Interfacing HDF5 with A Scalable Object-centric Storage System on Hierarchical Storage

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Jingqing Mu∗, Jerome Soumagne∗, Suren Byna†, Quincey Koziol†, Houjun Tang†, Richard Warren∗

∗The HDF Group
†Lawrence Berkeley National Laboratory

Outline

- Challenges and Motivation
- Proactive Data Containers (PDC)
- HDF5 Virtual Object Layer (VOL) and PDC
- Performance Evaluation
- Conclusion and Future work

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Challenges and Motivation

- **Upcoming HPC systems: extreme parallelism, heterogenous memory hierarchy and rapidly increasing amount of data**
- **Several challenges for I/O libraries**
  - Limitation of POSIX I/O w.r.t. extreme parallelism
  - Inability to move data btw different levels of storage transparently and efficiently
- **Solutions and directions**
  - Object-based storage semantics
  - Storage abstraction and asynchronous I/O
- **Is it possible to prevent application code changes?**

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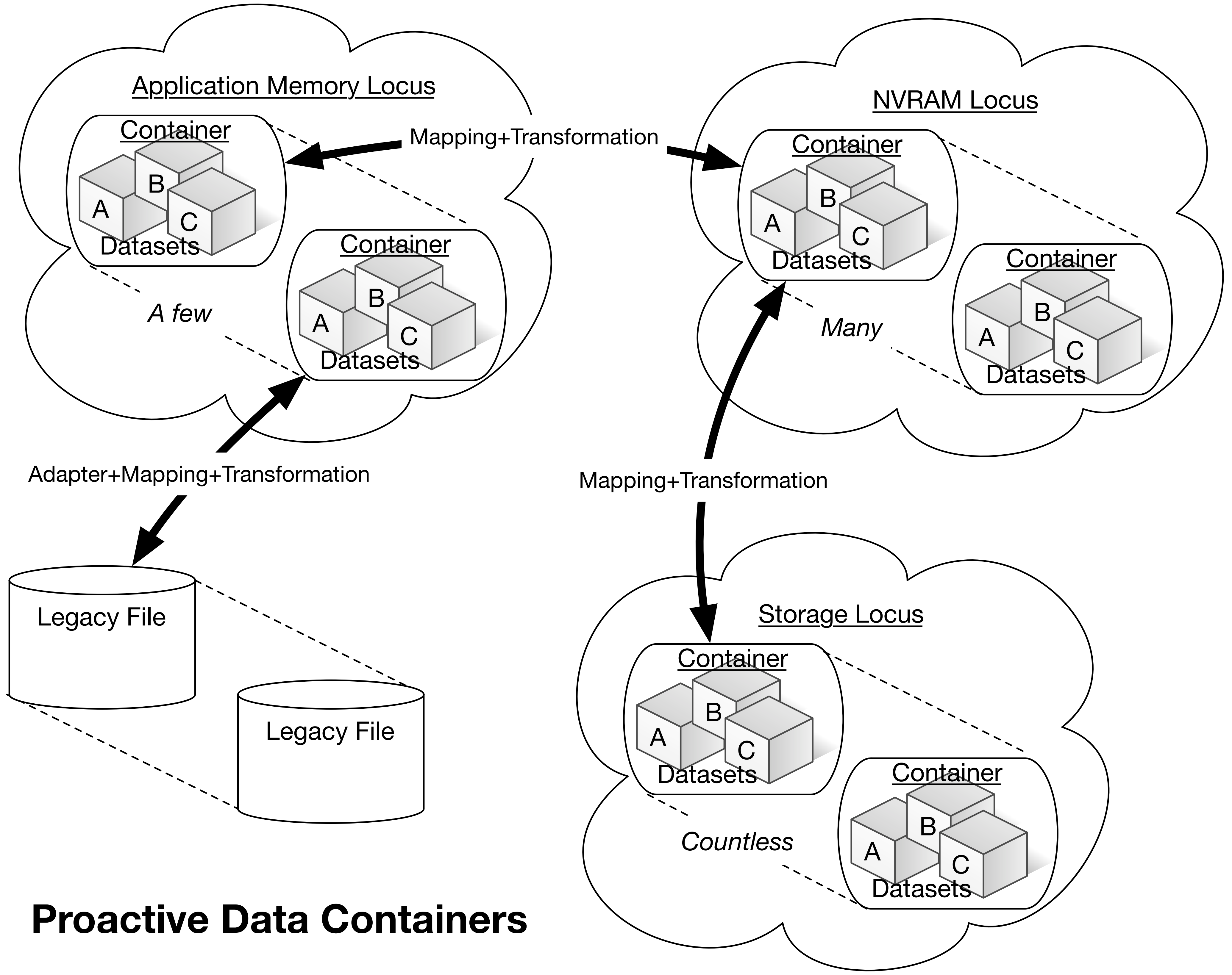
Proactive Data Containers (PDC)

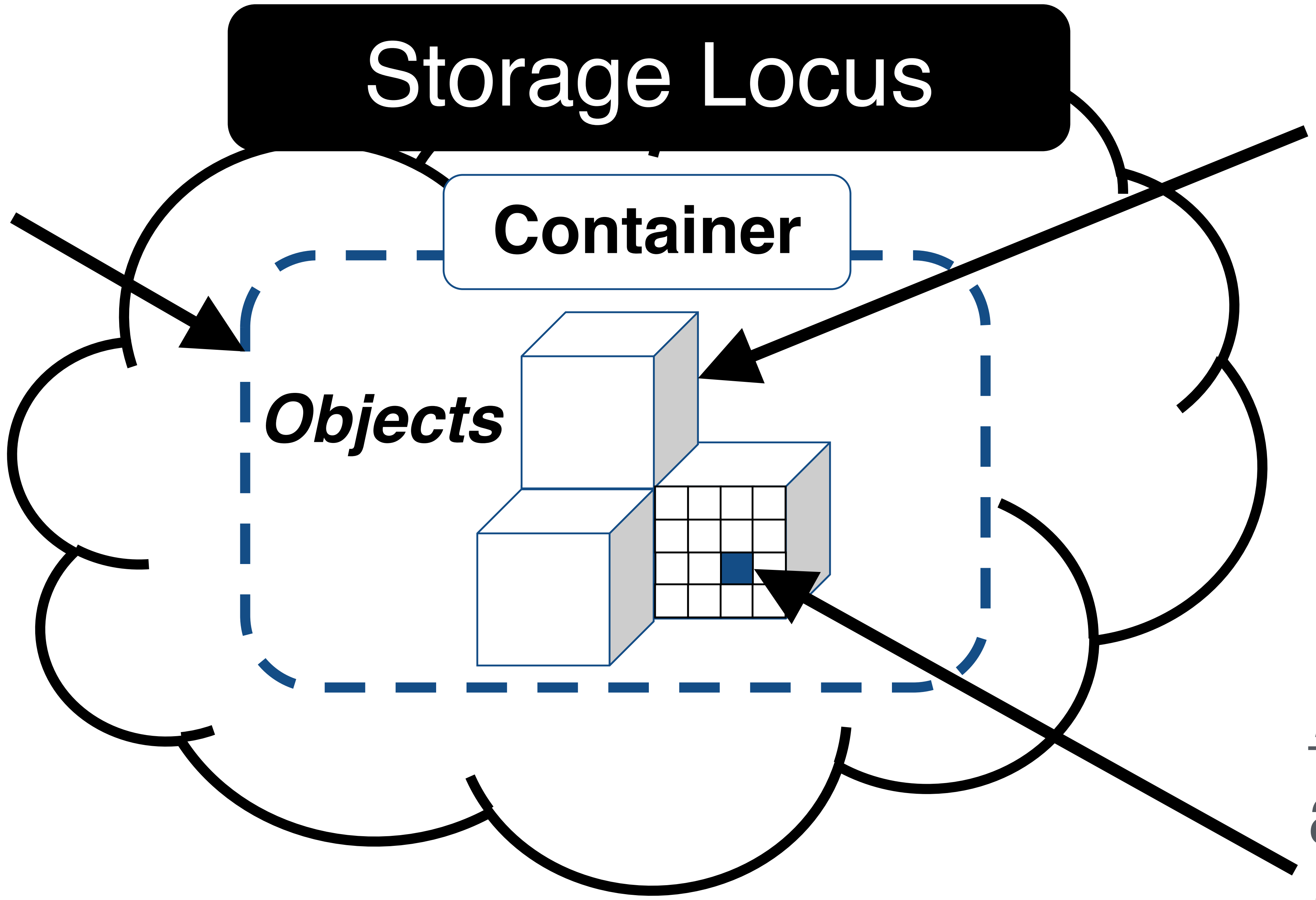
- Explore next generation storage systems and interfaces
- Object centric storage
- Autonomous data management
  - Proactive use of memory hierarchy
- Support for extracting information from data
  - Information management
  - Simulation time analytics
  - Interaction among multiple datasets



