SCALABLE COMPUTING SOFTWARE LABORATORY

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Enosis: Bridging the Semantic Gap between File-based and Object-based Data Models

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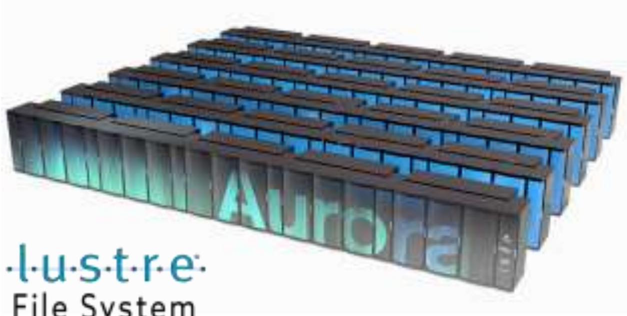
Outline

- Introduction
- Background
- Approach
- Evaluation
- Conclusions
- Q&A

What is this talk about?

- Highlights of this work:
  - Key characteristics of file-based and object-based storage systems.
  - Design and implementation of a unified storage access system that bridges the semantic gap between file-based and object-based storage systems.
  - Evaluation results show that, in addition to providing **programming convenience and efficiency**, our library, Enosis, can grant **higher performance** avoiding costly data movements between file-based and object-based storage systems.

Different communities - different systems



The tools and cultures of HPC and BigData analytics have diverged, to the detriment of both;
unification is essential to address a spectrum of major research domains.

- D. Reed & J. Dongarra

Enosis: Unified Storage Access System

Challenges of storage unification

- Wide range of issues:
  1. There is a gap between
     a) **traditional storage solutions** with semantics-rich data formats and high-level specifications, and
     b) **modern scalable data frameworks** with simple abstractions such as key-value stores and MapReduce.
  2. There is a big difference in architecture of programming models and tools.
  3. Lack of management of
     1. heterogeneous data resources
     2. diverse global namespaces stemming from different data pools.

Our thesis

- A radical departure from the existing software stack for both communities is not realistic.
- Future software design and architectures will have to raise the abstraction level and therefore,
  - **bridge the semantic and architectural gaps.**
- We envision
  - a data path agnostic to the underlying data model
  - leverage each storage system's strengths while complementing each other for known limitations.

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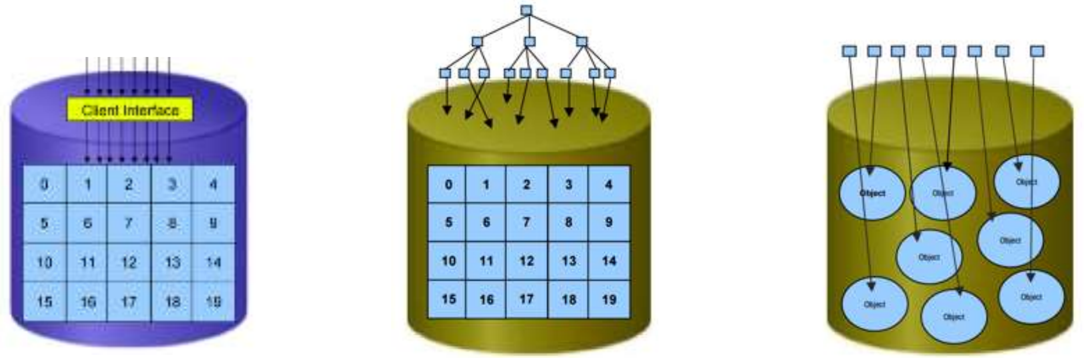
Data formats and storage systems

- Data are typically represented as files, blocks, or objects.
- Two major camps of storage solutions:
  - File-based storage systems
    - POSIX-I/O with fwrite(), fread(), MPI-I/O with MPI_File_read(), MPI_File_Write()
    - High-level I/O libraries e.g., HDF5, pNetCDF, MOAB etc
  - Object-based storage systems
    - REST APIs, Amazon S3, OpenStack Swift with get(), put(), delete()

