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SSDs

The Unwritten Contract

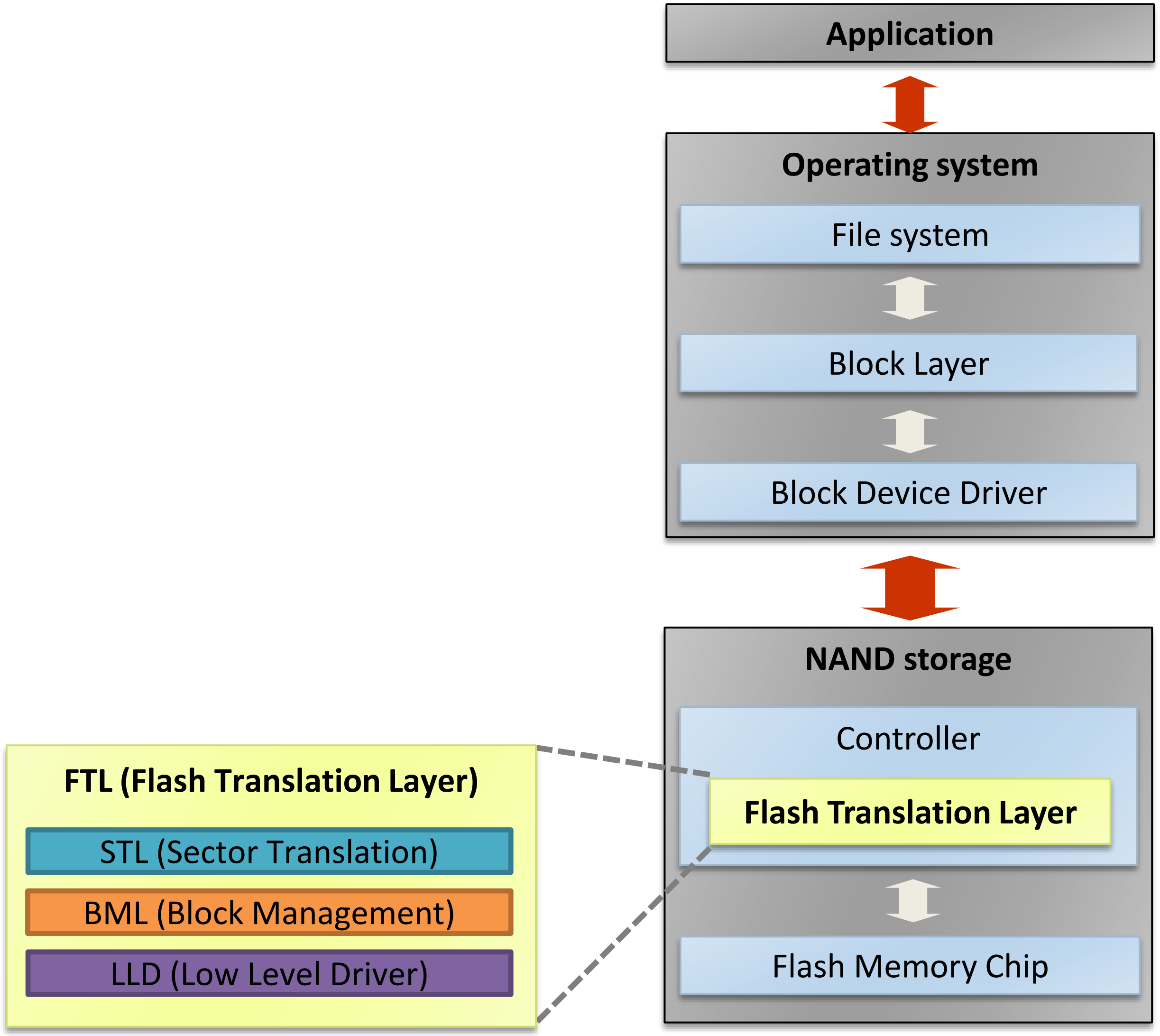
- Several assumptions are no longer valid

Assumptions	Disks	SSDs
Sequential accesses much faster than random	✓	✗
No write amplification	✓	✗
Little background activity	✓	✗
Media does not wear down	✓	✗
Distant LBNs lead to longer access time	✓	✗

Source: A. Rajimwale et al., "Block Management in Solid-State Devices," USENIX ATC, 2009.

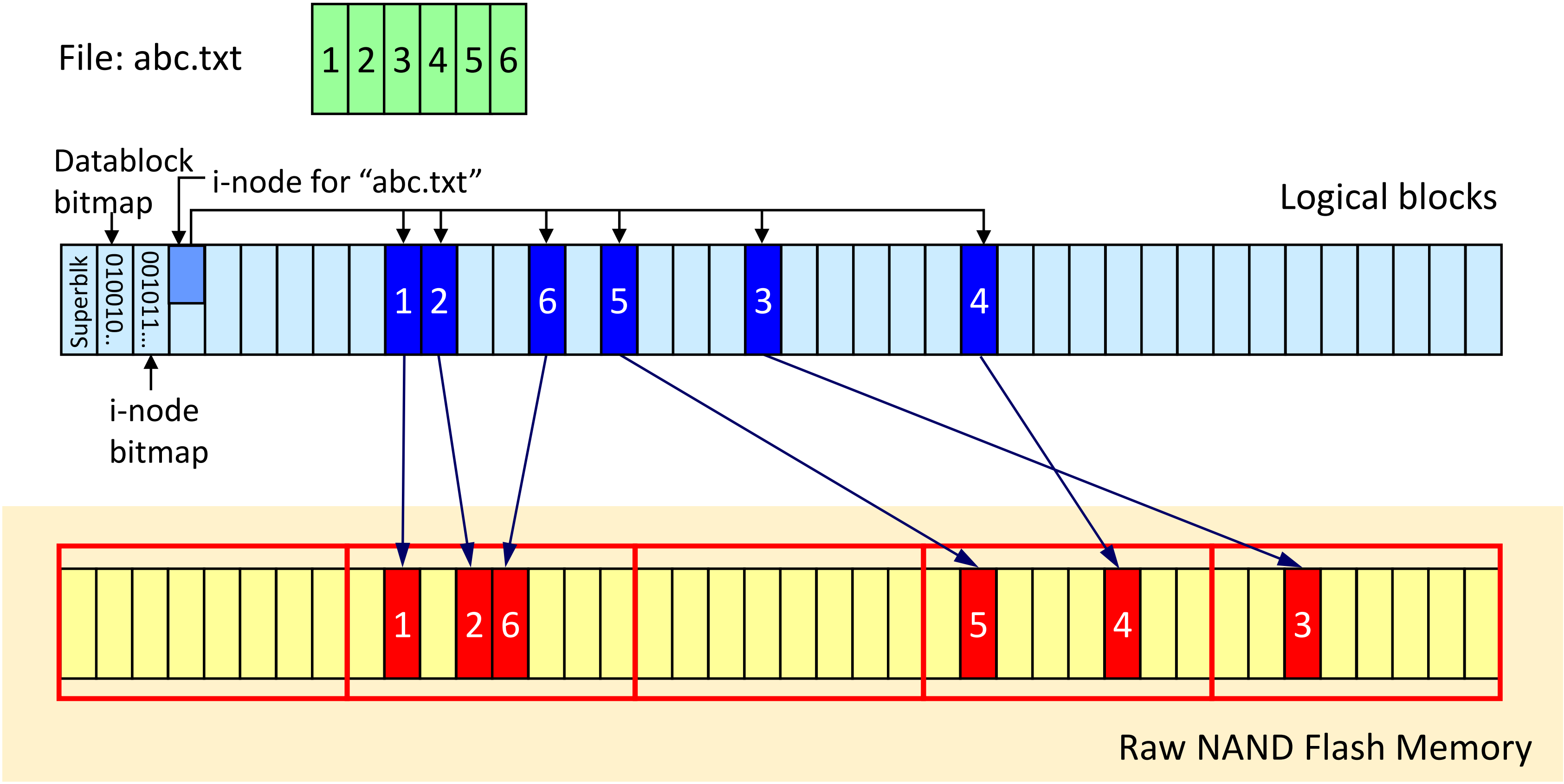
FTL Architecture

- **Sector Translation Layer**
  - Address mapping
  - Garbage collection
  - Wear leveling
- **Block Management Layer**
  - Bad block management
  - Error handling
- **Low Level Driver**
  - Flash interface



File System vs. FTL

- What happens on file deletion?



TRIM

- ATA interface standard (T13 technical committee)
  - "The data in the specified sectors is no longer needed"
  - Originally proposed as a non-queued command, but SATA 3.1 introduces the queued TRIM command
  - UNMAP, WRITE SAME with unmap flag in SCSI, DEALLOCATE in NVMe
- Types
  - Non-deterministic Trim: reads may return different data
  - Deterministic Trim: reads return the same data
  - Deterministic Read Zero after Trim: all reads shall return zero
- TRIM commands can be automatically issued on file deletion or format
- fstrim: discard unused blocks on a mounted file system

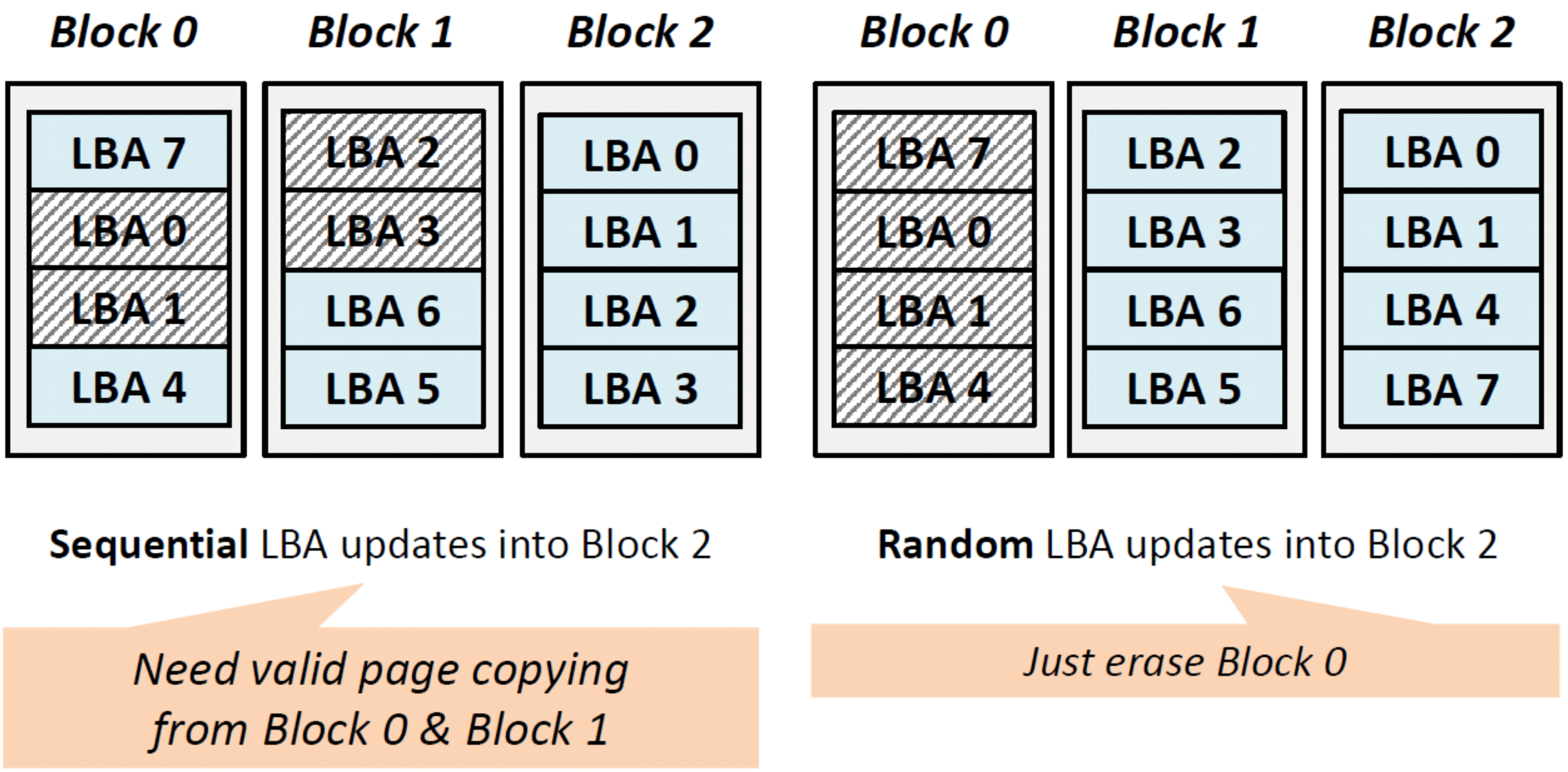
The Multi-streamed Solid-State Drive

(J.-U. Kang et al., HotStorage, 2014)