Proactive Data Containers

Proactive Data Containers (cont'd)

PDC organizes data as a set of ***objects*** within a ***Container***

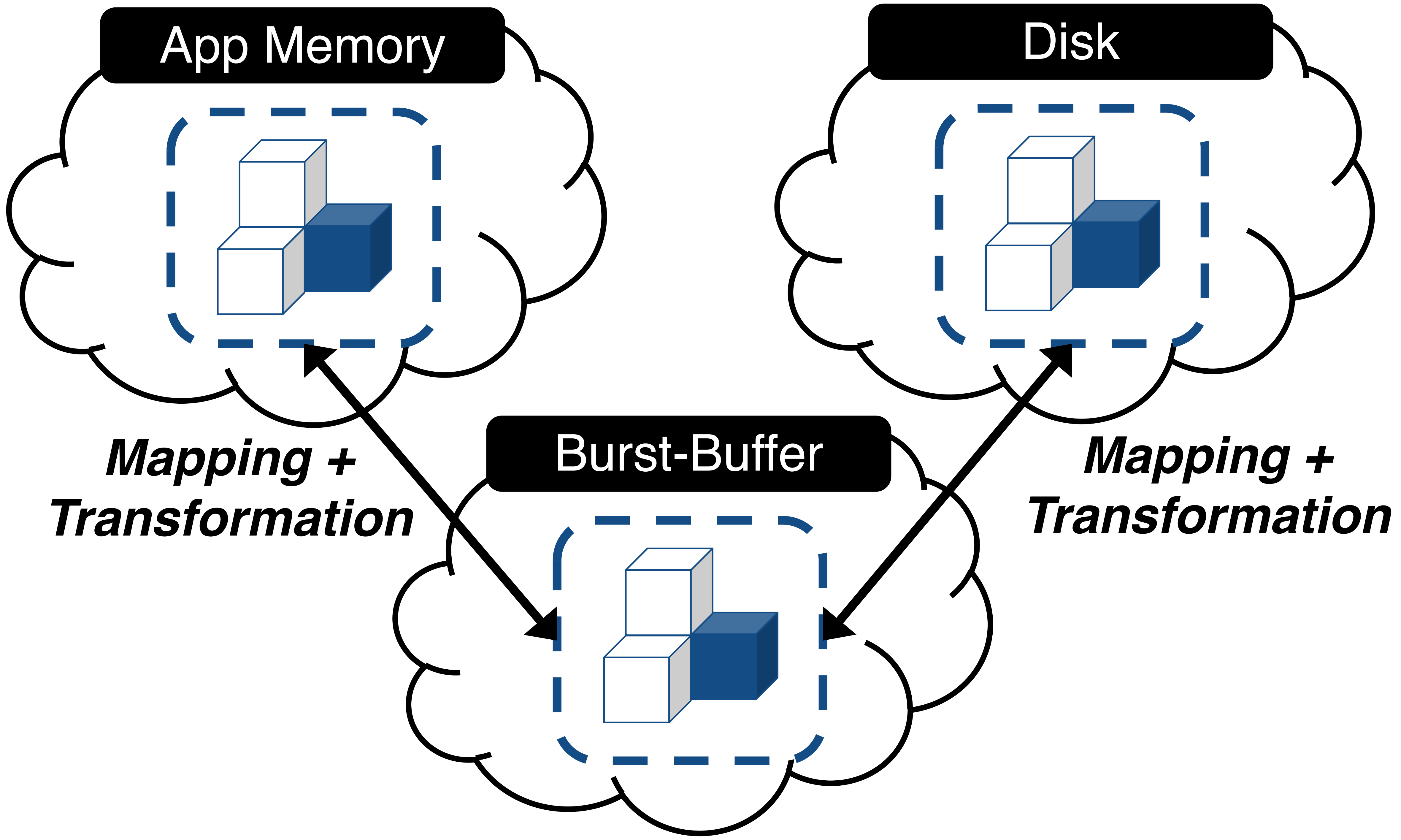


Object is a generic term to describe byte streams in an abstract manner

Region is the basic and fine-grain unit for data movement operations in PDC

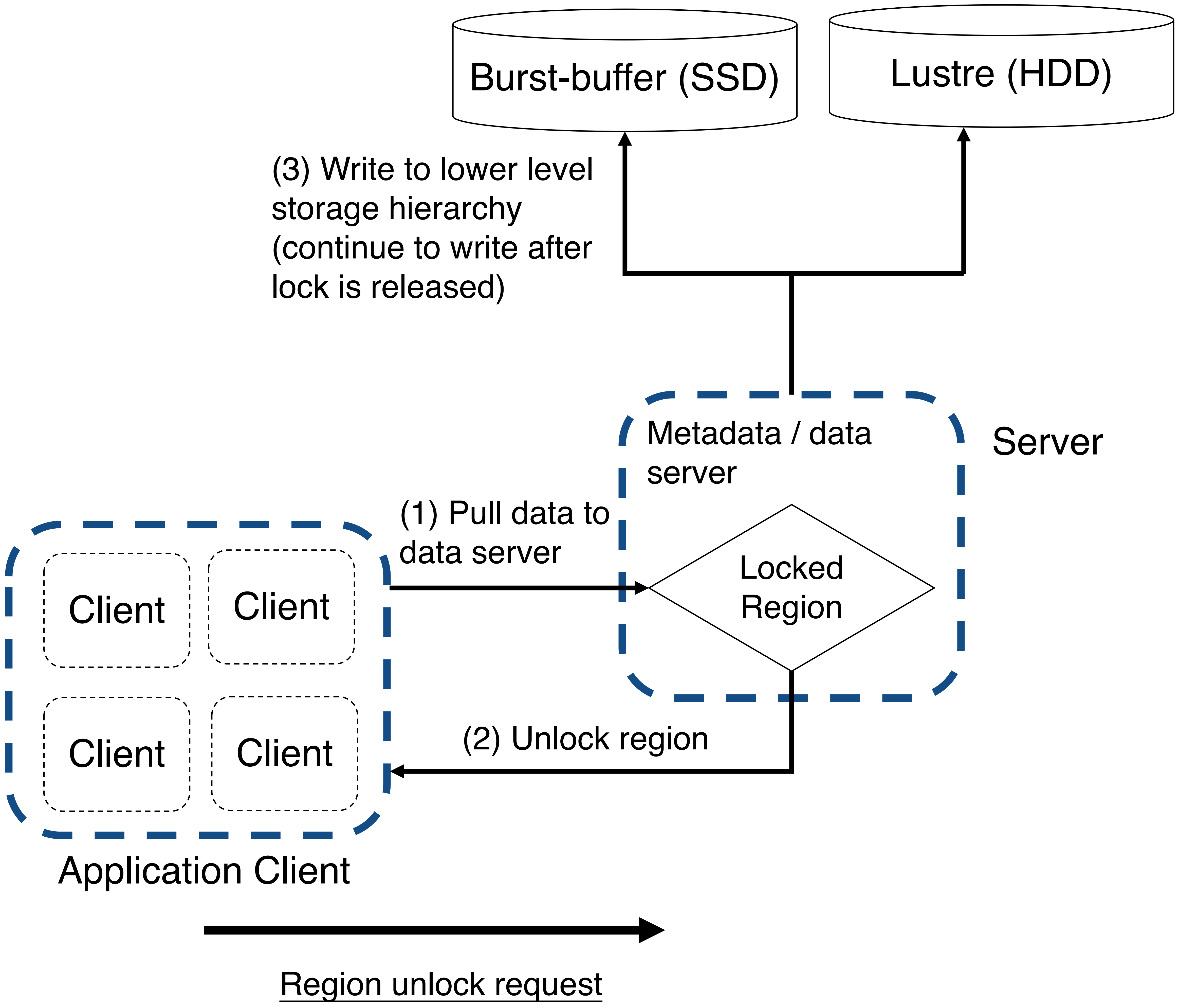
Proactive Data Containers (cont'd)

