BFO: Batch-File Operations on Massive Files for Consistent Performance Improvement

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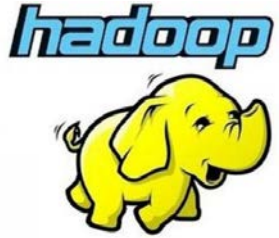
Outline

- Background
- BFO Design
- Evaluation
- Conclusion

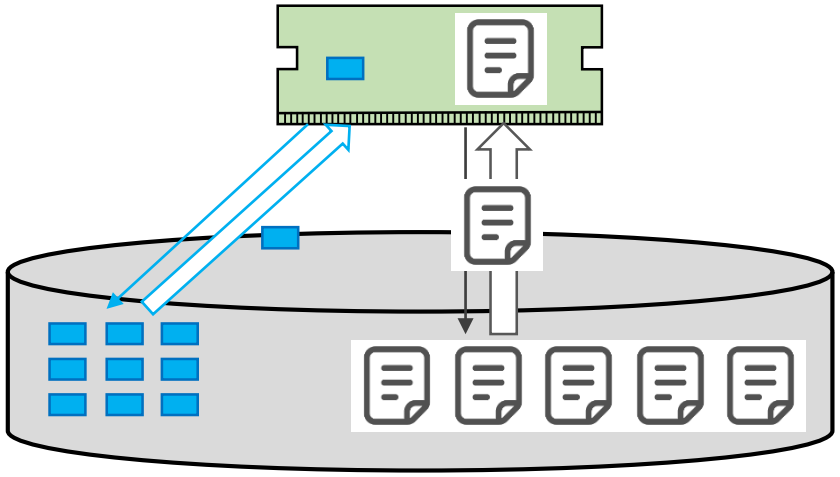
Background

- Batch-file Operations
  - Accessing a batch of files
- Many applications need batch-file operations
  - Backup applications
  - File-level data replication and archiving
  - Big data analytics systems
  - Social media and online shopping websites
- Traditional access approaches access files one by one
  - Called single-file access pattern
  - Inefficient for small files



Background

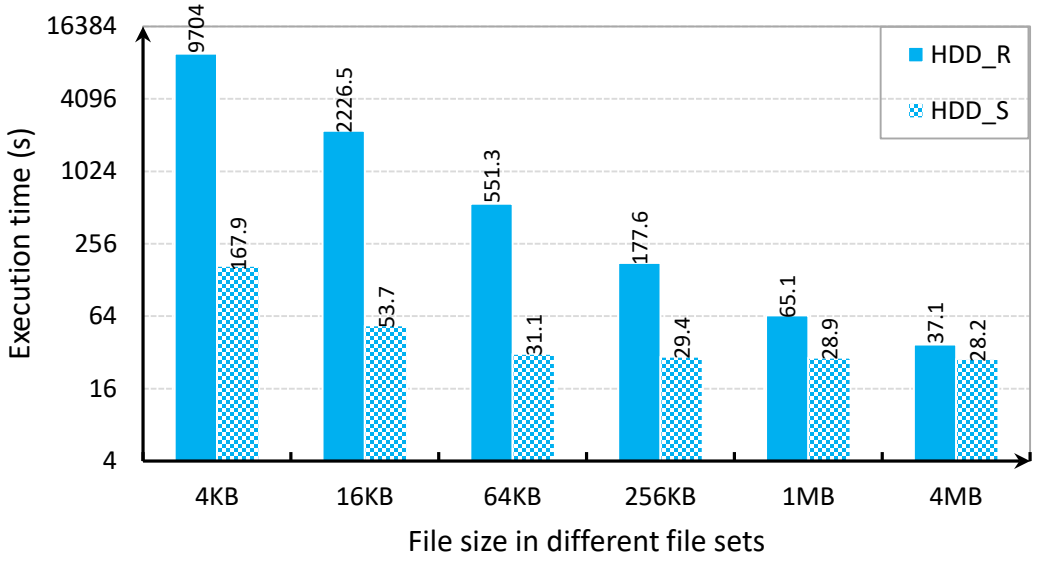
- Small files in file systems
  - Desktop file system: more than 80% of accesses are to files smaller than 32B.
  - Cloud and HPC cluster: 25%~40% files < 4KB.
- Single-file access pattern for small files
  - Accessing metadata
  - Fetching file data, and so on

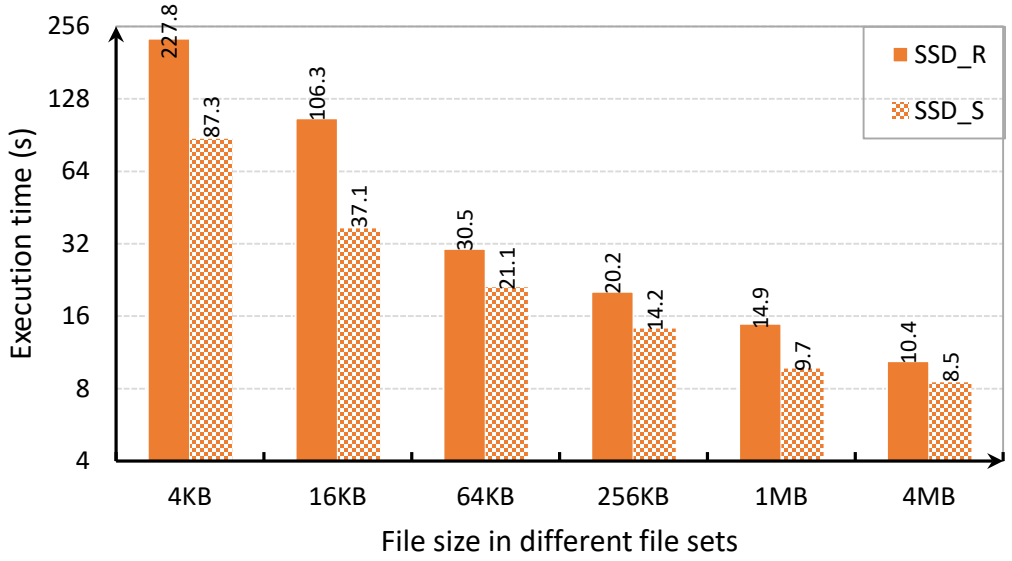


- IO operations dominate batch-file access
  - Metadata access contributes 40% time for accessing a small file on disk.
  - Random data IOs

Overall access performance

- Read performance





Setup:

- File sets: 4GB data with different file sizes (i.e., from 4KB to 4MB)
- Devices: HDD & SSD
- Orders: Random & Sequential

Overall access performance

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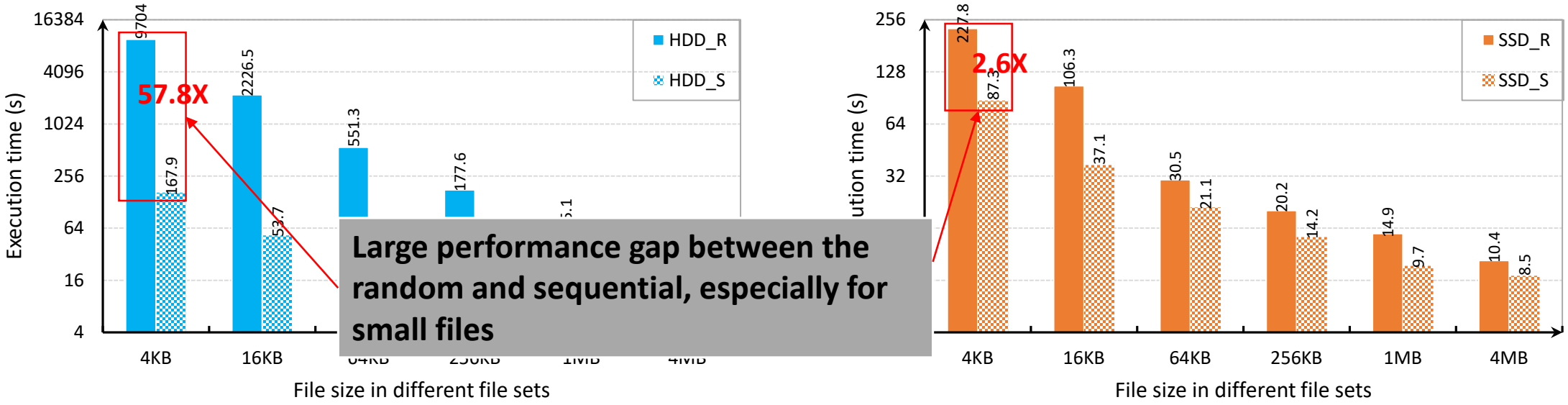