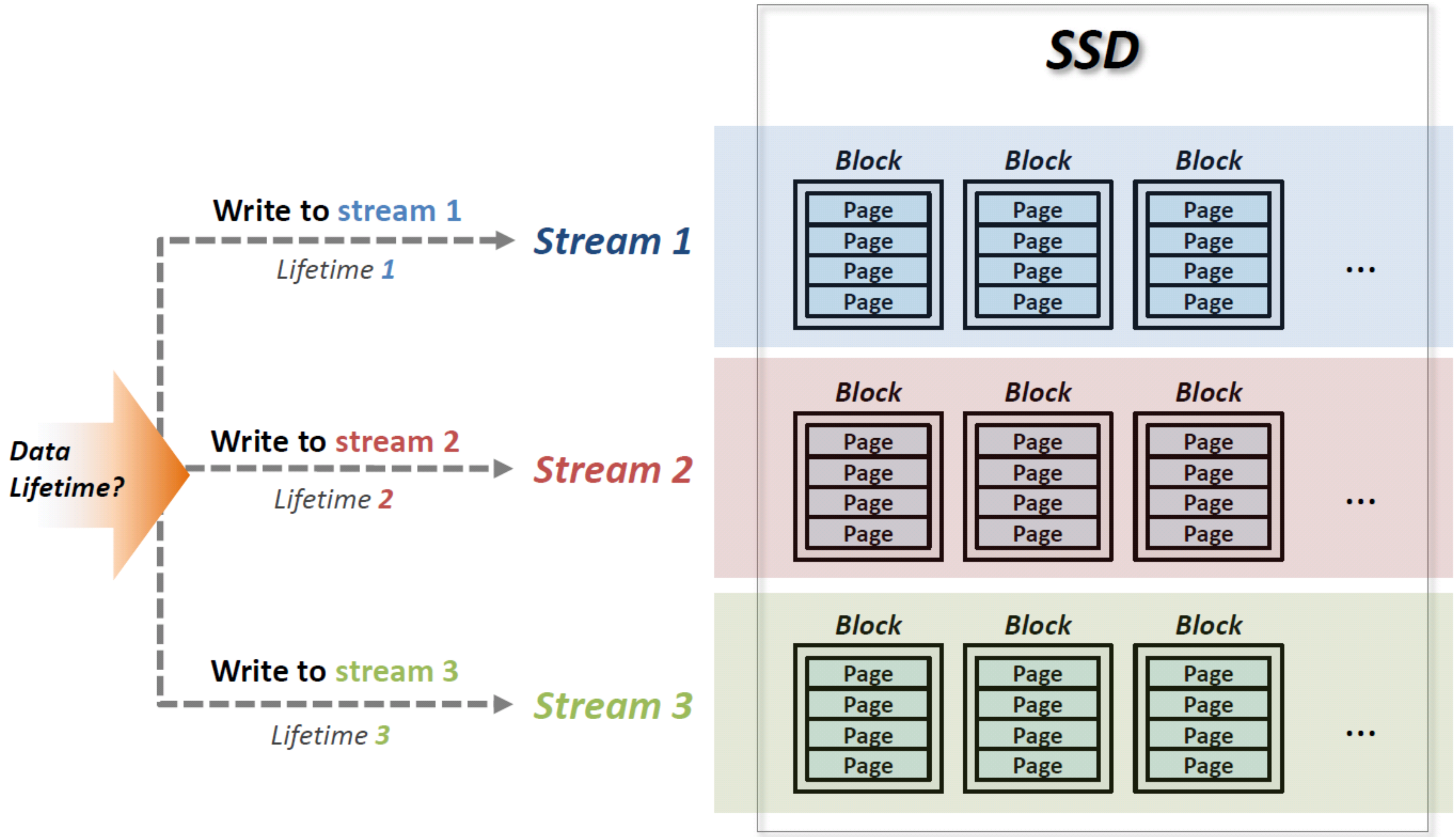
Some of slides are borrowed from the authors' presentation.

Effects of Write Patterns

- Previous write patterns (= current state) matter



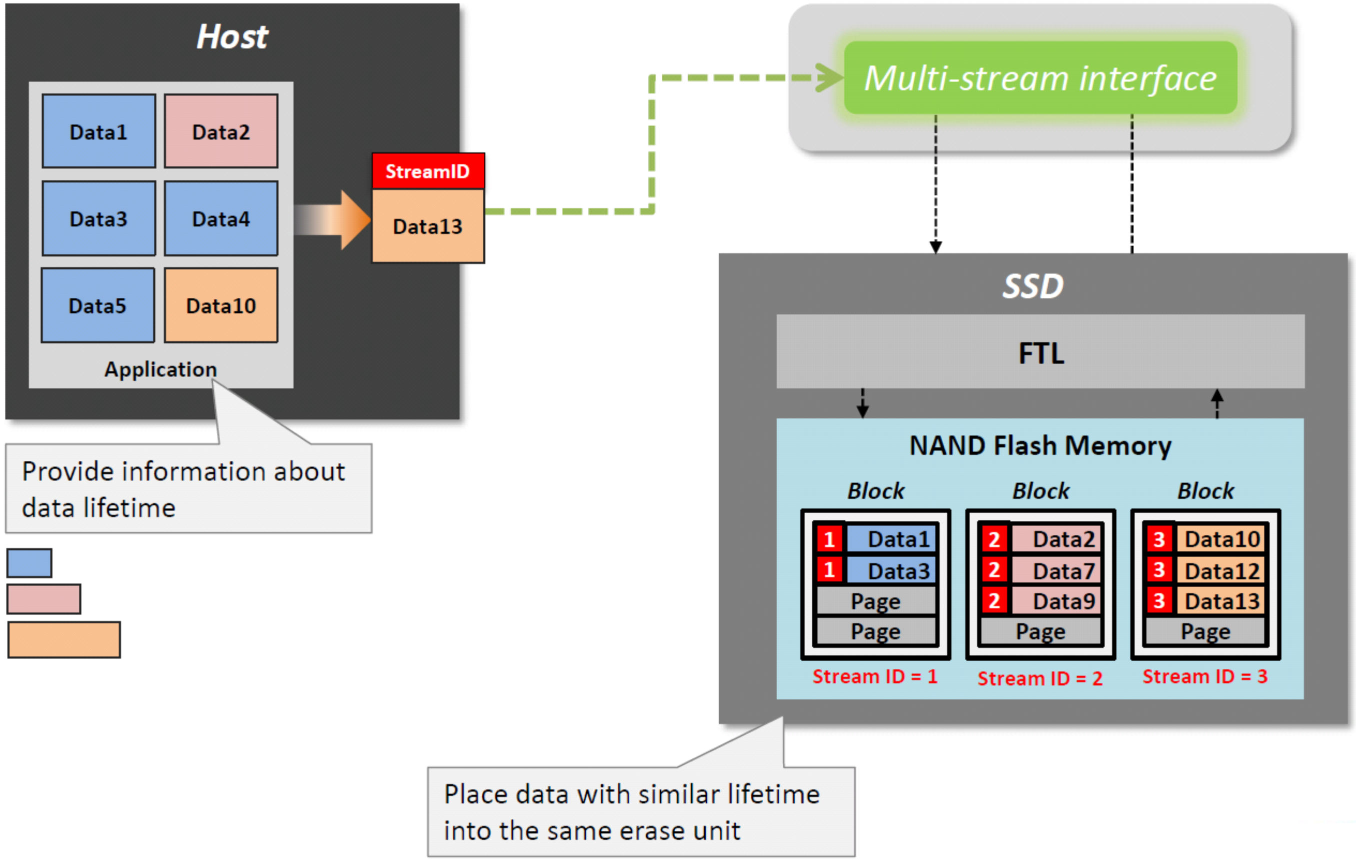
Stream



Data Lifetime?
Write to stream 1
Lifetime 1
Write to stream 2
Lifetime 2
Write to stream 3
Lifetime 3
Stream 1
Stream 2
Stream 3
SSD
Block
Page
…