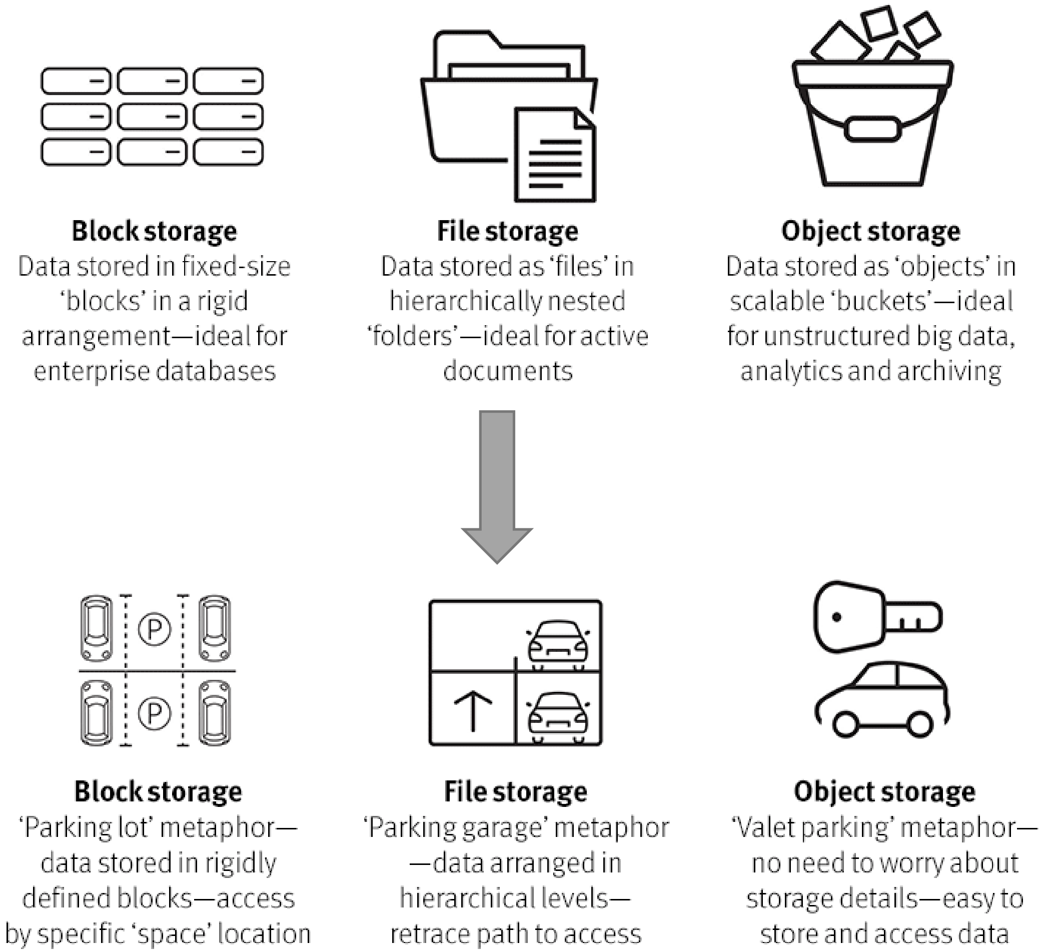


Blocks | Files | Objects

Interface and API

- Storage expectations:
  - MPI and scientific computing
  - Hadoop ecosystem and BigData computing
  - POSIX compliant or not?
  - Structured, semi-structured, and unstructured data
  - Consistency models: strong vs eventual?

Data models differences



Source: Dell EMC

Category	Object Storage	File Storage
Data unit	Objects	Files
Update	Create new object	In-place updates
Protocols	REST and SOAP	NSF with POSIX
Metadata	Custom	Fixed attributes
Strengths	Scalability	Simplified access
Limitations	Frequent updates	Heavy metadata
Performance	High throughput	Streaming of data

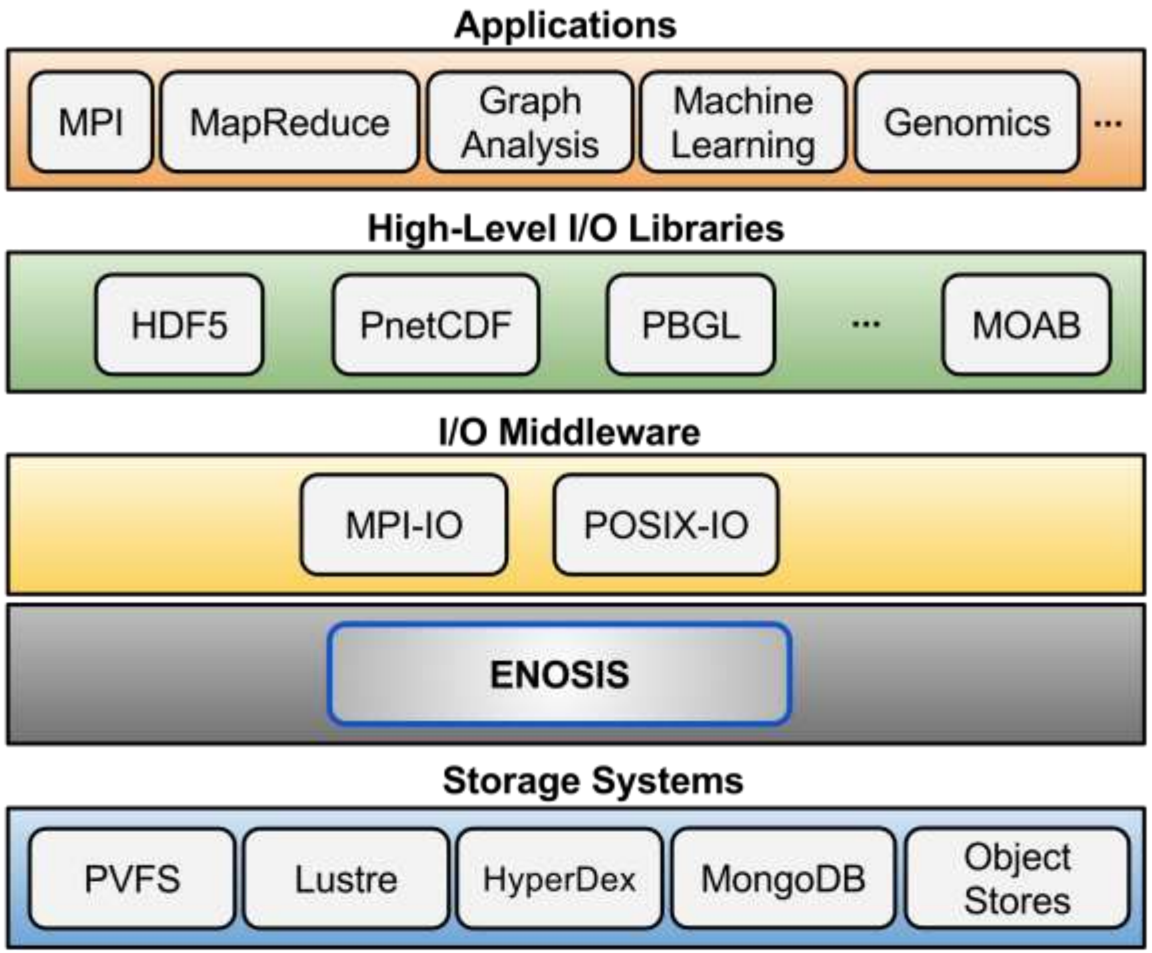
- There is no "one-storage-for-all" solution.
- Each system is great for certain workloads
- Unification is essential

Related work

- From the File system side:
  - CephFS
  - PanasasFS
  - OBFS: A File System for Object-based Storage Devices OSD
- From the Object store side:
  - AWS Storage Gateway
  - Azure Files and Azure Disks
  - Google Cloud Storage FUSE