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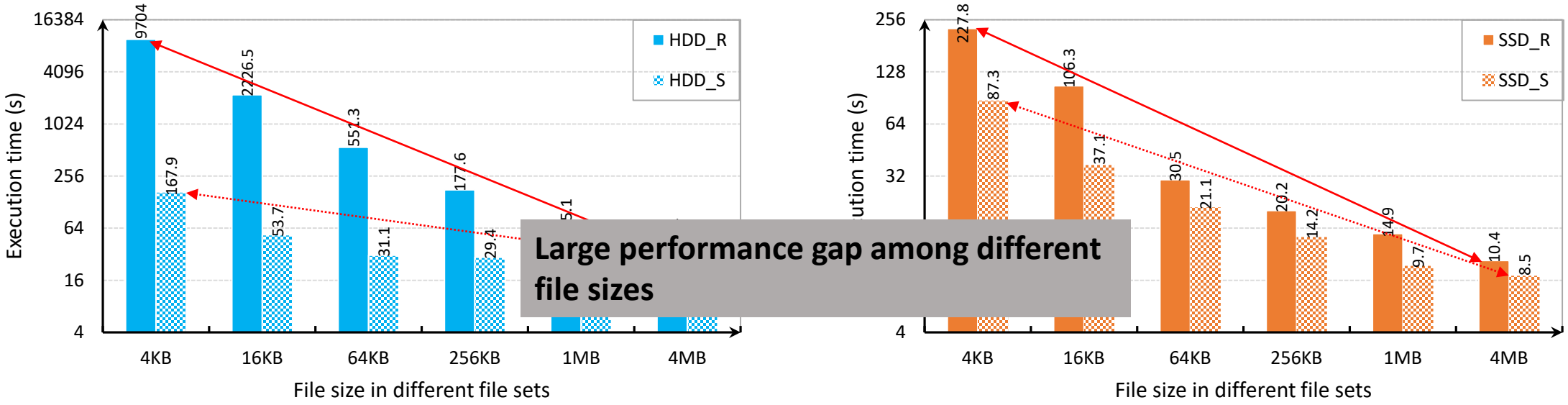

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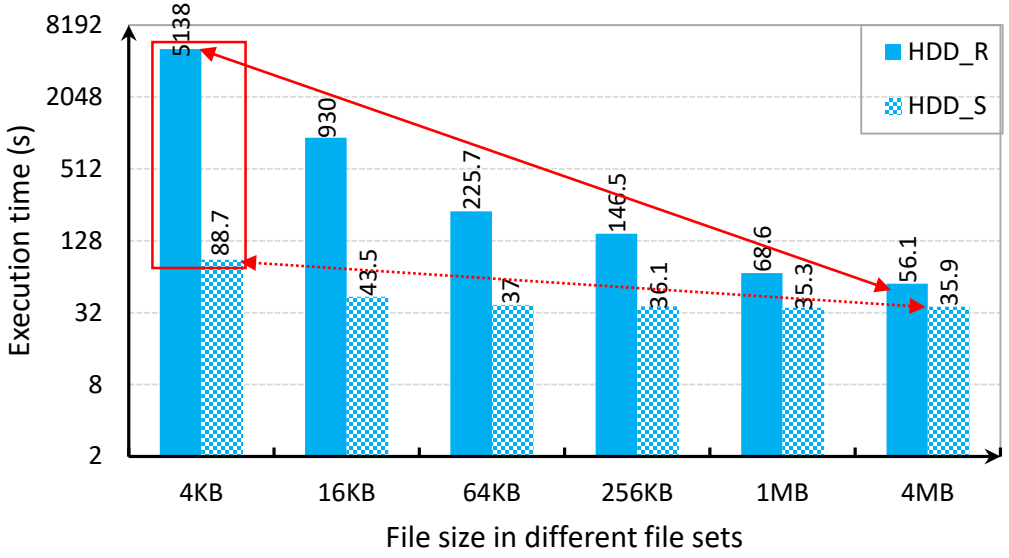
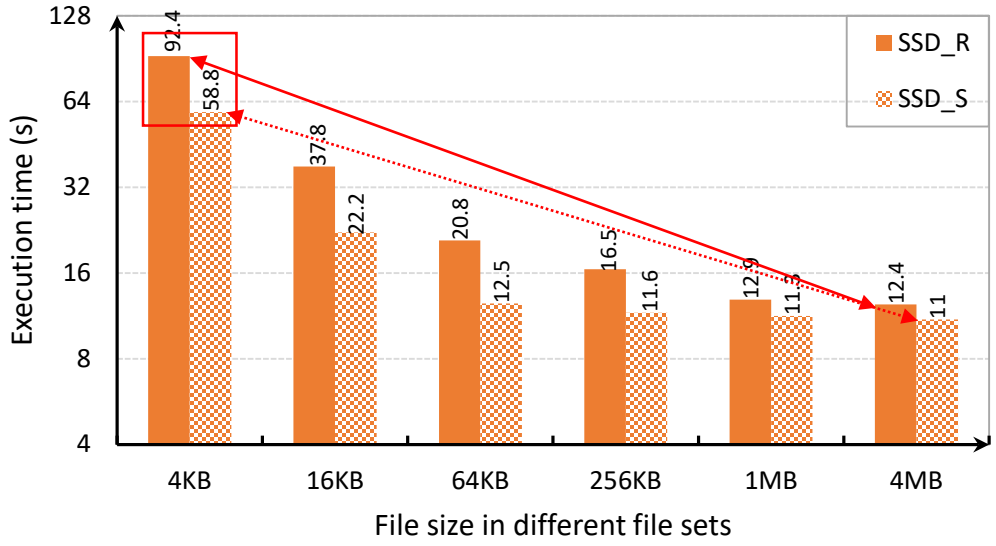
Problem

- Write performance





Observation: the single-file access approach is very inefficient

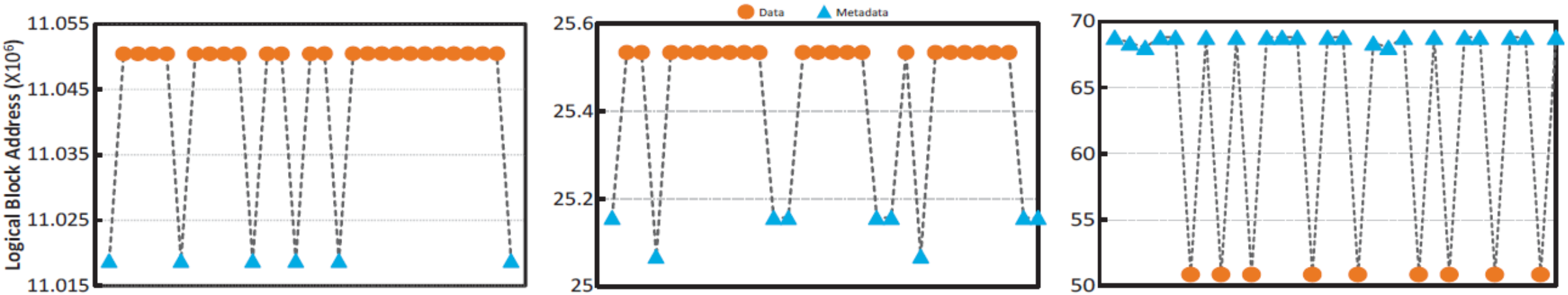
- **for small files (below 1MB);**
- **in a random manner .**

Related Works

- Application-level optimization (Fastcopy)
  - Multi-threading, large buffer
- Prefetching mechanism (Diskseen, ATC'07)
  - Depending on the future access behaviors
- Block-level I/O scheduler (split-level I/O scheduling, SOSP'15)
  - Serializing the file accesses
- Packing metadata and data together (CFFS, FAST'16)
  - Redesigning new file systems

Problem Analysis

- File Access behaviors
  - Reading a file set with three representative file systems



(a) Ext4 (b) Btrfs (c) F2FS

Problem Analysis

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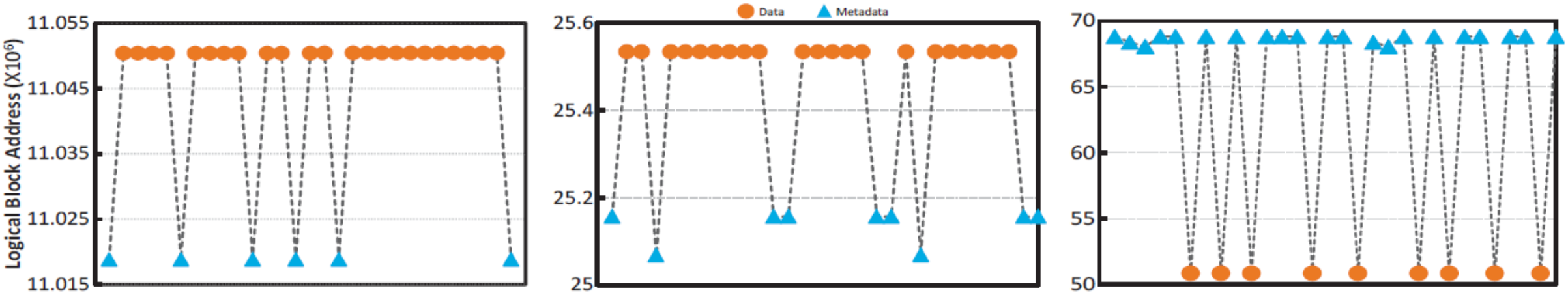
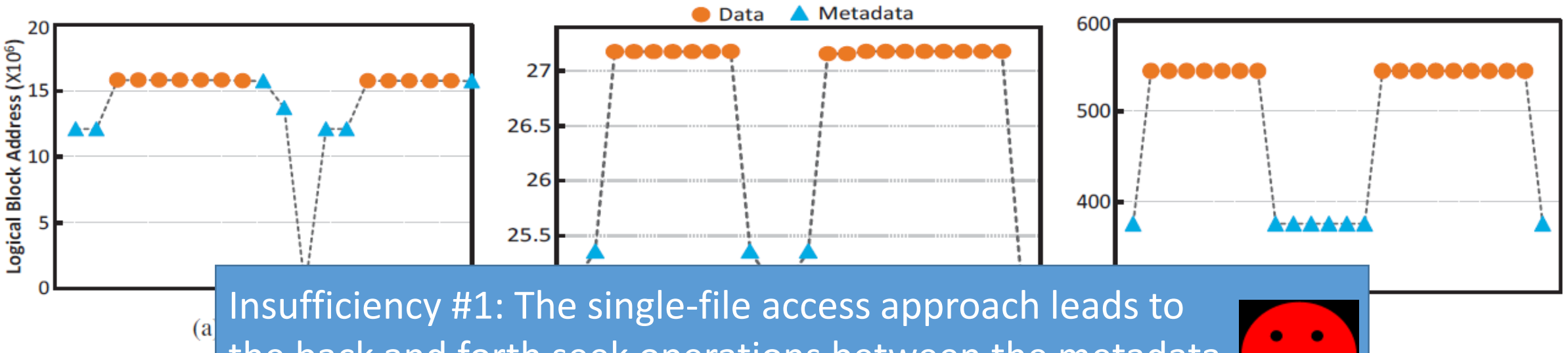