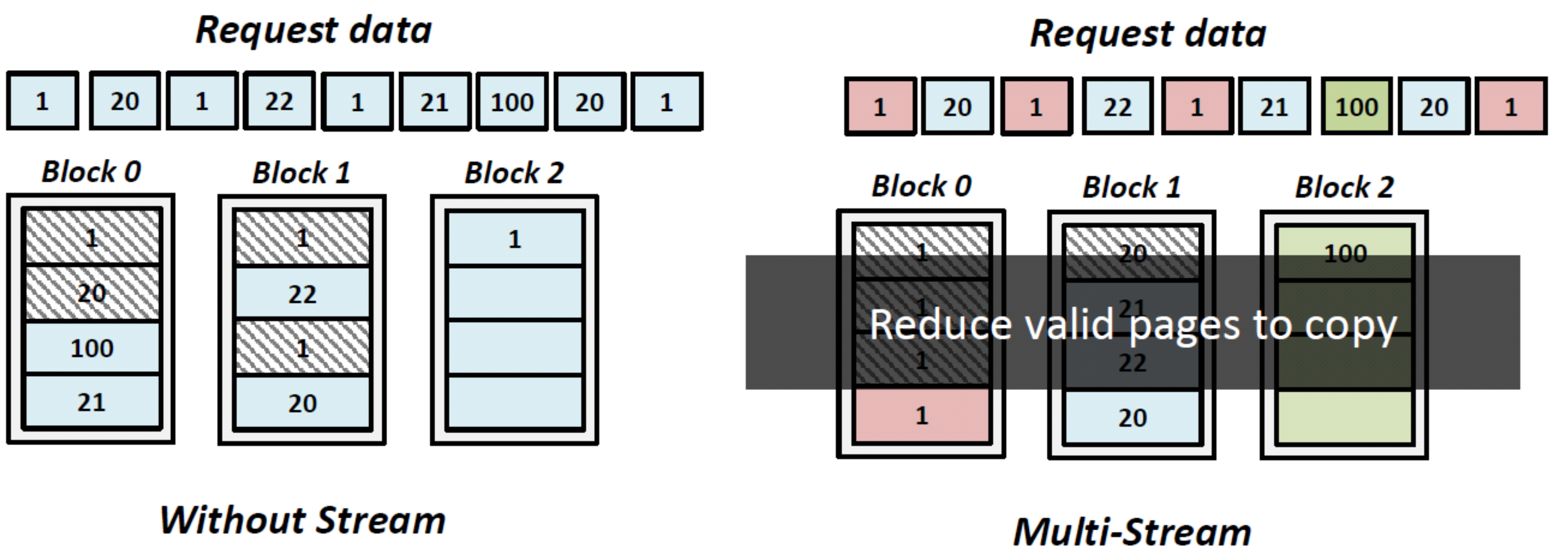
The Multi-streamed SSD

- Mapping data with different lifetime to different streams



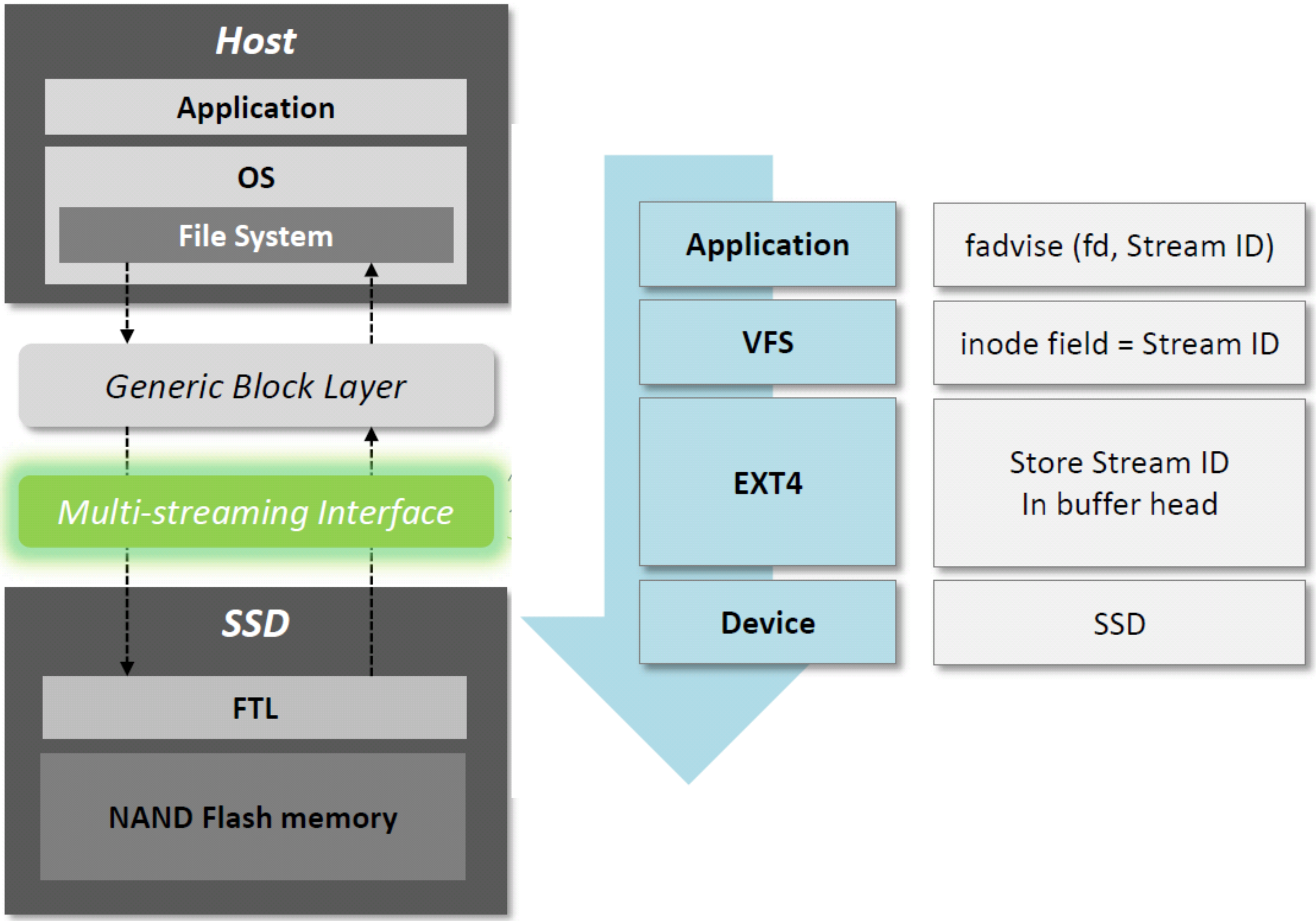
Working Example

- High GC efficiency → Performance improvement

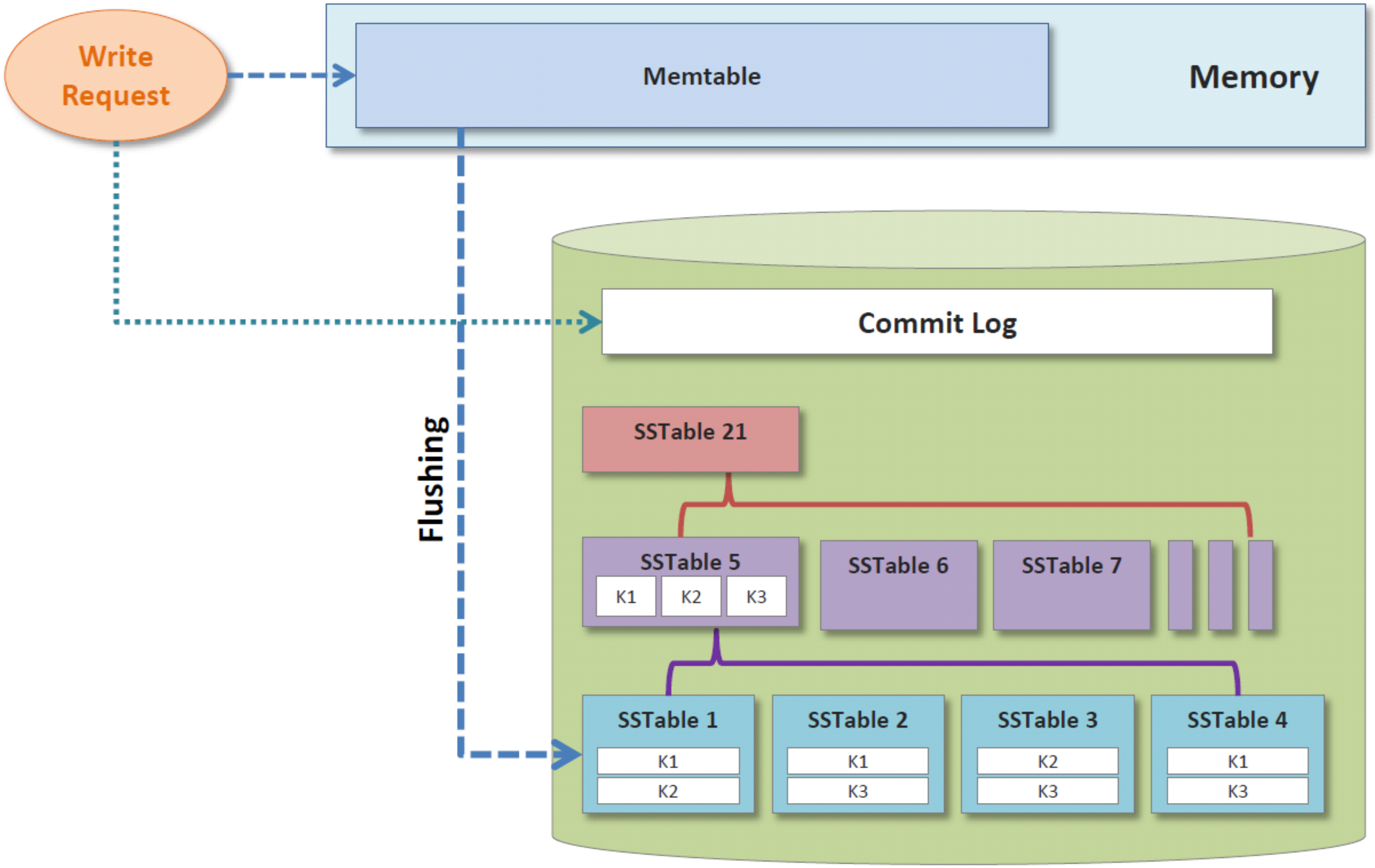


For effective multi-streaming,
proper mapping of data to streams is essential!

