The Multi-streamed Solid-State Drive

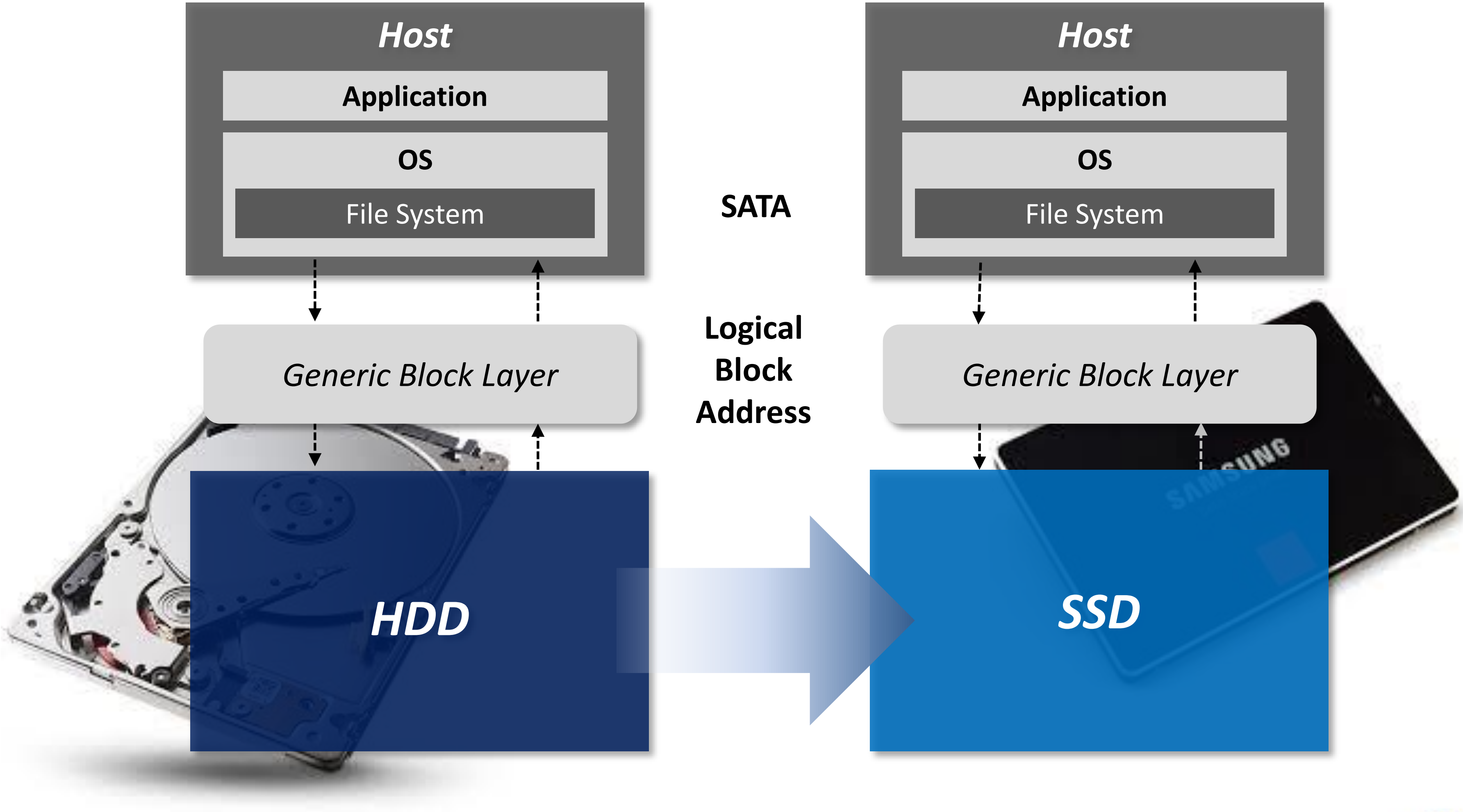
Jeong-Uk Kang, Jeeseok Hyun, Hyunjoo Maeng*, and Sangyeun Cho

Memory Solutions Lab.
Memory Division, Samsung Electronics Co., Ltd

SSD as a Drop-in Replacement of HDD

SSD shares a common interface with HDD

- The block device abstraction paved the way for wide adoption of SSDs



Host

Application

OS

File System

Generic Block Layer

HDD

SATA

Logical Block Address

Host

Application

OS

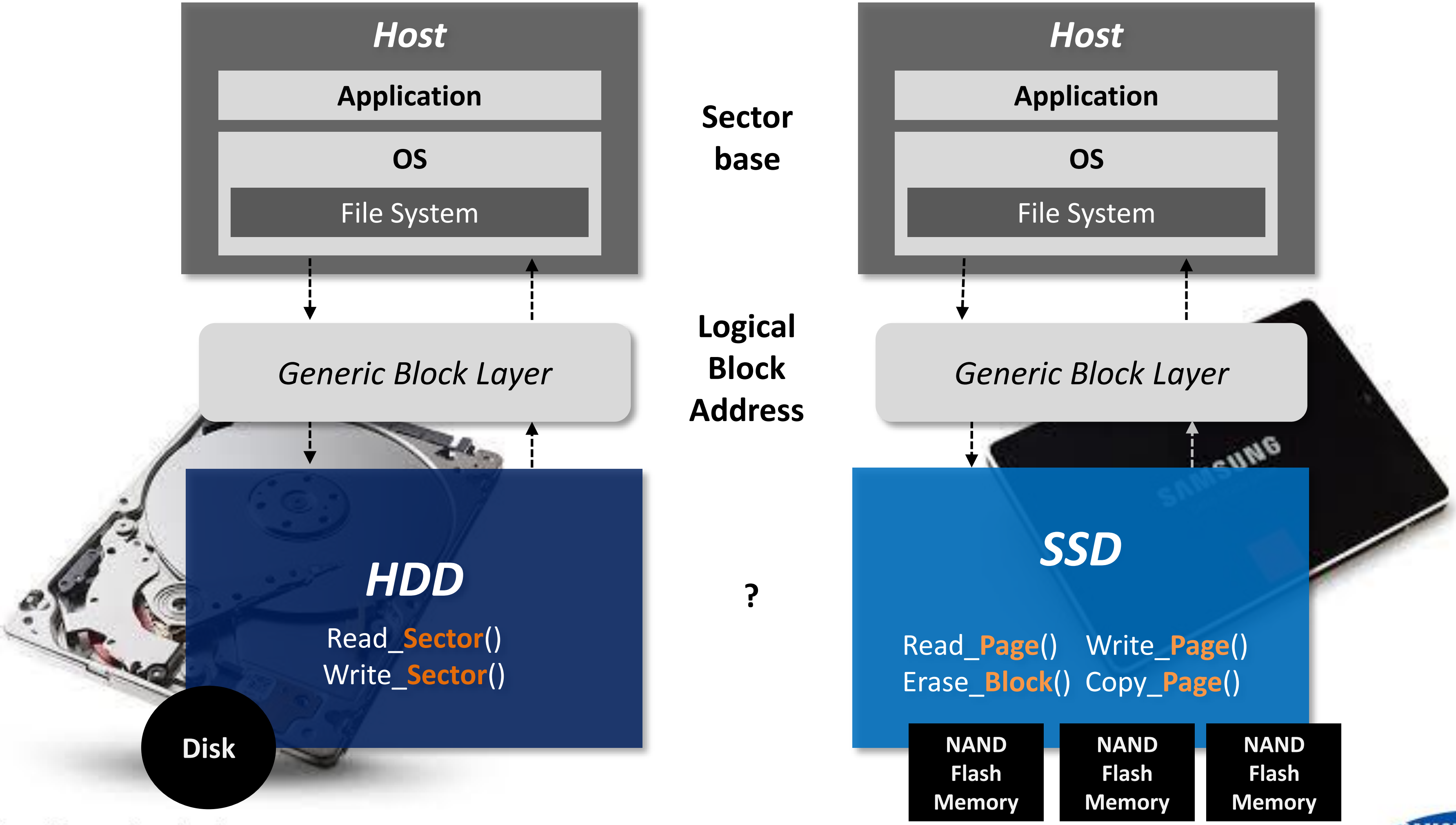
File System

Generic Block Layer

SSD

Great, BUT…

- **Rotating media and NAND flash memory are very different!**



Host

Application

OS

File System

Generic Block Layer

HDD

Read_Sector()
Write_Sector()

Disk

Sector base

Logical Block Address

?

Host

Application

OS

File System

Generic Block Layer

SSD

Read_Page() Write_Page()
Erase_Block() Copy_Page()

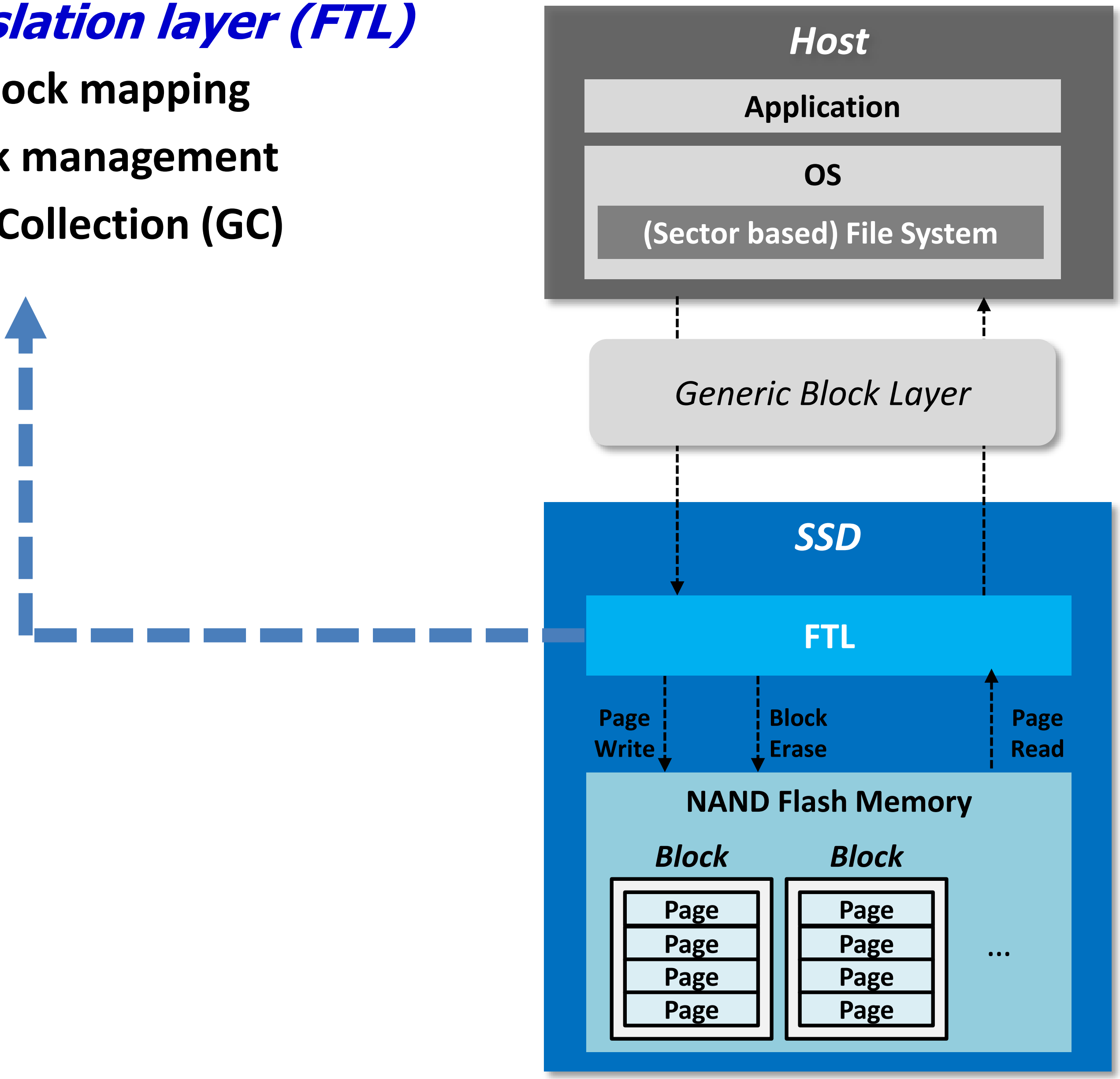
NAND Flash Memory

NAND Flash Memory

NAND Flash Memory

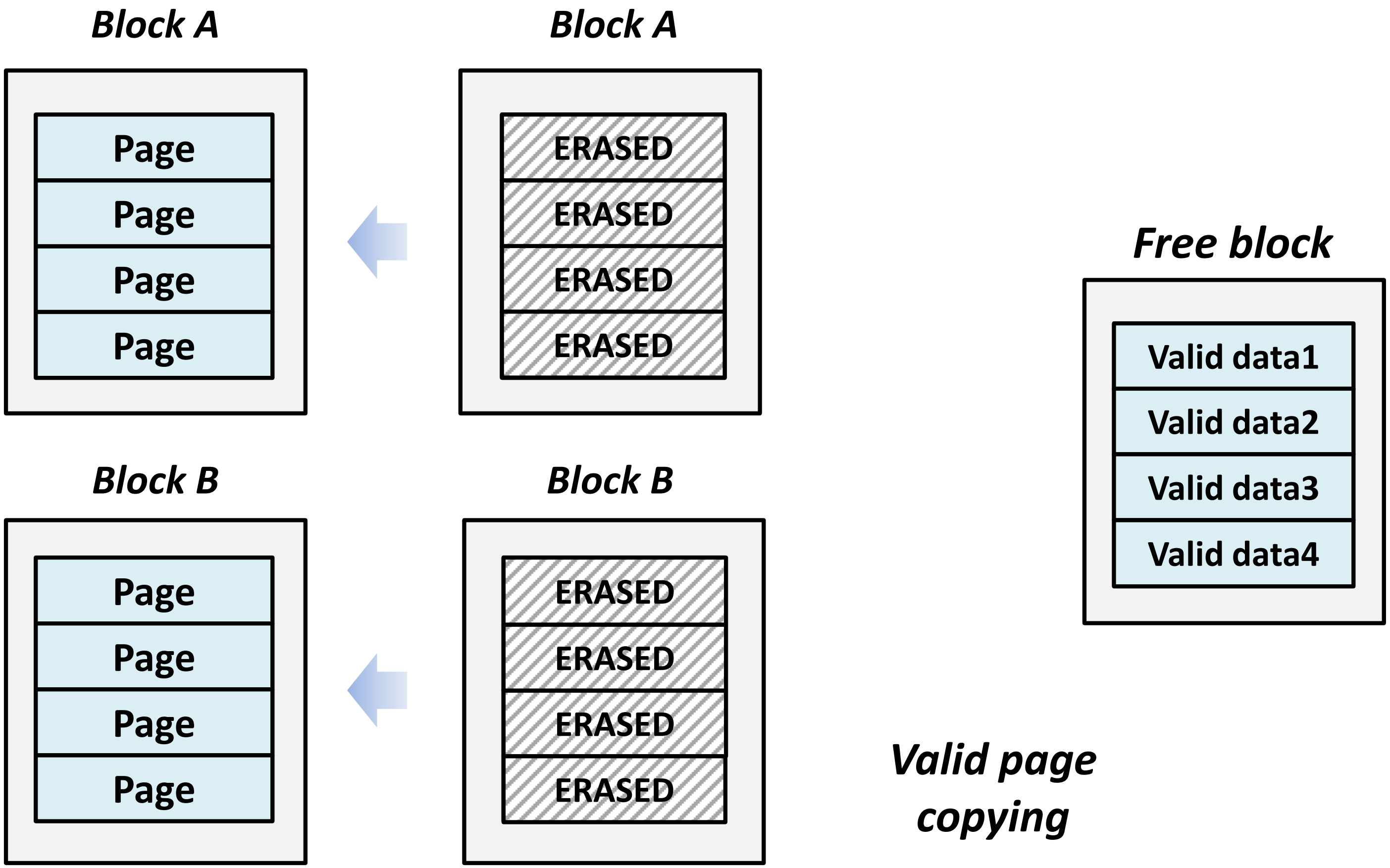
The Trick is FTL!