(a) Ext4 (b) Btrfs (c) F2FS

Problem Analysis

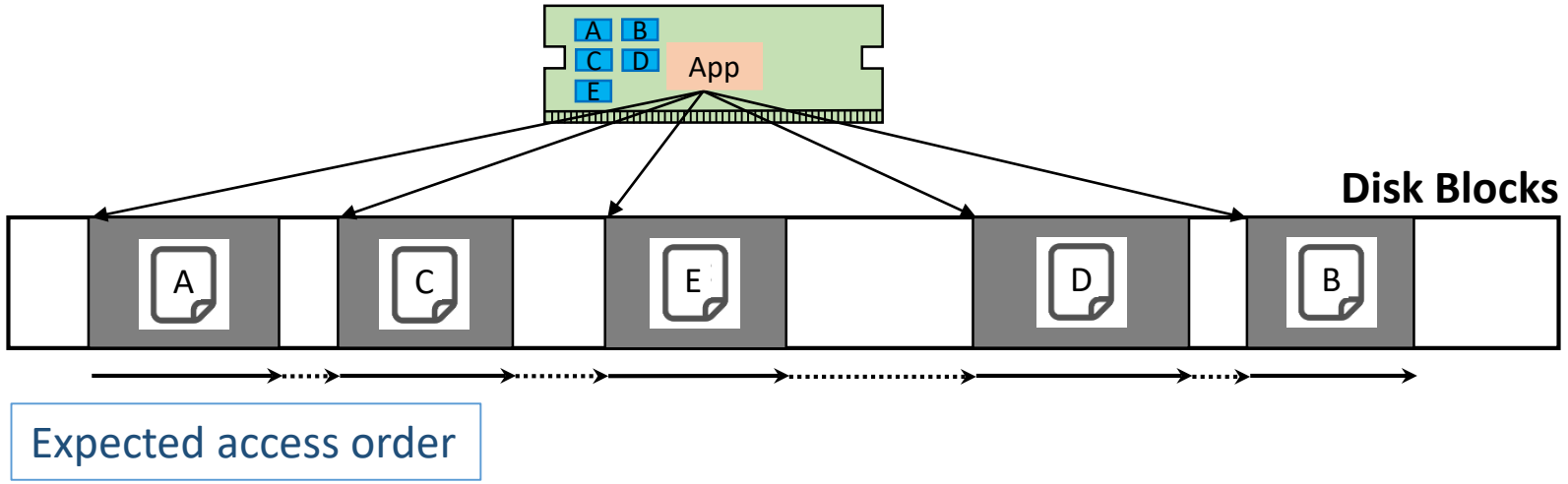
- File Access behaviors
  - Reading a file set with three representative file systems
  - Writing a file set with three representative file systems



Insufficiency #1: The single-file access approach leads to the back and forth seek operations between the metadata area and data area, resulting in many non-sequential I/Os.

Problem Analysis

- File Access behaviors
- Data Access behaviors (excluding the metadata)



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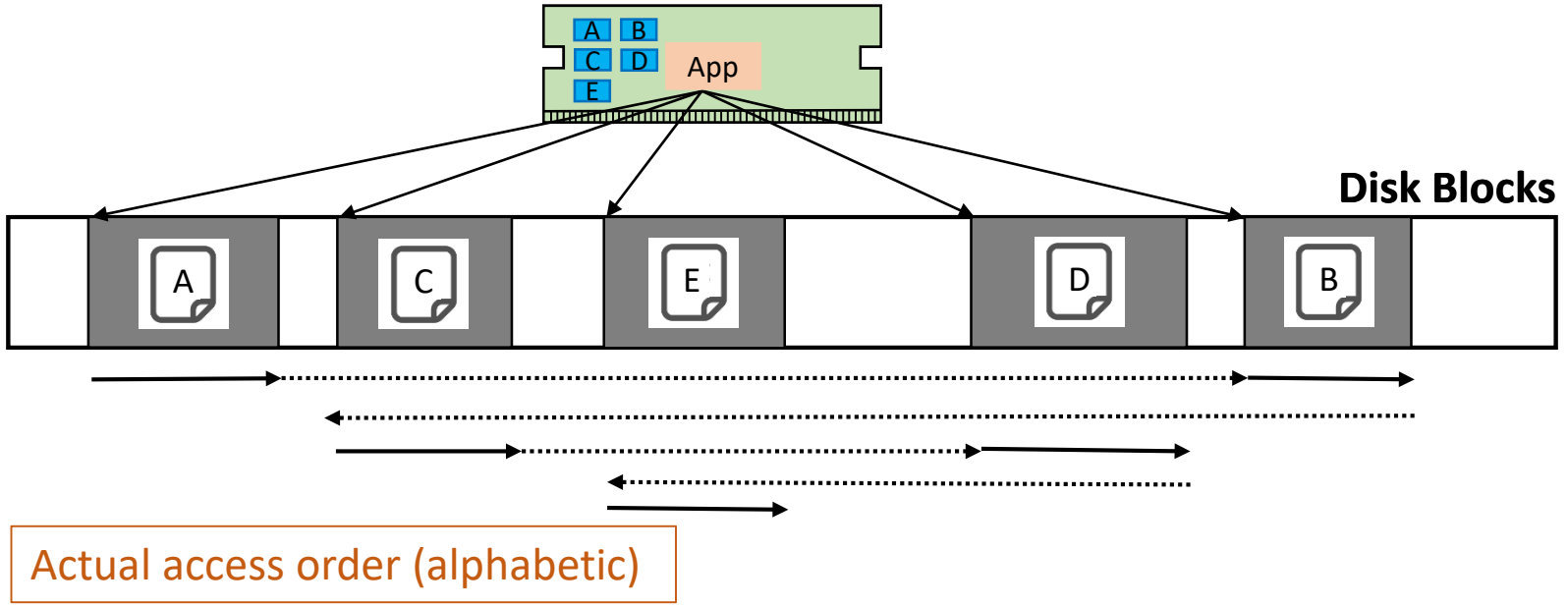

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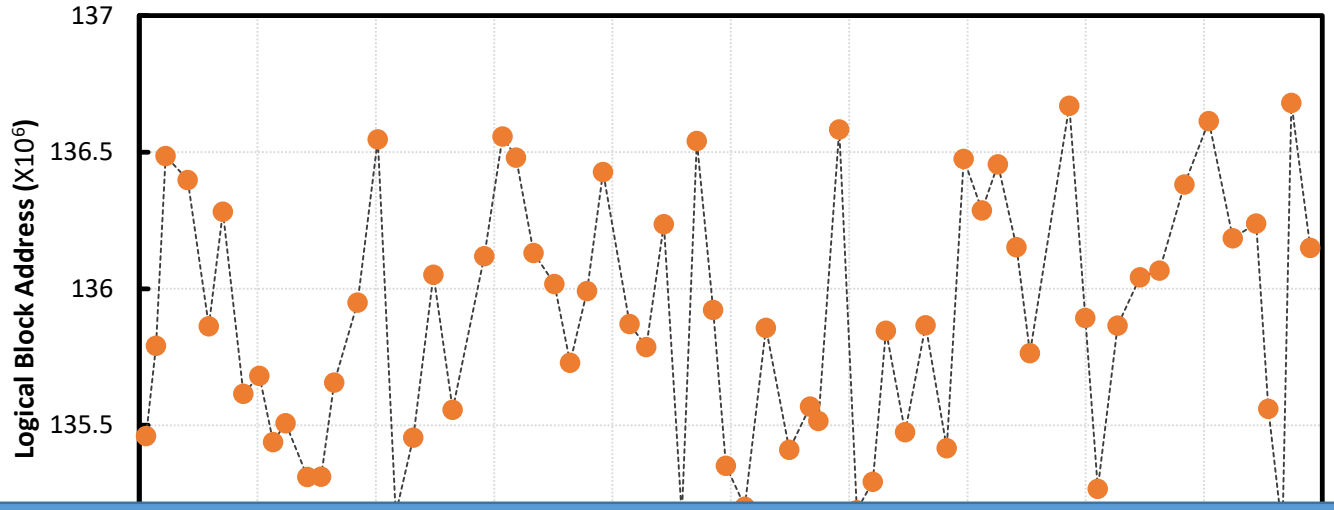

Insufficiency #2: The single-file access approach is unaware of the underlying data layout, and may read these files in any order, also leading to random I/Os.