Architecture

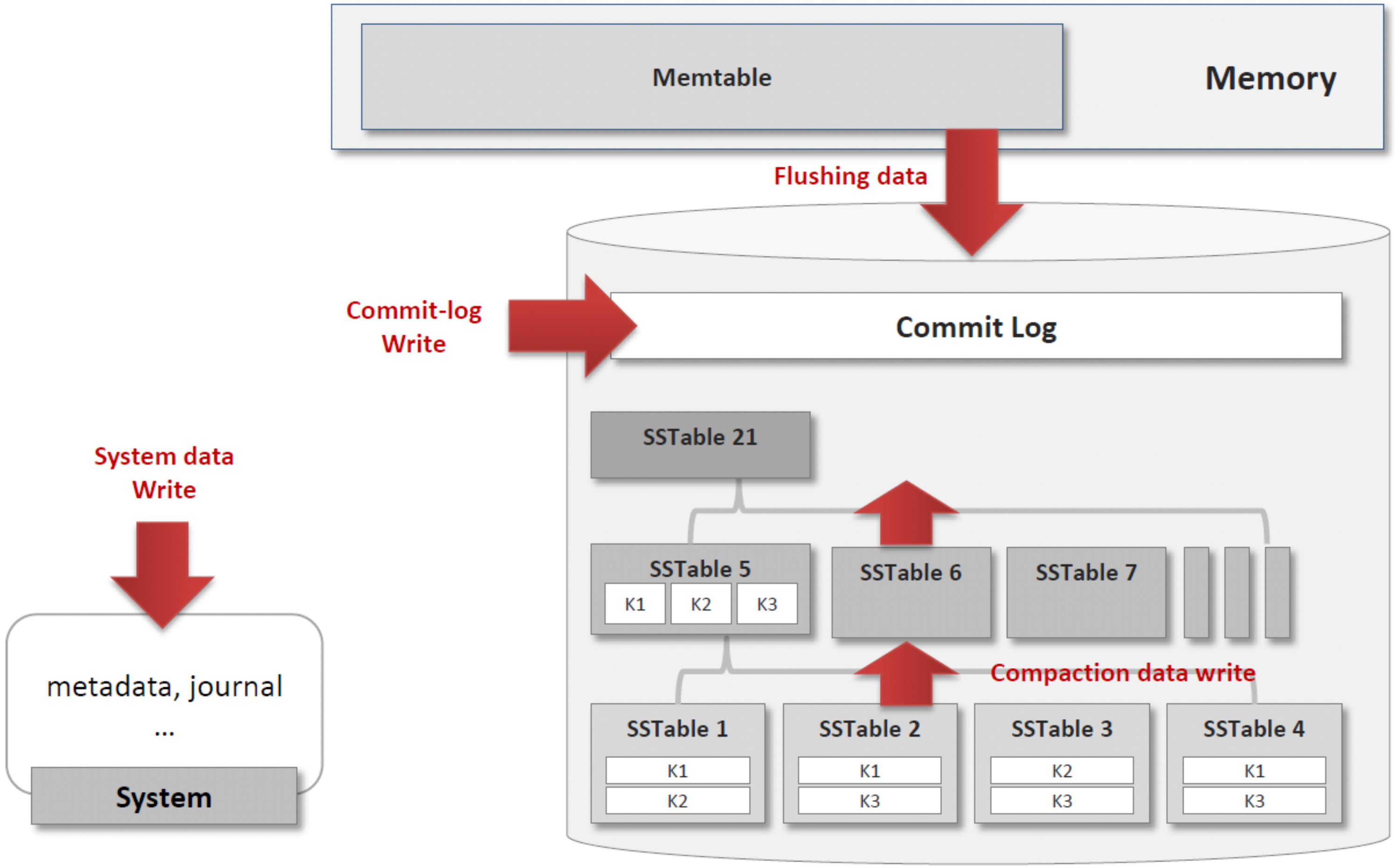


Case Study: Cassandra



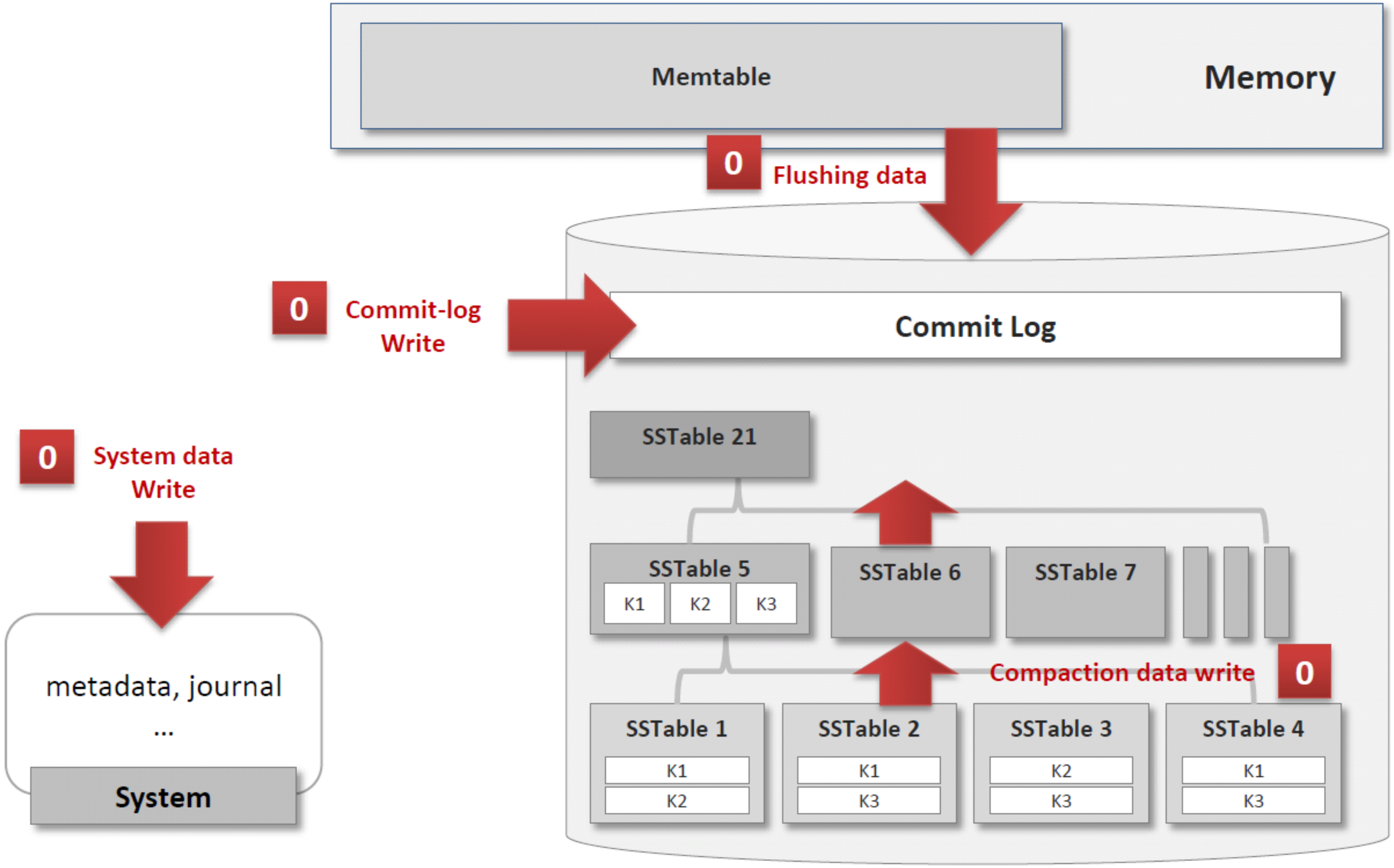
Cassandra's Write Patterns

- Write operations when Cassandra runs



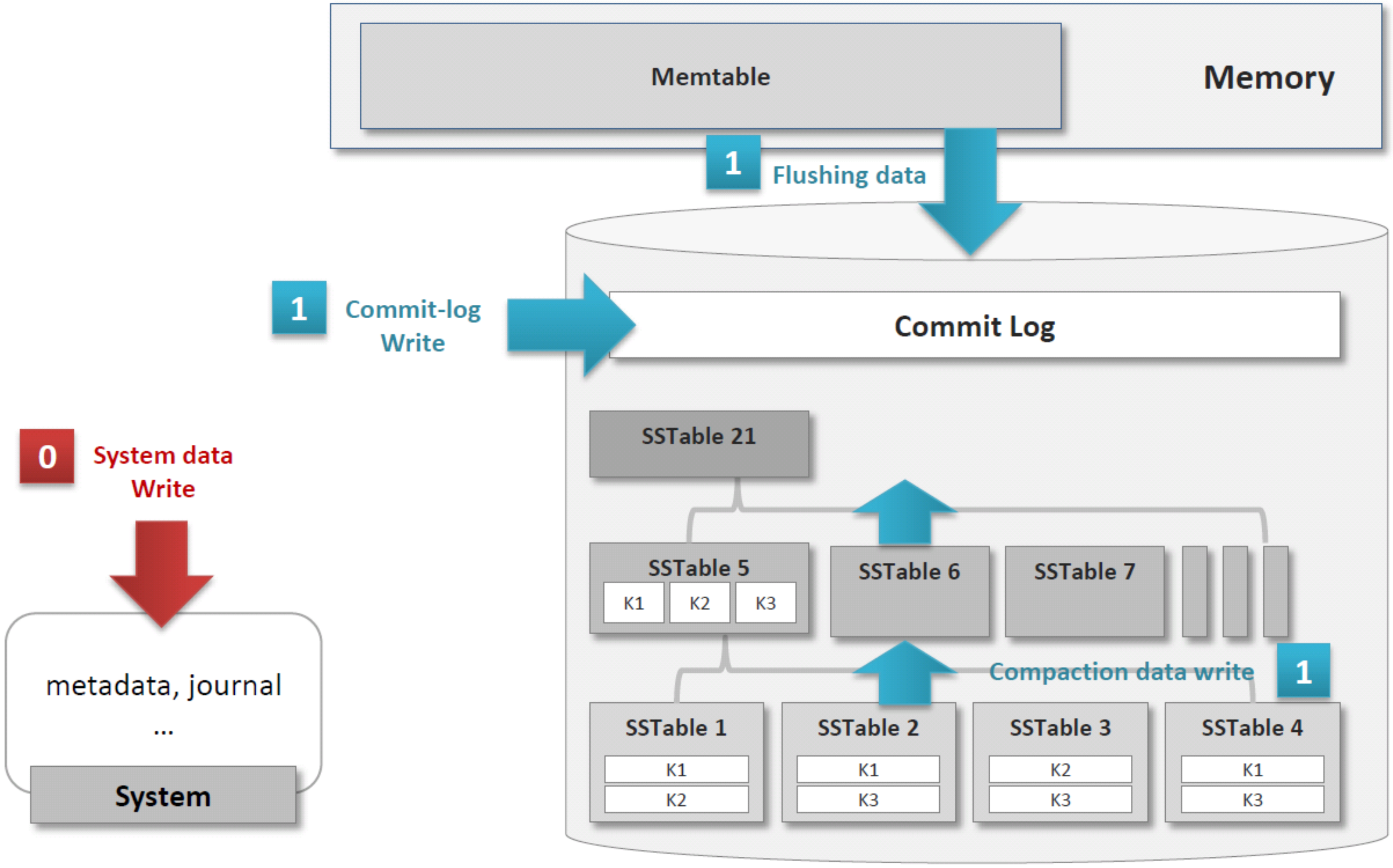
Mapping #1: Conventional

- Just one stream ID (= conventional SSD)



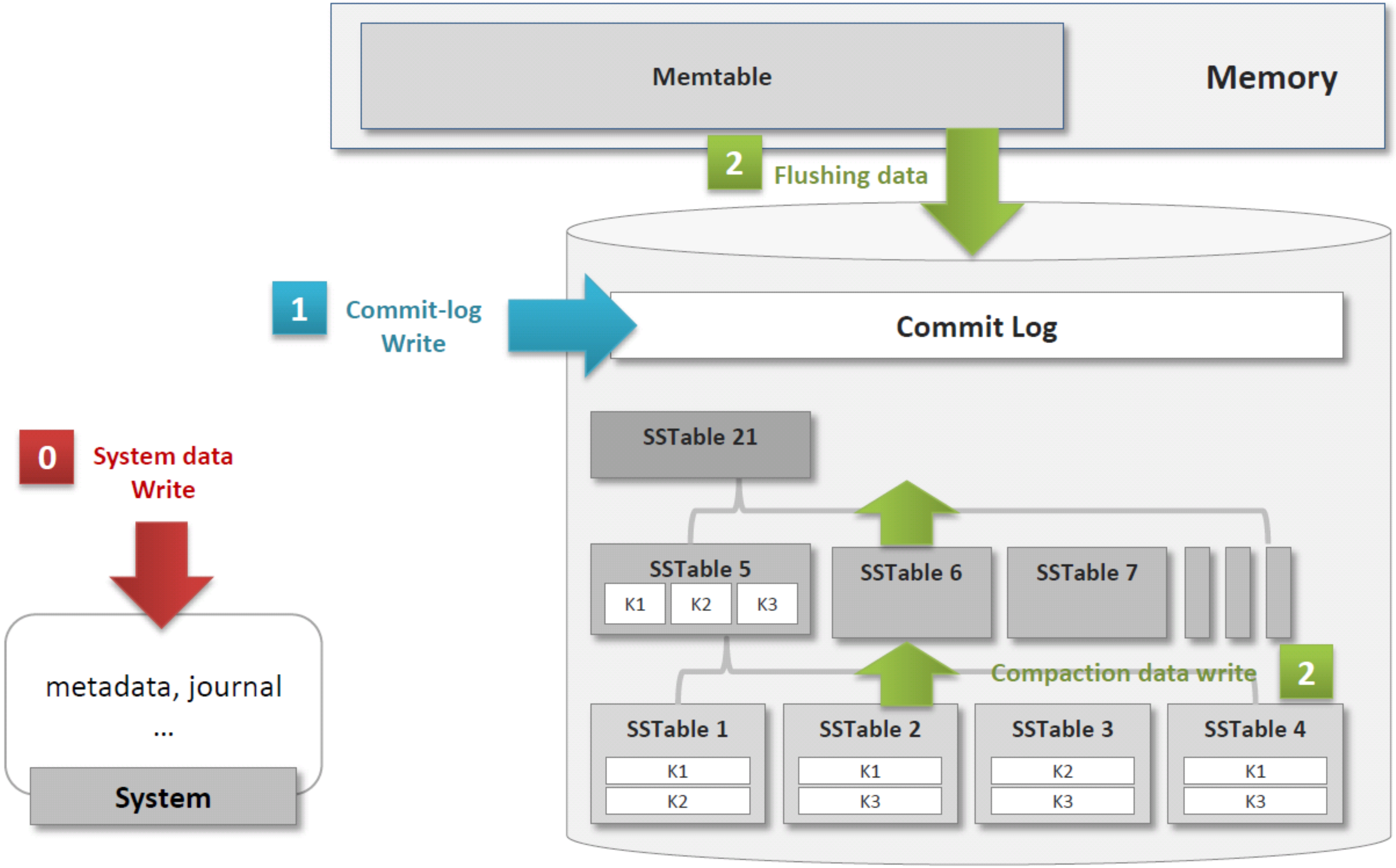
Mapping #2: Multi-App

- Separate application writes (ID 1) from system traffic (ID 0)