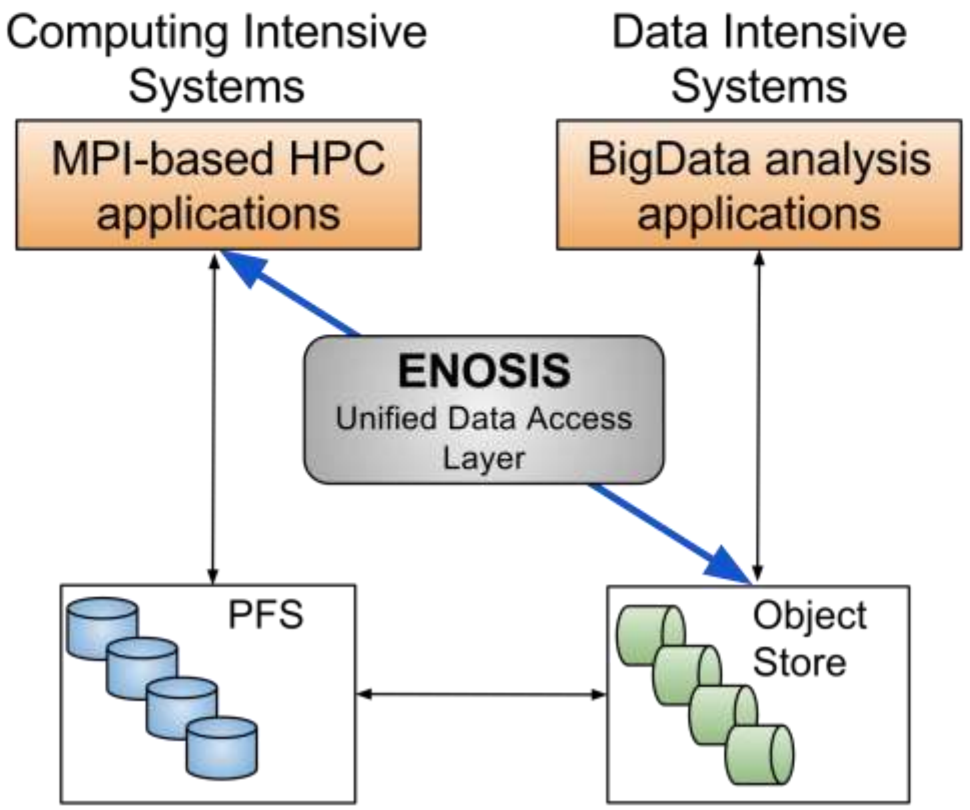
Enosis is a general solution that can bridge any File System with any Object Store and does NOT require change in user code and underlying system deployments.

Design



- Middle-ware library
- Link with applications (i.e., re-compile or LD_PRELOAD)
- Wrap-around I/O calls
- Written in C++, modular design
- Existing datasets loaded upon bootstrapping via crawlers
- Directory operations not supported
- Deletions via invalidation
- Enosis is Not yet-another file system on top of Object Store but a semantics bridge that maintains strong data consistency

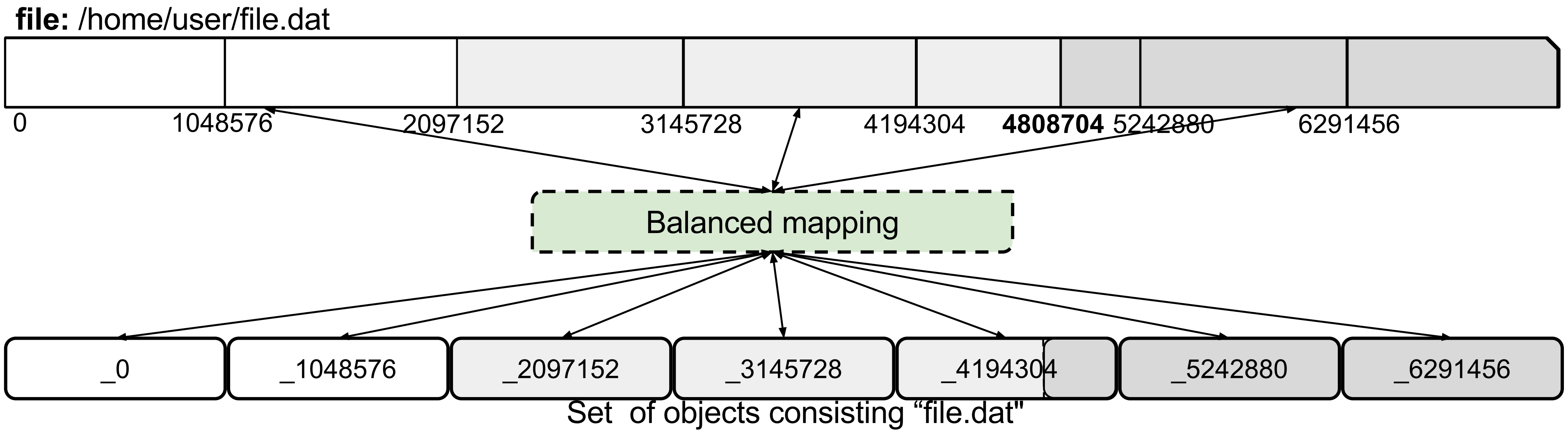
Design



- Three mapping strategies for POSIX files
  1. Balanced
  2. Read-optimized
  3. Write-optimized
- One new HDF5 mapping strategy
- A naïve strategy is when one file is mapped to one object
  - It is used as our baseline reference
  - It is what most connectors do