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  - BFOr
  - BFOw
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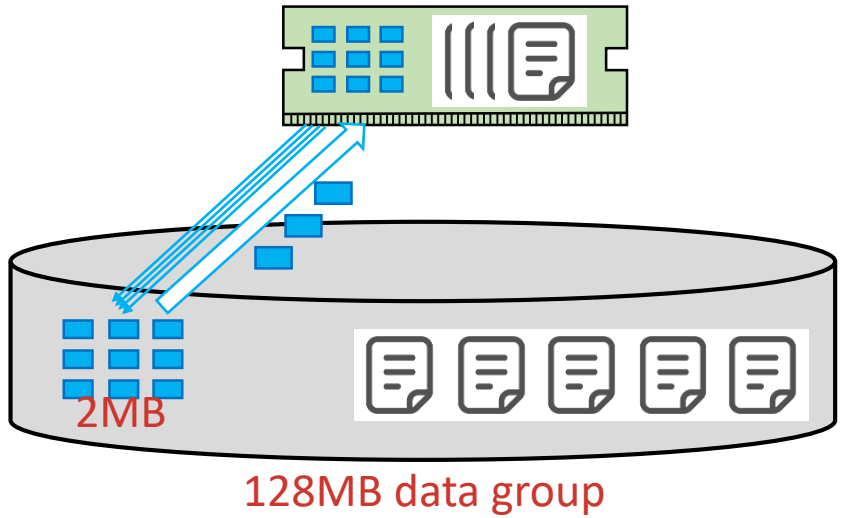
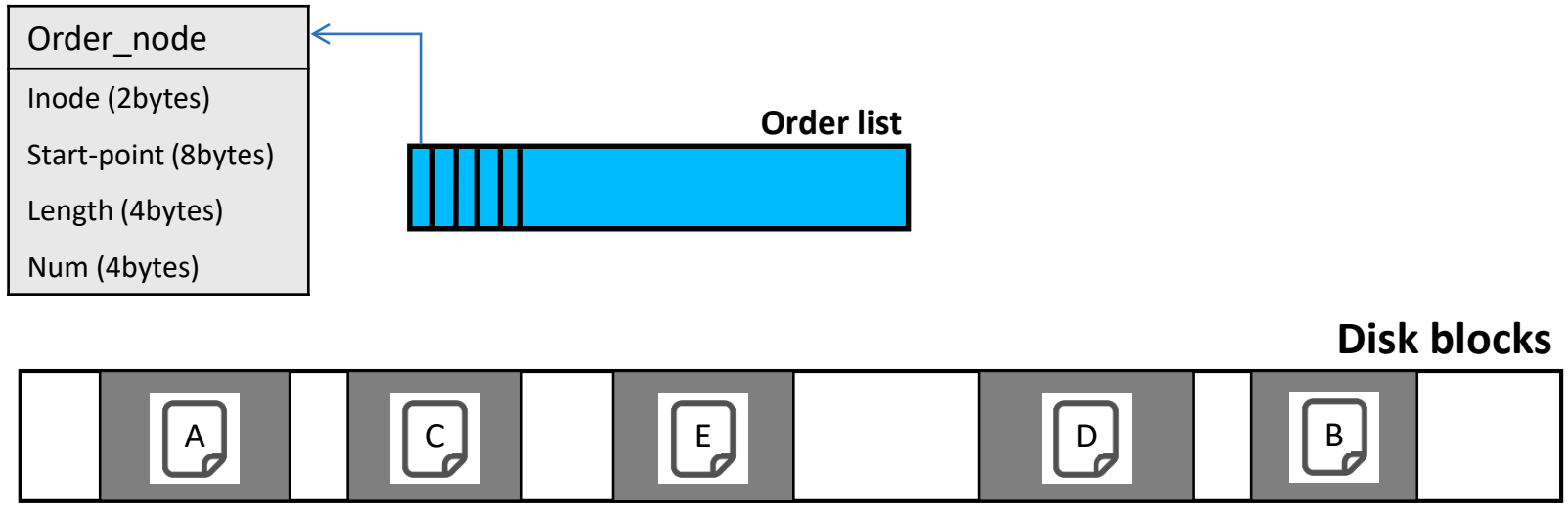
BFOr

- Two-phase read
  - Objective: Separately read the metadata and file data of all accessed files in batches
  - Phase 1: scanning the inodes
  - Phase 2: fetching all files' data
- Layout-aware scheduler



BFOr

- Two-phase read
- Layout-aware scheduler
  - Extracting the addresses from the inodes
  - Sorting the addresses of all files
  - Issuing read I/O in the order of the list



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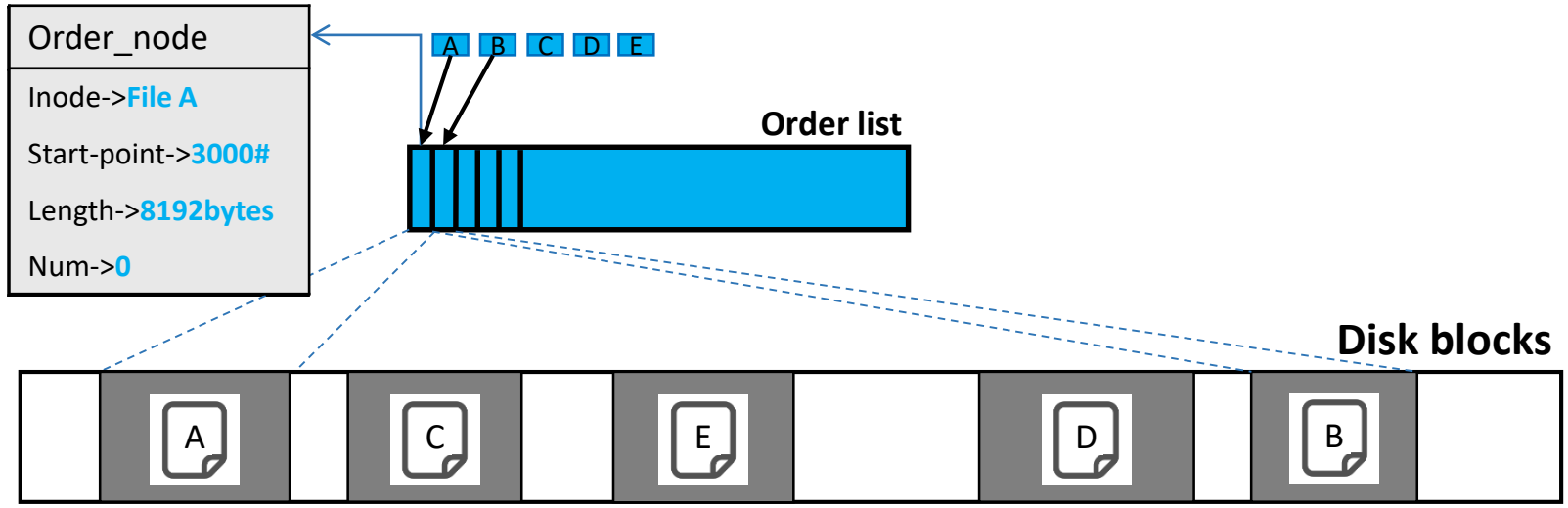