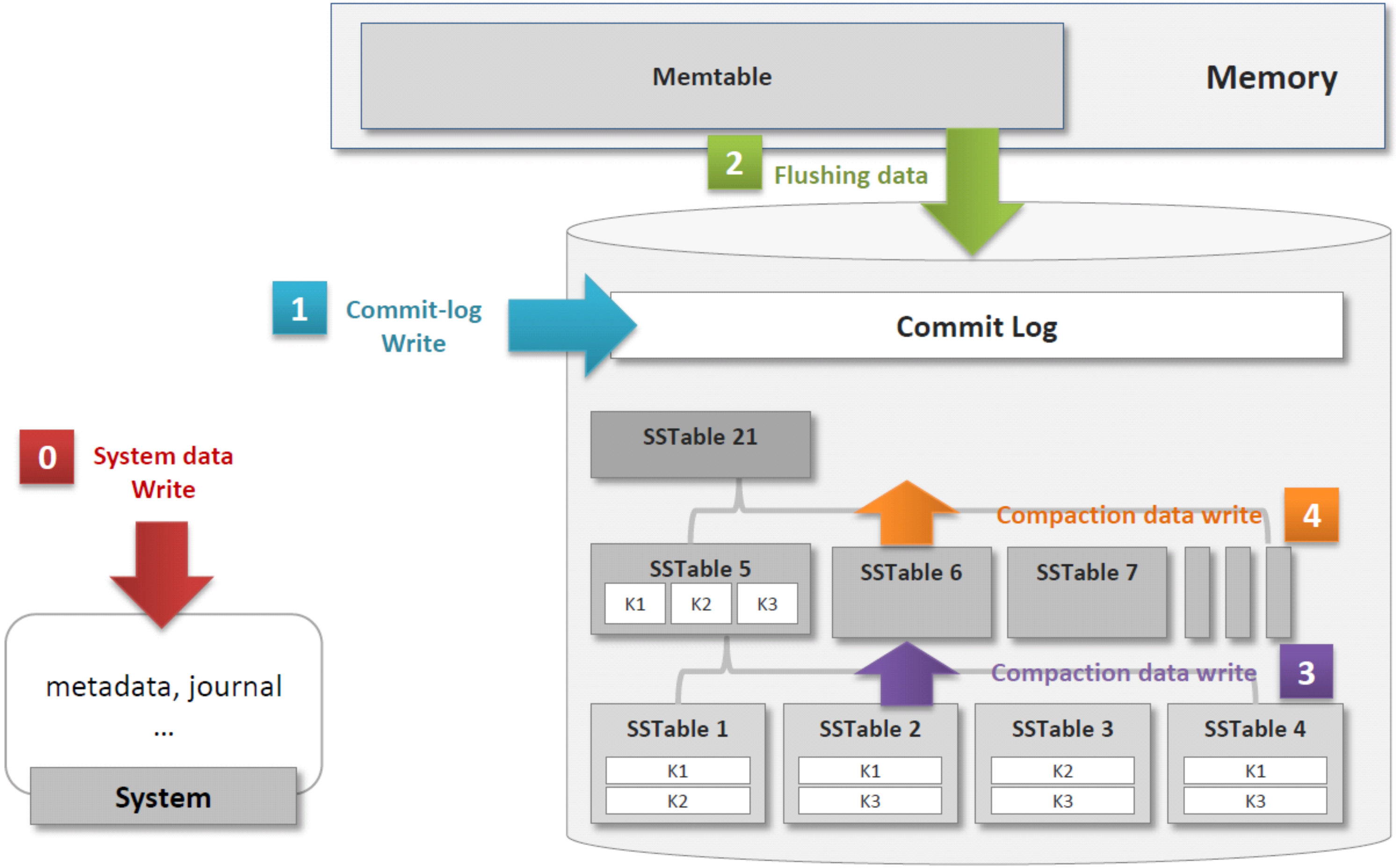
Mapping #3: Multi-Log

- Use three streams; further separate Commit Log



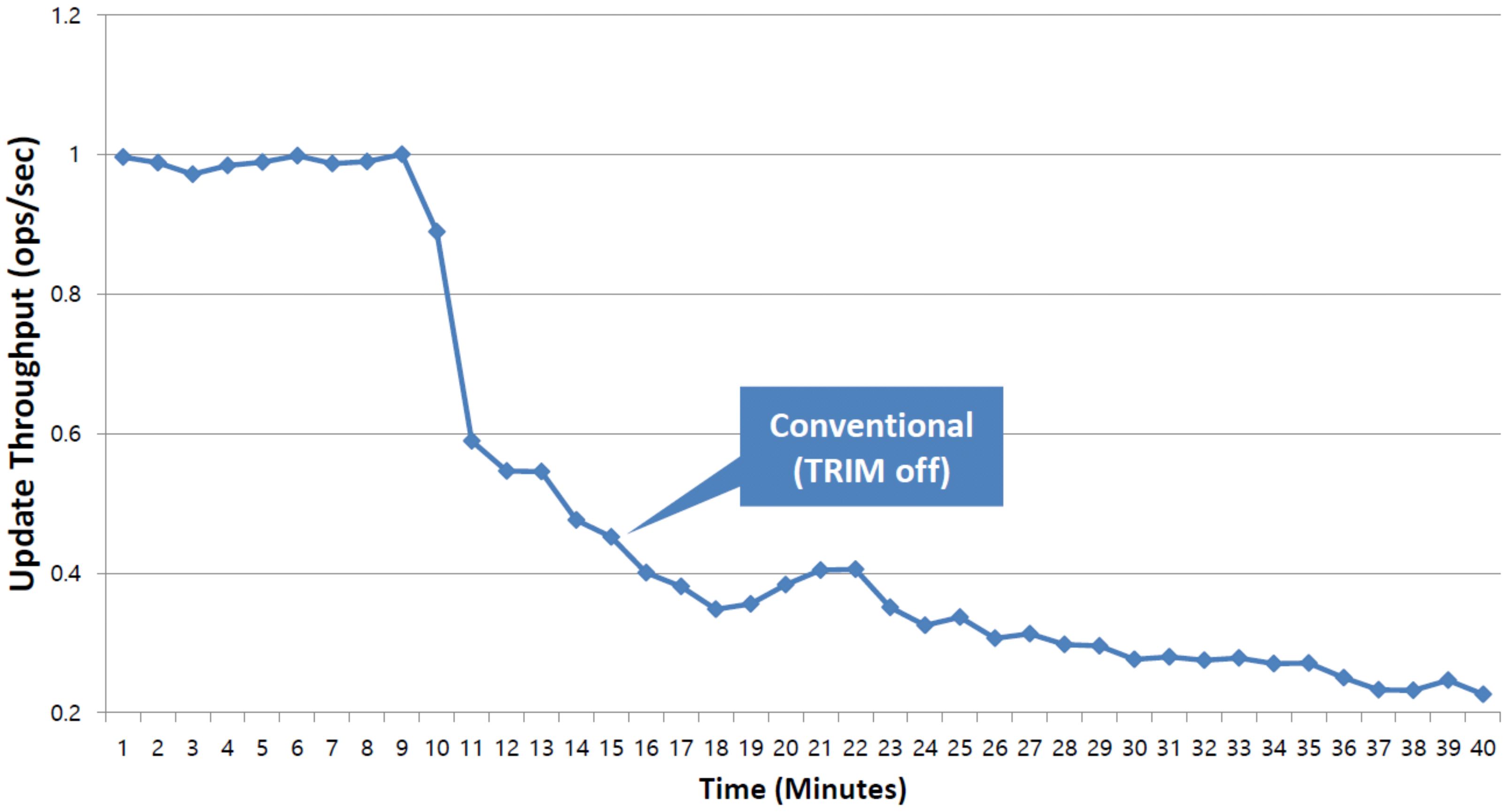
Mapping #4: Multi-Data

- Give distinct streams to different tiers of SSTables



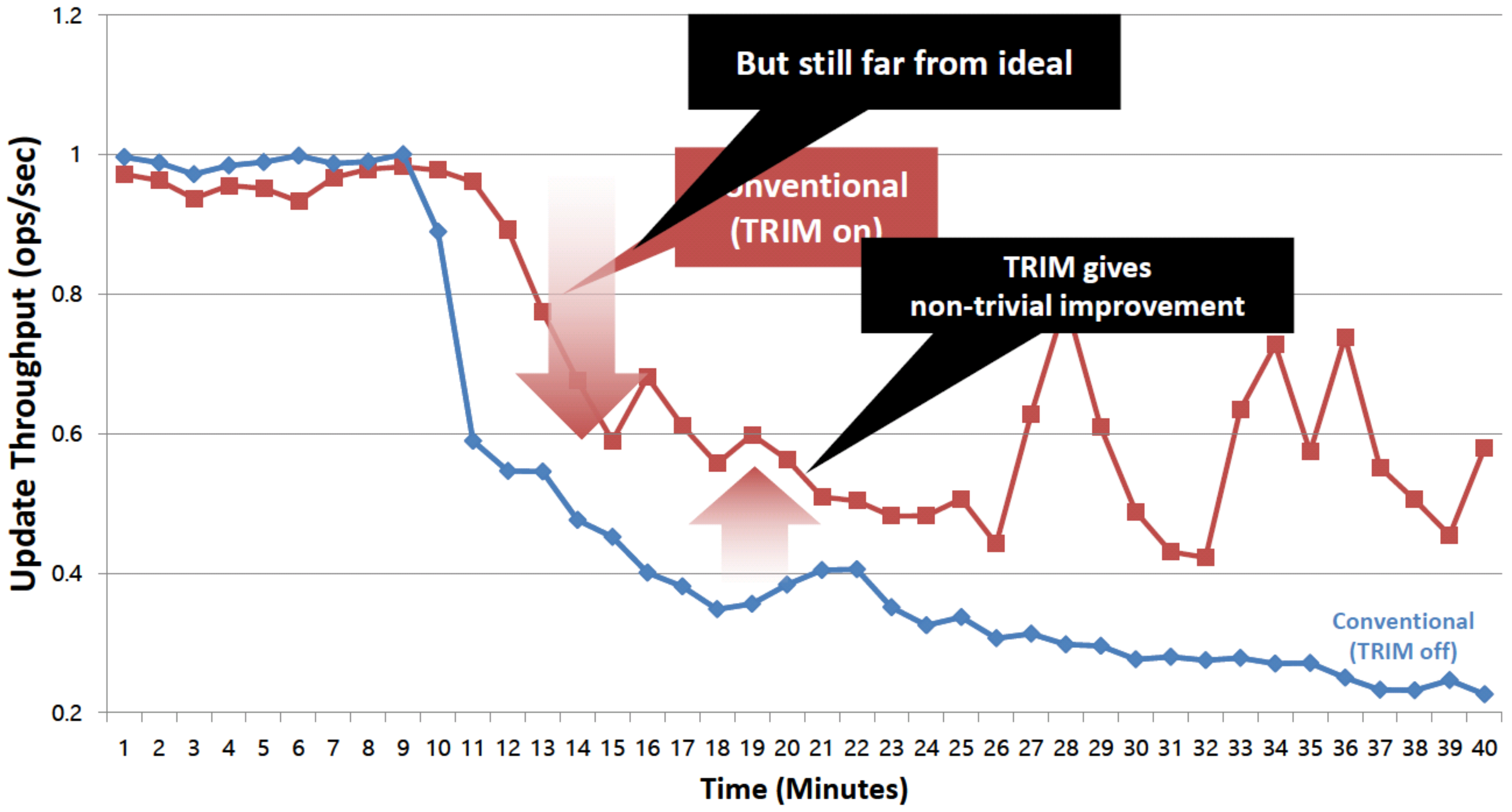
Results: Conventional

- Cassandra's normalized update throughput
  - Conventional "TRIM off"



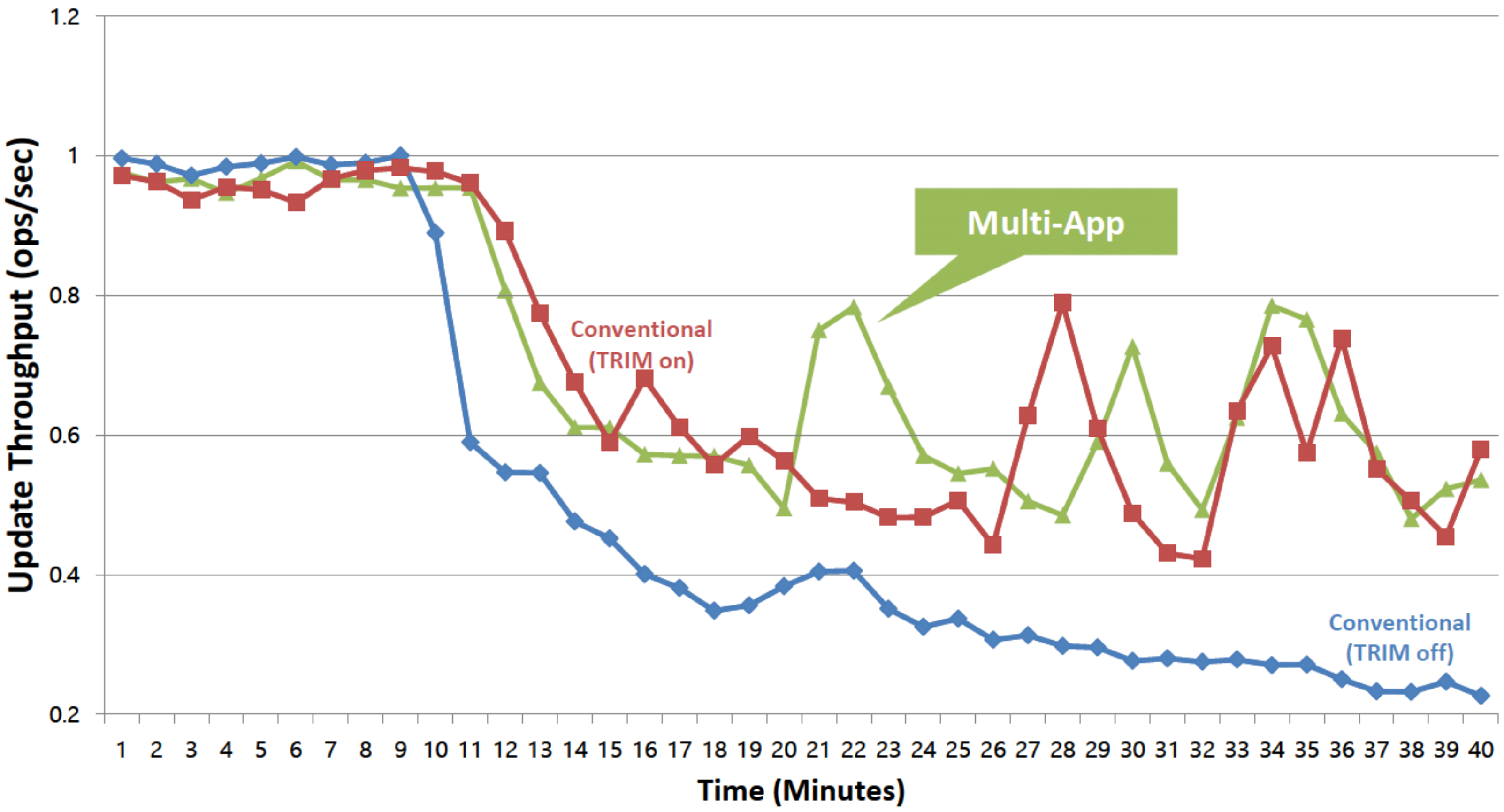
Results: Conventional with TRIM

- Cassandra's normalized update throughput
  - Conventional "TRIM on"



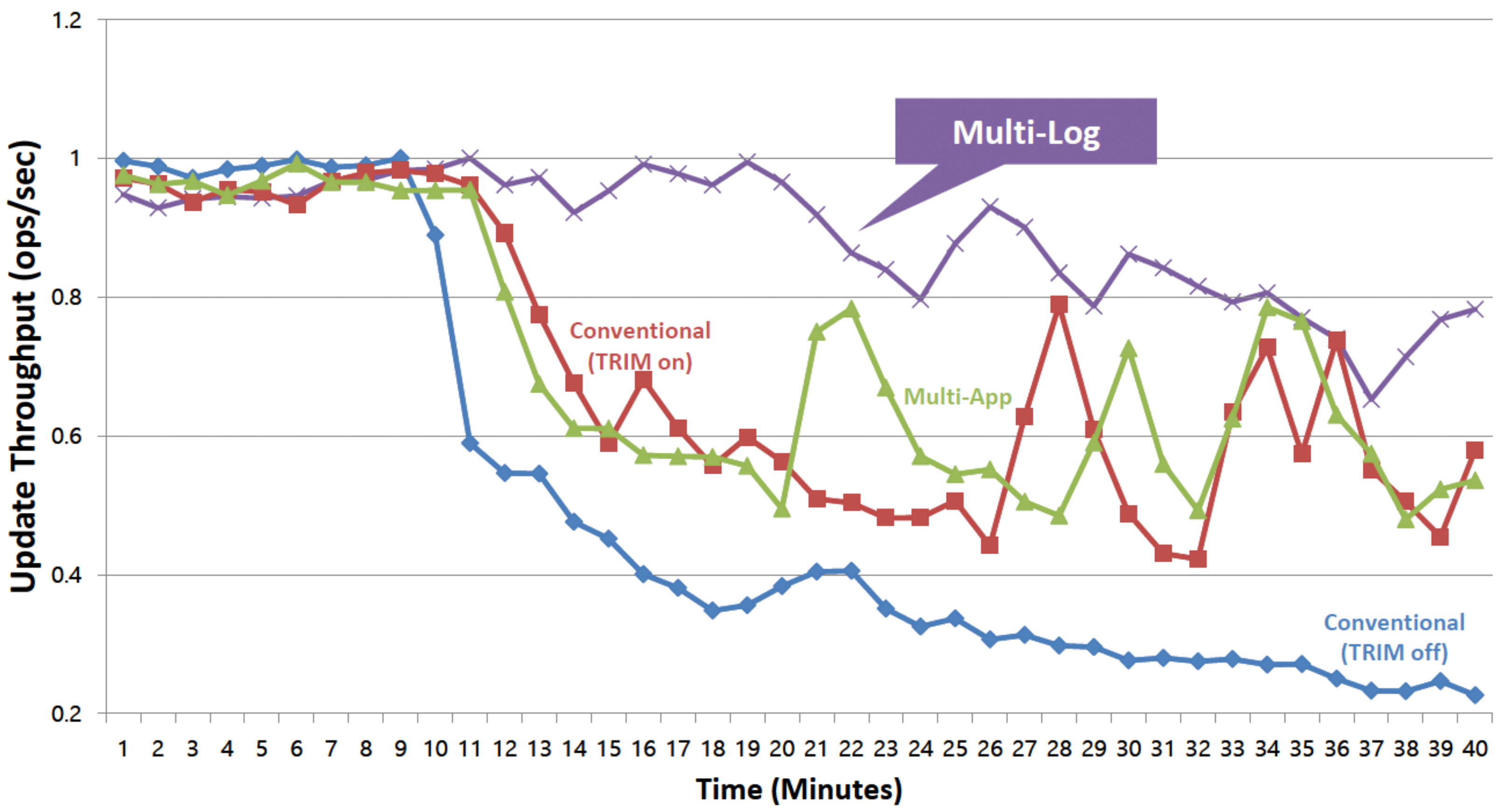
Results: Multi-App

- Cassandra's normalized update throughput
  - "Multi-App" (System data vs. Cassandra data)