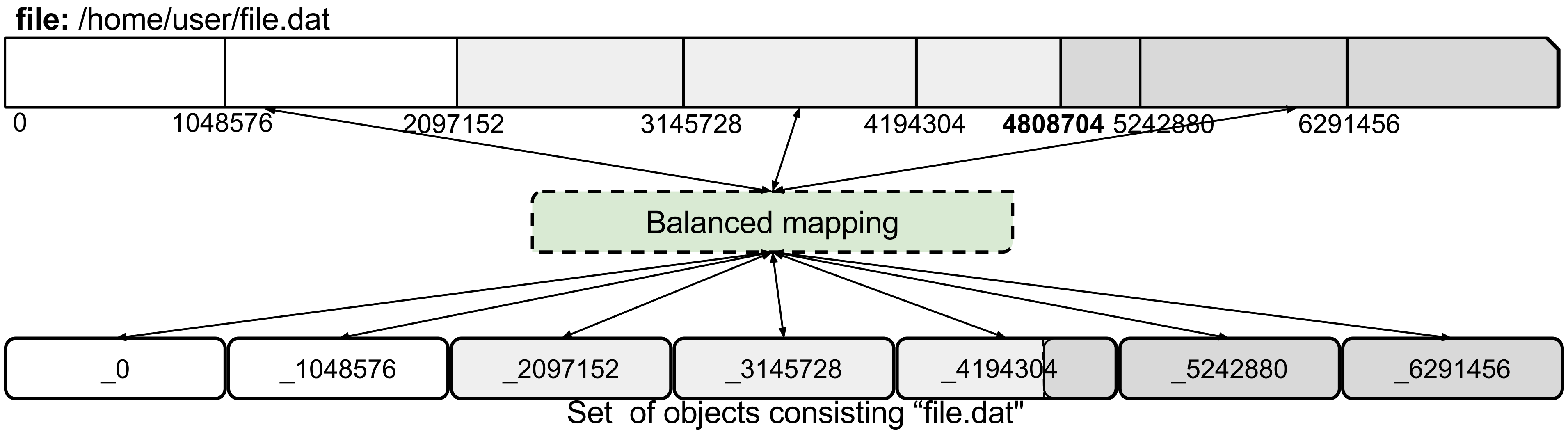
Design - Balanced Mapping

- Ideal for mixed workloads (both `fread()` and `fwrite()`).
- File is divided into predefined (but configurable), fixed-size, smaller units of data, called *buckets*.
- Natural mapping of **buckets-to-objects.**



Design - Balanced Mapping

- Bucket size is a tunable parameter and plays a big role in performance.
- After extensive testing, we found that a bucket size equal to the median of all request sizes is the best and more balanced choice.
- Corner buckets and updates might create more reading.



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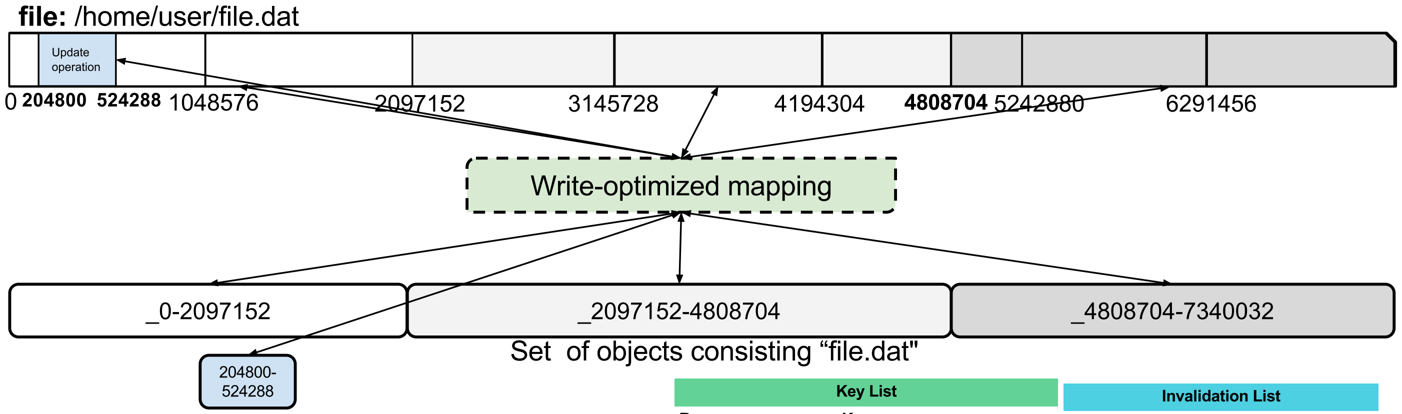
Design – Write-optimized Mapping

- Ideal for write-only or write-heavy (e.g., >80% write) workloads.
- Each request creates a new object.
- A mapping of offset ranges to available keys is kept in a B+ tree for fast searching.

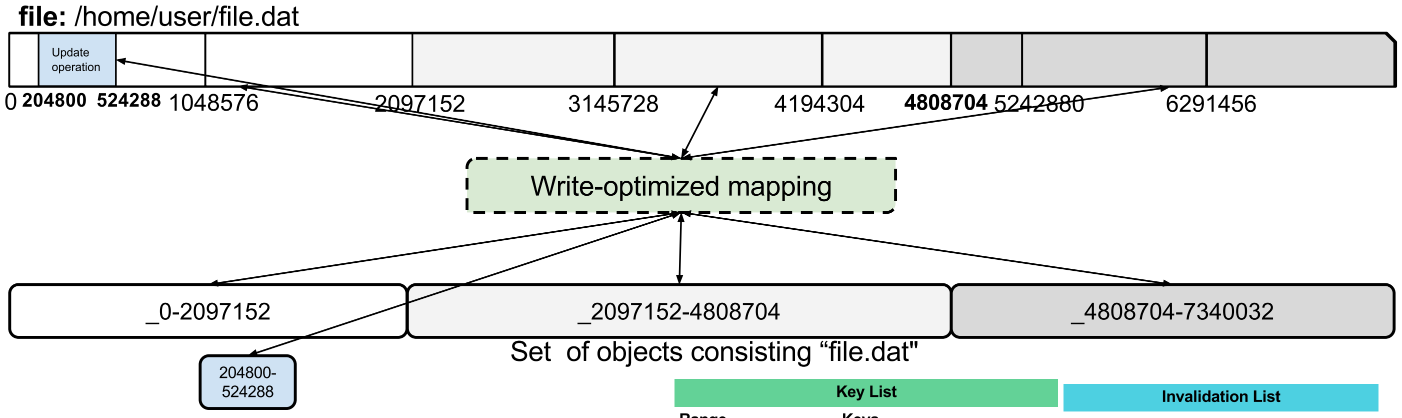


Key List	
Range	Keys
0 - 2097152	file.data_0-2097152
2097152 - 4808704	file.data_2097152-4808704
4808704 - 7340032	file.data_4808704-7340032
0 - 2097152	file.data_204800-524288

Invalidation List	
Key	Range
File.dat_0-2097152	204800 - 524288

Design – Write-optimized Mapping

- Update operations create a new object and invalidate the newly written part of the old object ensuring consistency.
- Results in fast writes in the expense of read operations.
- Any `fread()` first needs to retrieve all keys in the range, fetch the objects, concatenate the data, and finally return to the user.