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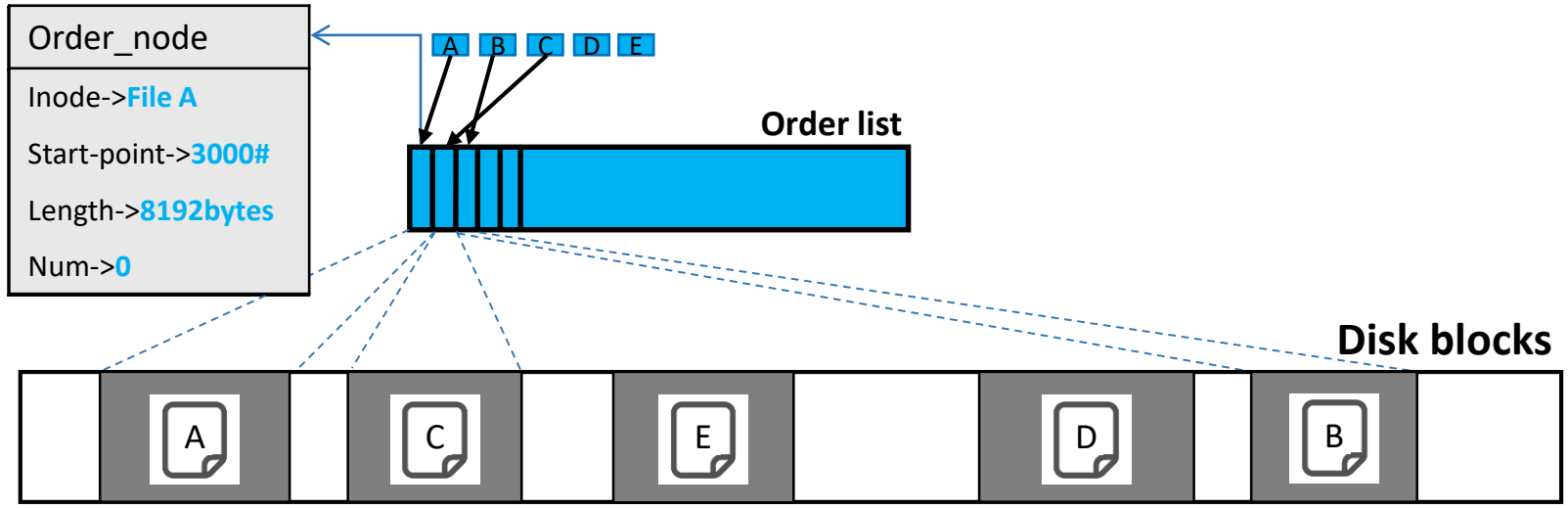

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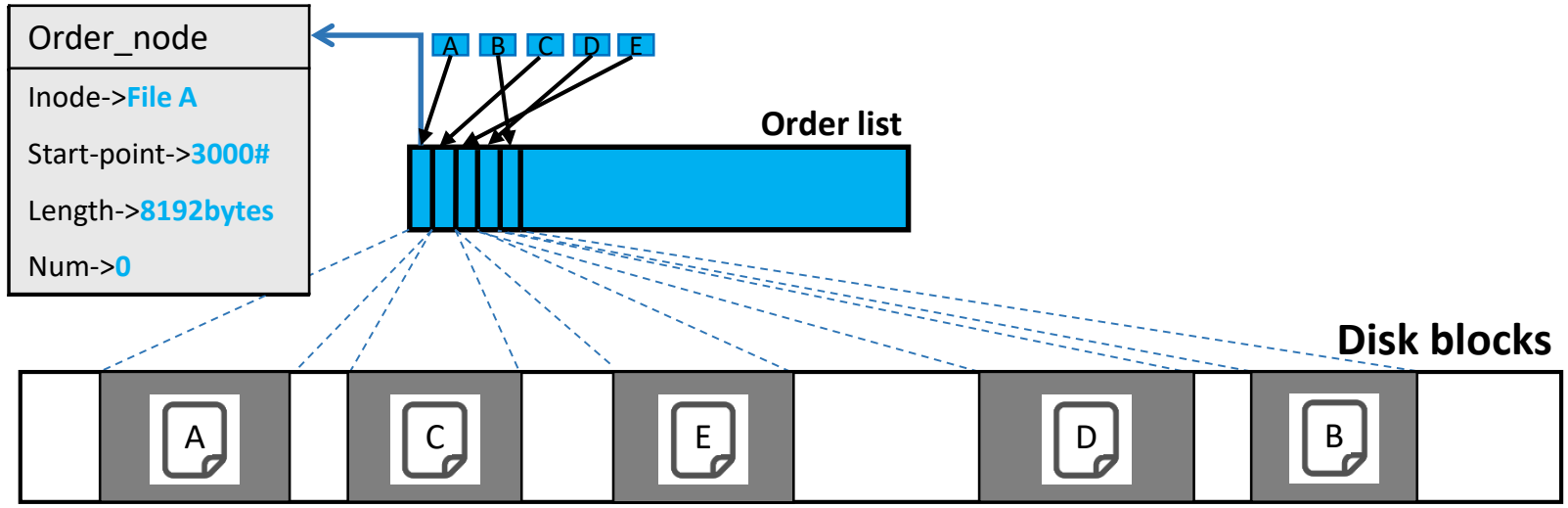
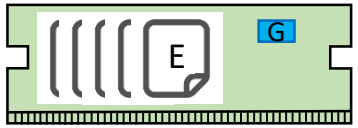


BFOw

- Two-phase write
  - Phase 1: creating a global file to store all data once
    - Creating G inode for the file
    - Creating Order_list to record the order of the written files
  - Phase 2: creating all inodes for all files
    - Extracting the address from the G inode
    - Creating all inodes with the address information and the Order_list
      - Current_FileAddr = Previous_FileAddr + FileLength
- Light-weight consistency strategy



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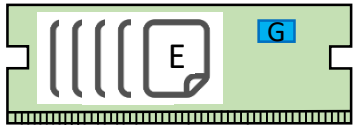

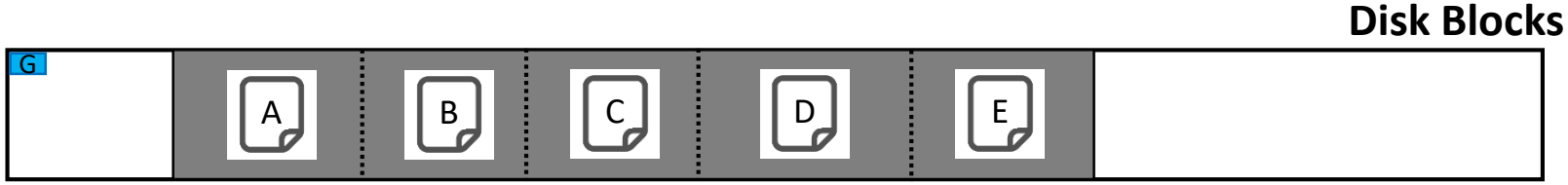

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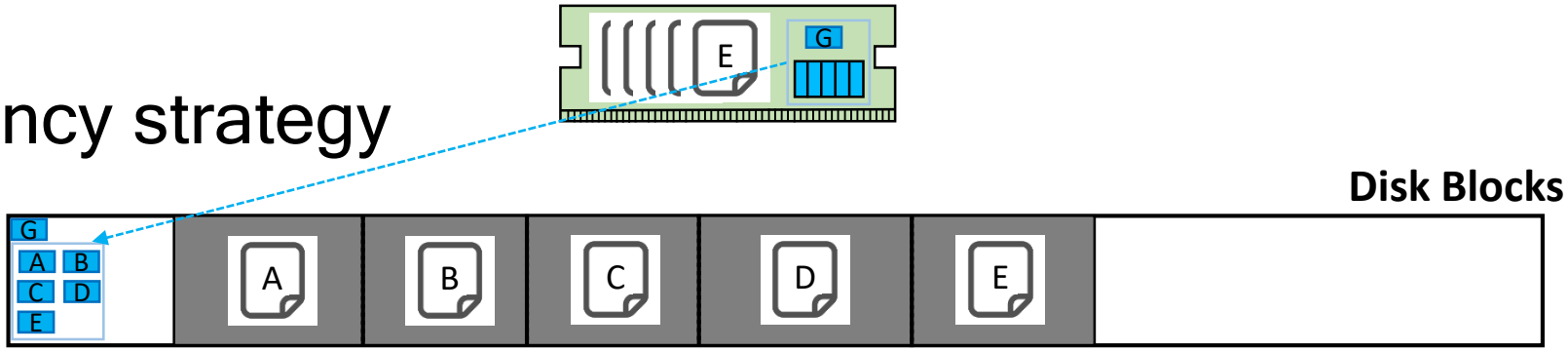
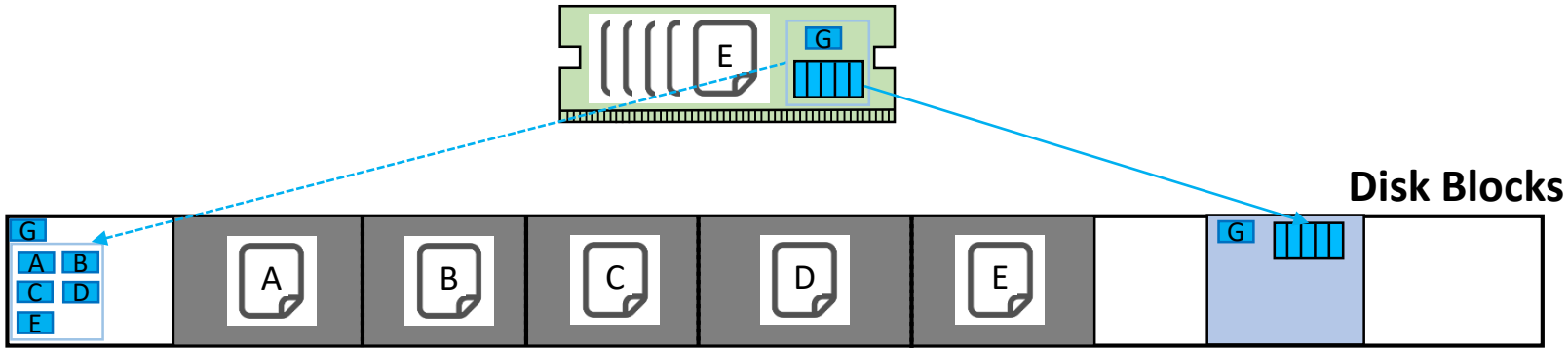