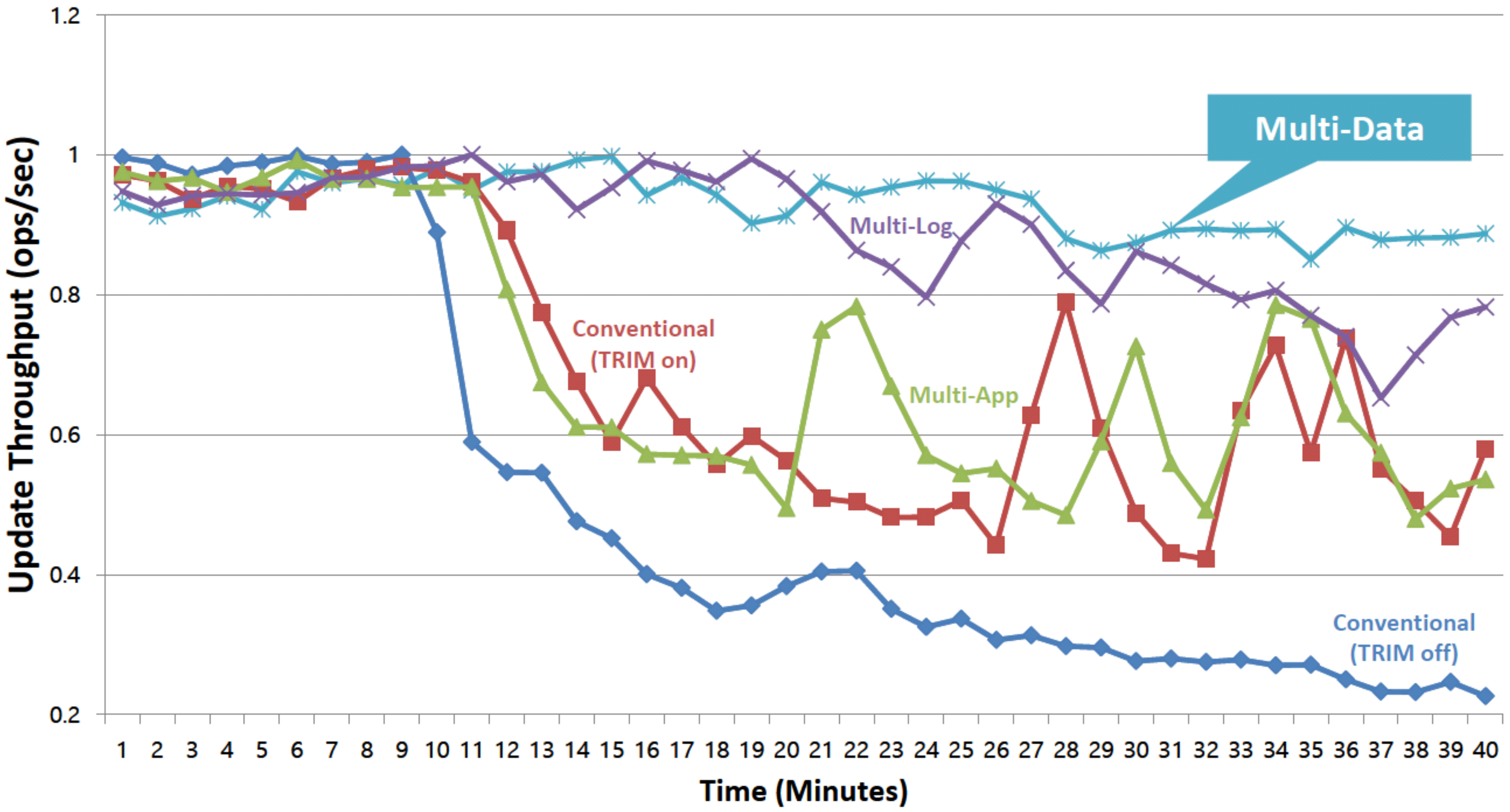
Results: Multi-Log

- Cassandra's normalized update throughput
  - "Multi-Log" (System data vs. Commit-Log vs. Flushed data)



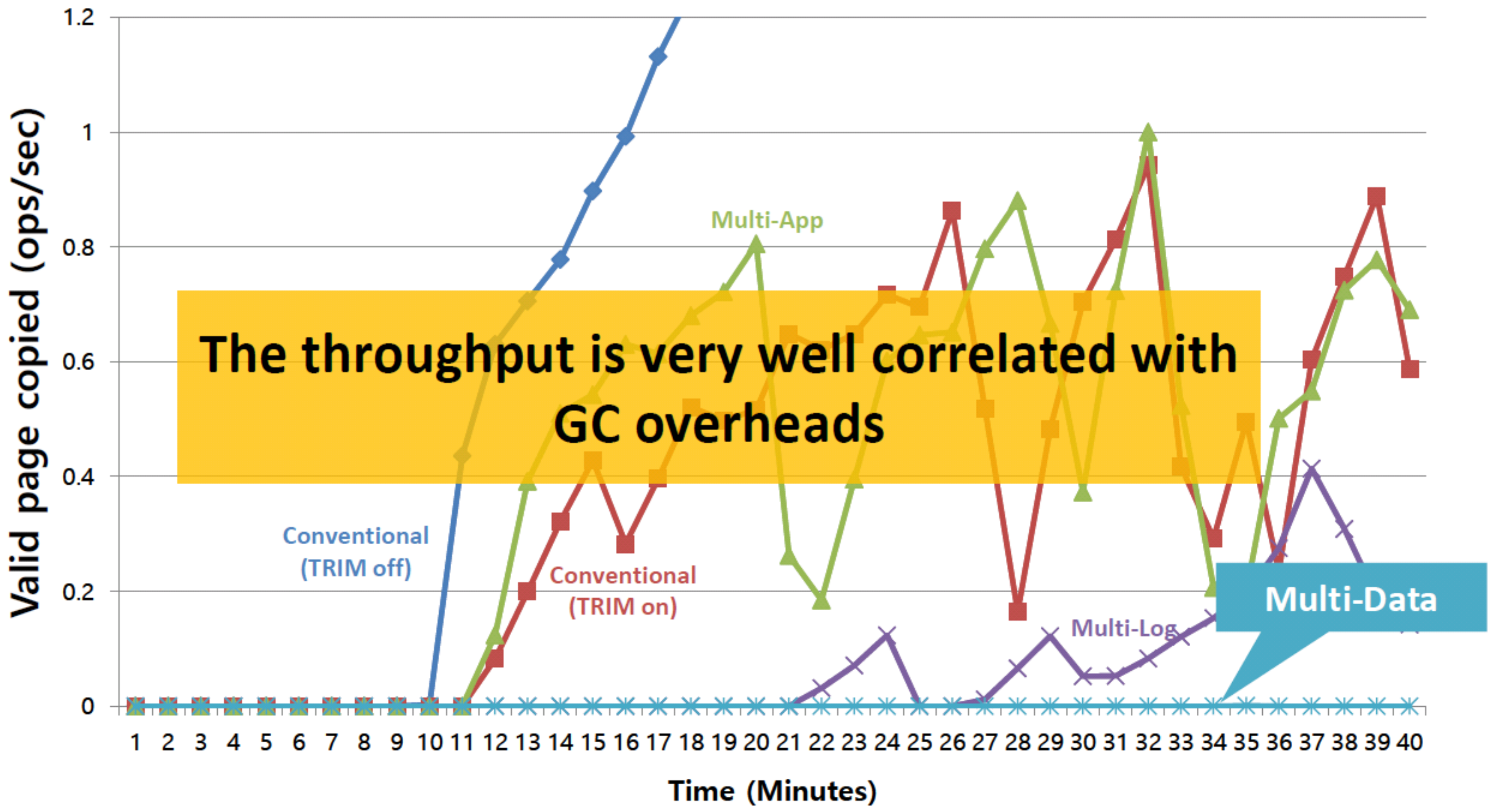
Results: Multi-Data

- Cassandra's normalized update throughput
  - "Multi-Data" (System data vs. Commit-Log vs. Flushed data vs. Compaction Data)



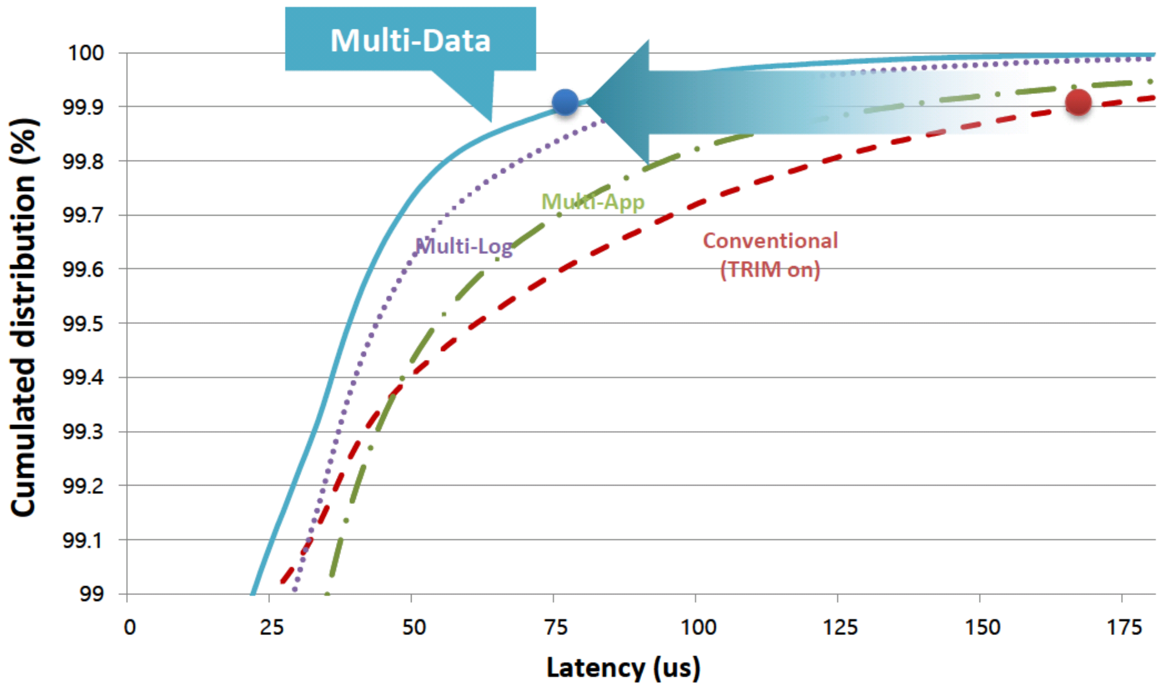
Results: GC Overheads

- Cassandra's GC overheads



Results: Latency

- Cassandra's cumulated latency distribution
  - Multi-streaming improves write latency
  - At 99.9%, Multi-Data lowers the latency by 53% compared to Normal



Summary

- Mapping application and system data with different lifetimes to SSD streams
  - Higher GC efficiency, lower latency
- Multi-streaming can be supported on a state-of-the-art SSD and co-exist with the traditional block interface

- Standardized in T10 SCSI (SAS SSDs) in 2015
- Standardized in NVMe 1.3 in 2017

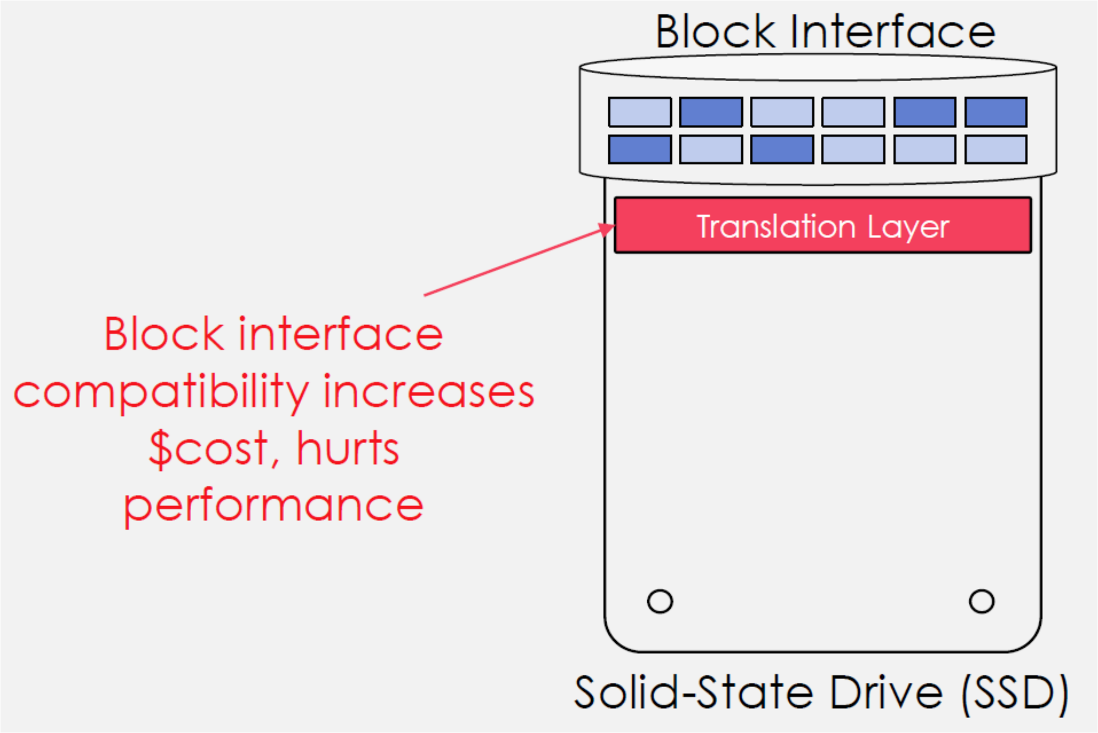
ZNS SSDs

(Matias Bjørling et al., USENIX ATC, 2021)

Some of slides are borrowed from the authors' presentation.