- **No explicit data movement**
- **Object mapping**
  - (Transformation)
  - Data movement operations *implicit*
  - Similar to `mmap()`
- **Concurrent access**
  - Explicit lock operation per region
  - Unlocked region = data movement can occur from/to that region
- **Primitives: map/unmap lock/unlock**



Proactive Data Containers (cont'd)

- **Client / server architecture**
- **Data movement and I/O realized *asynchronously***
  - Further transfers to deeper levels of the storage hierarchy can be handled by PDC server
  - Overlap computation with I/O operations
- **Application's buffers, when mapped, can only be used and modified once a lock is acquired**



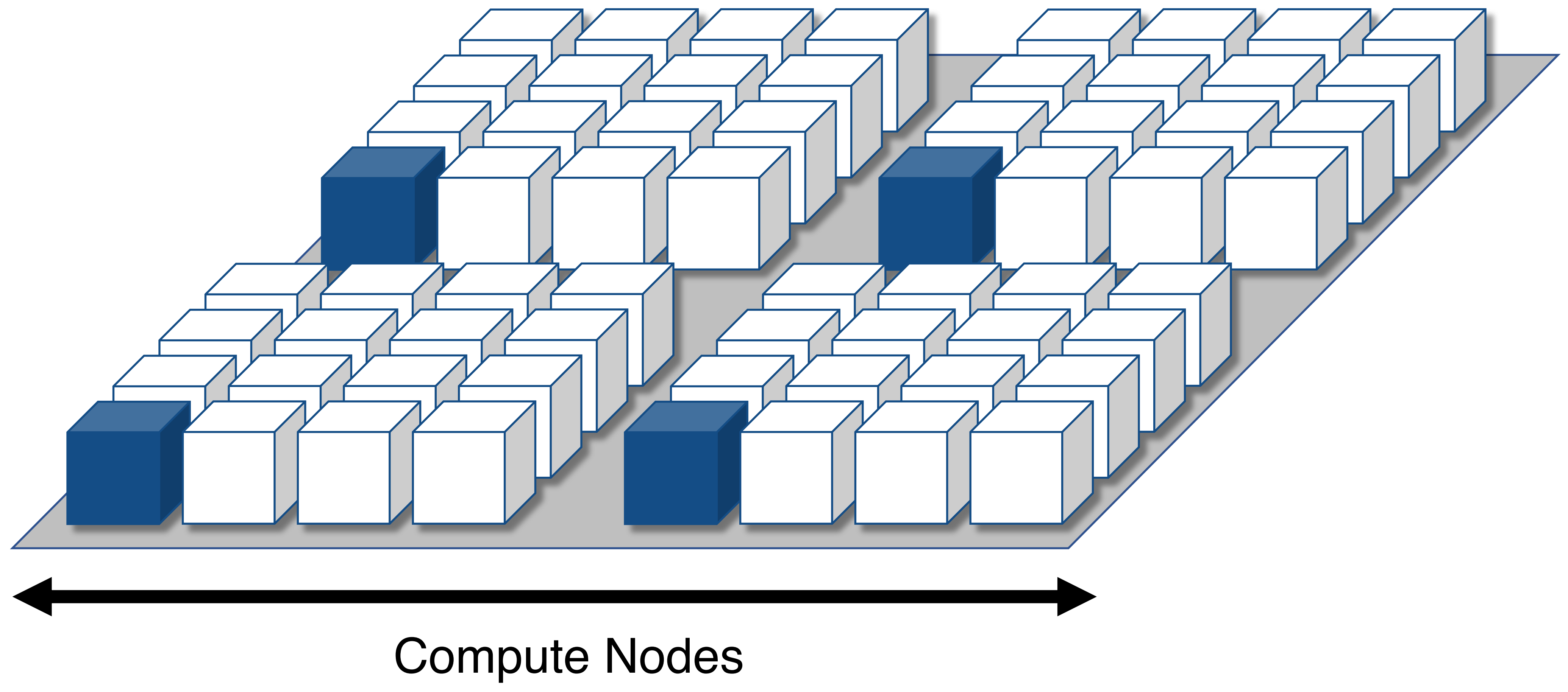
Proactive Data Containers (cont'd)

- **Deployment challenges**
  - Ease of deployment for application user
    - Cannot require root privileges
  - Resource management
    - Must co-exist with application

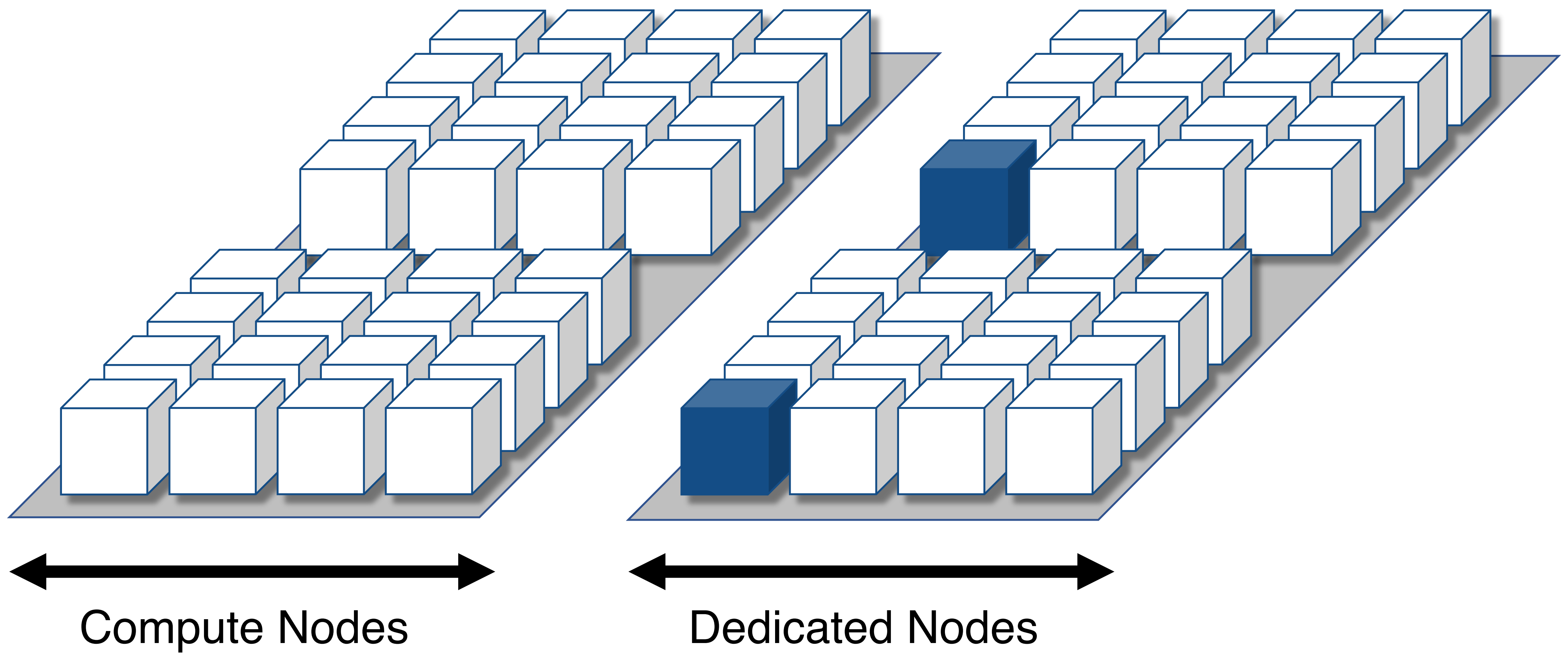
- **Multiple deployment options**
  - Shared-mode (co-located within the same node / run)
  - Dedicated mode (as a separate allocation)

Proactive Data Containers (cont'd)