Key List	
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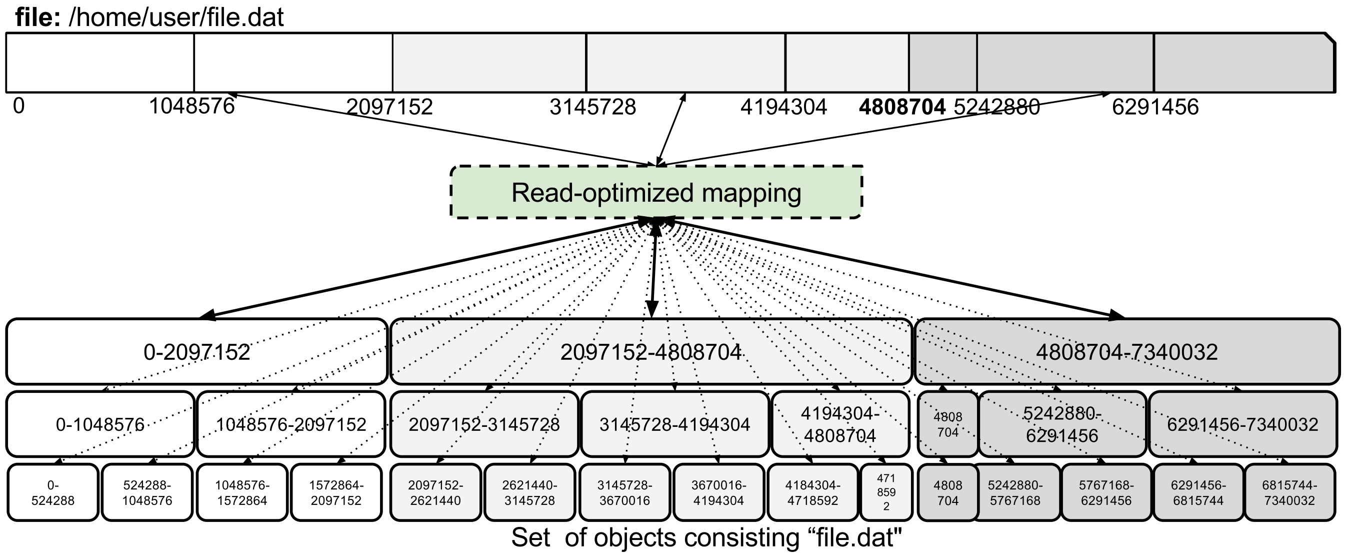
0 - 2097152	file.data_204800-524288

Invalidation List	
Key	Range
File.dat_0-2097152	204800 - 524288

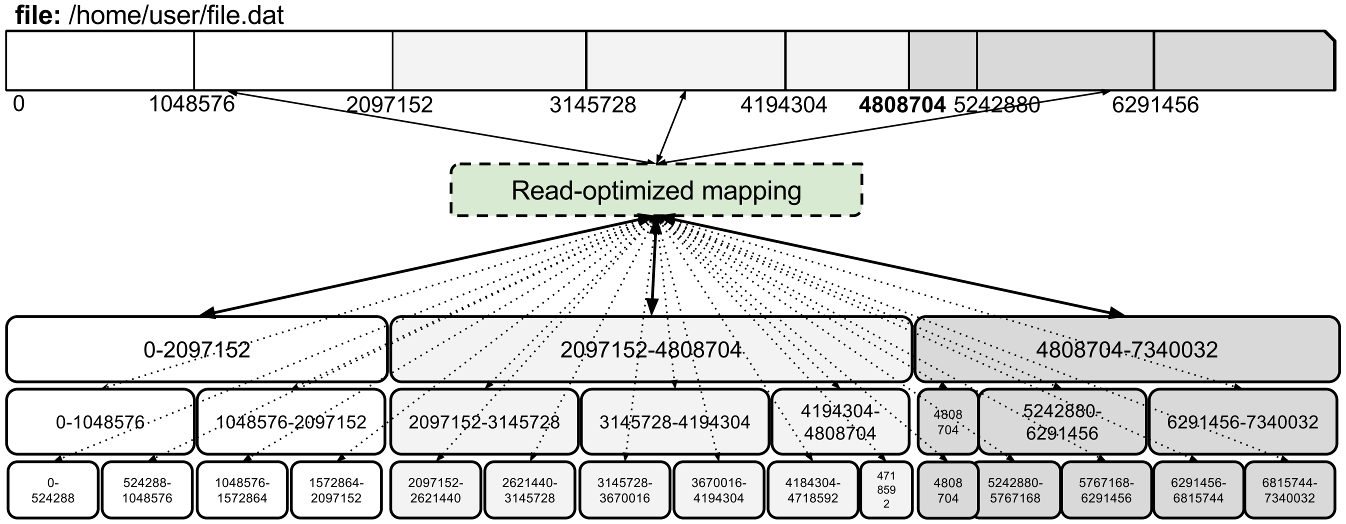
Design – Write-optimized Mapping

- Ideal for read-only or read-heavy (e.g., >90% read) workloads.
- Each write creates a plethora of new various-sized objects.
- Equivalent to concept of replication: sacrifice disk space to increase availability for reads.