- ***Flash translation layer (FTL)***
  - Logical block mapping
  - Bad block management
  - Garbage Collection (GC)



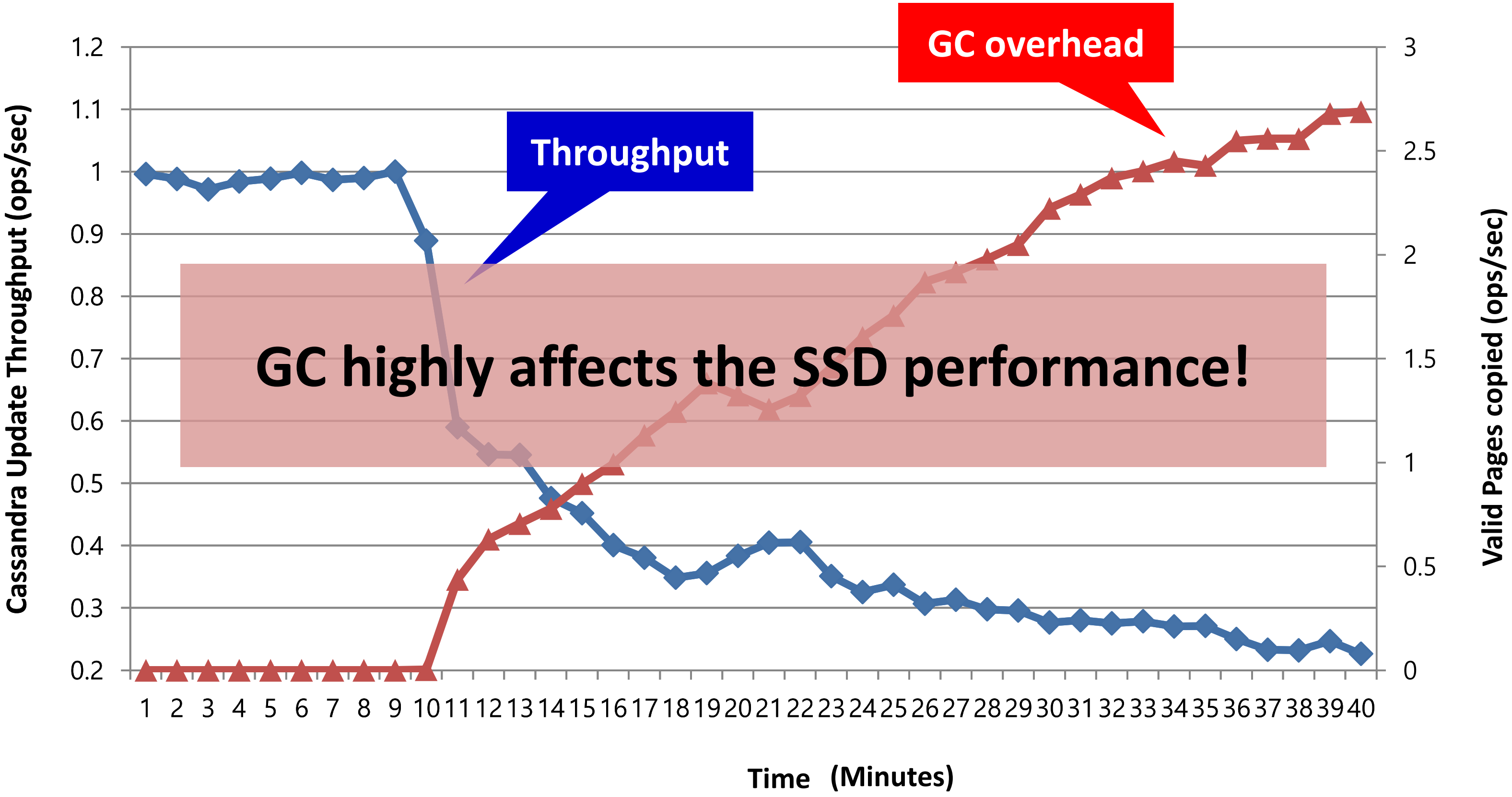
Garbage Collection (GC)

- **GC reclaims space to prepare new empty blocks**
  - NAND's "erase-before-update" requirement ⇒ Valid page copying followed by an erase operation
  - Has a large impact on SSD lifetime and performance



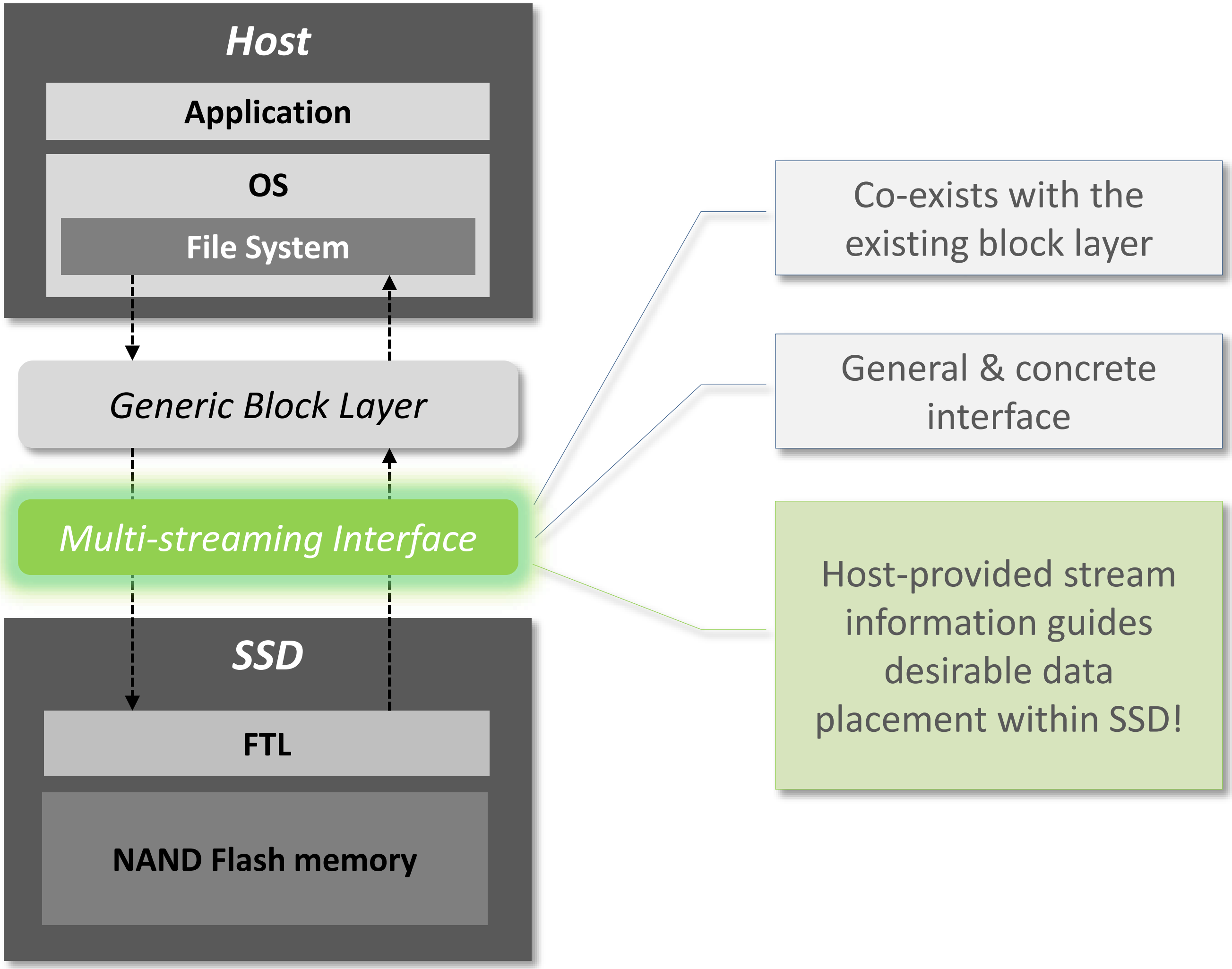
GC is Expensive!

- **Performance of SSD gradually decreases as time goes on**
  - **Example: Cassandra update throughput**



GC highly affects the SSD performance!

Our Idea: Multi-streamed SSD



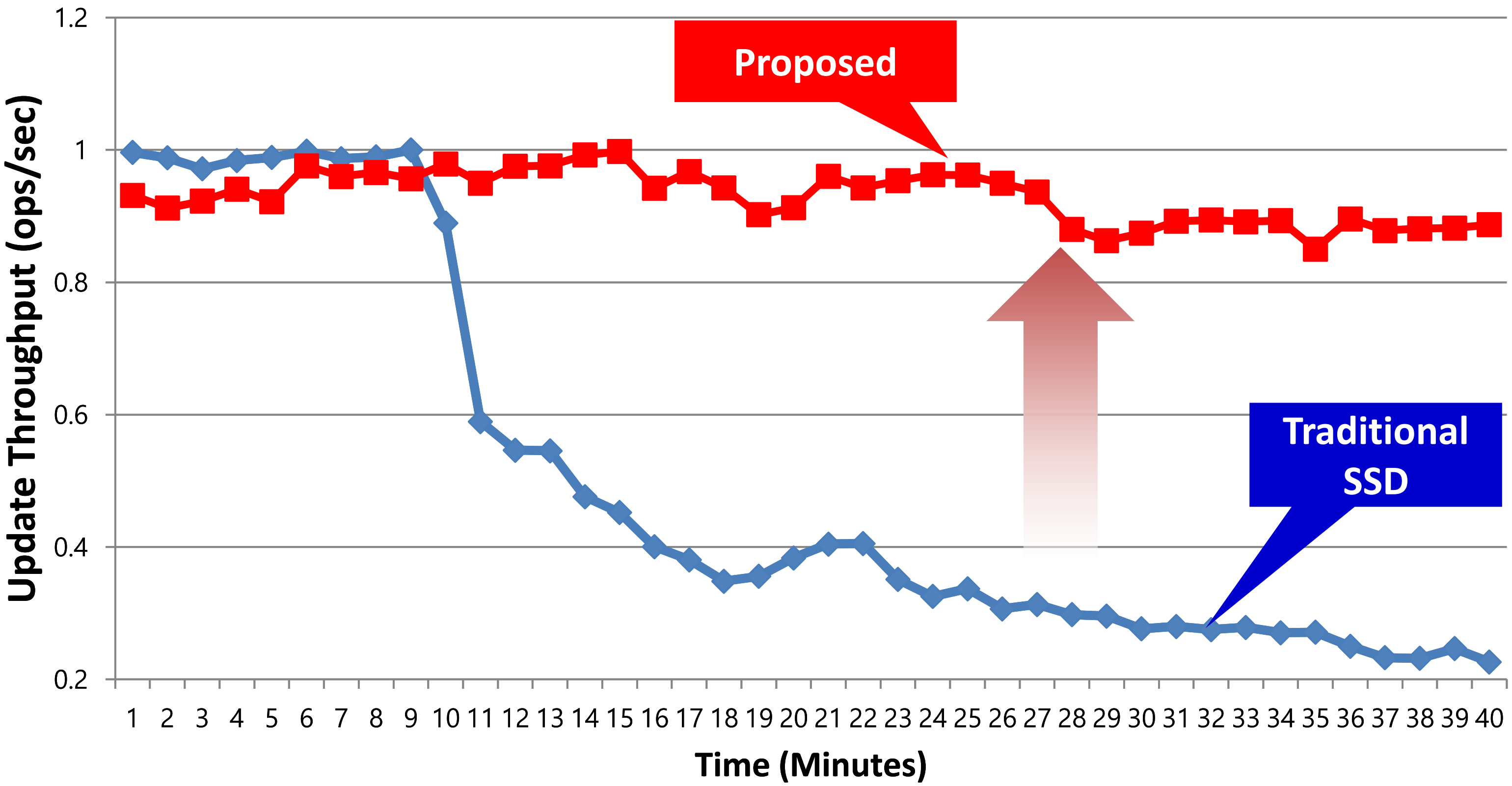
Co-exists with the existing block layer

General & concrete interface

Host-provided stream information guides desirable data placement within SSD!

