Object-based SCM - An Efficient Interface for Storage Class Memories

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Storage Class Memories

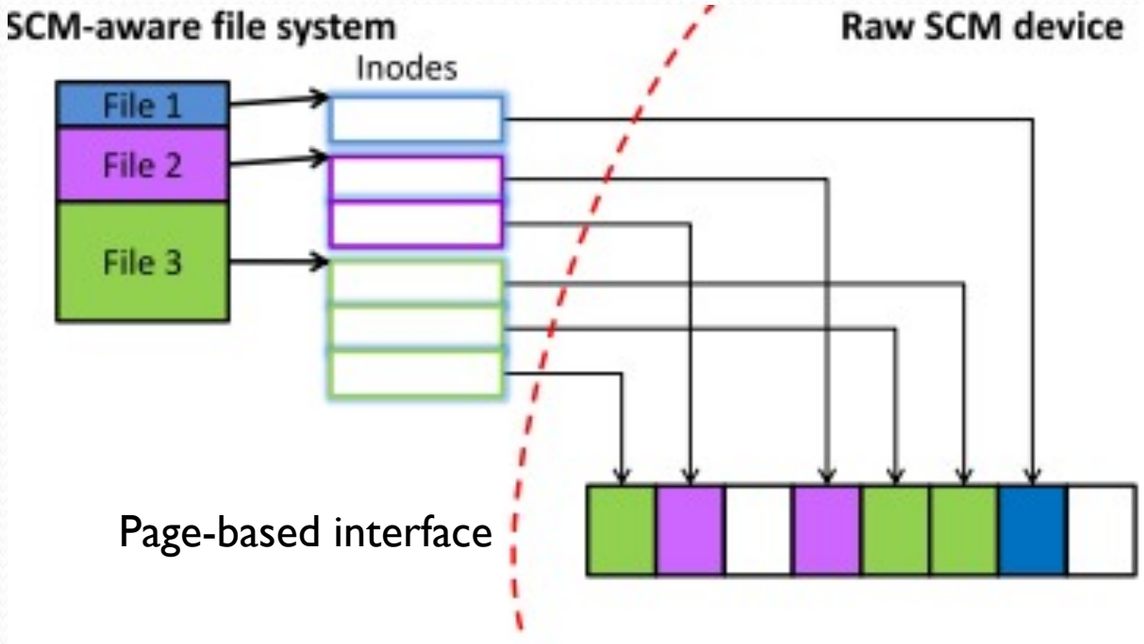
- A new class of data storage and memory device blurs the distinction between storage and memory
  - Fast read/write speed like DRAM, Non-volatility like disks
  - e.g. Memristor, Phase-change RAM, STT-RAM, Flash memory

- Differences in characteristics
  - Endurance
    - PRAM 10^8, RRAM 10^8 , STT-RAM 10^{15}, MEMRISTOR 10^8, FLASH 10^5
  - Asymmetric read/write performance
    - PRAM, FLASH
  - Destructive read
    - FRAM
  - Out-of-place update
    - FLASH

- The use of SCMs in current systems
  - Direct access: SCM-aware file system & custom designed device
  - FTL-based storage devices