Shared Mode



Dedicated Mode



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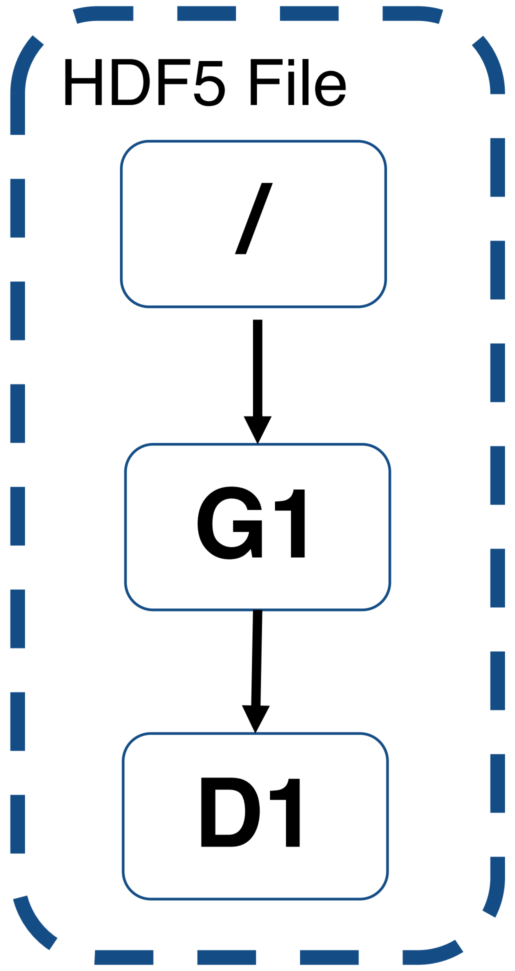
HDF5

- **Well-established I/O middleware package**
  - Scientific and industrial applications
- **File / Groups / Objects are base components of data model**
  - Example: 1 group + 1 dataset: “/G1/D1”

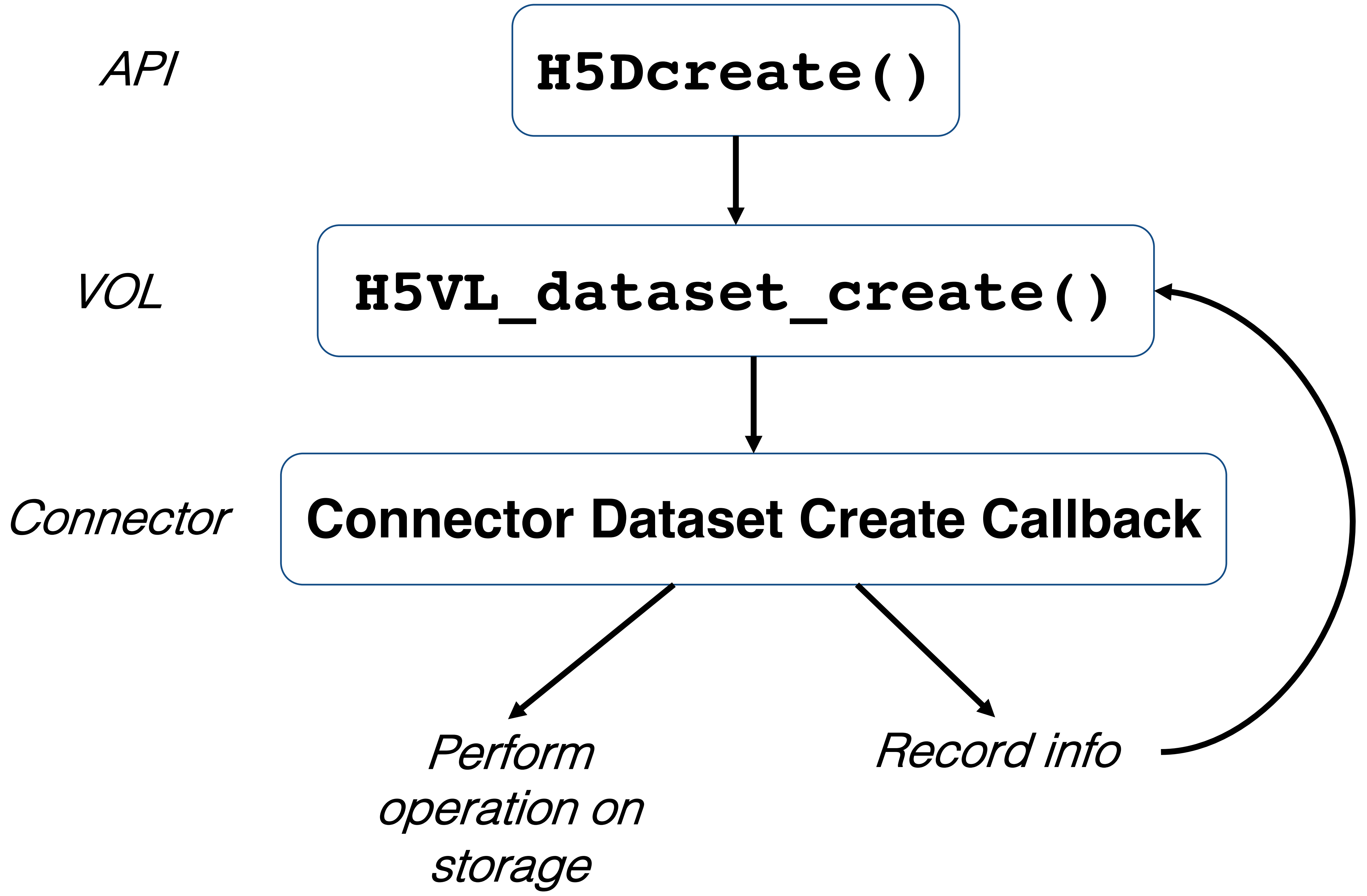


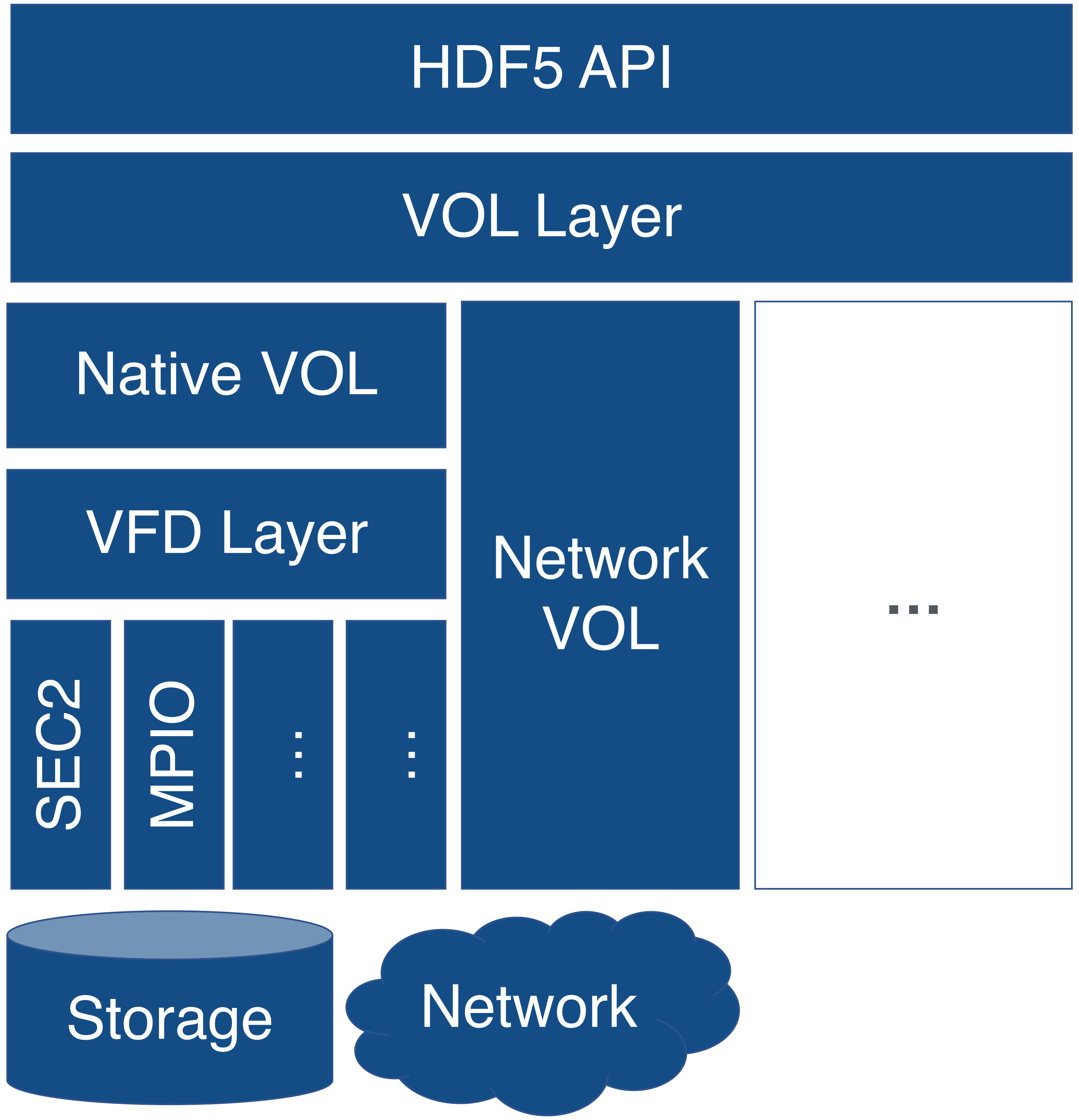
- **Parallel HDF5 uses “native” HDF5 on top of MPI I/O**
  - However tied to POSIX I/O