End Result

- **The multi-streamed SSD can sustain Cassandra update throughput**



Contents

Background

- Write optimization in SSD

The Multi-streamed SSD

- Our approach
- Case study

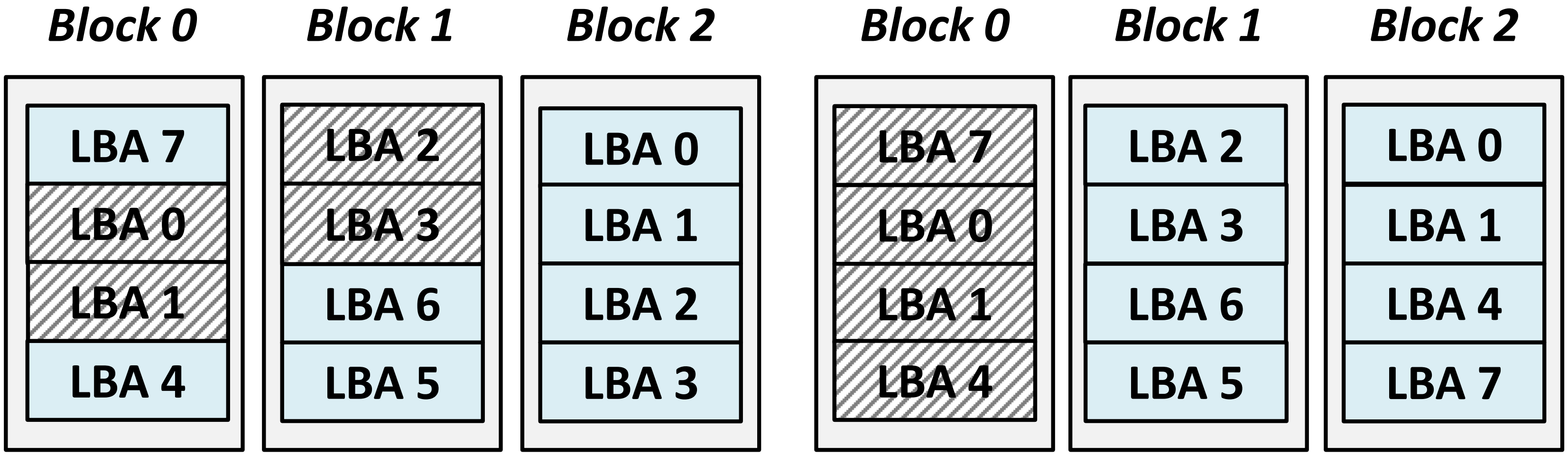
Evaluation

- Experimental setup
- Results

Conclusion

Effects of Write Patterns

- **Previous write patterns (=current state) matter**



Block 0	*Block 1*	*Block 2*
LBA 7	▨ LBA 2	LBA 0
▨ LBA 0	▨ LBA 3	LBA 1
▨ LBA 1	LBA 6	LBA 2
LBA 4	LBA 5	LBA 3

Sequential LBA updates into Block 2

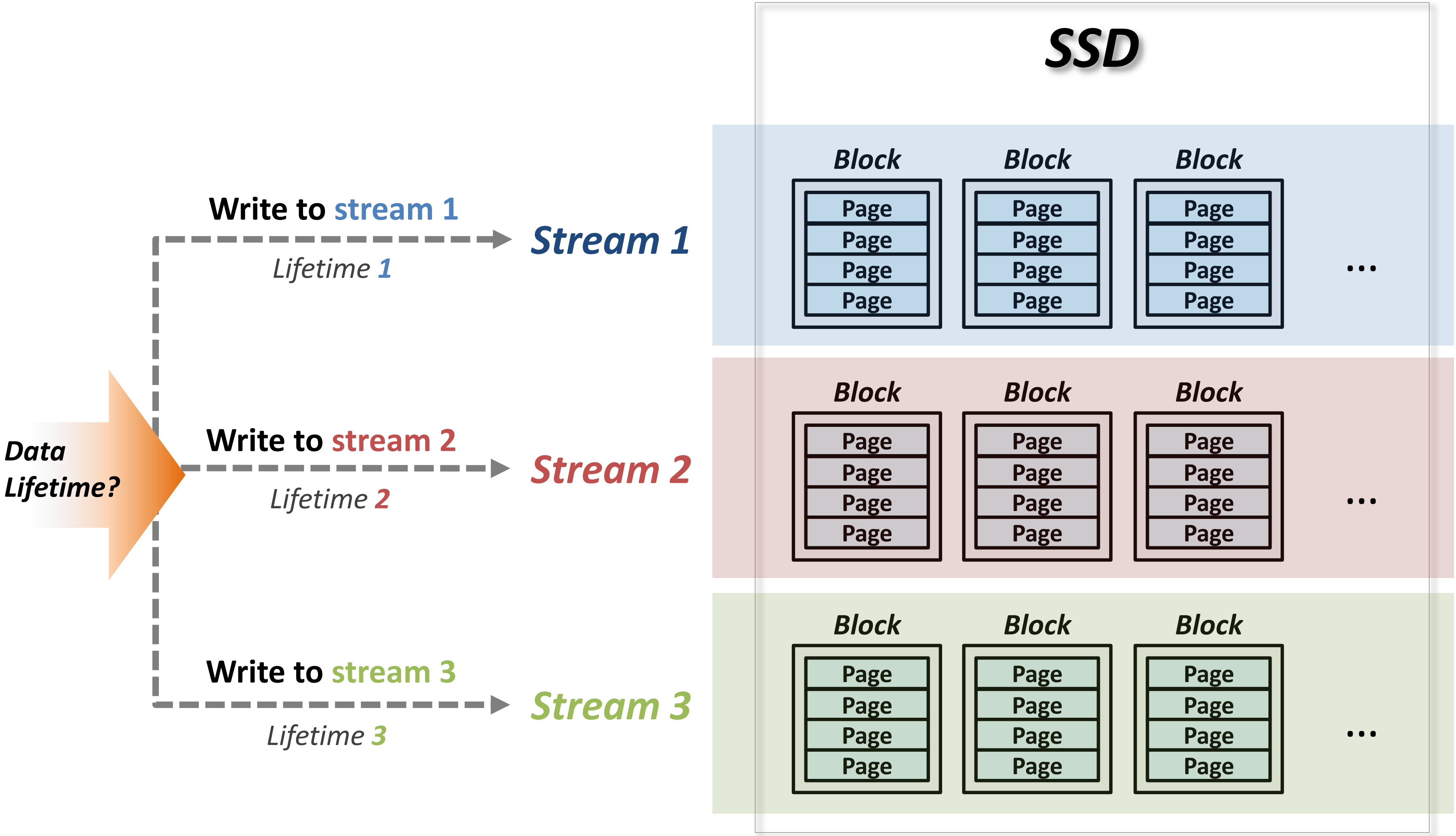
Need valid page copying from Block 0 & Block 1

Block 0	*Block 1*	*Block 2*
▨ LBA 7	LBA 2	LBA 0
▨ LBA 0	LBA 3	LBA 1
▨ LBA 1	LBA 6	LBA 4
▨ LBA 4	LBA 5	LBA 7

Random LBA updates into Block 2

Just erase Block 0

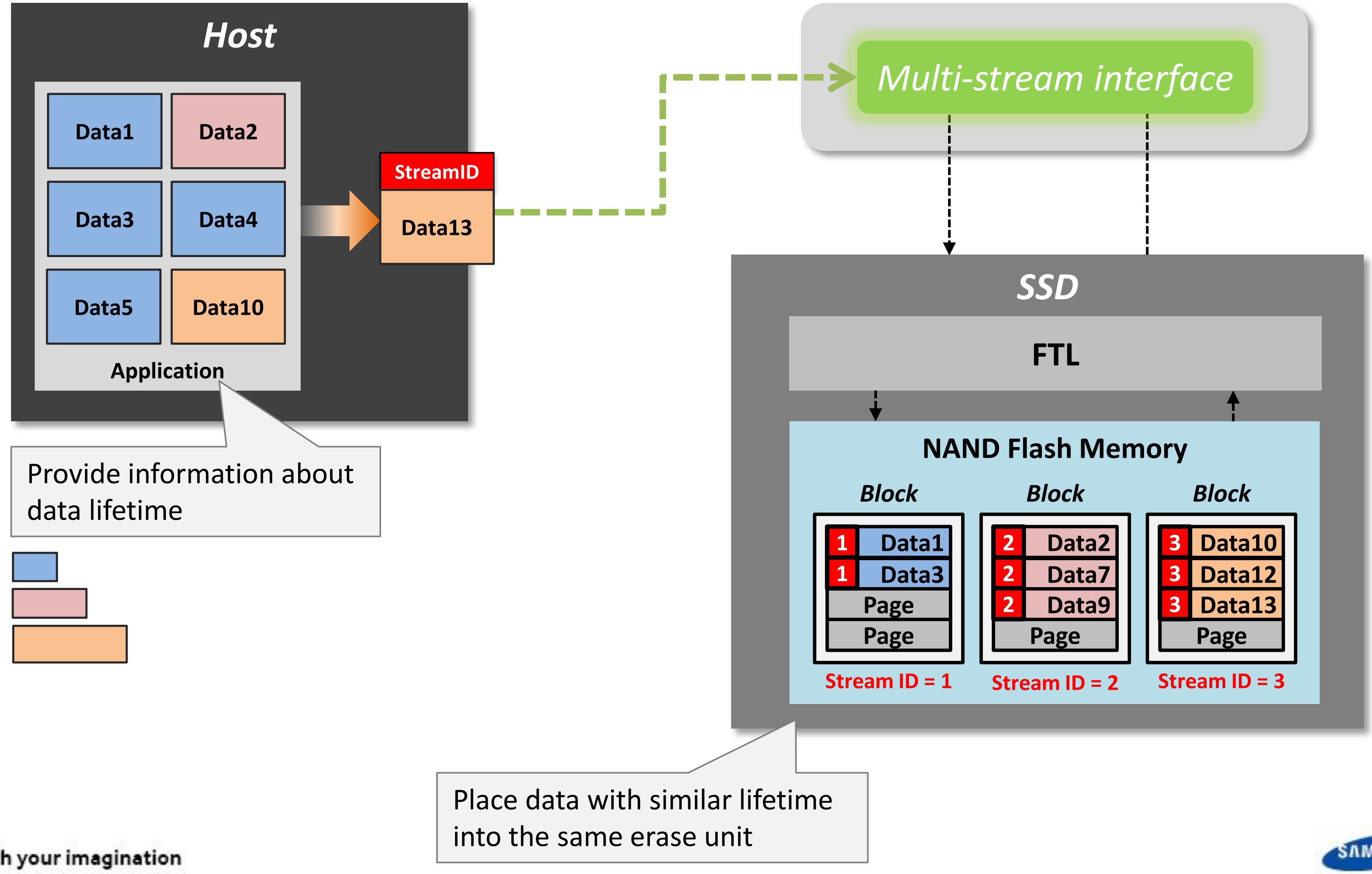
Stream


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

The Multi-streamed SSD

Multi-streamed SSD

- Mapping data with different lifetime to different streams



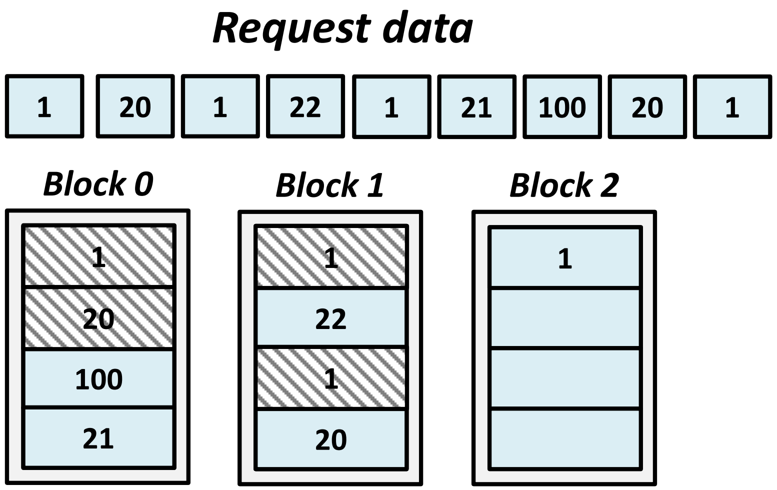
Provide information about data lifetime

Place data with similar lifetime into the same erase unit

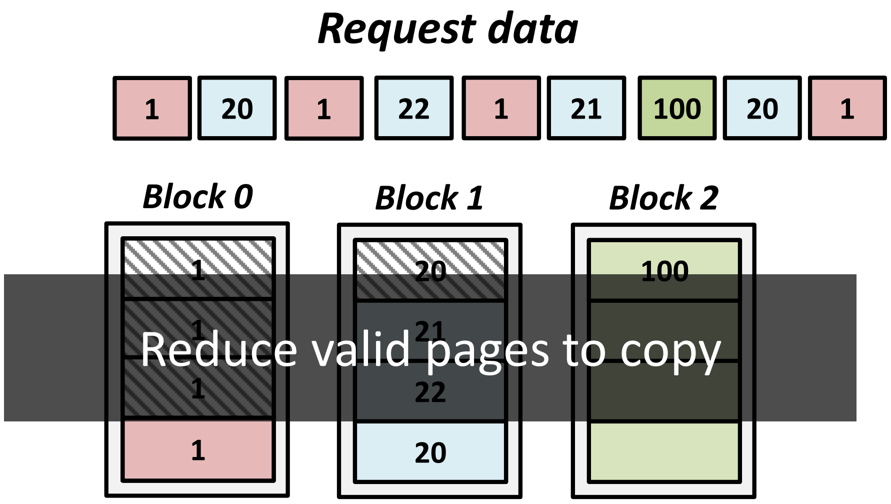
Working Example

Multi-streamed SSD

- High GC efficiency (Reduce GC overheads) → effects on Performance!