Current Interface for SCMs
Direct Access Model

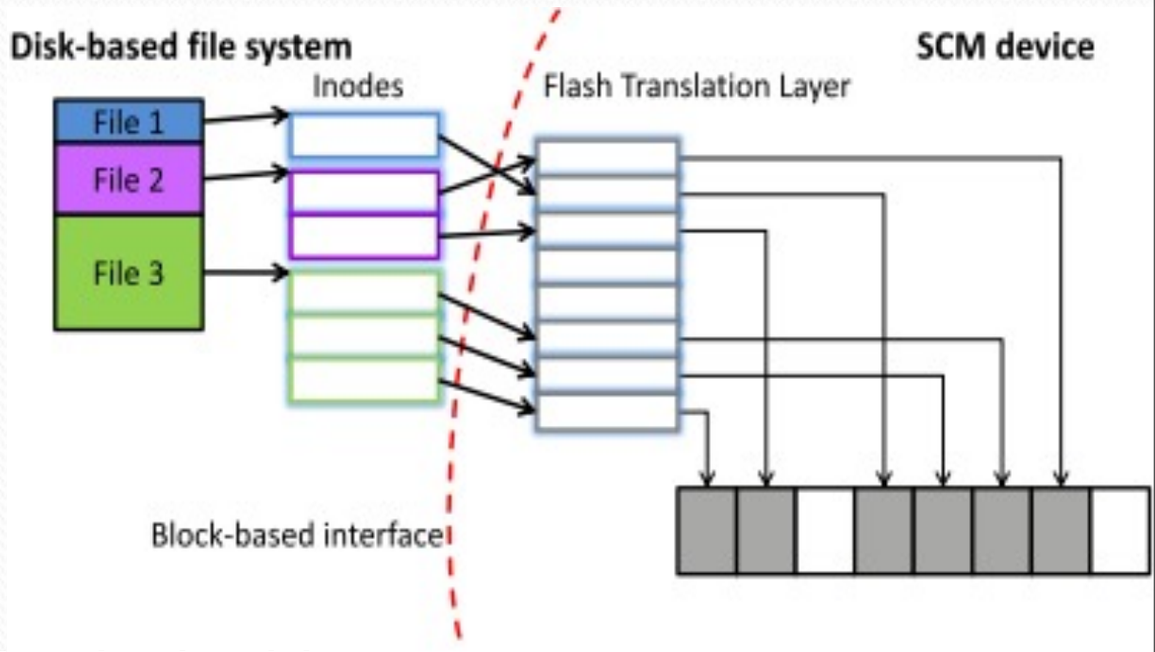
- Allows a file system to fully control the medium
  - A file system is designed to handle the characteristics of the target SCM
  - Raw medium can be accessed directly
    - memory bus, PCI-e slot



- ✚ Efficient
- ➖ Not easy to deploy
  - requires specific fs, hw, os
- ➖ Difficult to adopt new SCM

Current Interface for SCMs
FTL-based model

- Allows the legacy file systems to access SCMs as a block-based storage device
  - Device maintains a mapping table and uses block interface
  - SCM characteristics are handled by the device



- ✚ Compatibility
- ✚ Portability
- ➖ Sub-optimal performance
  - two translation layers
  - lacks of information about the requests (requires TRIM)
    - approaches to alleviate this problem:
      - Nameless writes: let inodes contain physical address
      - DFS: move FTL to the operating systems, not using block-interface anymore