Design – Write-optimized Mapping

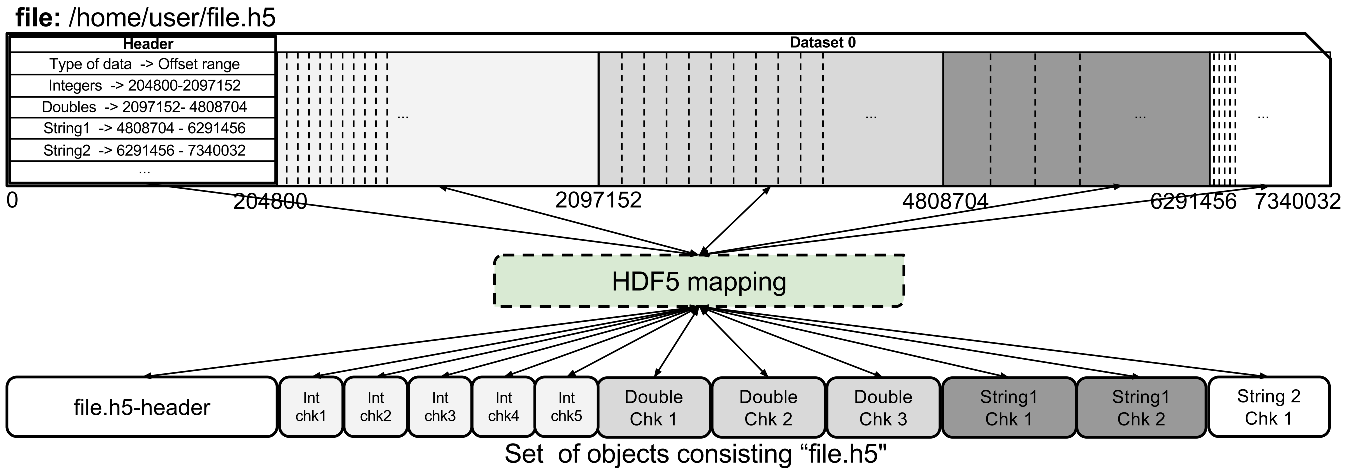
- Tunable granularity of creating objects. Suggested: 512KB
- All available keys in a range of offset are kept in a B+ tree.
- Results in fast reads in the expense of write operations and the extra disk space required.



Set of objects consisting "file.dat"

Design – HDF5 Mapping

- Exploit rich metadata info HDF5 offers (i.e., self-descriptive nature of the format) to create better mappings.
- Each HDF5 file creates 2 types of objects: header object and data object.
- Header object contains metadata information and is kept in memory for fast query. It is persisted upon file close.
- Variable-sized data objects are created based on each dataset's dimensions and datatype. E.g., every 20 integers -> 1 object

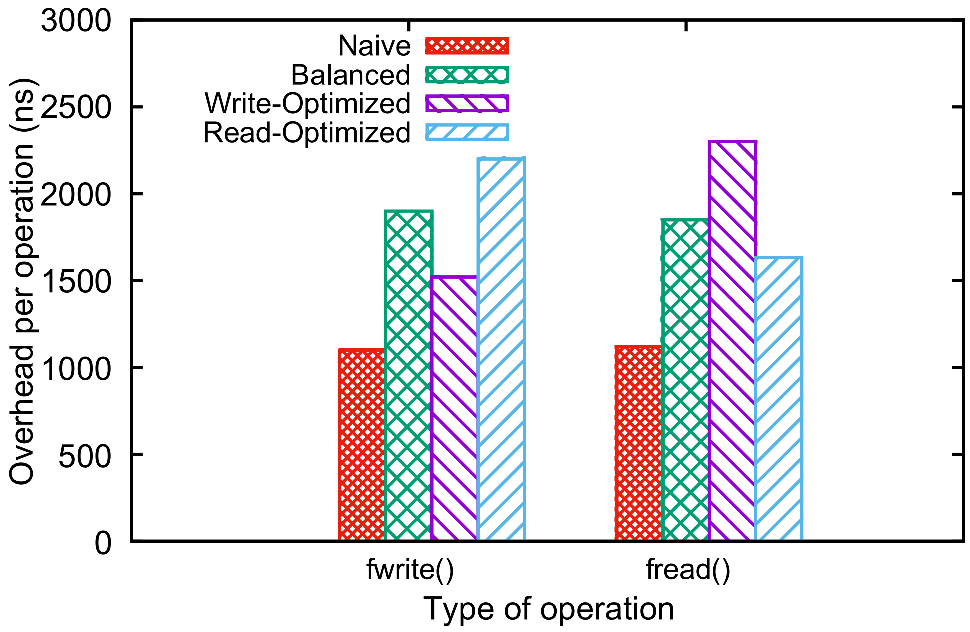


Evaluation Methodology

- Testbed: Chameleon System
- Appliance: Bare Metal
- OS: Centos 7.1
- Storage:
  - OrangeFS 2.9.6
  - MongoDB 3.4.3
- MPI: Mpich 3.2
- Programs:
  - Synthetic benchmark
  - Montage