Contiguously mapped memory space to disk

HDF5 Virtual Object Layer (VOL)

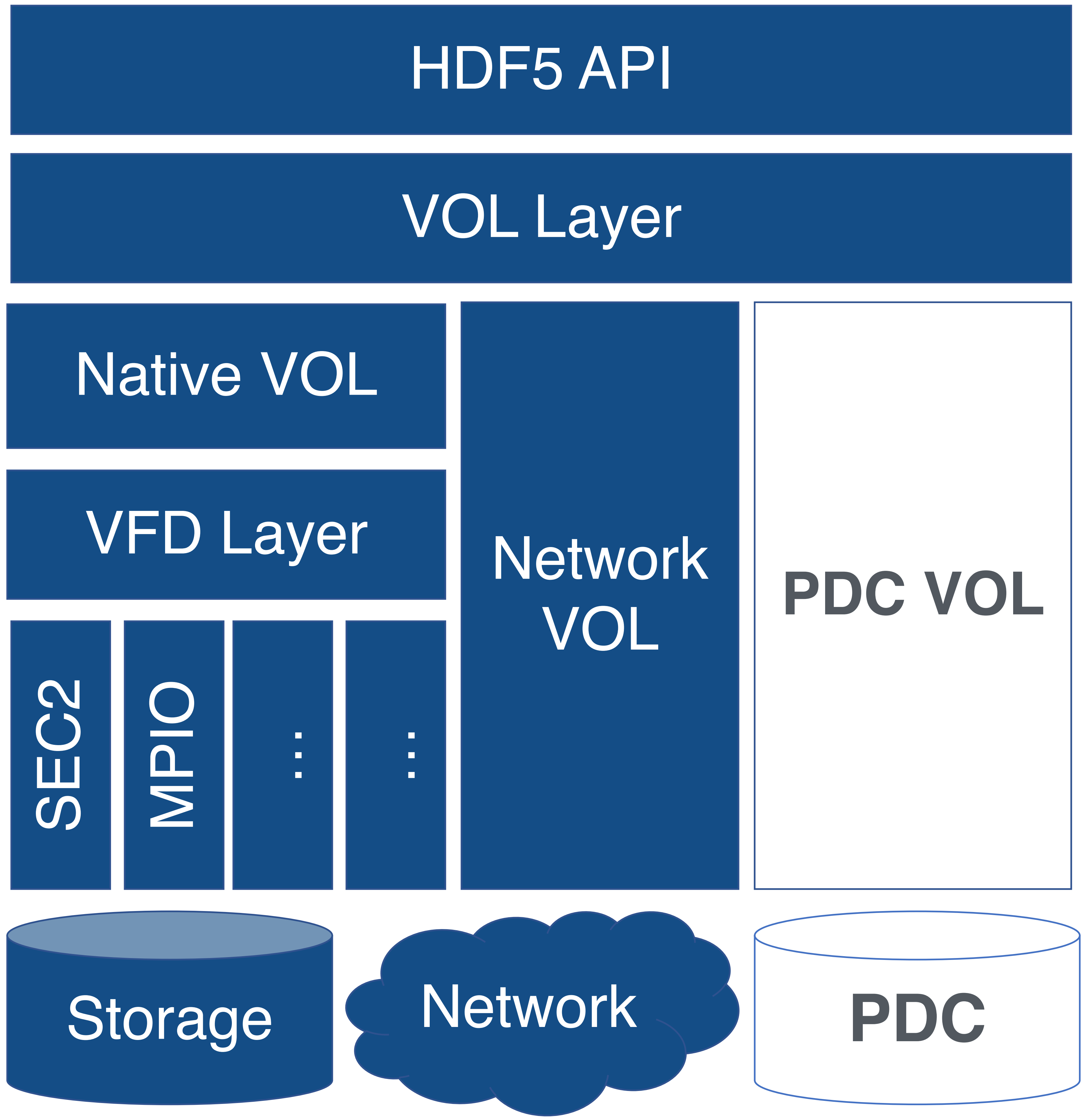
- Allows developers to redefine the HDF5 I/O API calls
- Re-route to corresponding VOL *connector* backend seamlessly
- Connector responsible for I/O calls





HDF5 VOL and PDC

- **Currently only implements a subset of the HDF5 API**
  - HDF5 files mapped to PDC containers
  - HDF5 datasets mapped to PDC objects
  - PDC regions similar to HDF5 selections
- **File create, open and close operations are a direct match to PDC container operations**



HDF5 VOL and PDC

- Dataset R/W operations require some extra handling
  - No explicit read and write semantics in PDC
  - Similar to `mmap()` way of writing to a file
    - `mmap()` + `memcpy()`
- Not a good match for PDC
  - Do not want to `map()` / `unmap()` in every call
  - Missing API functionality from HDF5

```
static herr_t
H5VL_pdc_dataset_write(void *_dset,
  hid_t mem_type_id, hid_t mem_space_id,
  hid_t file_space_id, hid_t dxpl_id,
  const void *buf, ...)
{
  // HDF5 selection to PDC region
  ...
  PDCbuf_obj_map((void *)buf, mem_type,
    mem_reg, dset->obj.obj_id, obj_reg);

  PDCreg_lock(dset->obj.obj_id, obj_reg,
    WRITE, NOBLOCK);
  ...
  PDCreg_unlock(dset->obj.obj_id,
    obj_reg, WRITE);

  PDCbuf_obj_unmap((void *)buf, mem_reg,
    dset->obj.obj_id, obj_reg);
}
```

HDF5 VOL and PDC

- **Applications can benefit from PDC with a single line code change**
- **Which benefits?**
  - Asynchronous I/O to subsequent levels of storage
  - Object oriented storage semantics
    - Storage and extraction of metadata
  - Analysis and transforms on PDC server (not demonstrated here)

```
/* Register PDC VOL */
pdc_vol_id = H5VLregister_connector(&H5VL_pdc_g,
    H5P_DEFAULT);

/* Create a new file access property */
fapl_id = H5Pcreate(H5P_FILE_ACCESS);

/* Set the VOL */
H5Pset_vol(fapl_id, pdc_vol_id, NULL);

/* Create file */
file_id = H5Fcreate(argv[1], H5F_ACC_TRUNC,
    H5P_DEFAULT, fapl_id);

/* Close property */
H5Pclose(fapl_id);

/* Close file */
H5Fclose(file_id);
```