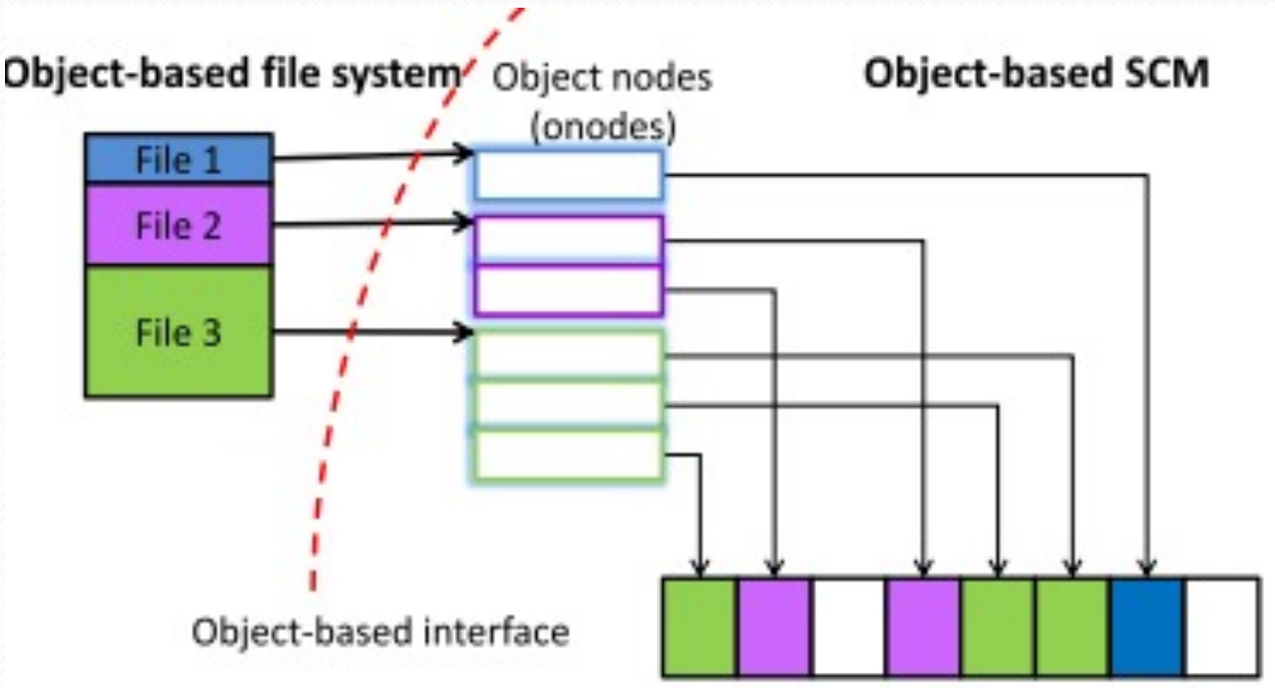
Object-based model for SCMs

- The object-based model
  - Offloads the storage management layer to the device
  - Encapsulates the VFS-level requests in an object with their metadata information

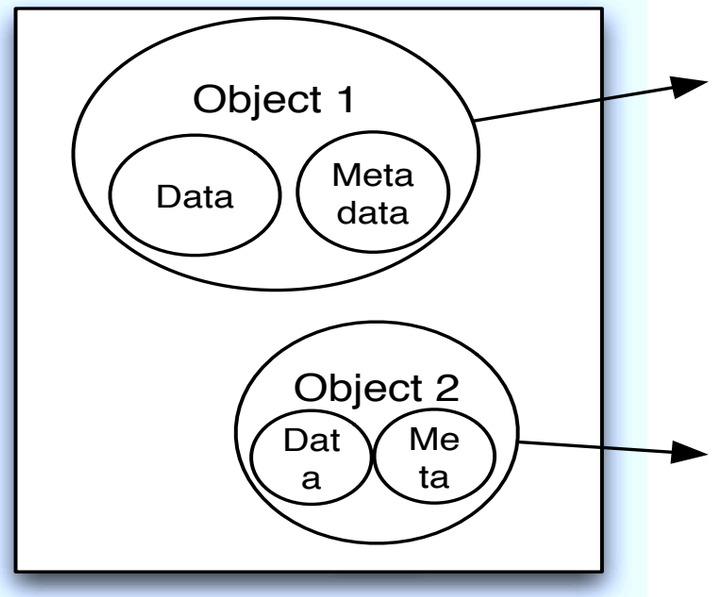
✚ Drop-in replacement for new type of SCM
  - object-based FS need not know about the underlying medium

✚ Better H/W optimizations
  - Rich information about the requests
  - The block management layer is inside
    e.g. splitting a large requests into concurrent writes to multiple SCM chips

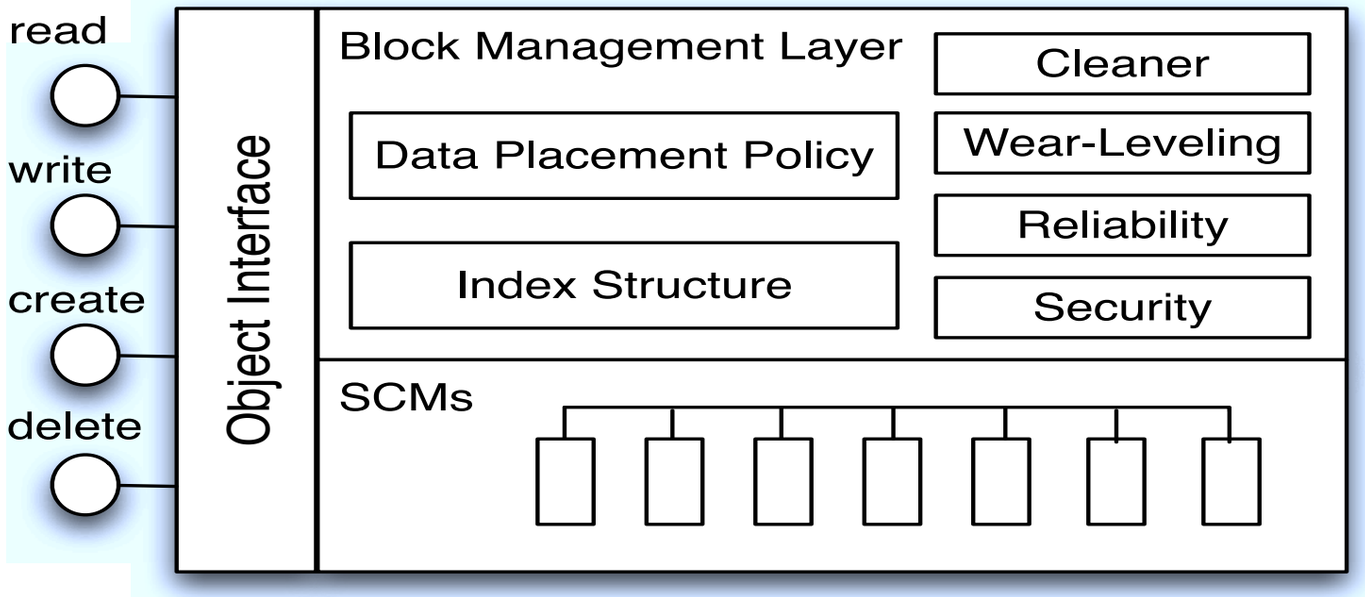
✚ The existence of objects
  - better space efficiency, reliability