Without Stream



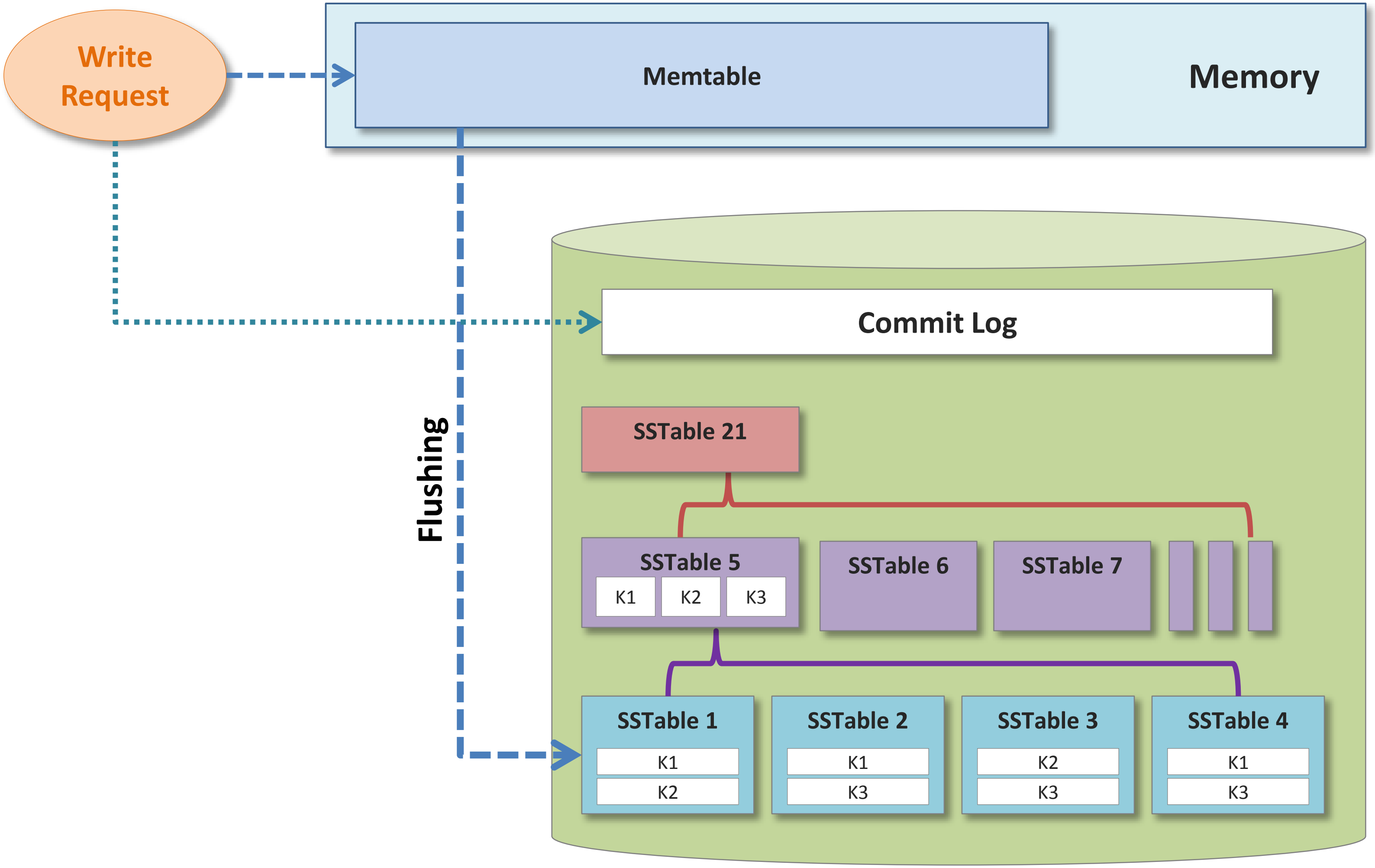
Reduce valid pages to copy

Multi-Stream

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

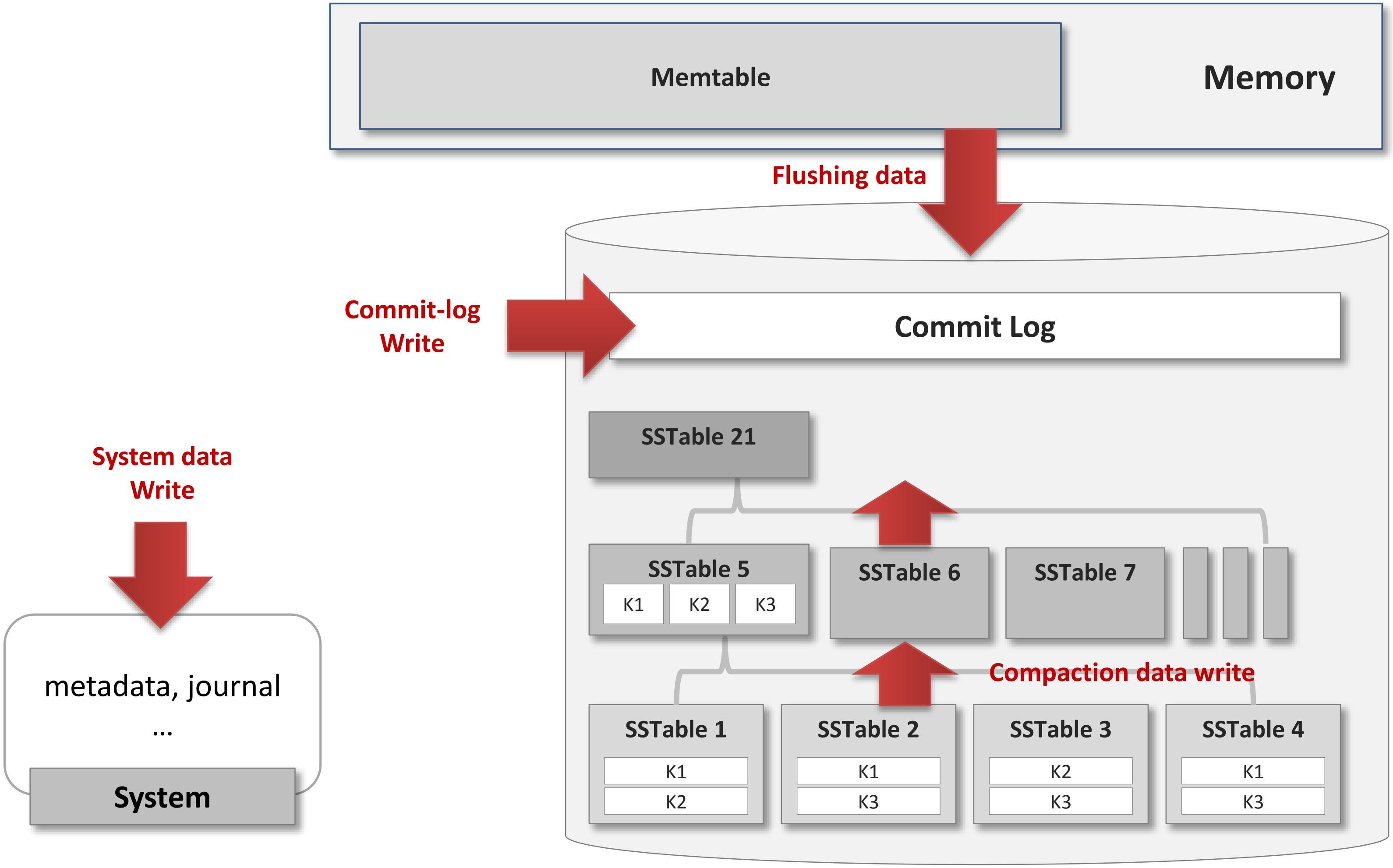
Case Study: Cassandra

- **Cassandra employs a size-tiered compaction strategy**



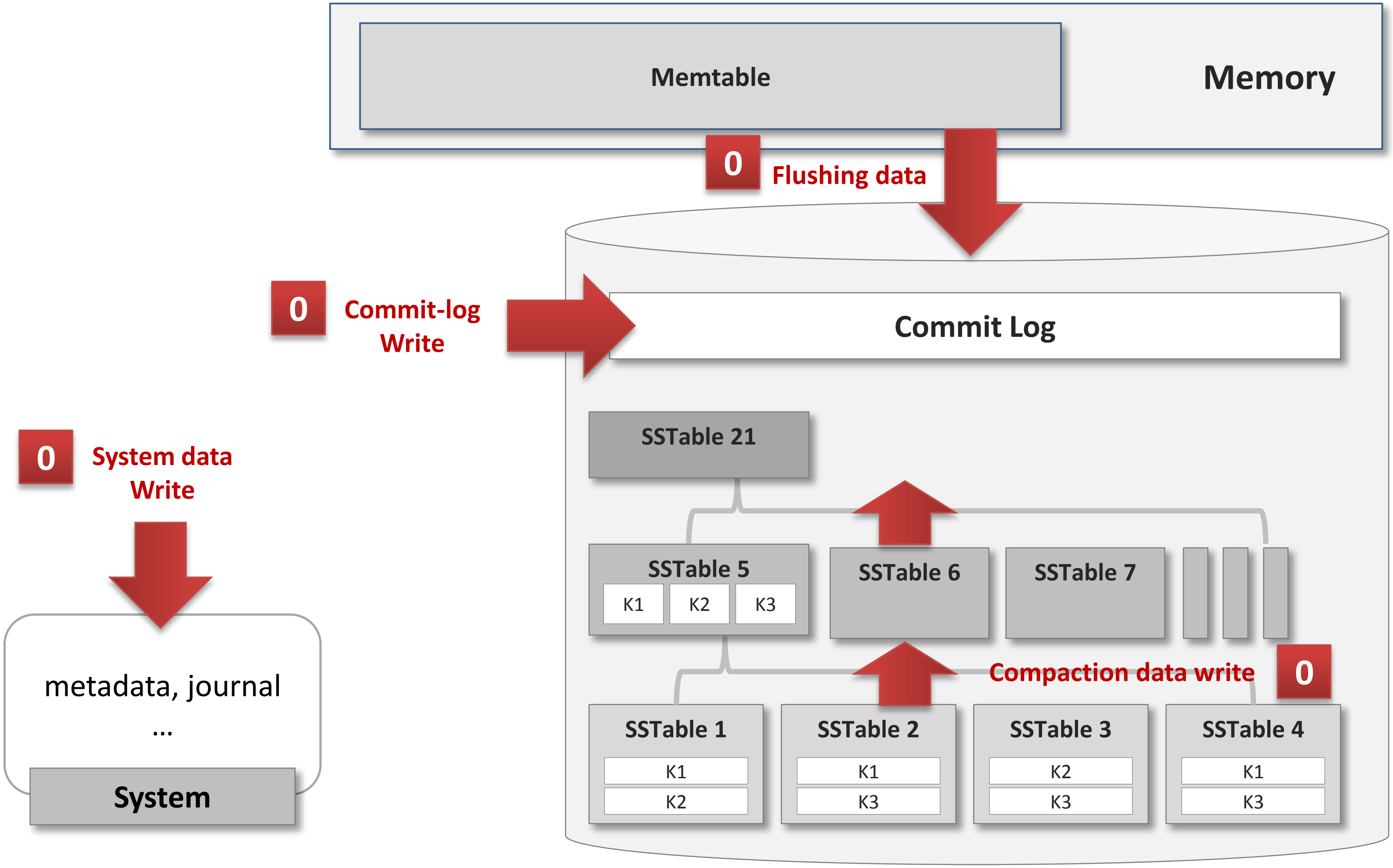
Summary of Cassandra's Write Patterns

- **Write operations when Cassandra runs**



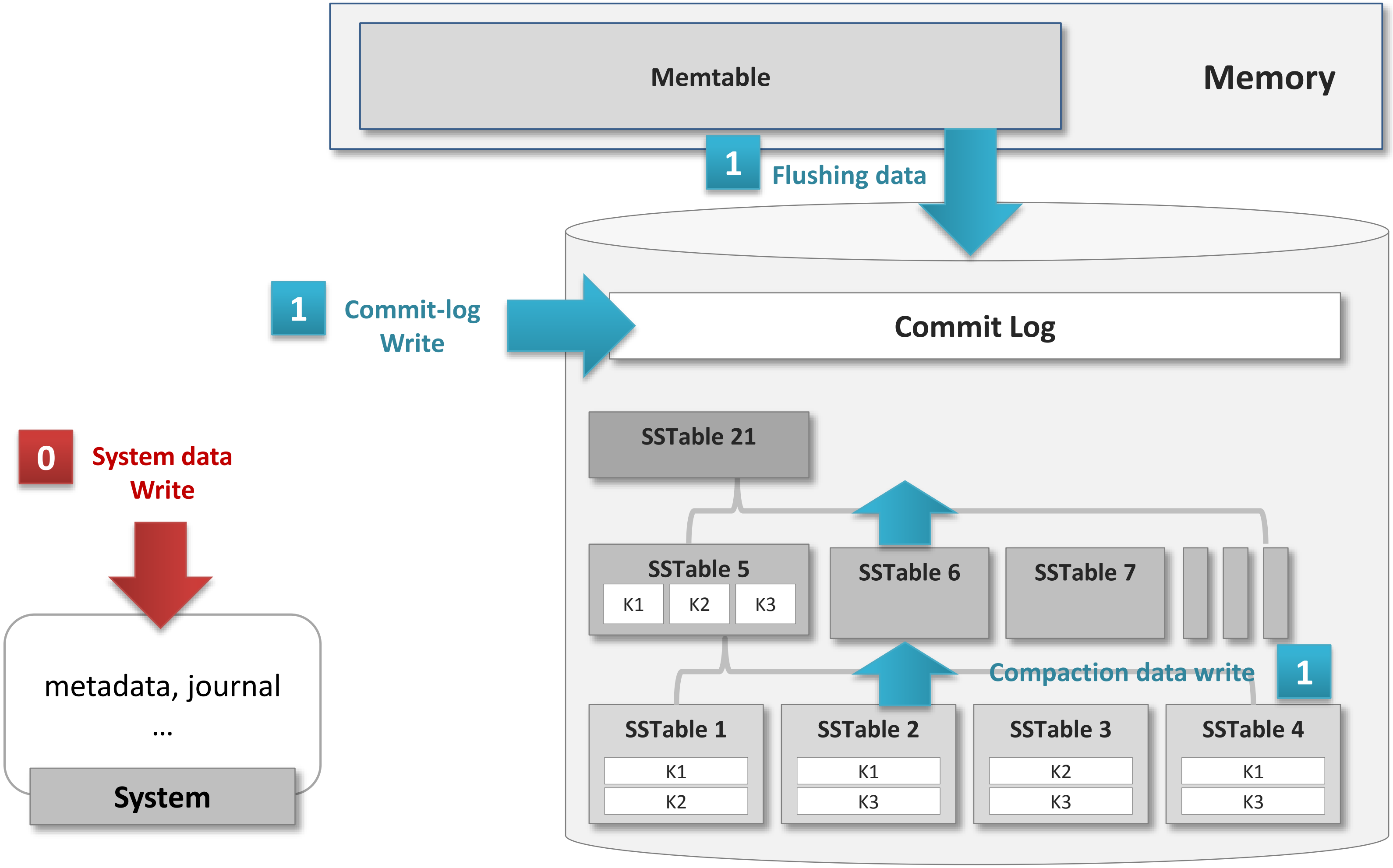
Mapping #1: "Conventional"