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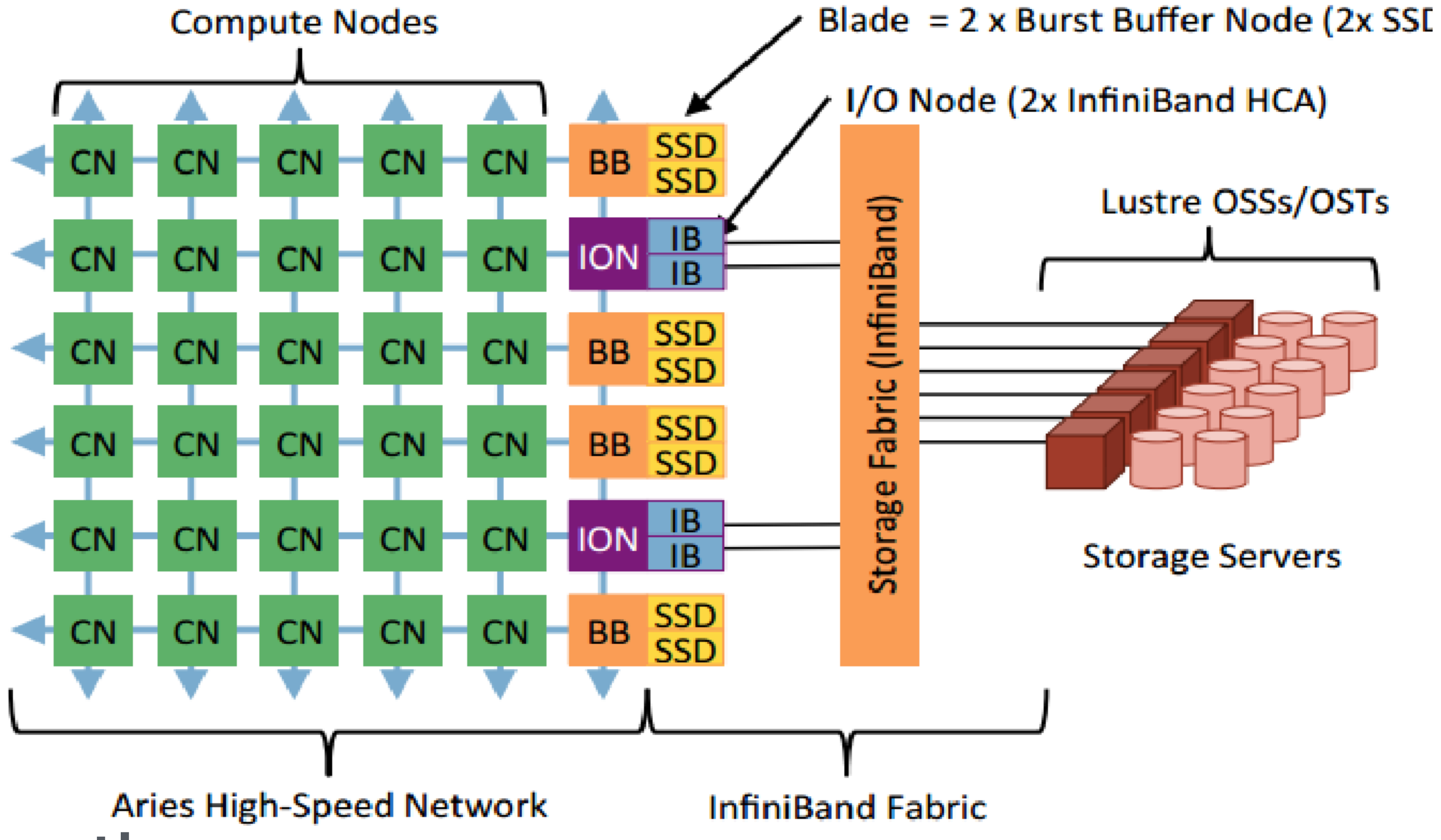
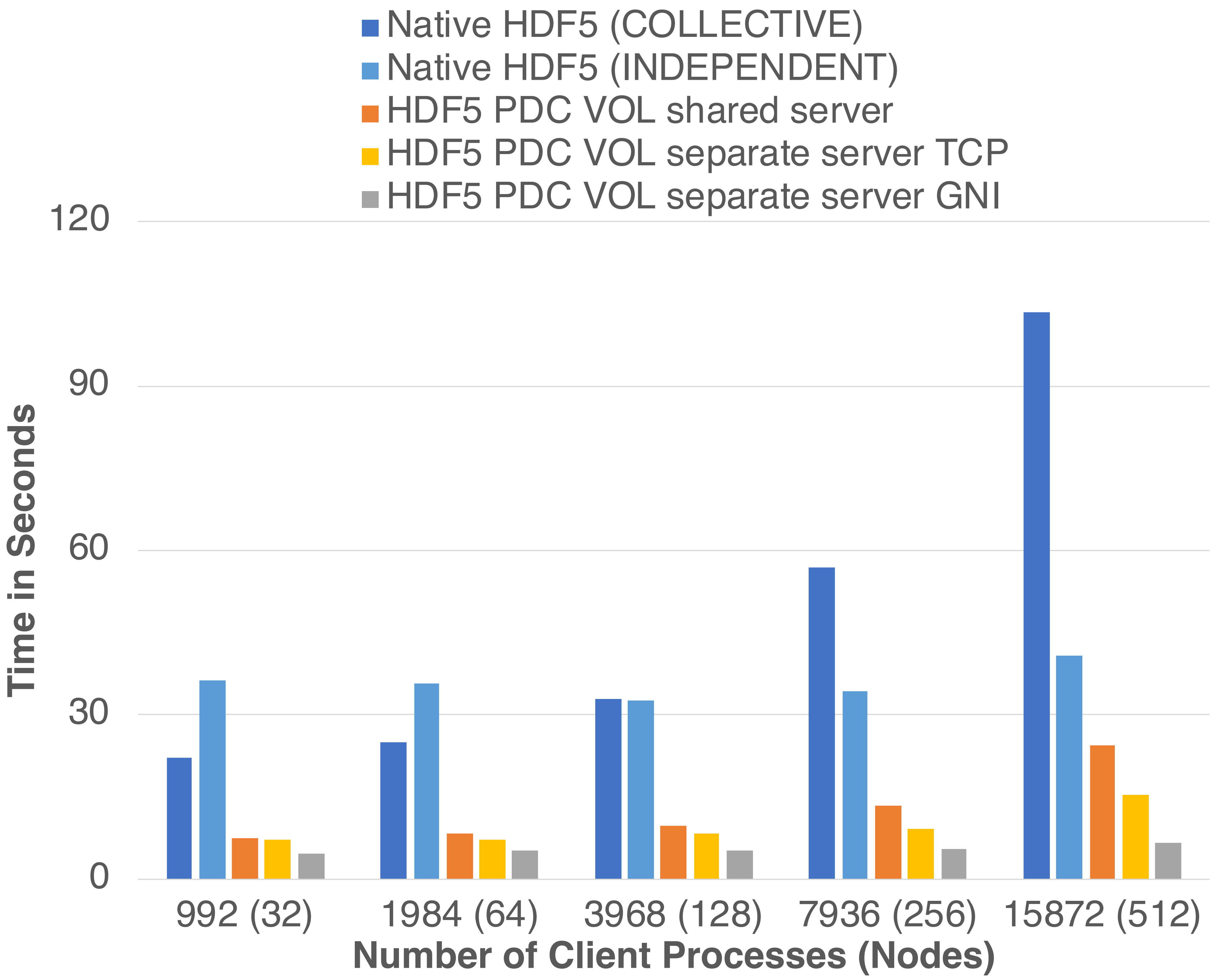
Experimental Setup

- **Cori supercomputer at LBNL**
  - 1600 “Haswell” compute nodes
  - 128 GB DRAM/node
  - 32 cores/node
  - SSD-based “Burst Buffer”
  - HHD-based shared file system Lustre
- **Shared mode**
  - 1 PDC server on each node, remaining 31cores for application
- **Dedicated mode**
  - PDC servers and user’s application are on separate nodes
- **Relies on Mercury (http://mercury-hpc.github.io) + Cray DRC + OFI libfabric**
- **Benchmarks**
  - VPIC-IO: I/O of a large-scale plasma physics simulation code
  - BD-CATS-IO: I/O of a big data clustering analysis code for particle data