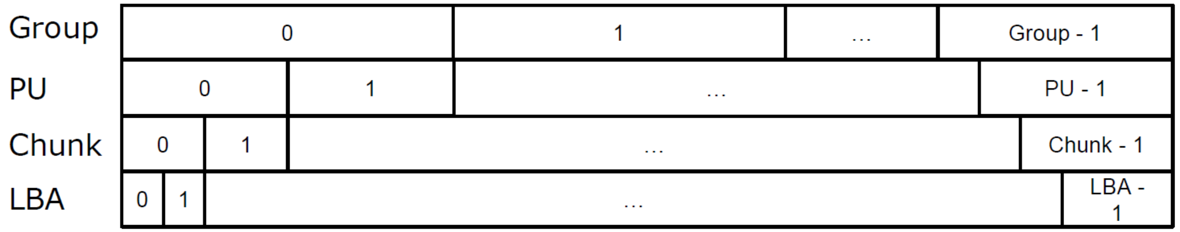
The Block Interface Tax

- For flash-based SSDs, the block interface is a poor fit
  - SSDs append pages to erase blocks, need to erase whole block before rewriting
- Data placement overhead
  - Media over-provisioning (7 ~ 28%)
  - Higher cost
  - Write amplification
  - Unpredictable latency
  - No isolation



History

- Baidu's Software Defined Flash (SDF) [ASPLOS '14, EuroSys '14]
  - Expose a channel as an independent device
- OCSSD 1.2
  - Physical Page Addressing: Channel, LUN (die), Plane, Block, Page, Sector
  - Exposes flash read/program/erase timings and MLC page pairing information
  - Everything in the host
- OCSSD 2.0 [FAST '17]
  - Physical Page Addressing: Group (channel), LUN (PU), Chunk, Logical block
  - Read/write/reset commands
  - Write sequentially within a chunk
  - Media management in the drive

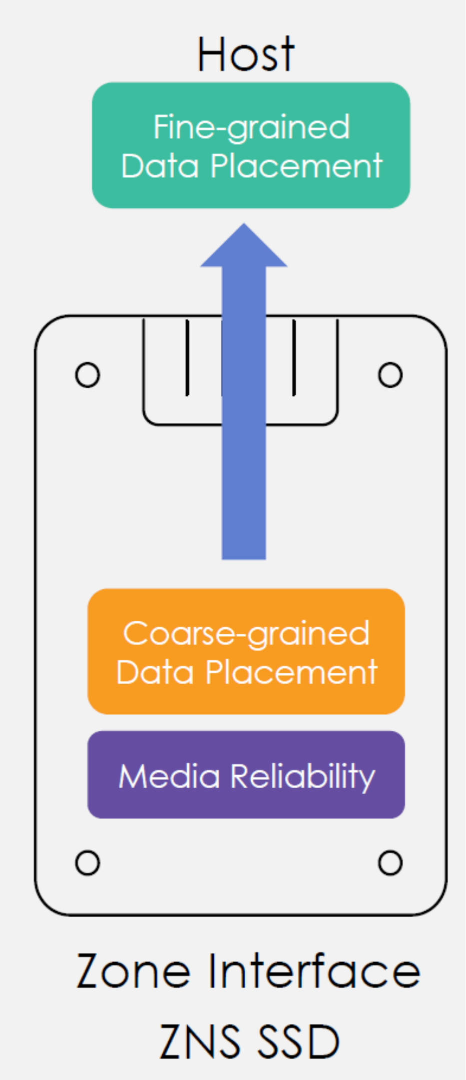


ZNS SSDs

- Sequential zone writes onto distinct erase blocks
  - Random writes are disallowed
  - Zones must be explicitly reset by the host
  - Data placement occurs at the coarse-grained level of zones

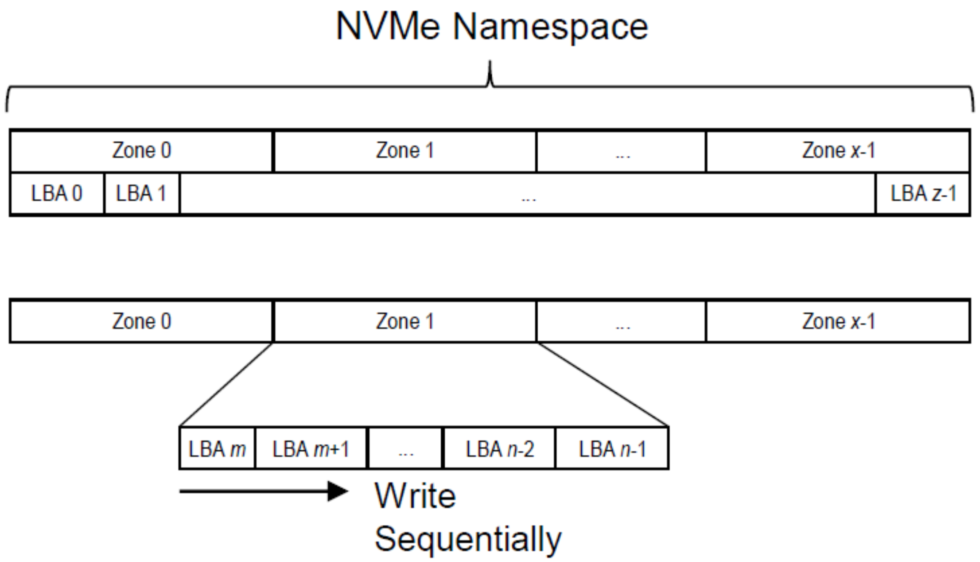
- ZNS SSDs relinquish GC responsibilities
  - GC of zones becomes the responsibility of the host

- Media reliability continues to be the full responsibility of the SSD



Zoned Storage Model

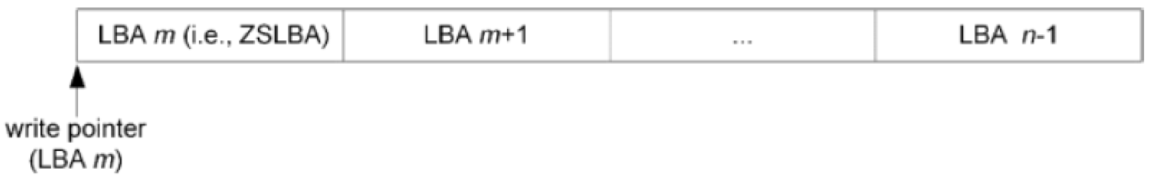
- Zones are laid out sequentially in an NVMe namespace
- The zone size is fixed and applies to all zones in the namespace
  - e.g., 512 MiB
- The command set inherits the NVMe Command Set
  - Built upon the conventional block interface (Read, Write, Flush and other commands)
  - Adds rules to collaborate on host and device data placement



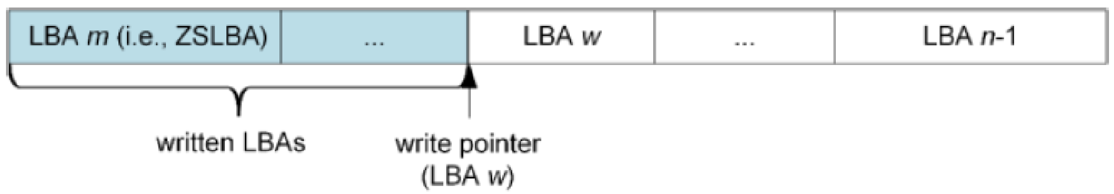
Writing to a Zone

- "Sequential Write Required"
  - Must be written sequentially
  - Must be reset if written to again
- Each zone has a set of associated attributes:
  - Write pointer
  - Zone starting LBA
  - Zone capacity
  - Zone state
- Very similar to writing zones with host-managed SMR HDDs

Empty Zone

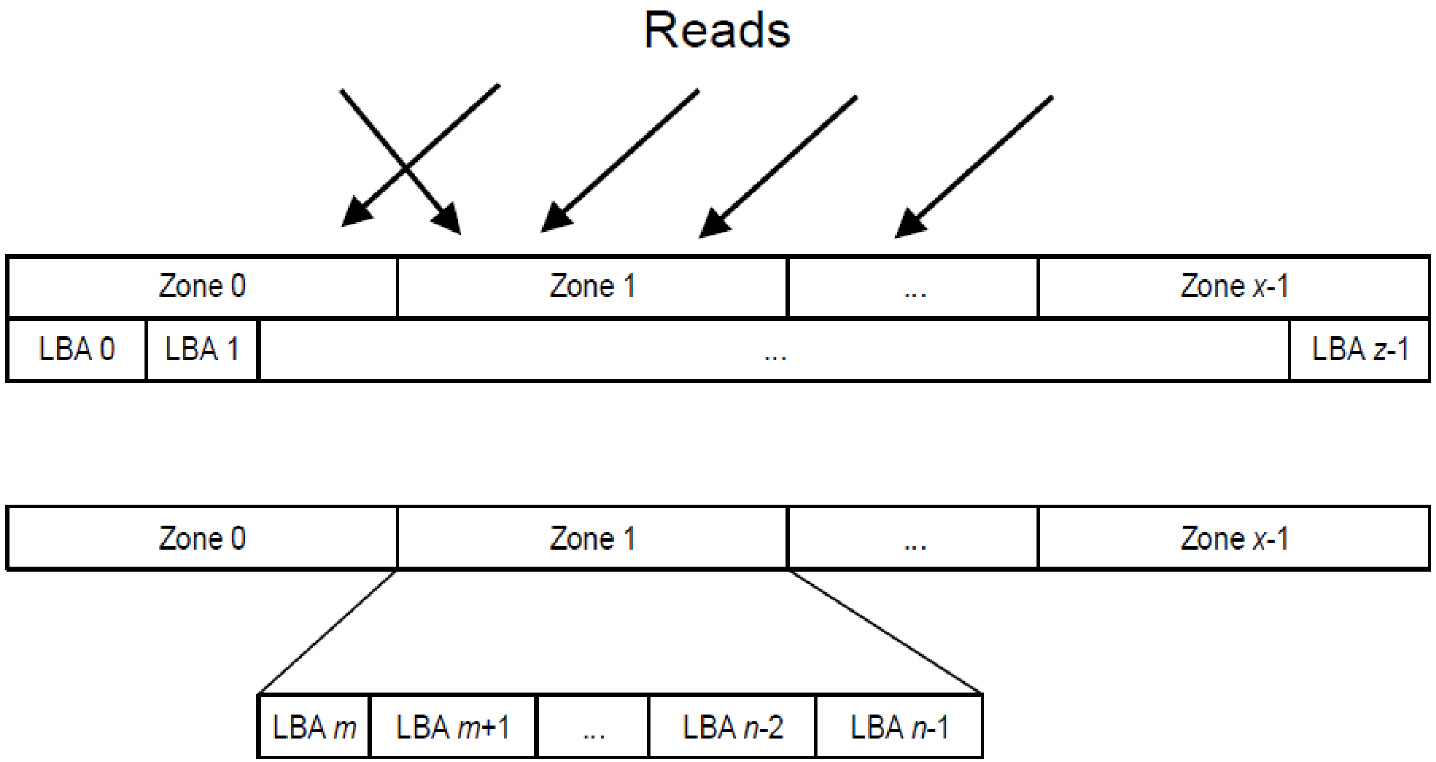


Partially Written Zone



Reading from a Zone

- Writes are required to be sequential within a zone
- Reads may be issued to any LBA within a zone and in any order