BFOw

- Two-phase write
- Light-weight consistency strategy
  - writing the Order_list into journal files as an atomic operation
  - recreating all inodes with the Order_list and G inode



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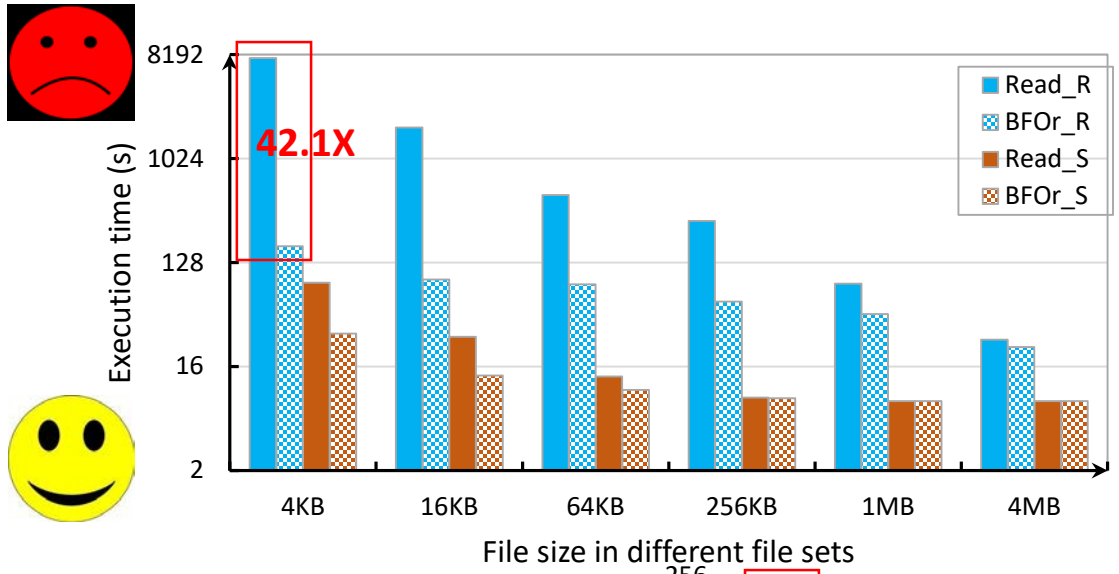
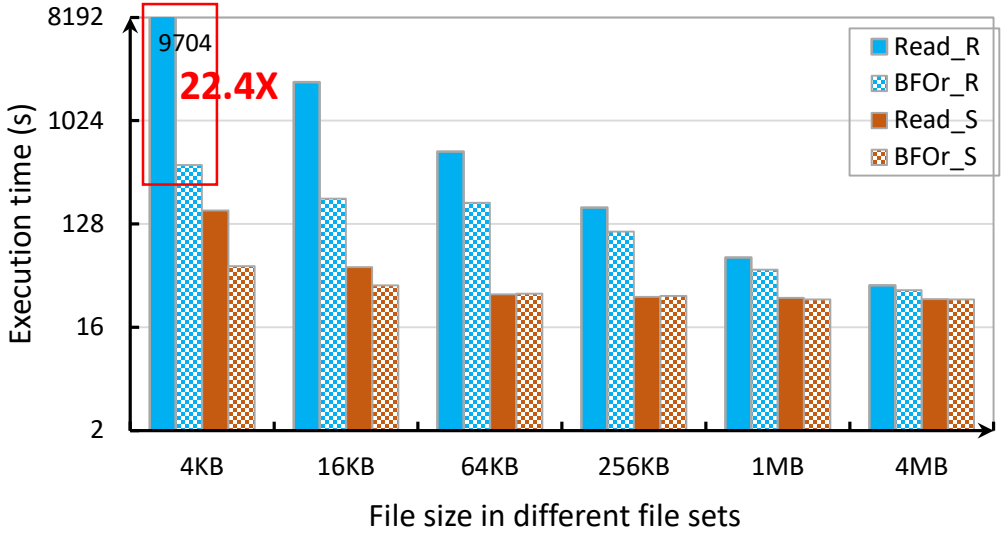
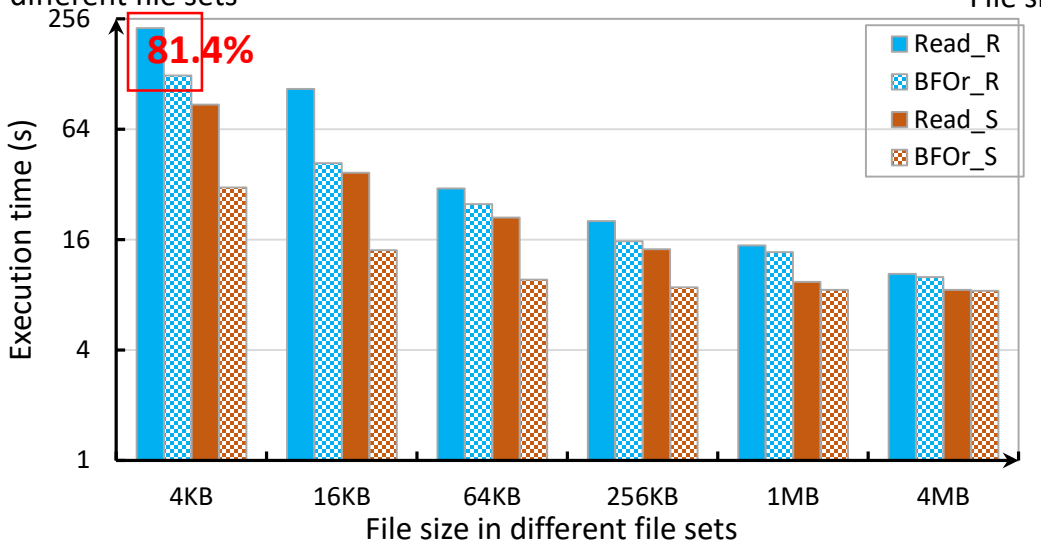
Experimental setup

- Prototyped BFO on ext4
- Intel Xeon E5 2620 @ 2.40GHz and 16GB RAM
- Storage devices
  - RAID0 with 5 Western Digital 7200RPM 4TB SAS HDD
  - A Western Digital 4TB SAS HDD
  - 480GB SAMSUNG 750 EVO SSD
- File sets
  - File sets created by Filebench
    - 4GB data with different file sizes (i.e., from 4KB to 4MB)
  - Linux-kernel source code