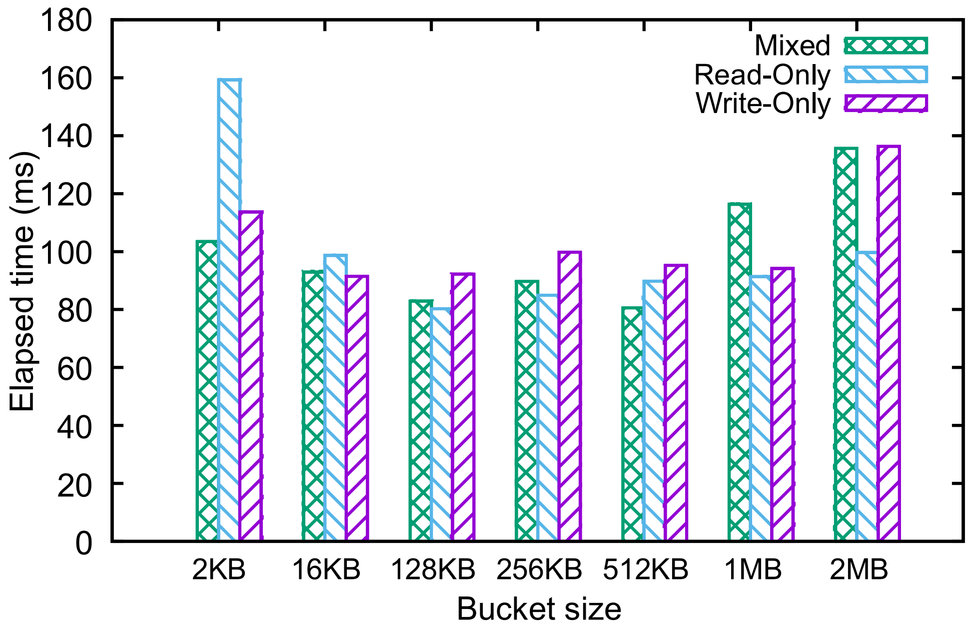
Evaluation Results – Library Overhead

- Input: 65536 POSIX calls
- Output: Average time spend in mapping in ns (per operation)
- Naïve: simple 1-file-to-1-object
- Overheads kept minimum
    - 0.0050 - 0.0080% of the overall execution time (Mapping time over I/O time)



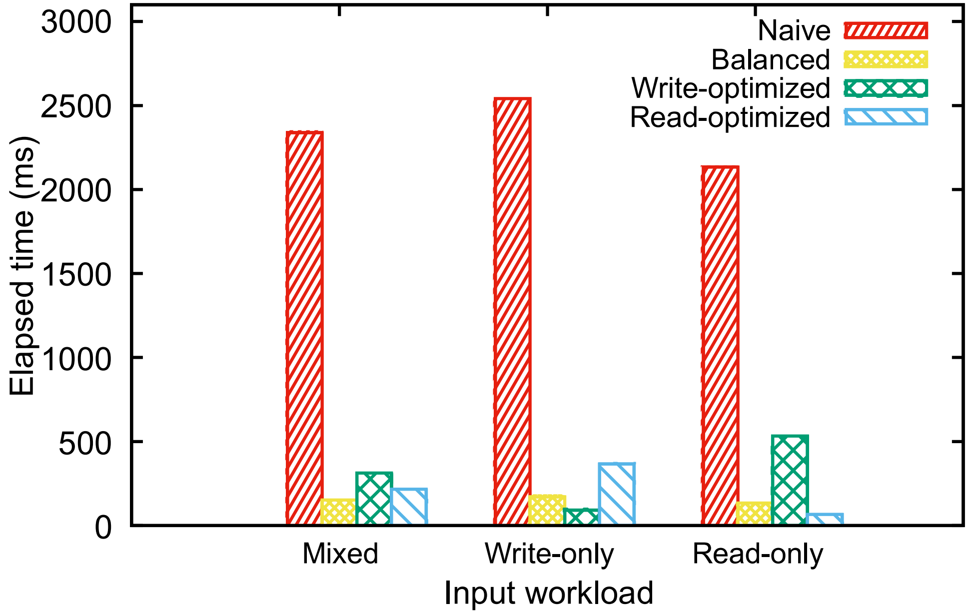
Evaluation Results – Bucket Size

- Balanced mapping uses buckets
- Input: 3 workloads
  - Mixed
  - Read-only
  - Write-only
- Request size: 128KB
- Output: Execution time in ms
- Best bucket size: close to median size of requests
  - Too small (i.e., 2KB) results in many objects
  - Too big (i.e., 2MB) results in excessive reading



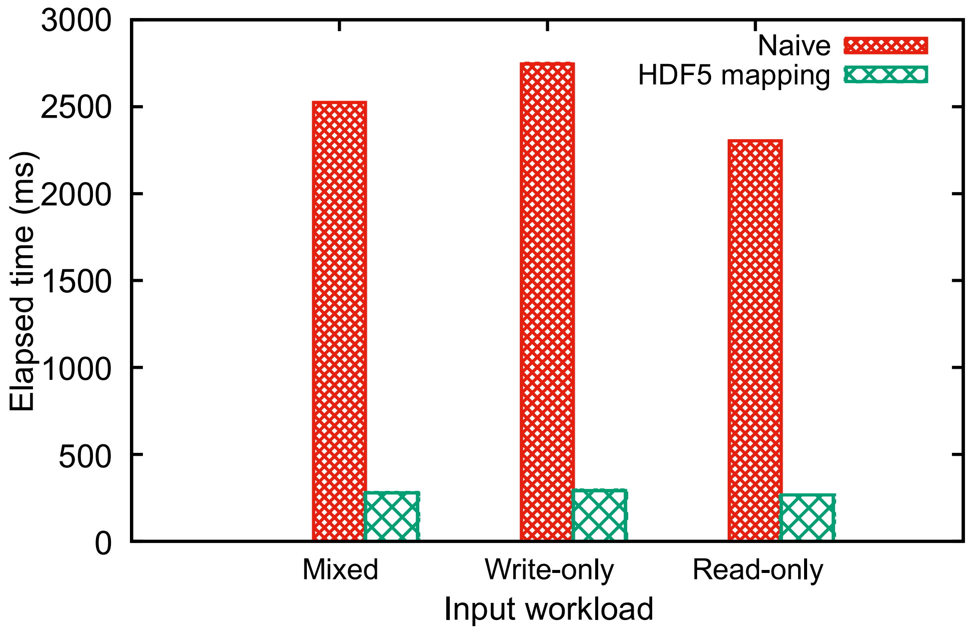
Evaluation Results – Synthetic Benchmark

- POSIX files
- Input: 3 workloads
  - Mixed
  - Read-only
  - Write-only
- Request size: 1MB
- Total I/O: 32MB
- Output: Execution time in ms
- Naïve: simple 1-file-to-1-object
- 15x speedup for Balanced and mixed input
- 32x speedup for Read-opt and read-only input
- 27x speedup for Write-opt and write-only input



