client processes from burst buffer on Cori.

Thanks!

Questions?

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