Overview
the object-based model for SCM



(a) Object-based file system.



(b) Object-based device.

Design Issues of Object-based SCM

- Core Subsystems
  - Data placement policy
  - Index structure
  - Wear-leveling and Cleaning

- Advanced Features
  - Object-level reliability
  - Object-level compression and encryption
  - Client library for object-based SCMs
  - Object-level transactions

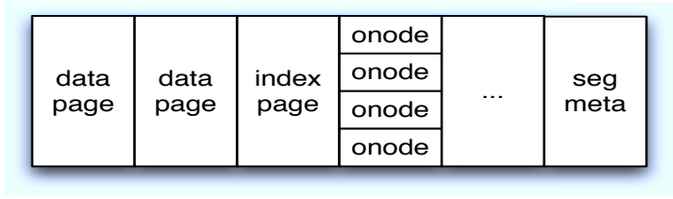
Object-based Flash
Data placement policy

- Goal: maximize the performance and the lifetime of Flash

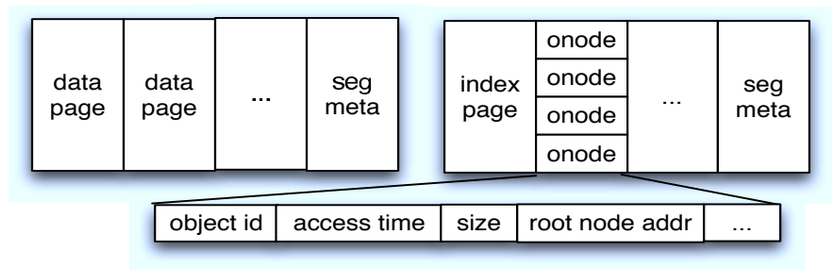
- A log-structure is typically used for Flash
  - wear-leveling
  - out-of-place update

- Separate frequently accessed data
  - metadata: object metadata, indices
  - access time

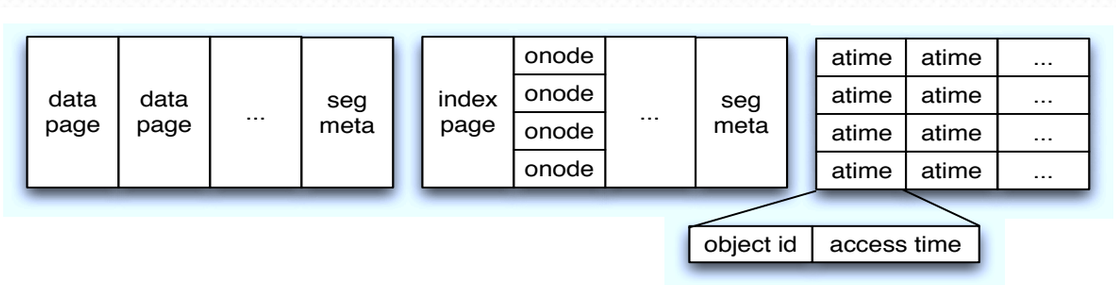
- Cleaner threshold
  - lower the priority of metadata segments



(a) Typical log-structured layout.



(b) Separation of data and metadata.



(c) Separation of data, metadata and access time.