- **Just one stream ID (= conventional SSD)**



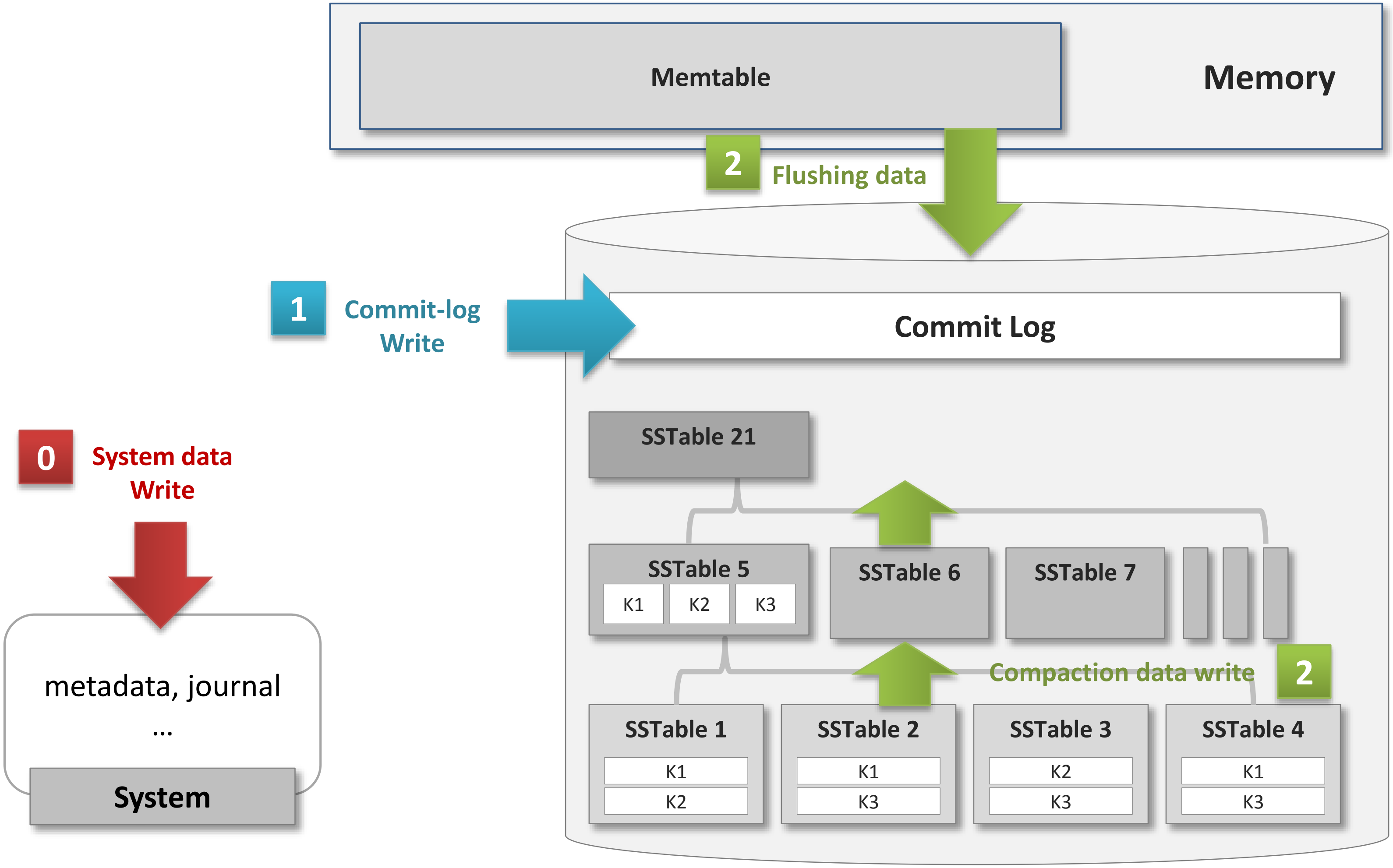
Mapping #2: "Multi-App"

- **Add a new stream to separately handle application writes (stream ID 1) from system traffic (stream ID 0)**



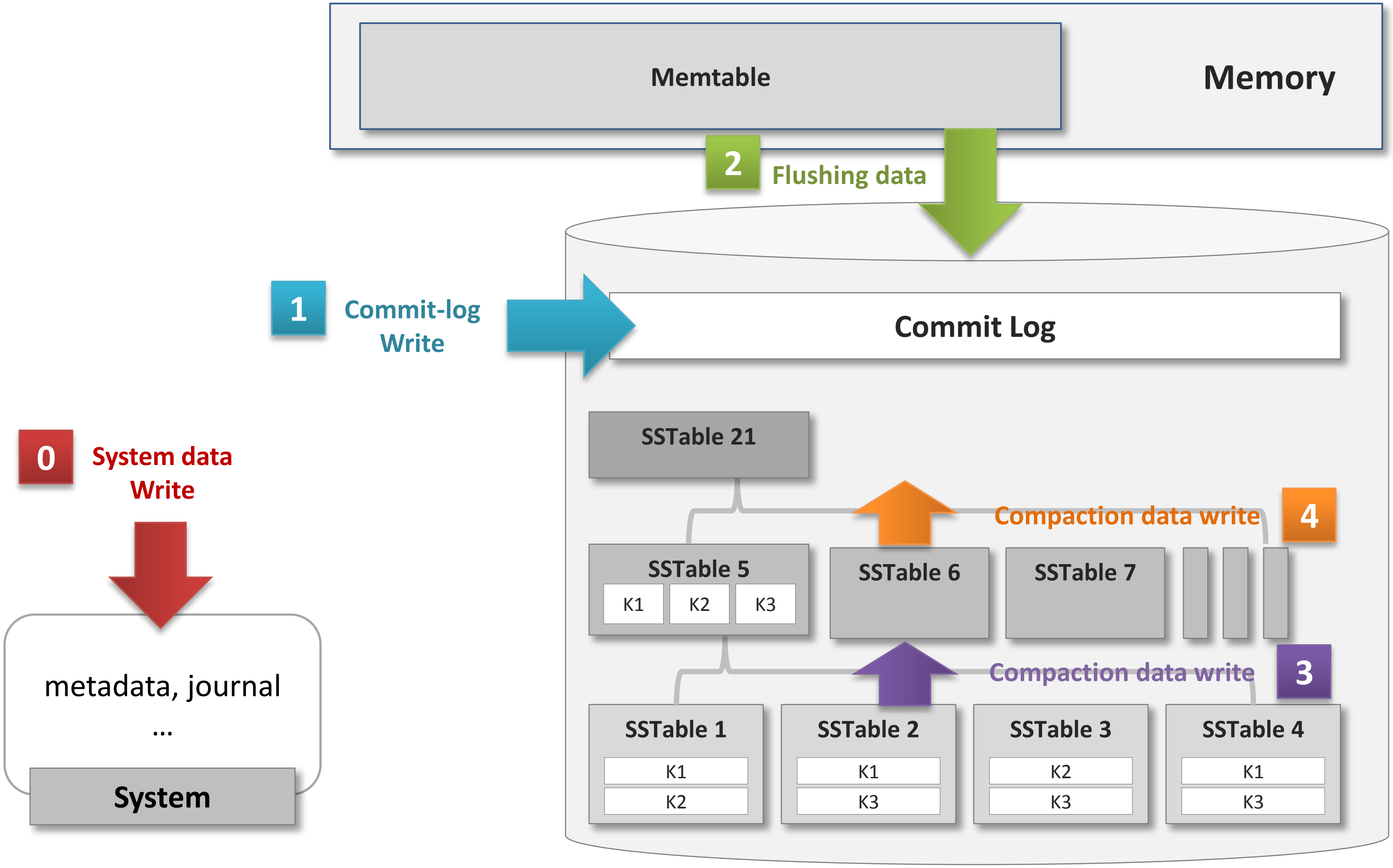
Mapping #3: "Multi-Log"

- **Use three streams; further separate Commit Log**



Mapping #4: "Multi-Data"

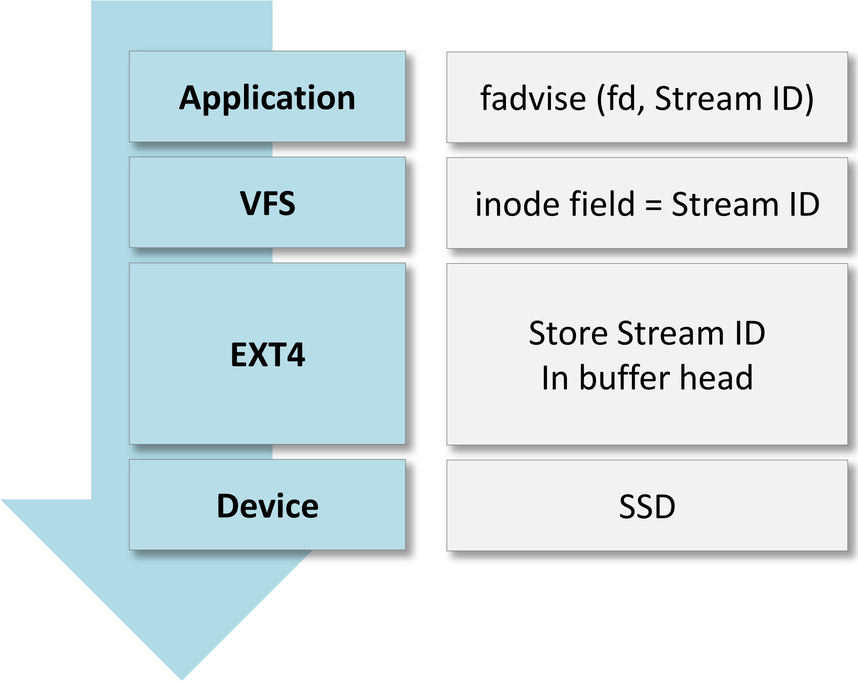
- **Give distinct streams to different tiers of SSTables**



Experimental Setup

- **Multi-stream SSD Prototype**
  - **Samsung 840 Pro SSD**
    - 60 GB device capacity
- **YCSB benchmark on Cassandra**
  - **Write intensive workload**
    - 1 K data x 1,000,000 record counts
    - 100,000,000 operation counts
- **Intel i7-3770 3.4 GHz processor**
- **2 GB Memory**
  - **Accelerates SSD aging by increasing Cassandra's flush frequency**

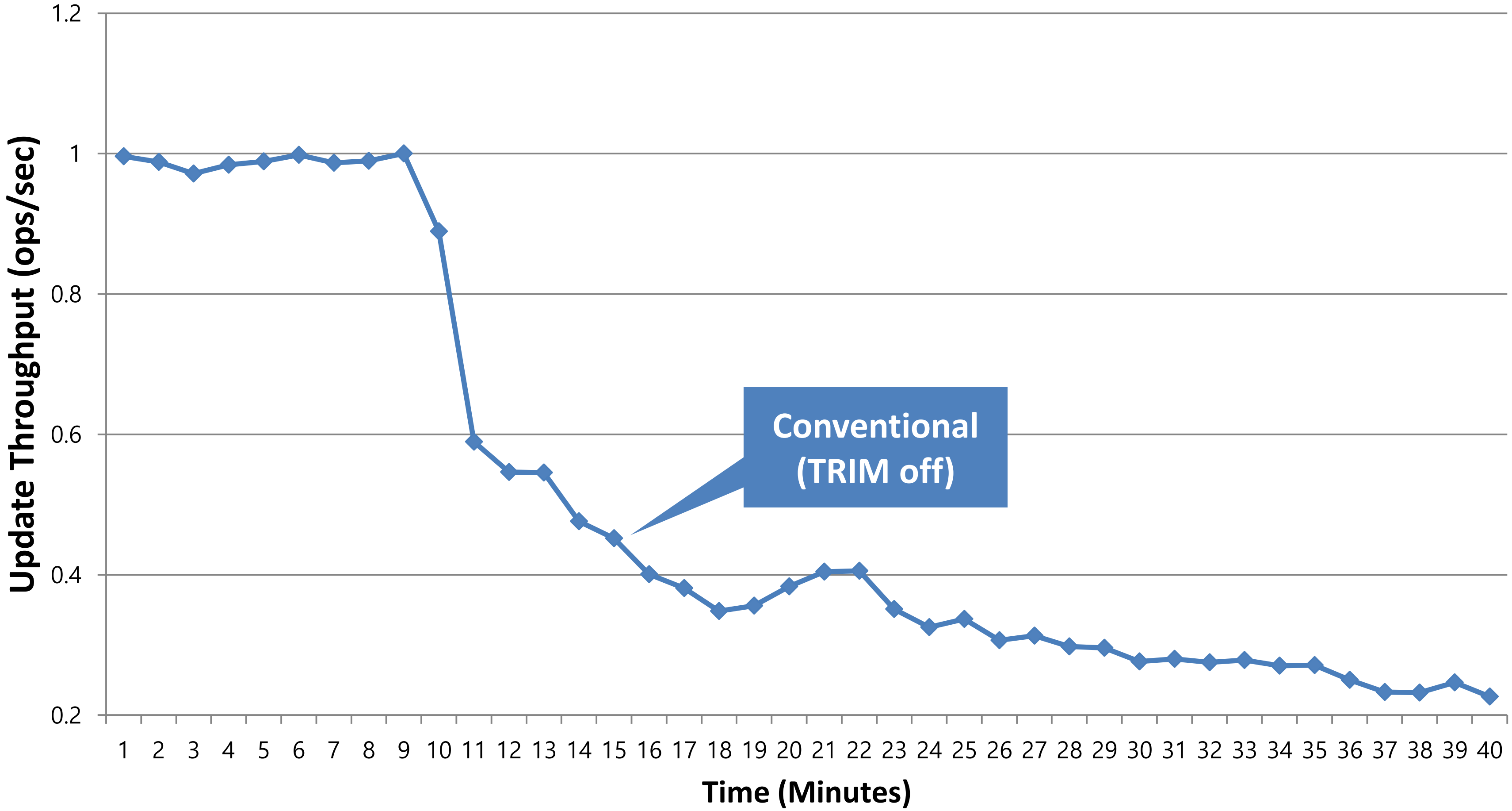
- **Linux kernel 3.13 (modified)**
  - **Passes the stream ID through fadvise() system call**
  - **Stores in the inode of VFS**