Read Performance







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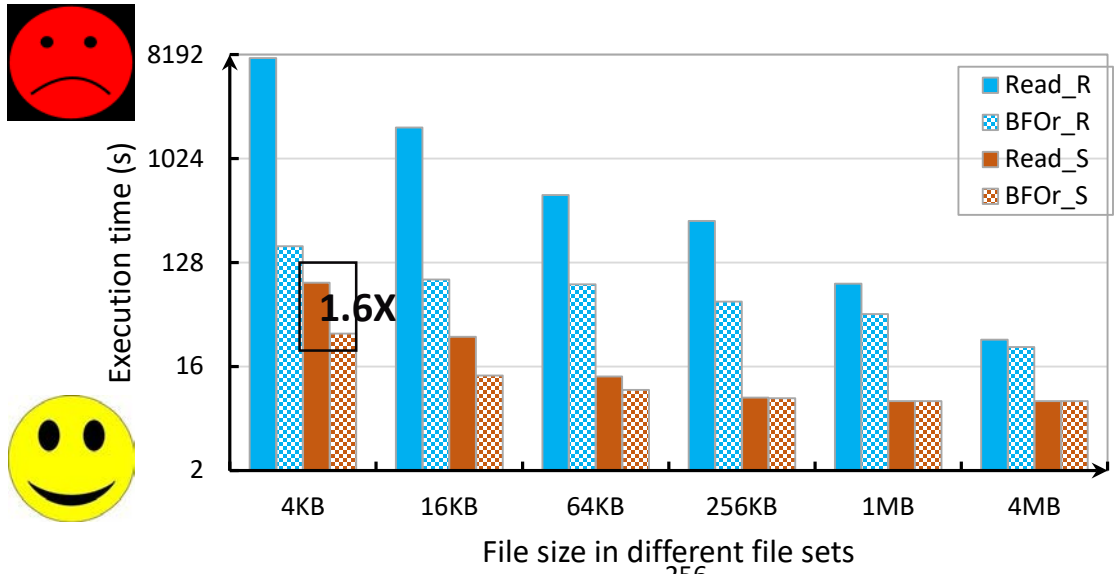
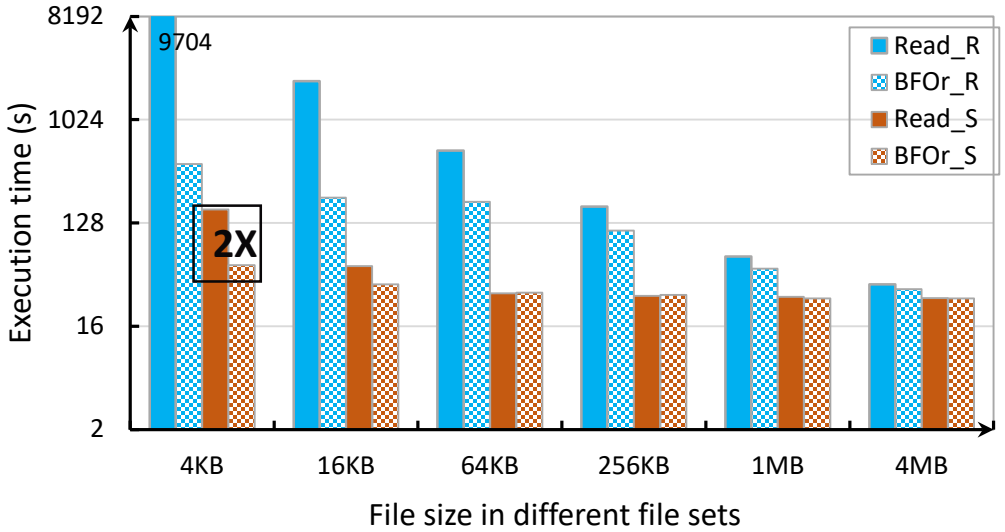
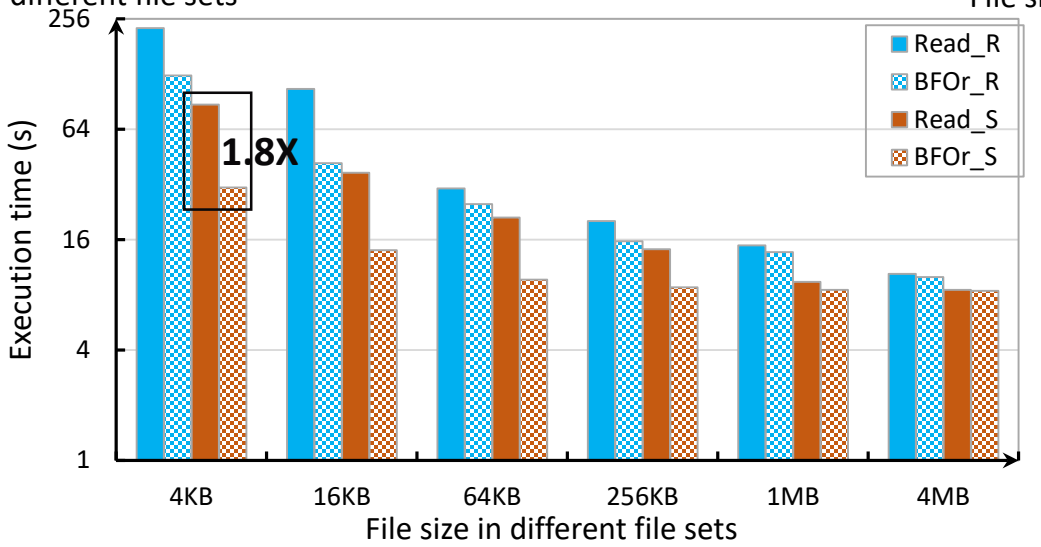
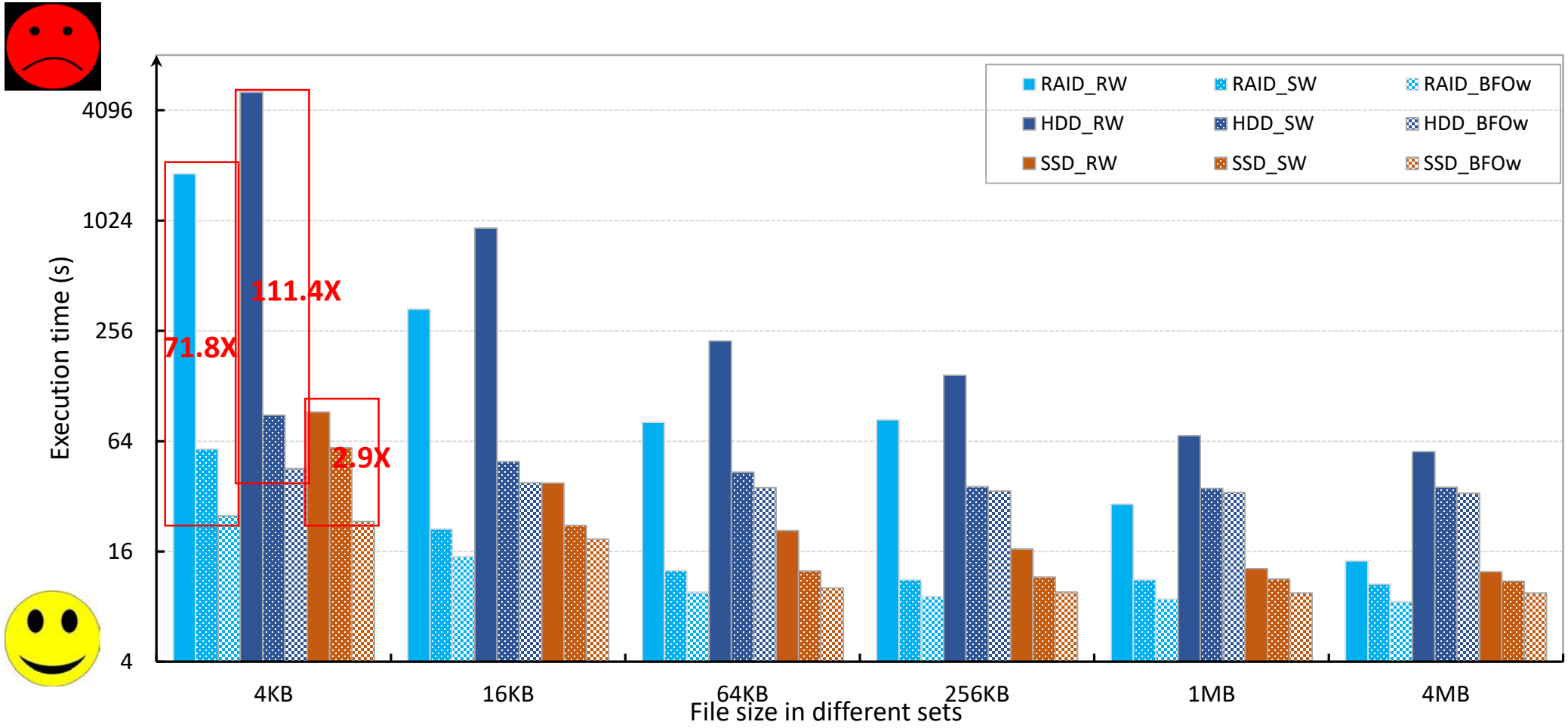