Object-based Flash Index Structure

- Goal: improve space efficiency
  - reduces the number of I/Os
  - increase the lifetime of Flash

- An index structure designed for a Flash-aware file system can be used
  - OSD and Flash-aware file system have the same level of information
  - SSD uses heuristics to extract those information from the request patterns
    e.g. detecting sequential writes in FAST

- Wandering Tree
- Two optimizations
  - Extent-based allocation for large objects
  - Write buffer for small objects

Object-based Flash Wear-leveling and Cleaning

- Wear-leveling is to maintain the wear-level of each erase unit and use them evenly
  - use a log-structure and a cleaner

- Selecting target segments to be cleaned
  - Erase count
  - Age of the segments (current time - erased time)
  - The number of live data pages in each segment
  - Type of segments: data, metadata, access time
    - e.g. metadata segments tend to be updated more frequently than data segments -> skip selecting metadata segments until they contains very small # of live pages

Object-based Flash Advanced Features

- Object-level Reliability
  - Per-page error correction code can only detect and correct a certain number of bits
    - cannot protect against misdirected writes, whole page failures
  - Detection
    - Use algebraic signature to generate a fingerprint of each page (stored in the spare area)
  - Correction
    - Per-object parities
      - parities for all data pages
      - parities for all index pages
      - a copy of an onode
    - Users can adjust the number of parities and replicas to meet their requirements
- Consistency check
  - misdirected writes:
    - read all data pages belonging to an object, and compare with parities
  - page failures
    - recover from temporal/permanent page failures regardless the number of bit-flips within a page

Object-based Flash Advanced Features

- Object-level compression and encryption
  - Selective-compression/encryption
    - infer the type of an object, and determine if a compression or encryption is required
  - Right order: compress followed by encrypt
- Client library
  - Allows users to customize the OSDs by providing hints to the devices e.g. bypassing VFS for small objects
  - File system can also use hints: embedding inodes in onodes