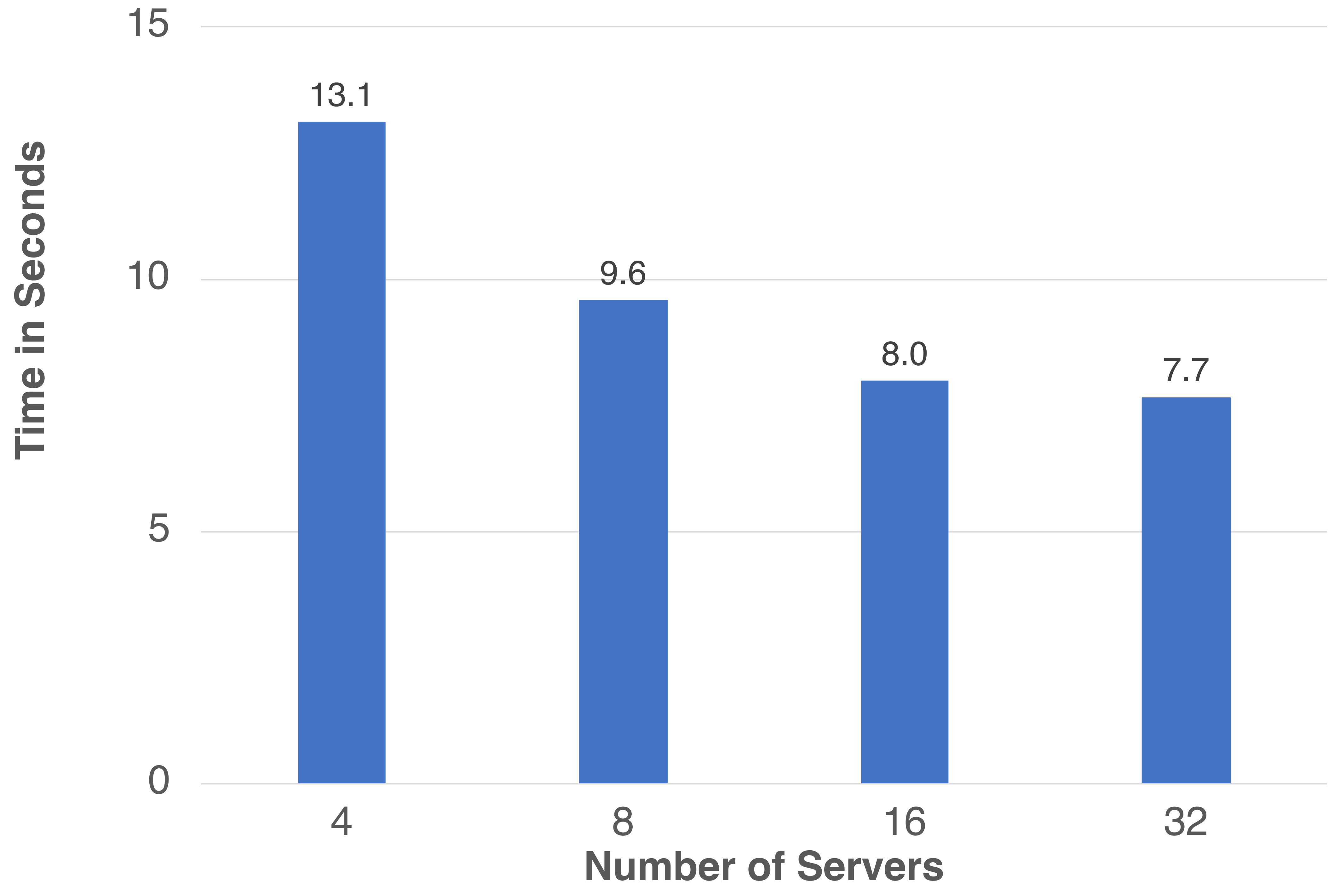
Performance evaluation

- **H5Dwrite() performance**
  - Varying number of PDC servers
  - VPIC-IO
- **Results**
  - Shared mode is 3.3X and 3.5X faster compared to independent and collective native HDF5 on average
  - Dedicated mode is 4.7X and 4.4X faster
  - Dedicated mode with Cray GNI is 8.3X and 6.6X faster



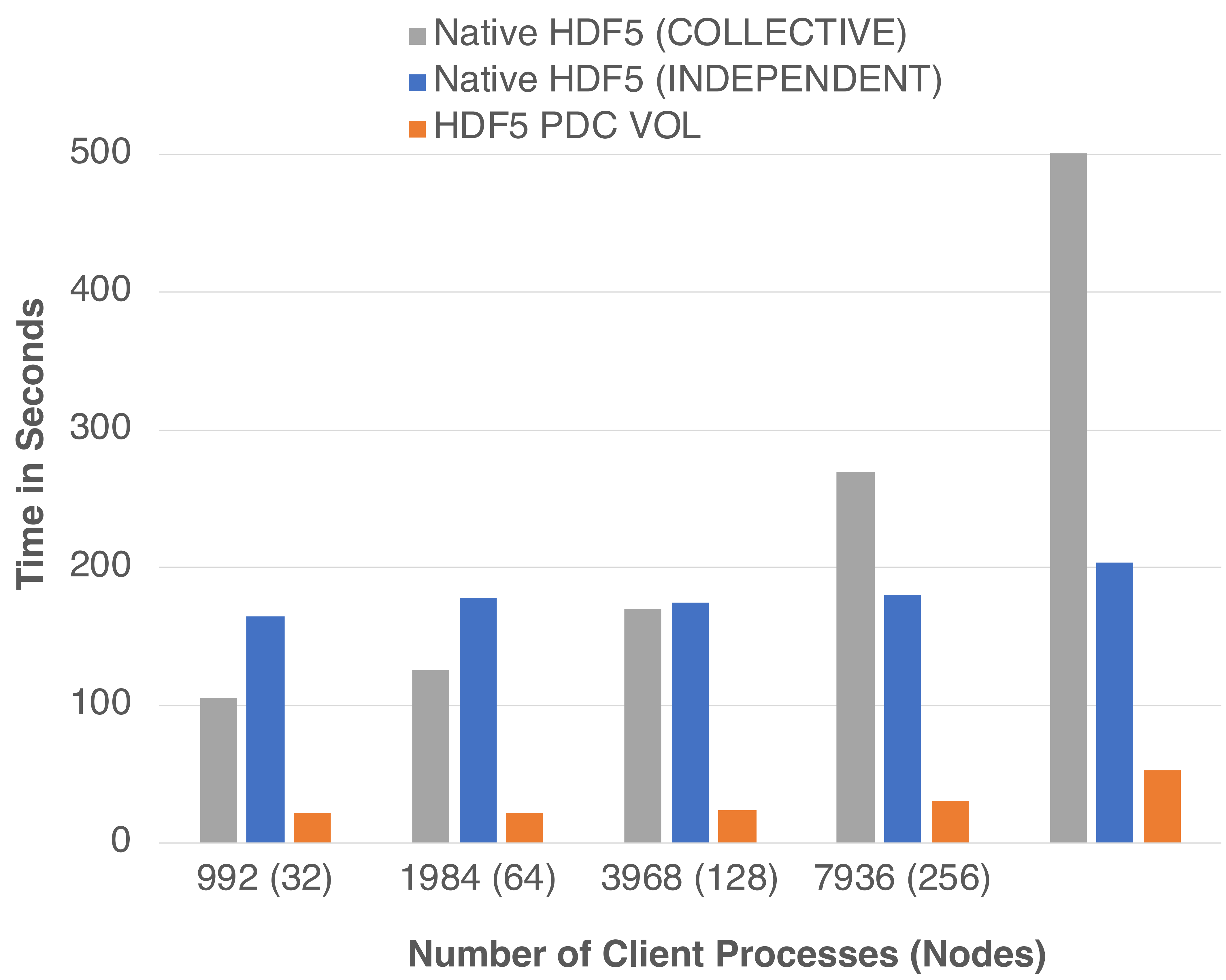
Performance evaluation (cont'd)

- **H5Dwrite() performance**
  - Varying number of PDC servers with fixed 32 node clients
  - Dedicated mode w/ up to 32 nodes
  - VPIC-IO
- **Results**
  - Having less than a half of the nodes still provides good performance