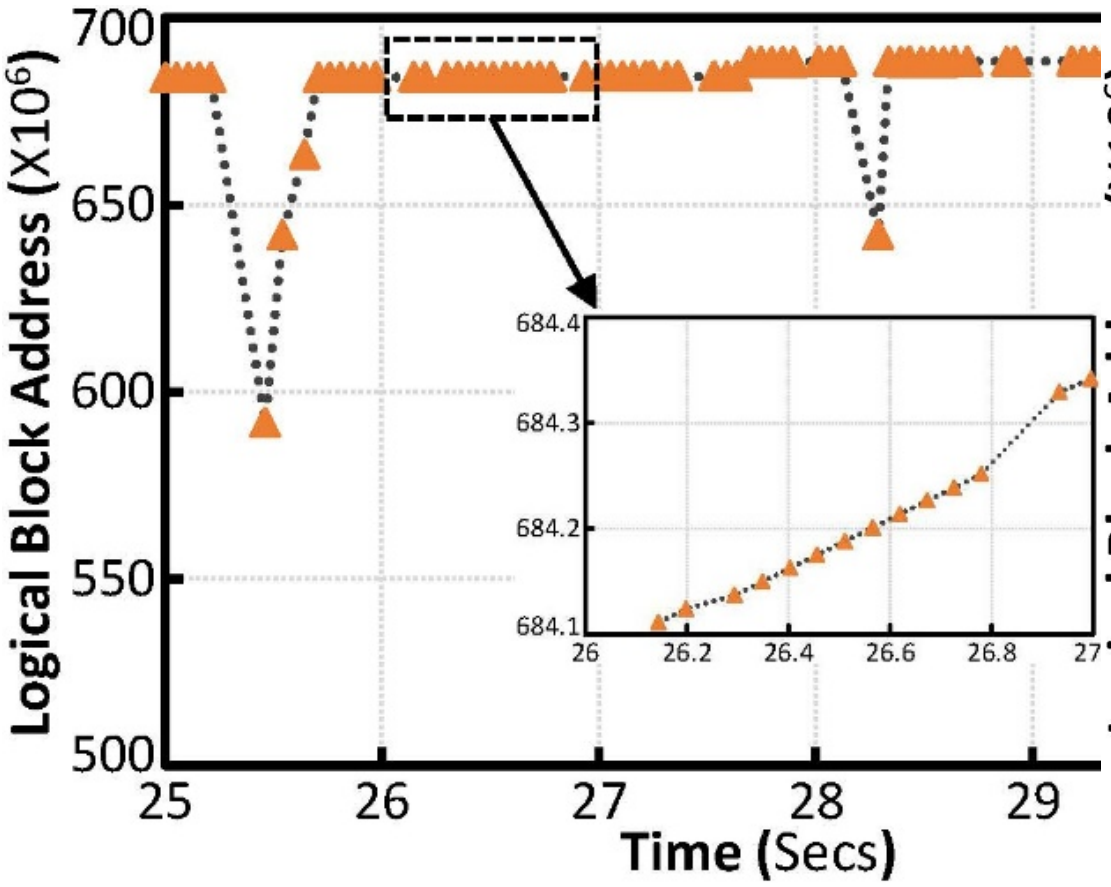


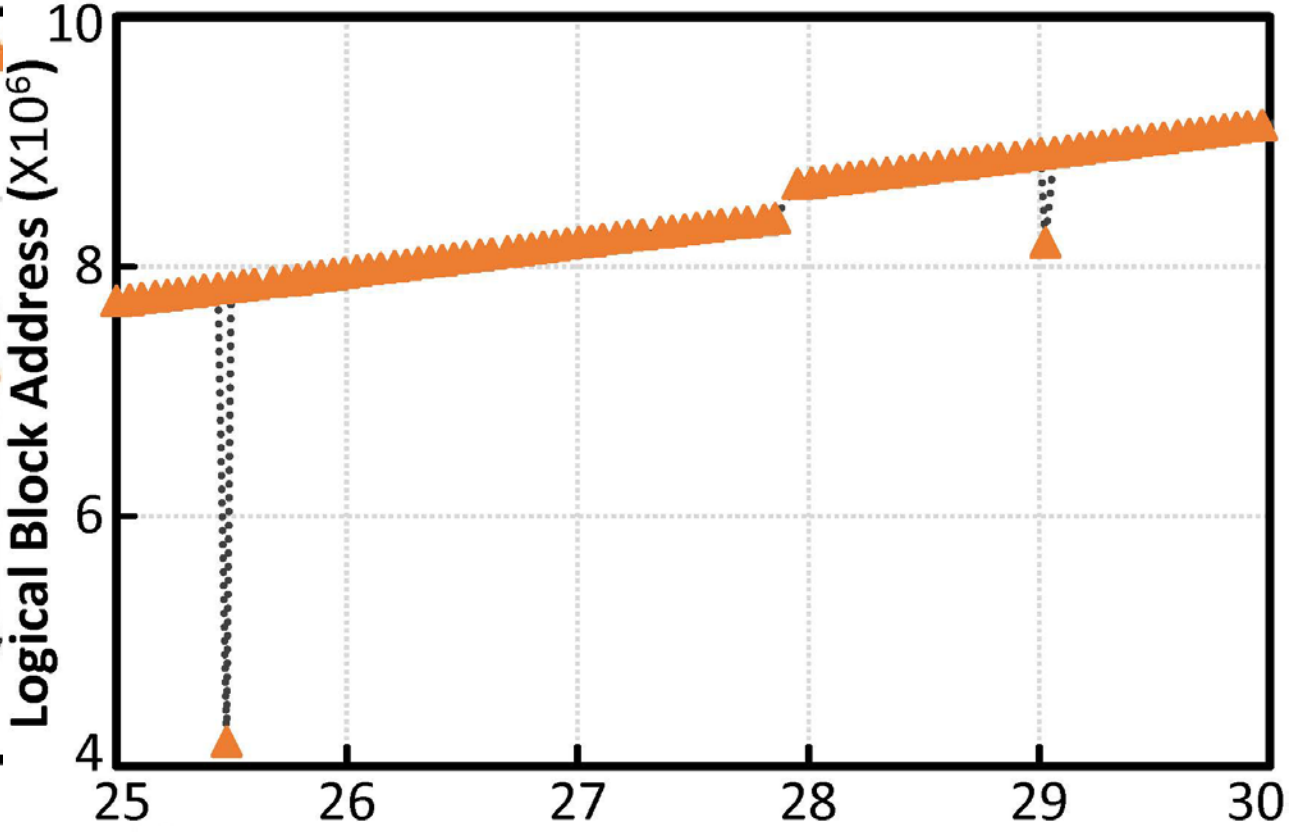


Write Performance

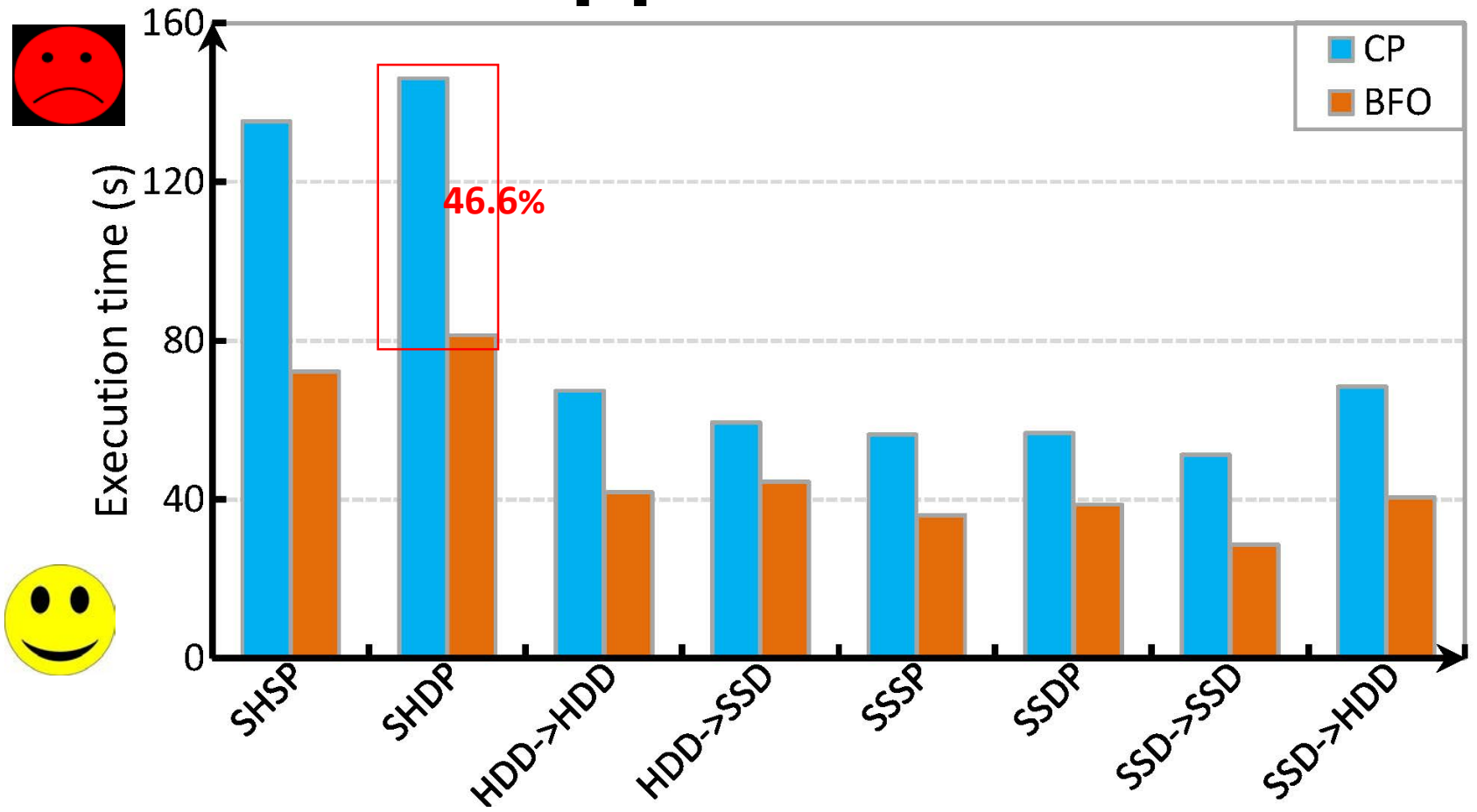


Access Behaviors





Real-world Applications



The execution time of copying a file set with different storage devices. SHSP (SSSP): within the same partition of the same HDD (SSD), SHDP (SSDP): between the different partitions of the same HDD (SSD).

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Conclusion

- We experimentally investigate the root cause of the inefficiency of the traditional single-file access pattern for batched files.
  - Seeking forth and back between metadata area and data area.
  - Accessing all files in random order.
- We present BFO, for batch-file access, with optimized batch-file read (BFOr) and write (BFOw).
  - Two-phase access.
  - Layout-aware scheduler.
  - Light-weight consistency strategy
- BFO improves the access performance consistently, and removes a significant amount of random and non-sequential I/Os.

Thank You

Q&A