Implementation Object-based Flash

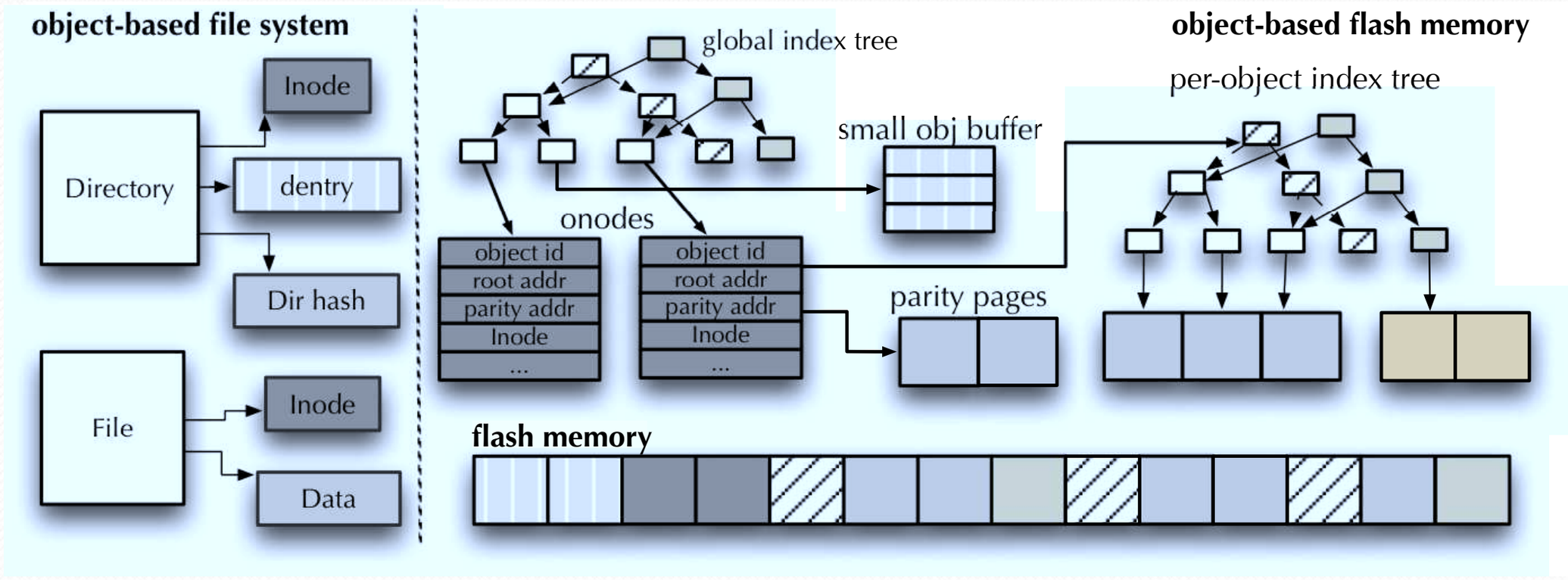
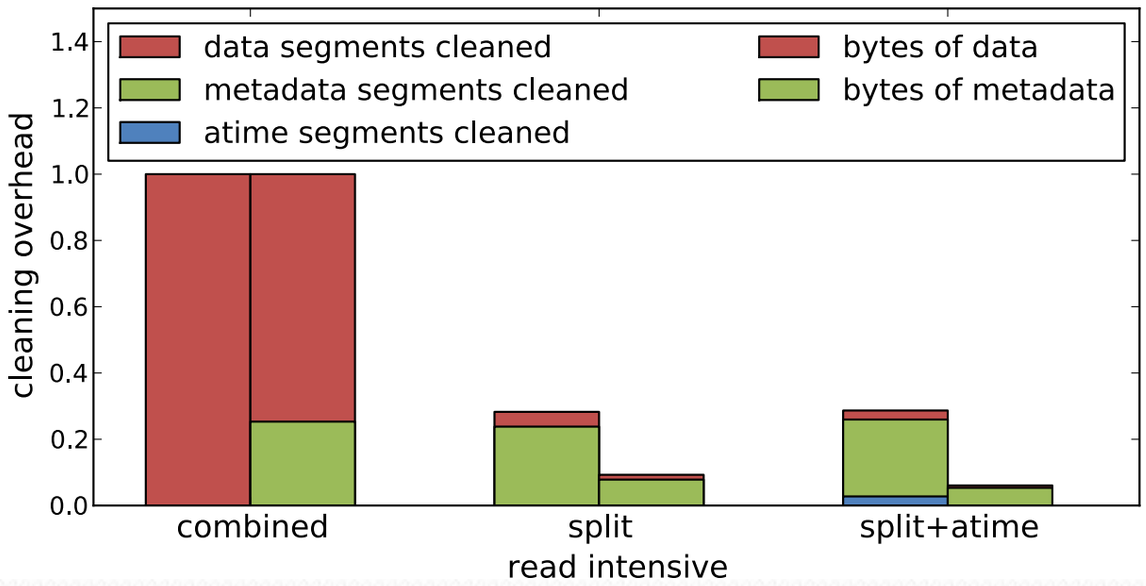


Figure 4. The implementation of Object-based flash memory

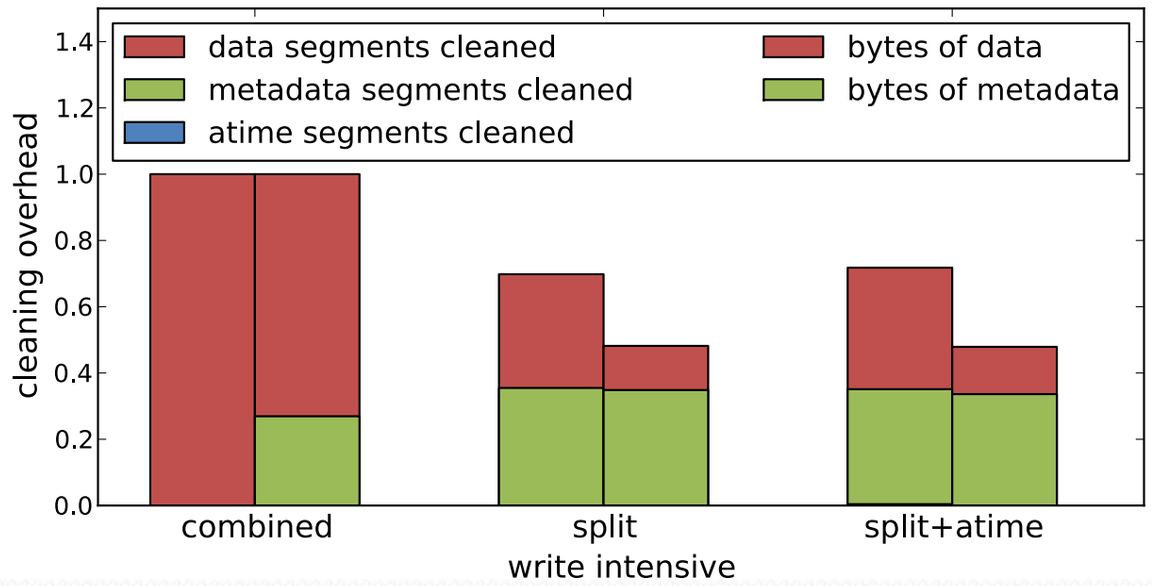
- Hash-directory
- Small object buffer
- Three data placement policies
- Next-K algorithm
- Wandering tree with extents
- Embedding inodes in onodes
- Object-level Reliability