Results

Cassandra’s normalized update throughput

- Conventional “TRIM off”

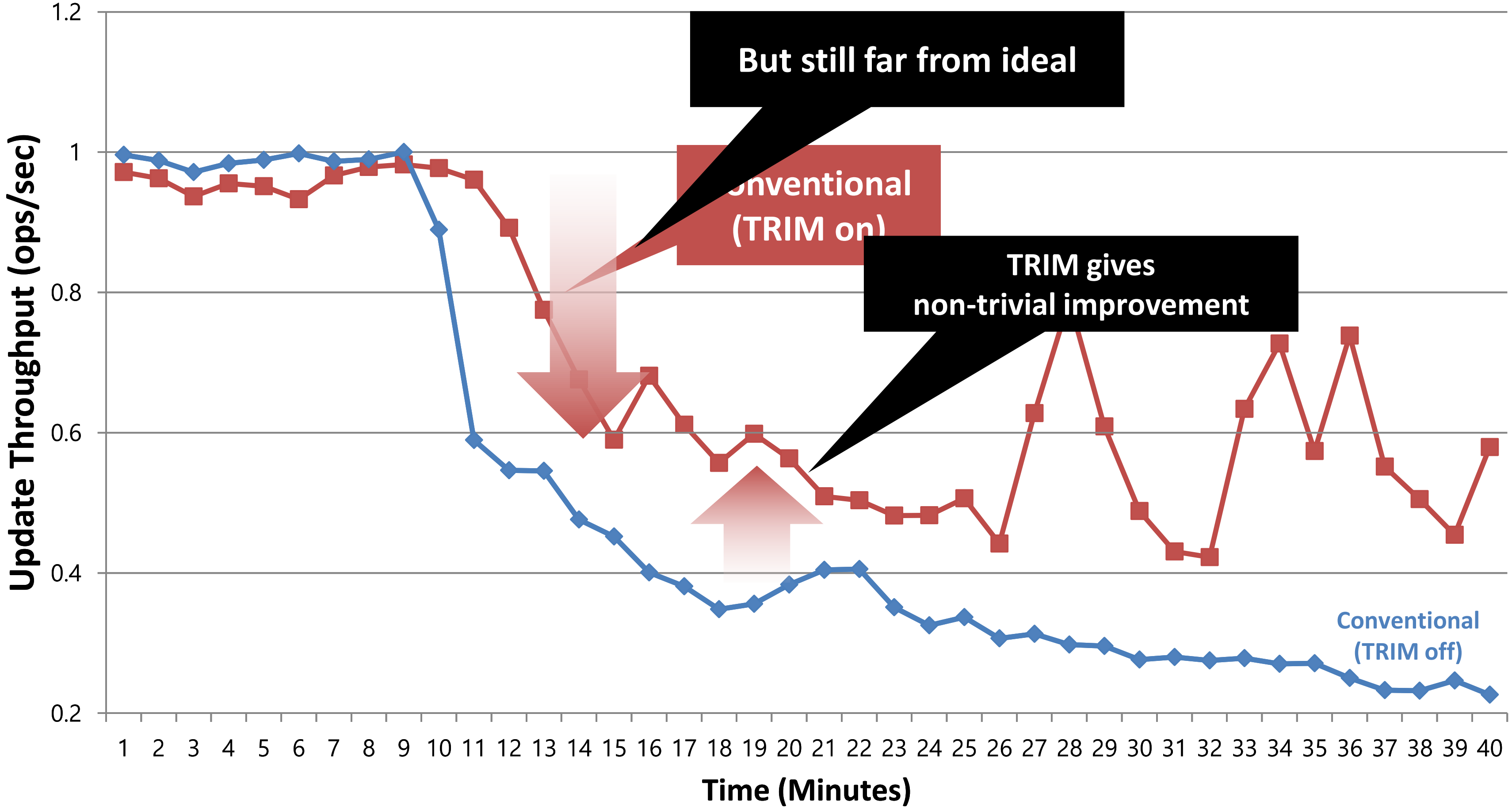


Conventional (TRIM off)

Results

Cassandra’s normalized update throughput

- Conventional “TRIM on”

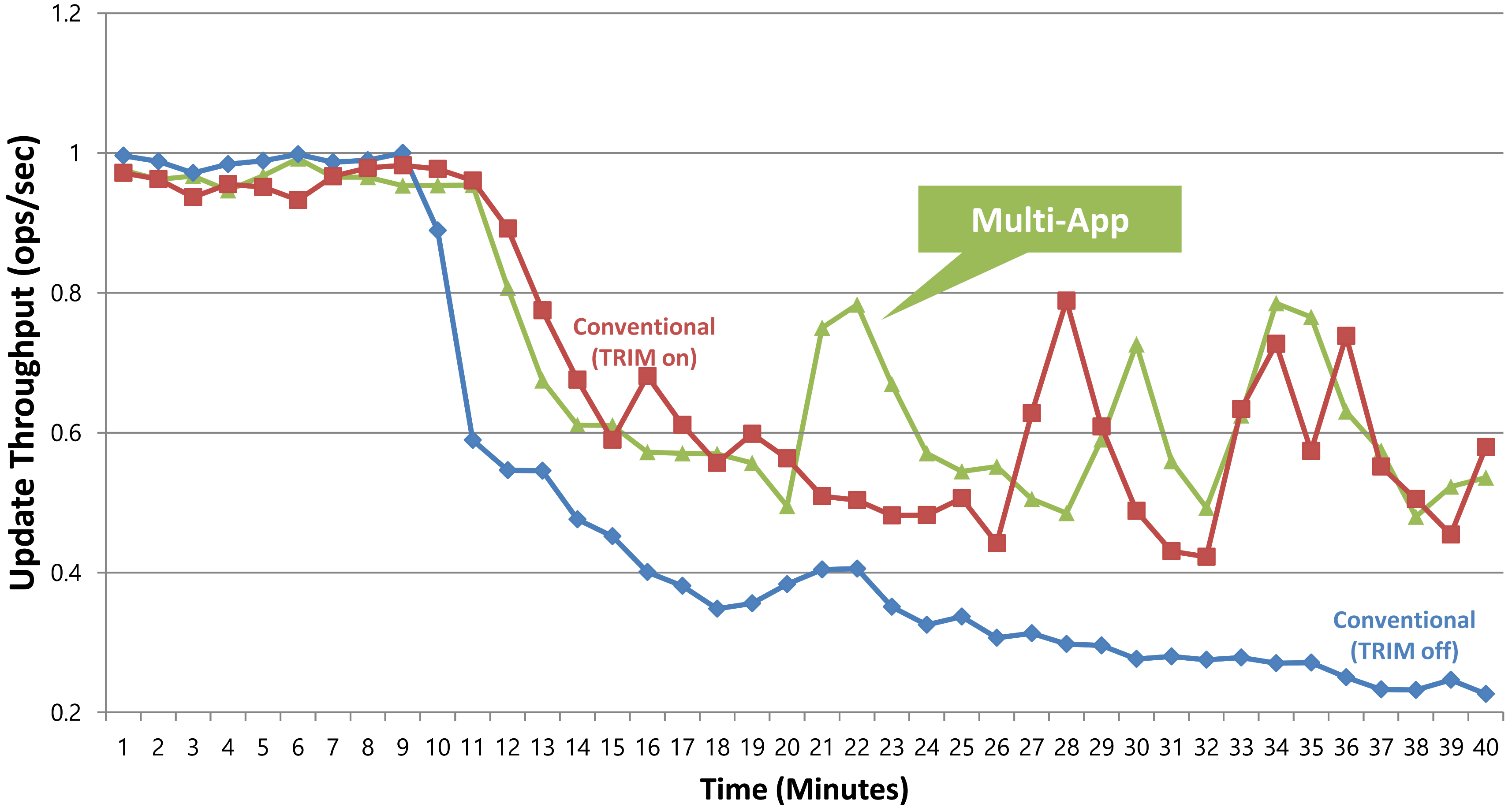


But still far from ideal

TRIM gives
non-trivial improvement

Results

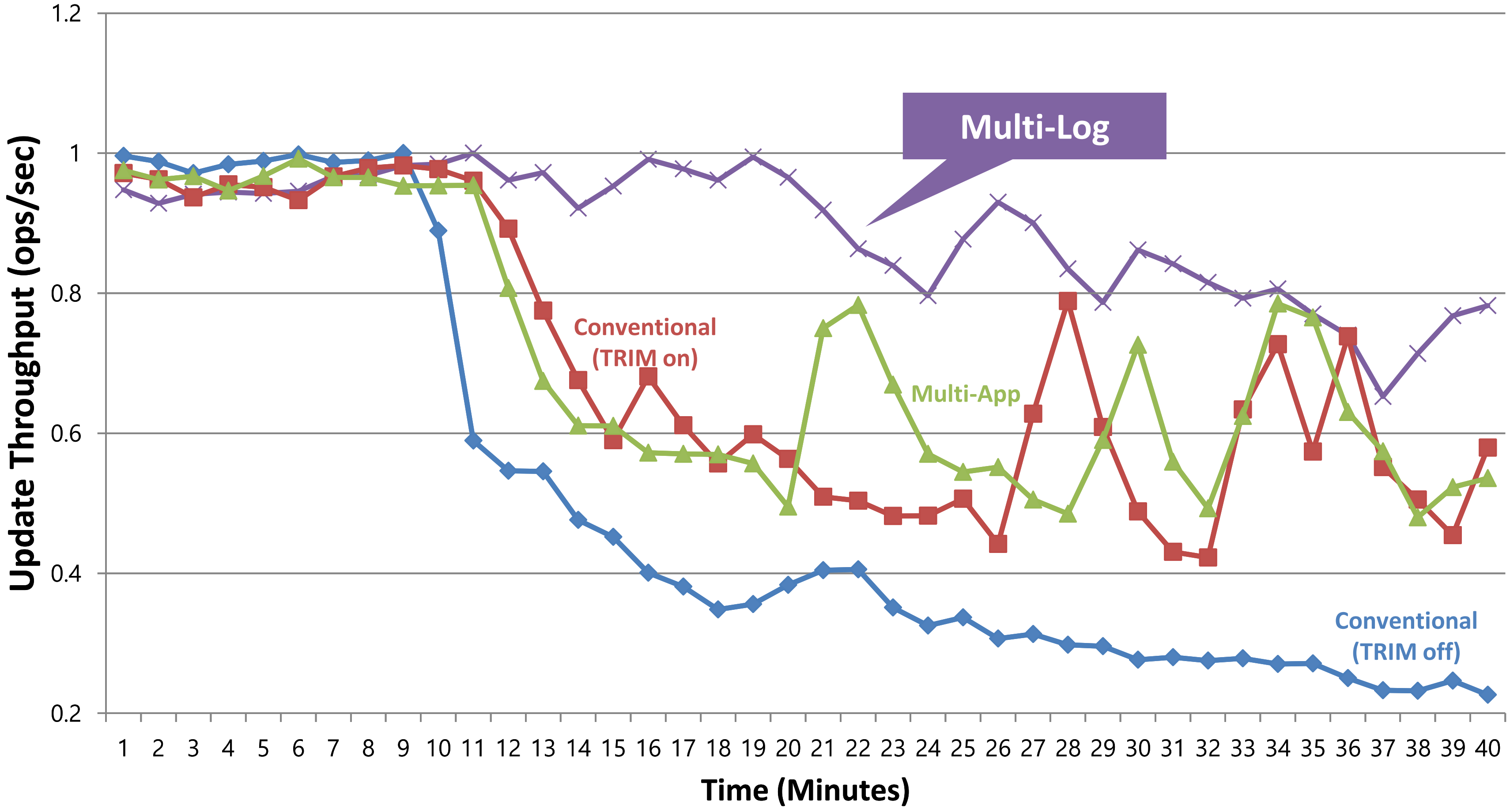
- **Cassandra's normalized update throughput**
  - **"Multi-App" (System data vs. Cassandra data)**