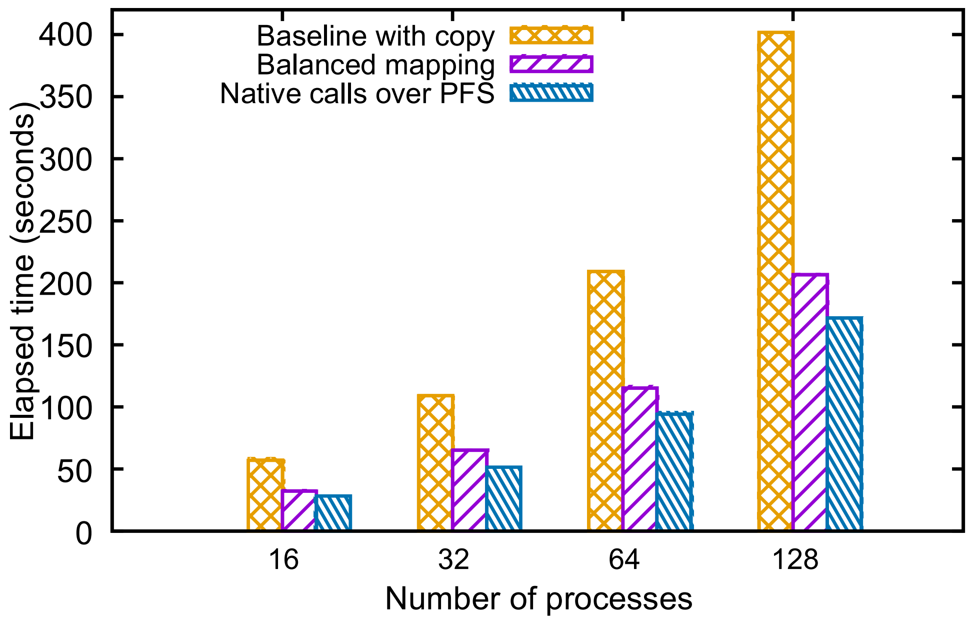
Evaluation Results – Synthetic Benchmark

- HDF5 file:
  - One dataset, integer datatype
- Input: 3 workloads
  - Mixed
  - Read-only
  - Write-only
- Request size: 1MB
- Total I/O: 32MB
- Output: Execution time in ms
- Naïve: simple 1-file-to-1-object
- 9x speedup for writes
- 8x speedup for reads



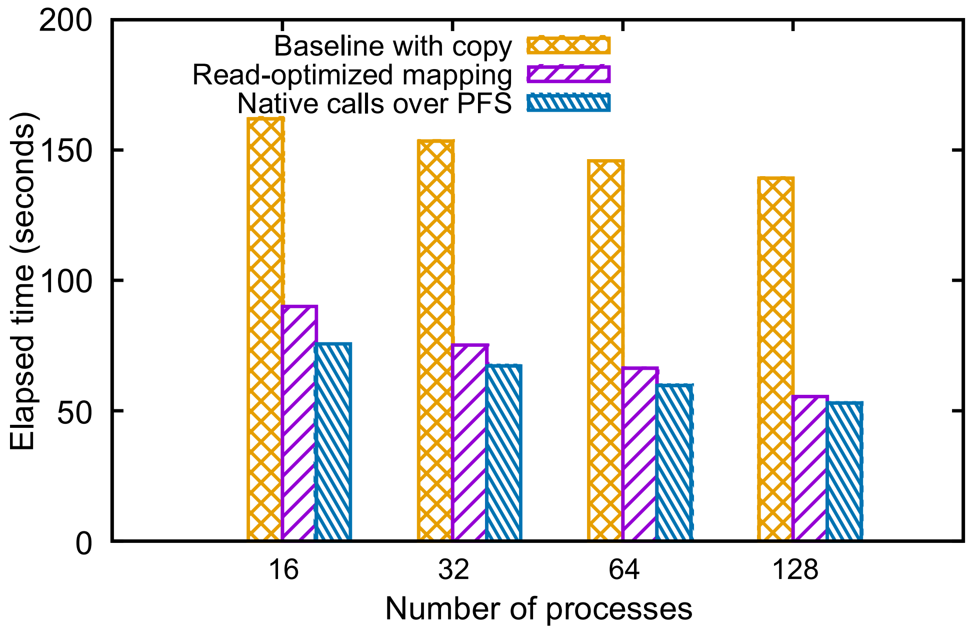
Evaluation Results – IOR

- Setup:
  - 4 client nodes, 4 servers
  - Num processes: 16, 32, 64, 128
  - Balanced Mapping mode
  - Strong scaling
- IOR:
  - MPI-IO
  - Block size = 2MB
  - Transfer size = 512KB
  - Total I/O = 512MB per process
  - File-per-process
  - DirectIO (-B, -Y options)
- OS buffering disabled
- Output: Execution time in seconds
- Baseline: first copy the input files from MongoDB to OrangeFS and then run IOR
- More than **2x speedup**



Evaluation Results – Montage

- Setup:
  - 4 client nodes, 4 servers
  - Num processes: 16, 32, 64, 128
  - Read-Optimized Mapping mode
  - Weak scaling
- Montage:
  - POSIX-IO
  - Total I/O = 24GB
- OS cache disabled and flushed before
- Output: Execution time in seconds
- Baseline: first copy the input images from MongoDB to OrangeFS and then run Montage
- More than **2x speedup**



Conclusions & Future Steps

- File-based vs Object-based Storage solutions
- Four new algorithms to map a file to one or more objects
- Evaluation shows:
  - 2x-30x speedup compared to 1-to-1 naïve mappings
  - More than 2x in real application scenarios
- Future work:
  - A new I/O management framework that integrates different storage subsystems and thus, get us closer to the convergence of HPC and BigData.
  - A system that offers universal data access regardless of the storage interface. Our mappings is a great first step ☺

Questions


thank you
danke
рахмат
謝謝
ngiyabonga
teşekkür ederim
gracias
merci
obrigado
bedankt
dziękuje
спасибо
Баярлалаа
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