SMR HDDs and ZNS SSDs

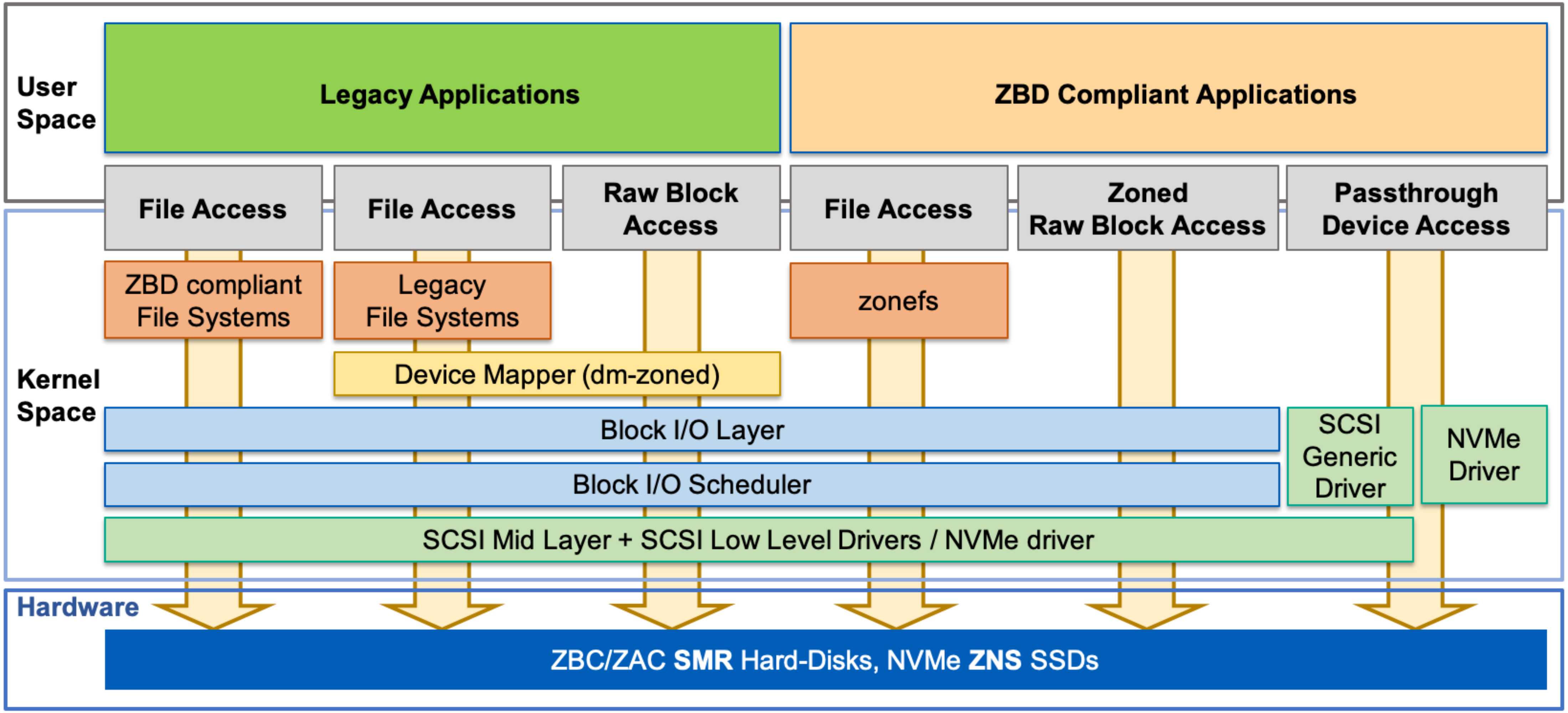
- Host-managed SMR HDDs
  - Implements the SMR (ZAC/ZBC) specifications
  - ZAC: Zoned Device ATA Command Set in T13/SATA
  - ZBC: Zoned Block Commands in T10/SAS

- NVMe ZNS SSDs
  - Implement the Zoned NameSpace Command Set specification
  - Aligned with ZAC/ZBC to allow interoperability

- A single unified software stack support both storage types
  - Utilizes the already mature Linux storage stack built for SMR HDDs

Image from https://blog.westerndigital.com/what-is-zoned-storage-initiative/

Linux Zoned Block Device Support



https://zonedstorage.io/linux/overview/

Use Cases

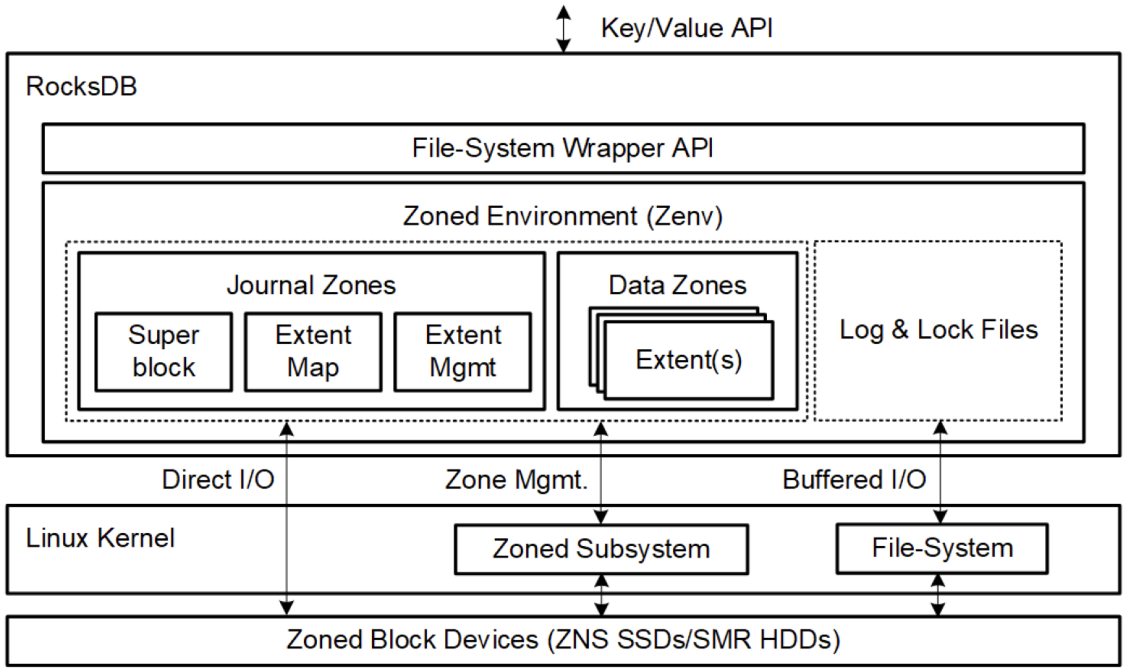
- **Host-side FTL**
  - Exposes the ZNS SSD as a conventional block SSD
  - High system overhead (DRAM and CPU)
  - For workloads with random write characteristics

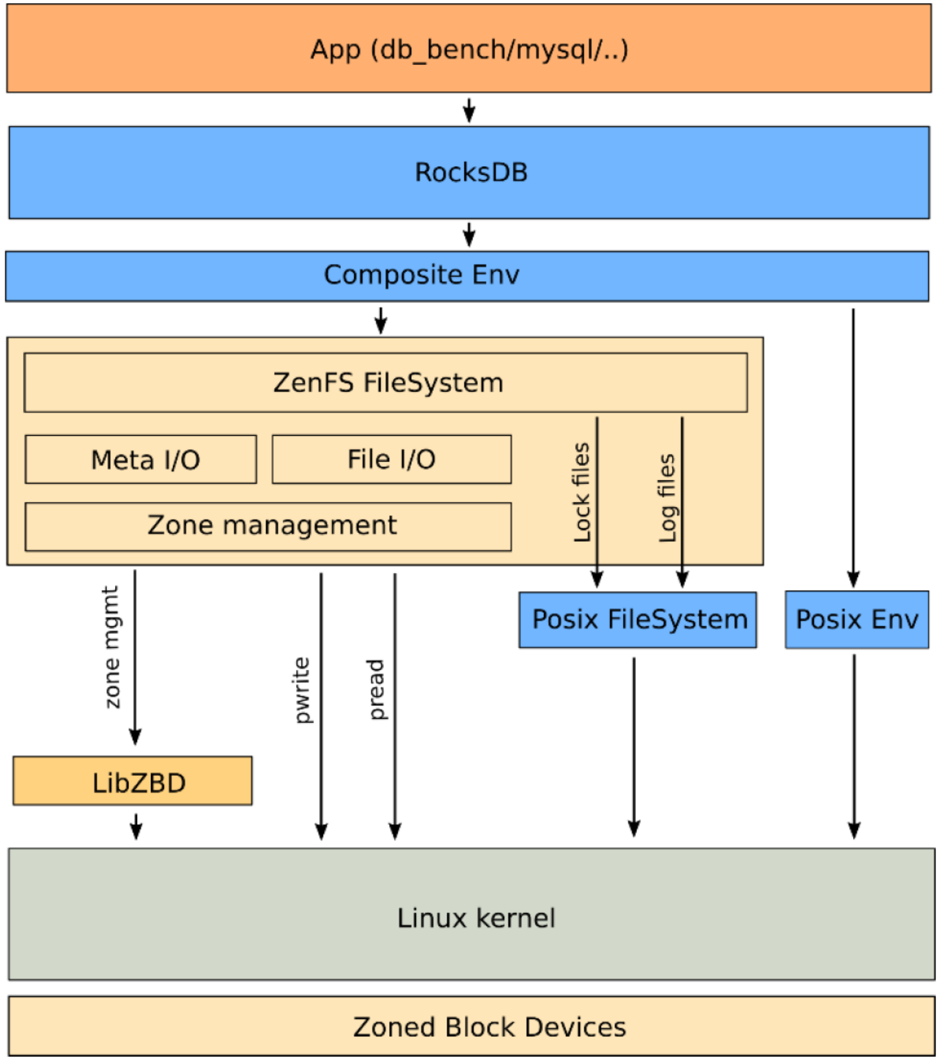
- **File systems**
  - ZNS SSD-aware file systems (e.g., f2fs + zones)
  - Efficient use of resources
  - Some inefficient data placement causes host GC

- **End-to-end data placement**
  - Application-specific data placement (e.g., RocksDB + ZenFS)
  - No indirection overhead caused by FTL nor file system
  - Highest performance, lowest write amplification

RocksDB on ZNS SSD

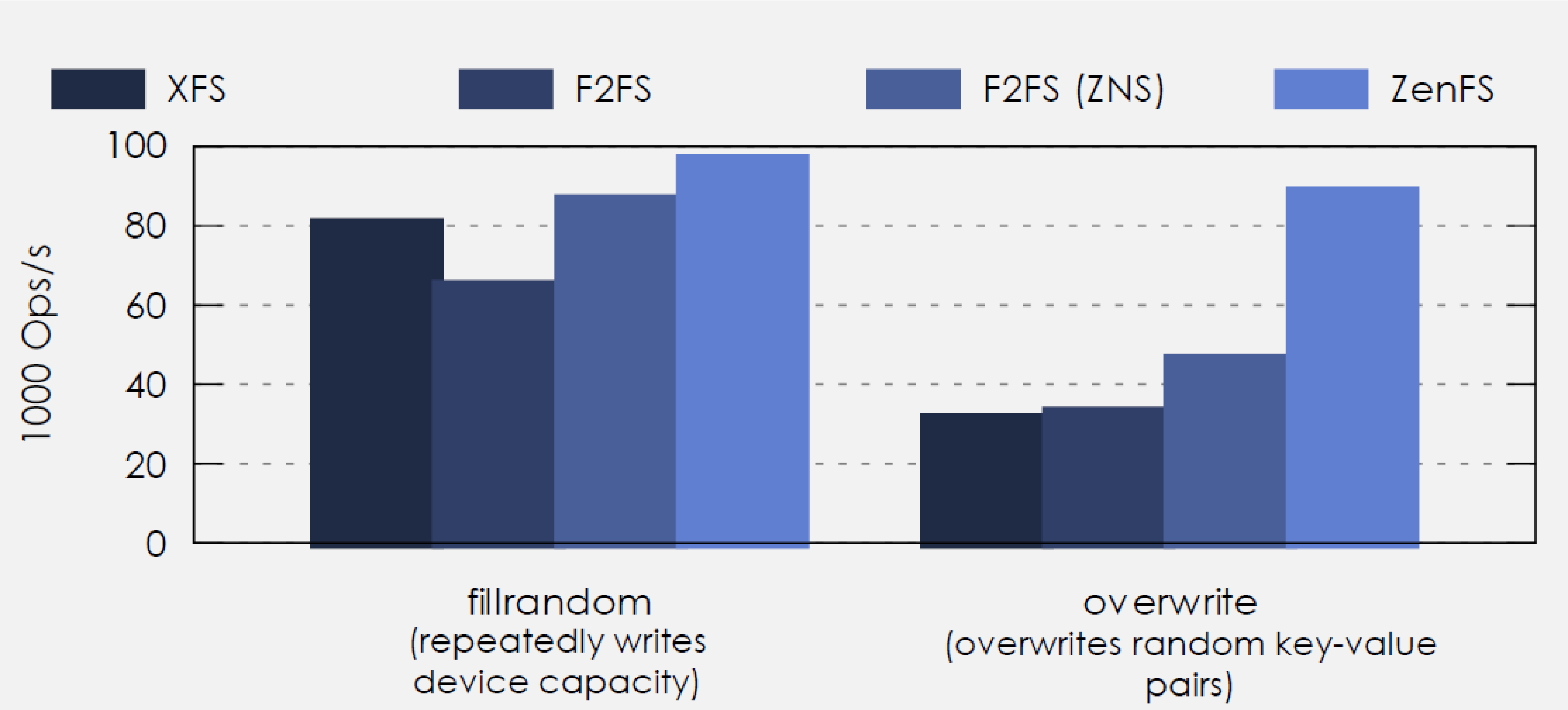
- ZenFS
  - A storage backed for RocksDB
  - Extent-based
  - No GC





RocksDB: Writes

- Double the throughput over 28% OP SSDs
- Write amplification: ZNS 1.0x, XFS 2.0x, vanilla F2FS 2.4x



Summary: ZNS SSD

- ***What's good?***

- ***What's bad?***