Results

Cassandra's normalized update throughput

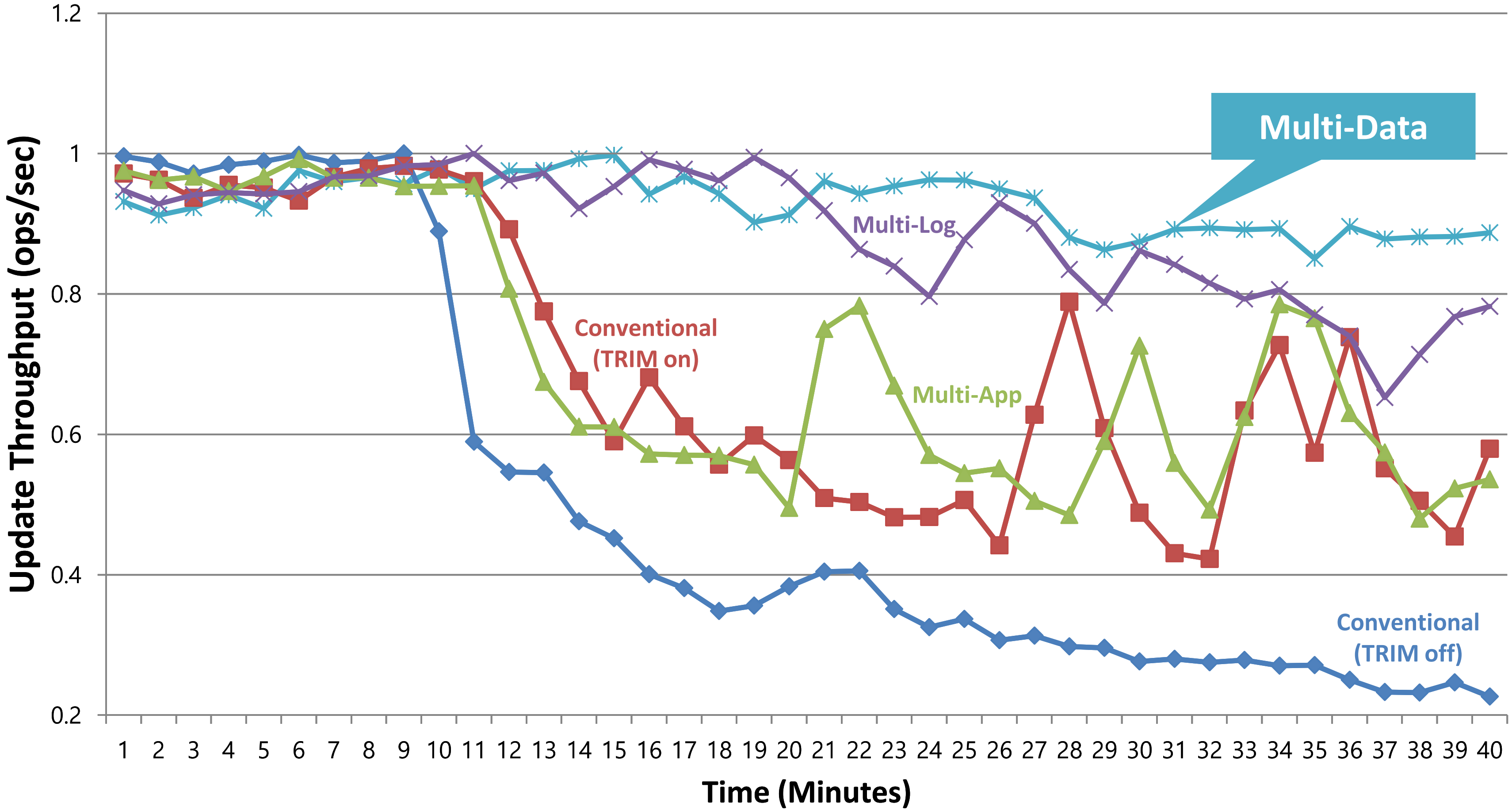
- "Multi-Log" (System data vs. Commit-Log vs. Flushed data)



Results

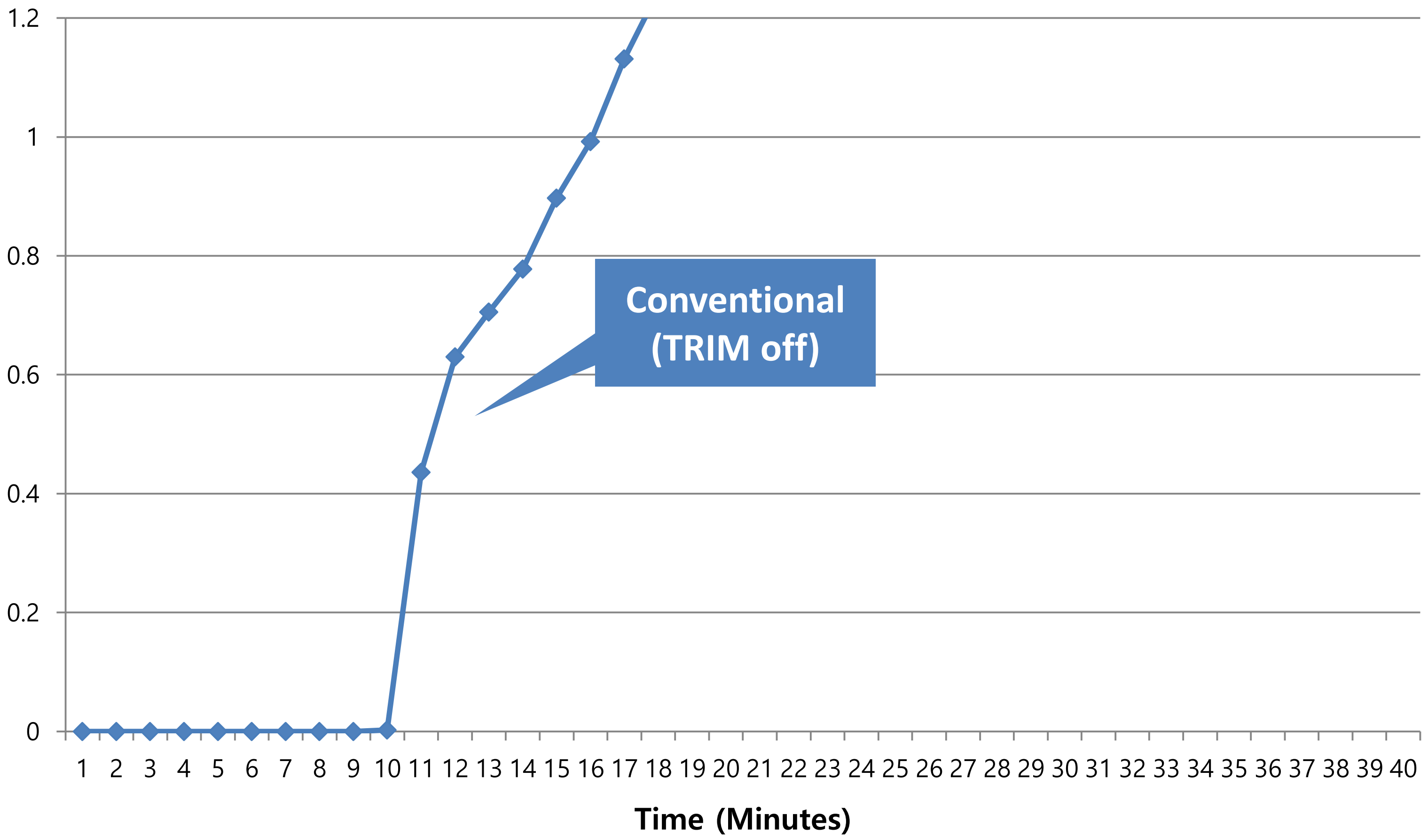
Cassandra's normalized update throughput

- "Multi-Data" (System data vs. Commit-Log vs. Flushed data vs. Compaction data)



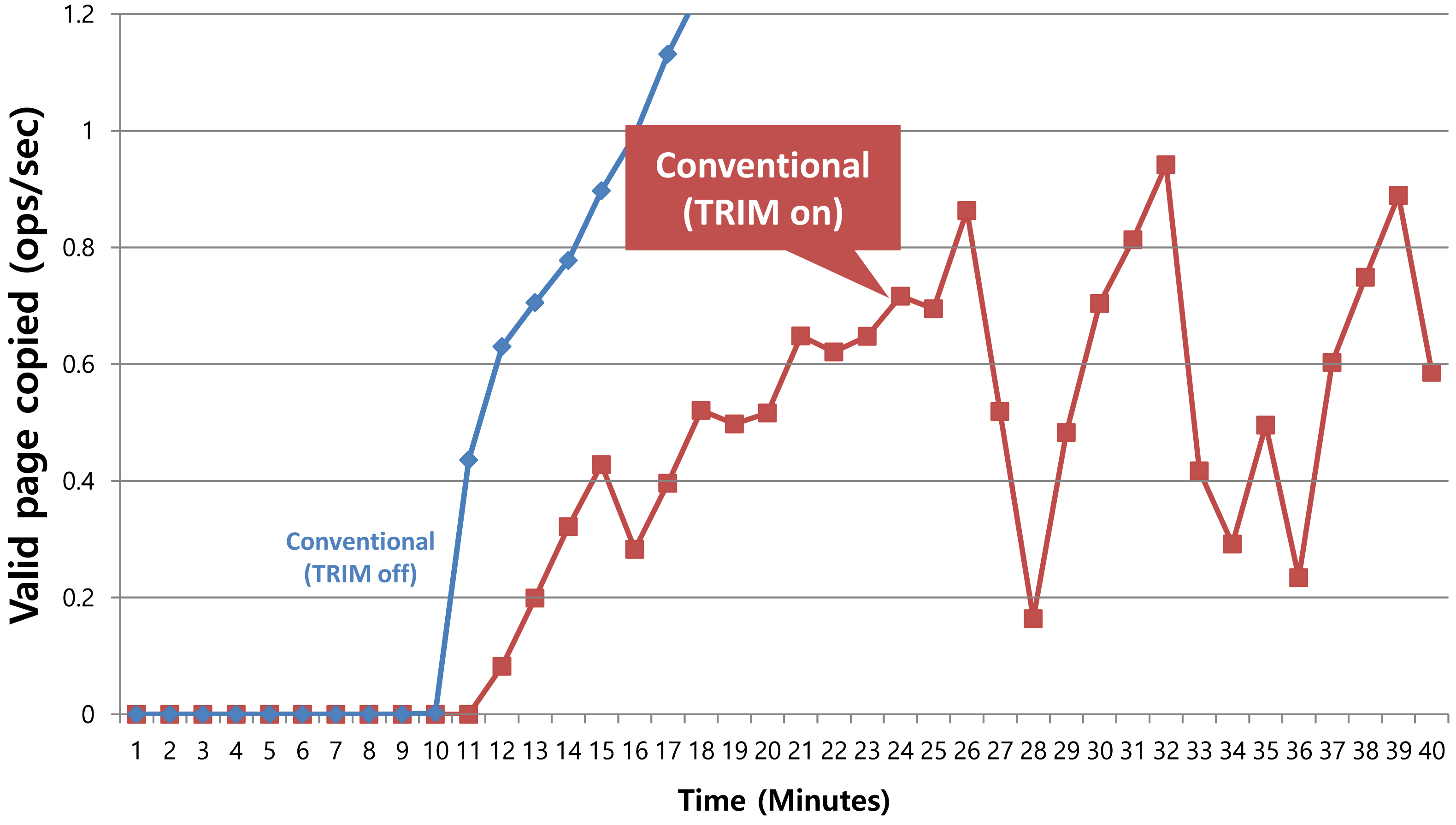
Result #2

- **Cassandra's GC overheads**
  - **Conventional "TRIM off"**



Cassandra’s GC overheads

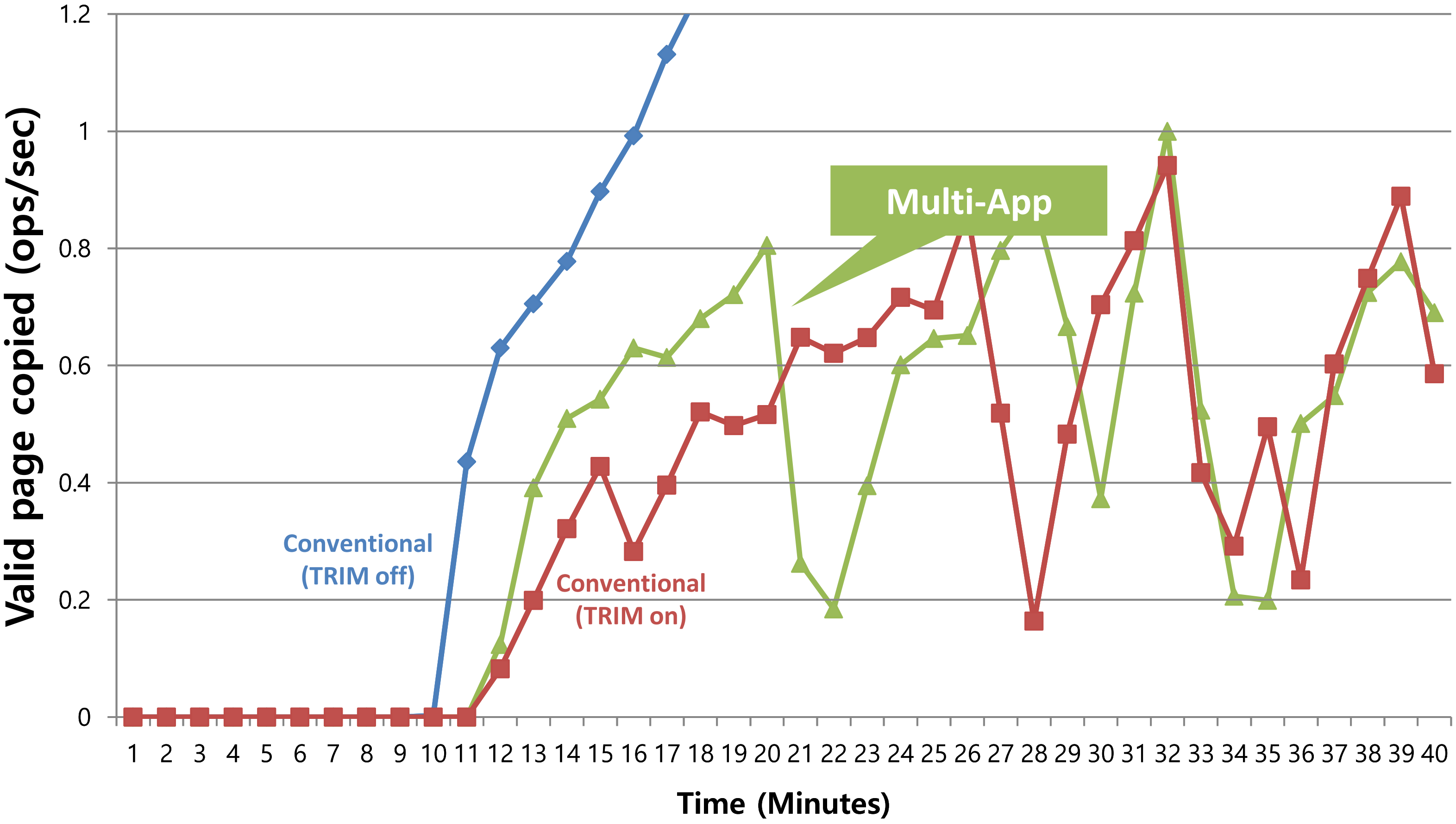
- Conventional “TRIM on”