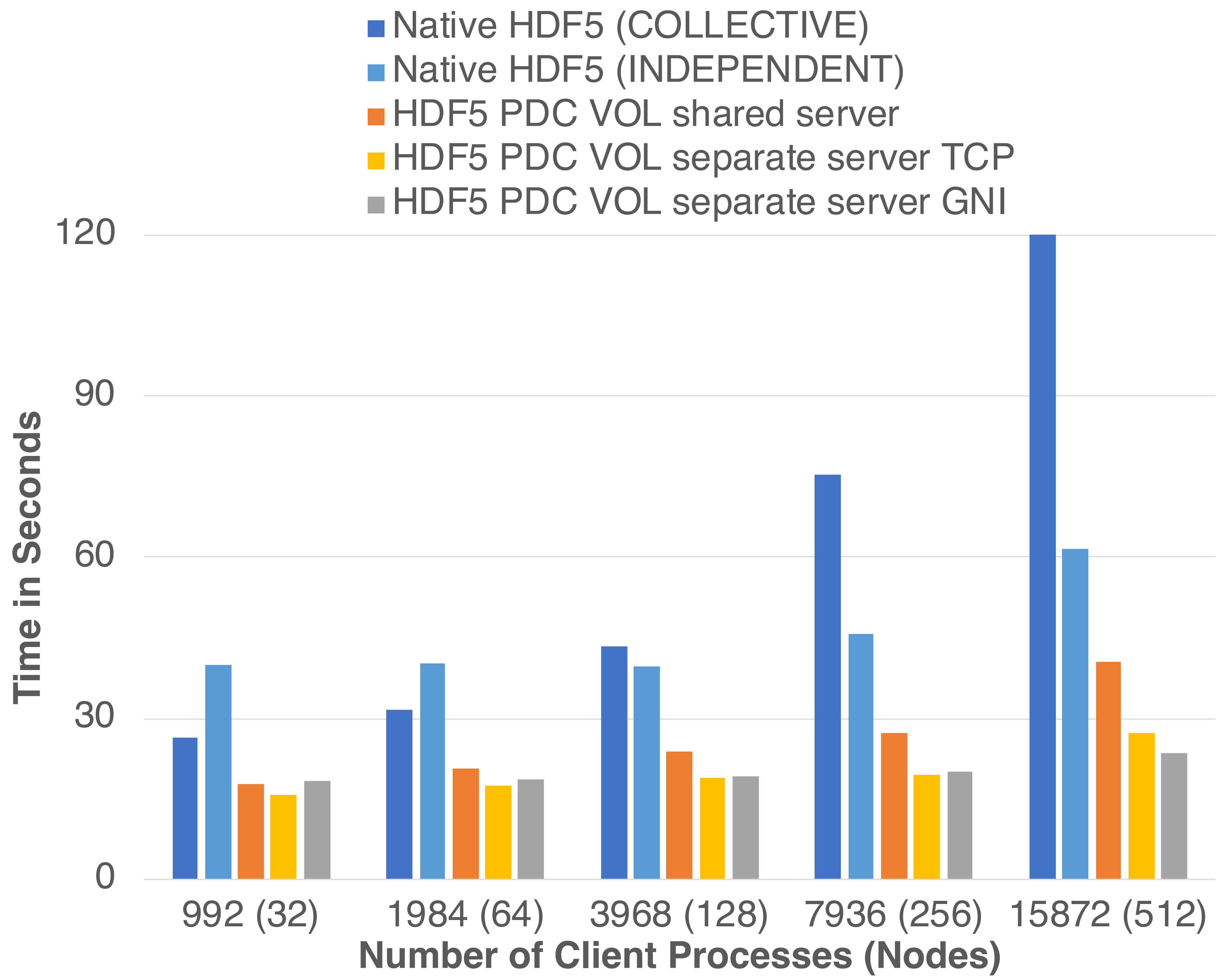
Performance evaluation (cont'd)

- **H5Dwrite() performance**
  - 5 time steps
  - Shared-mode
  - VPIC-IO
- **Results**
  - An average speedup of 7.3X and 6.6X compared to native HDF5 collective and independent I/O separately



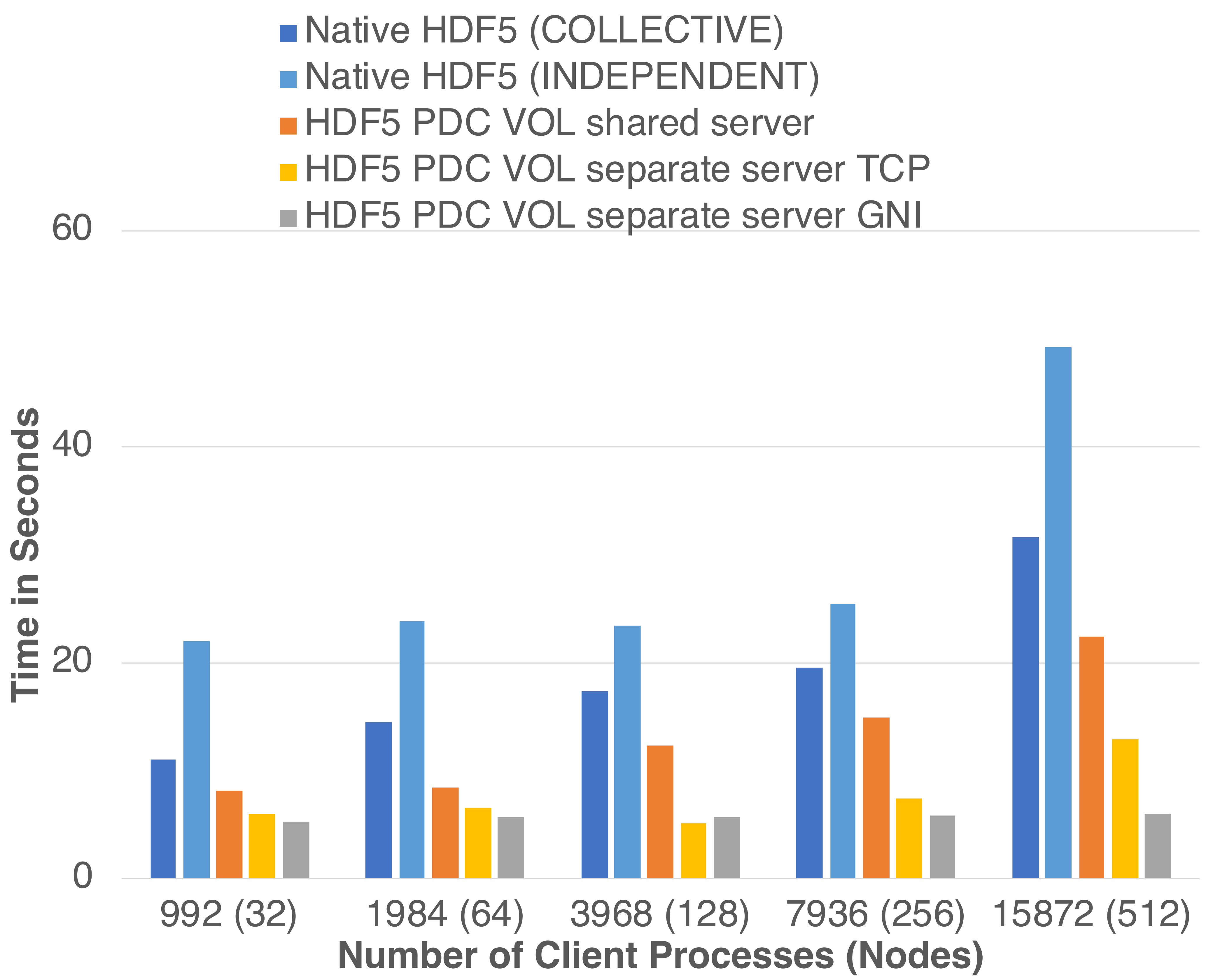
Performance evaluation (cont'd)

- **H5Dwrite() performance**
  - Single time step
  - Total Execution Time for VPIC-IO
- **Results**
  - Achieves 2.9X and 2.5X faster performance compared to HDF5 collective and independent I/O methods respectively



Performance evaluation (cont'd)

- **H5Dread() performance**
  - BD-CATS-IO
- **Results**
  - Shared mode is 1.4X and 2.3X faster compared to collective and independent native HDF5 on average
  - Dedicated mode is 2.5X and 3.8X faster
  - Dedicated mode with Cray GNI is 3.3X and 5.0X faster



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Conclusion and Future Work

- **HDF5 PDC VOL connector**
  - Async I/O and transparent data movement to multi storage tiers
  - Object-oriented storage
- **Minimal to zero code modification (none w/ environment variable)**
- **Use native network fabric transports such as Cray GNI**

- **Current limitation of HDF5 API**
  - Explicit read and write of data
  - Will look at bringing map semantics into HDF5
  - However would require application code changes
- **External VOL connector development**

Questions

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