Evaluation
Data placement policies

Postmark Benchmark



(a) Read-intensive workload

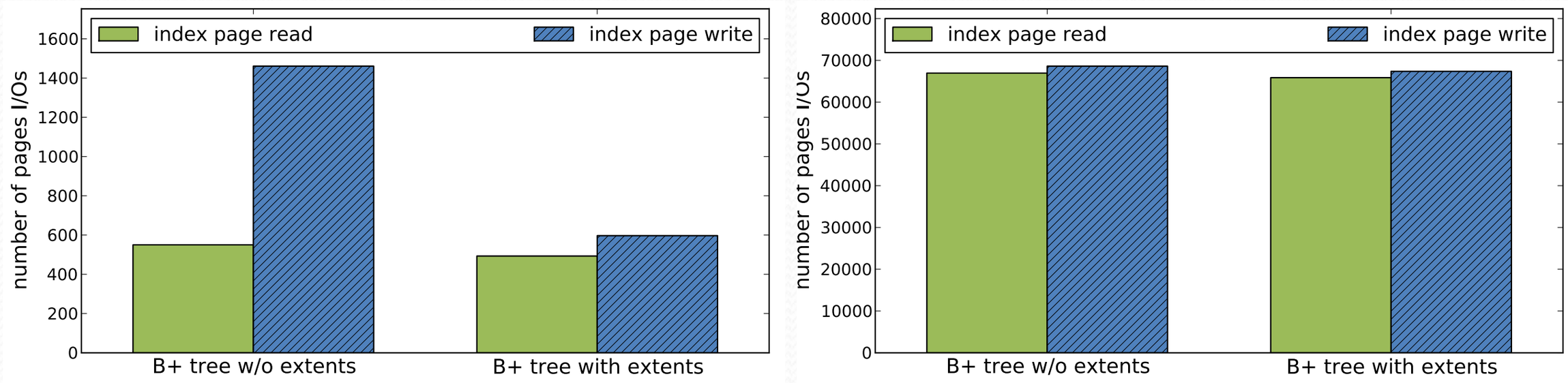


(b) Write-intensive workload

- object inode and index nodes are frequently written to update access time
- access times and modified fields are written together

- Left bar: the total number of segment cleaned
- Right bar: the number of bytes copied during cleaning