Results

Cassandra’s GC overheads

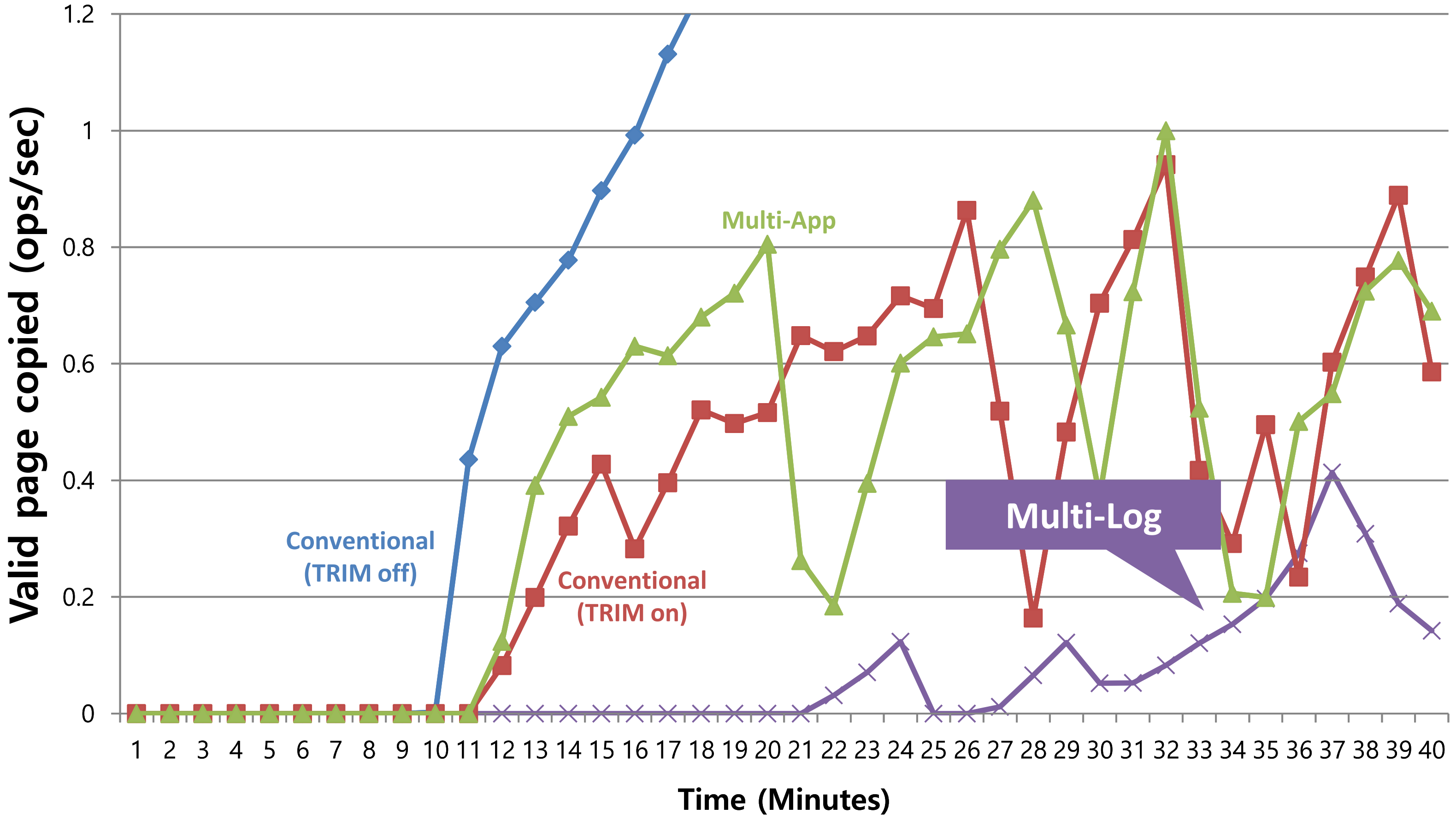
- “Multi-App” (System data vs. Cassandra data)



Results

Cassandra's GC overheads

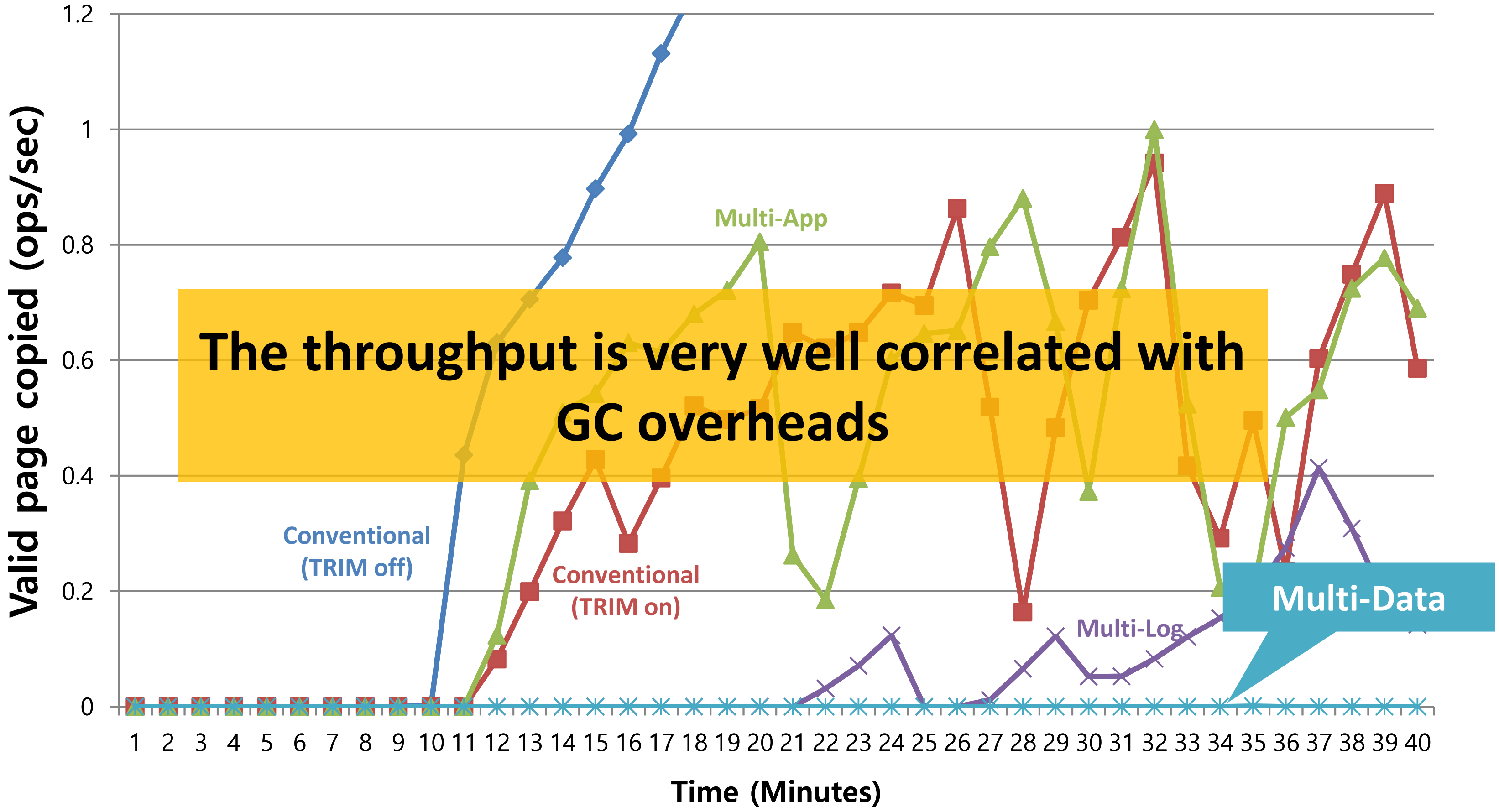
- "Multi-Log" (System data vs. Commit-Log vs. Flushed data)



Results

Cassandra's GC overheads

- "Multi-Data" (System data vs. Commit-Log vs. Flushed data vs. Compaction data)

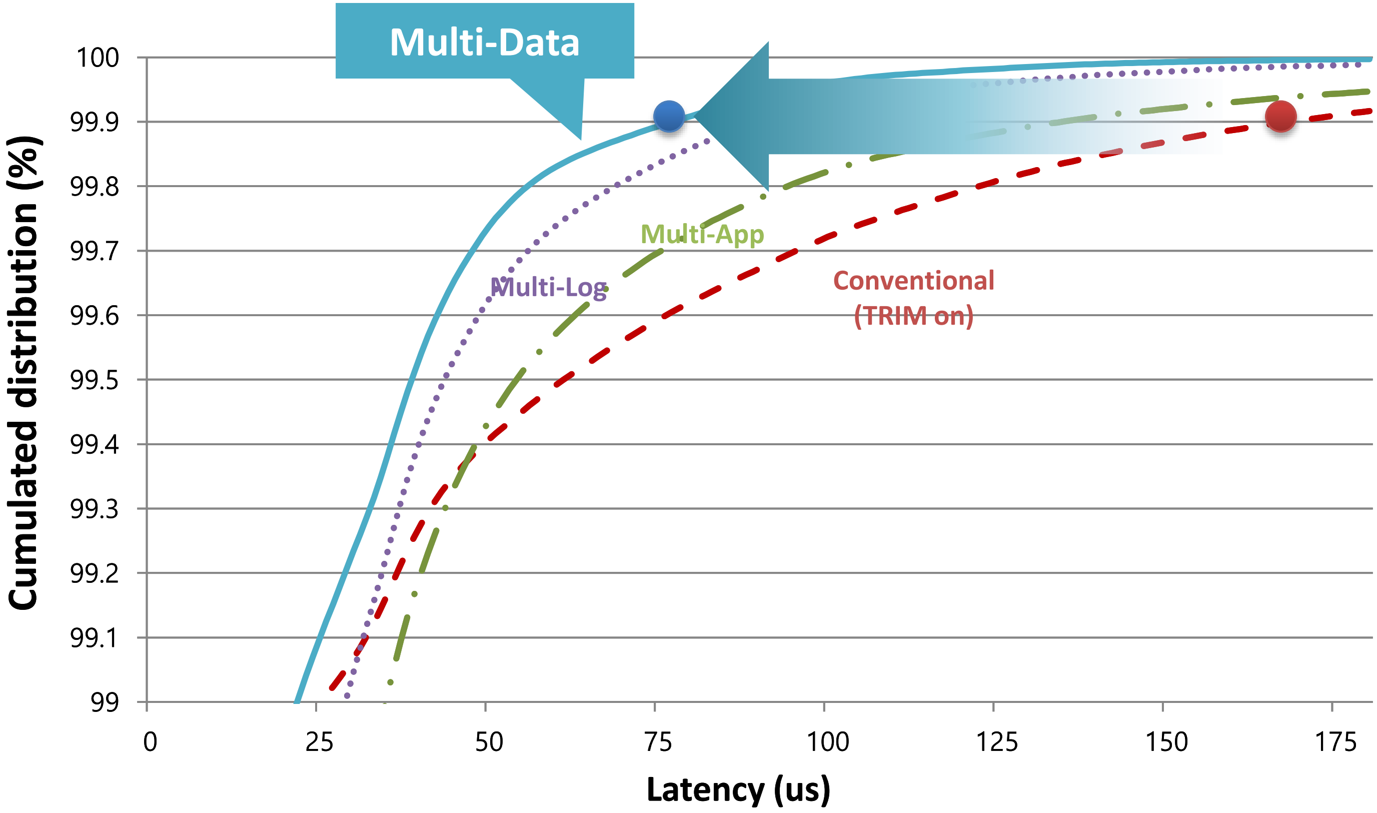


The throughput is very well correlated with GC overheads

Result #3

Cassandra's cumulated latency distribution

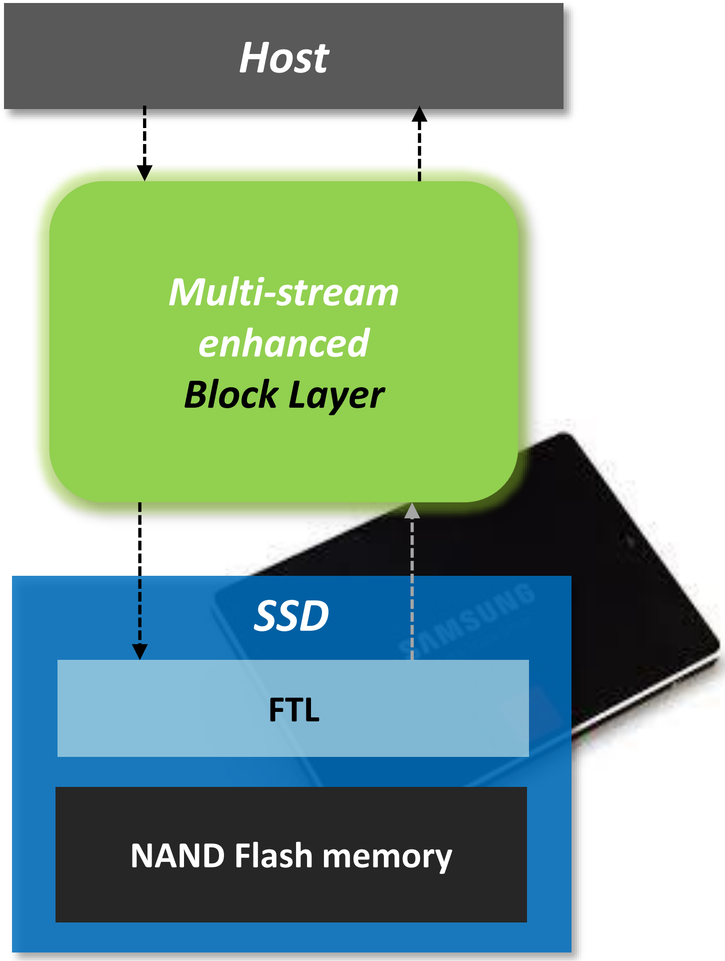
- Multi-streaming improves write latency
- At 99.9%, Multi-Data lowers the latency by 54 % compared to Normal



Conclusion

Multi-streamed SSD

- 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
- Multi-stream interface can be standard for using SSD more efficiently



Be at the Center of a Revolution

Less Energy. More Speed.

Thank you.