Evaluation
Extent-based Allocation



(a) Largefile benchmark

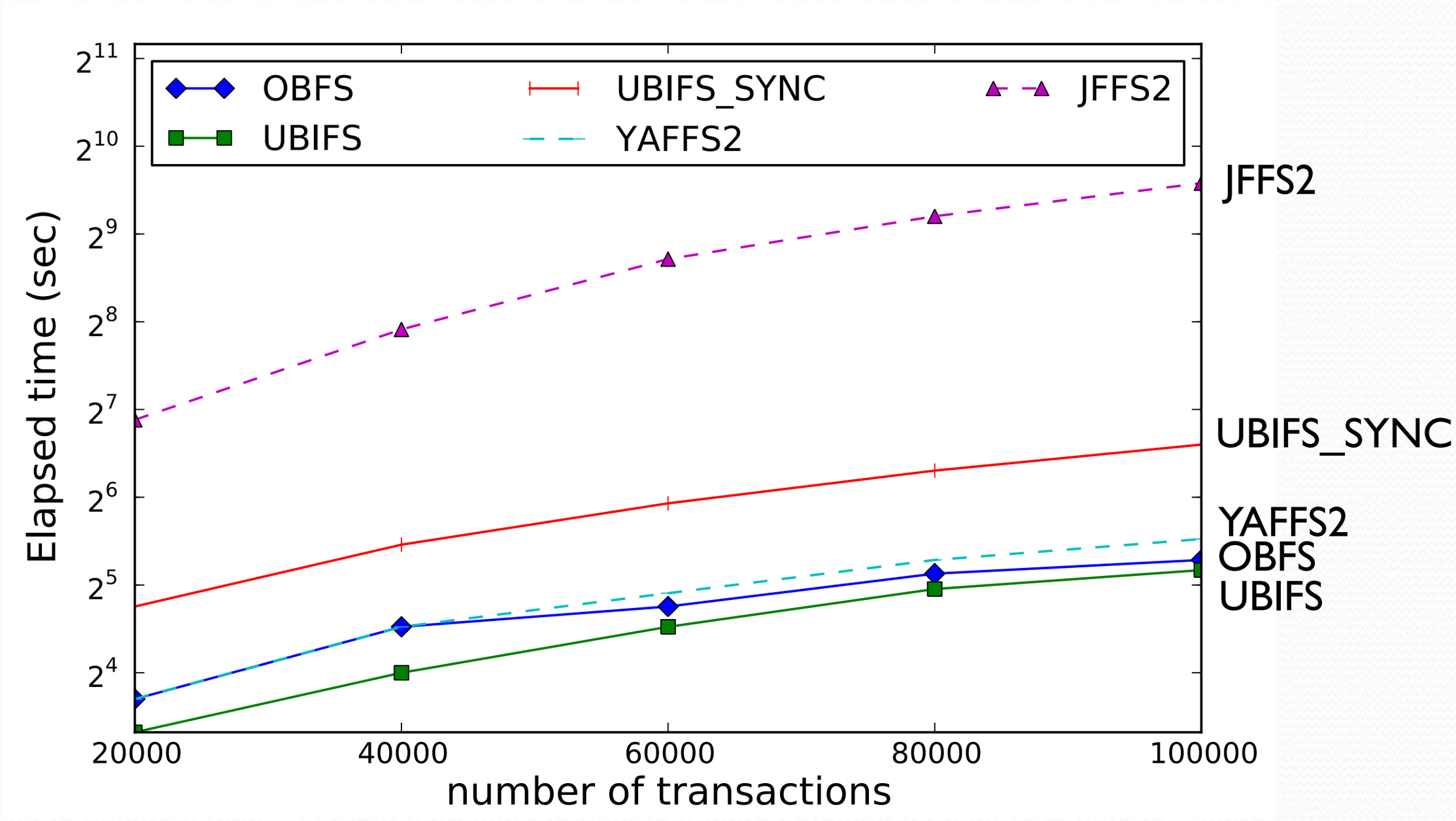
(b) Postmark benchmark

Figure 6. Effects of an extent-based allocation

Evaluation
Effects of Informed placement

	w/o inode_embed	w/o small obj buf	with all
pages read	378101	389165	364142
pages write	92006	91606	66615
seg write	718	714	288
seg clean	240	235	65

Evaluation
Overall Performance



Conclusion

- The object-based model
  - enables SCM devices to overcome the disadvantages of the current interfaces
  - provides new features such as object-level reliability and compression

- Object-based SCM prototype
  - Implemented in the 2.6 Linux kernel to explore the design issues of the object-based Flash

  - Separating frequently accessed data can significantly affect the cleaning overhead
  - Extent-based allocation works well for large objects
  - Achieve compatible performance with other flash-aware file systems

Fast-SSDs

- Fast-SSDs
  - Use PCI-E to avoid the limitation of block-interface
  - Move some parts of a FTL to the host
    - Obtain more information from the running FS, and use them to optimize the FTL
    - Translation Layer
    - Cache

- Advantage
  - High Performance

- Disadvantage
  - Platform, FS dependent(need for a module per each FS)
  - Two translation tables
  - Memory footprint
  - Less portability

Comparison of the three models

	Direct Access Model	FTL-based Model	Object-based Model
Performance			
Portability			
Design Flexibility			
Support for new types of SCM			
System change			
Legacy FS support			

Evaluation
Effects of cleaning threshold