Write Dependency Disentanglement with HORAE

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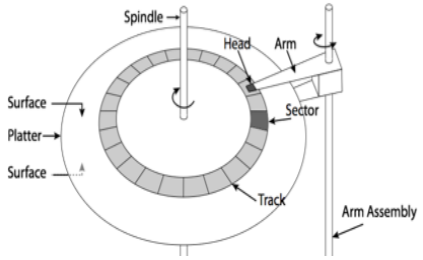
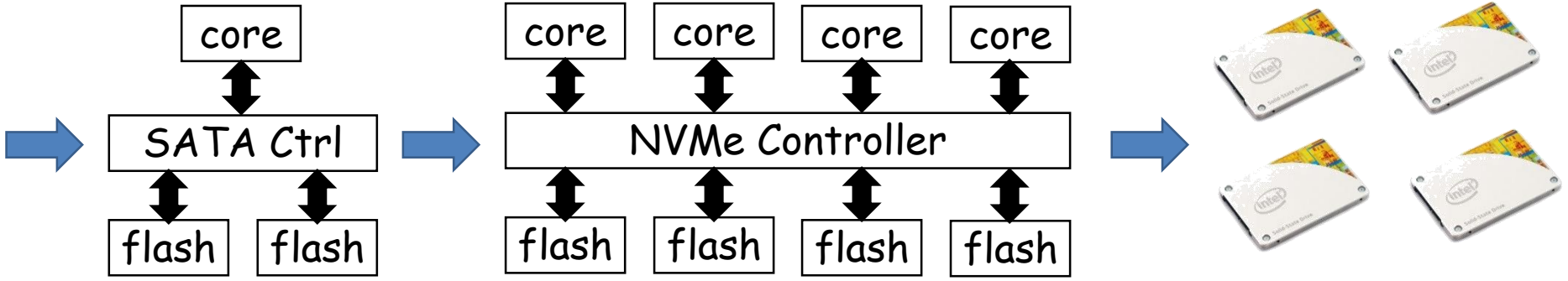
1. Background and Motivation

Background: Storage Trend

Modern storage delivers higher bandwidth and concurrency.

	HDD	SATA SSD	NVME SSD	All SSD Array
Bandwidth	~80MB/s	~500MB/s	~6GB/s	~48GB/s





Single-Head Concurrency (1)

Multi-Channel Concurrency (1~8)

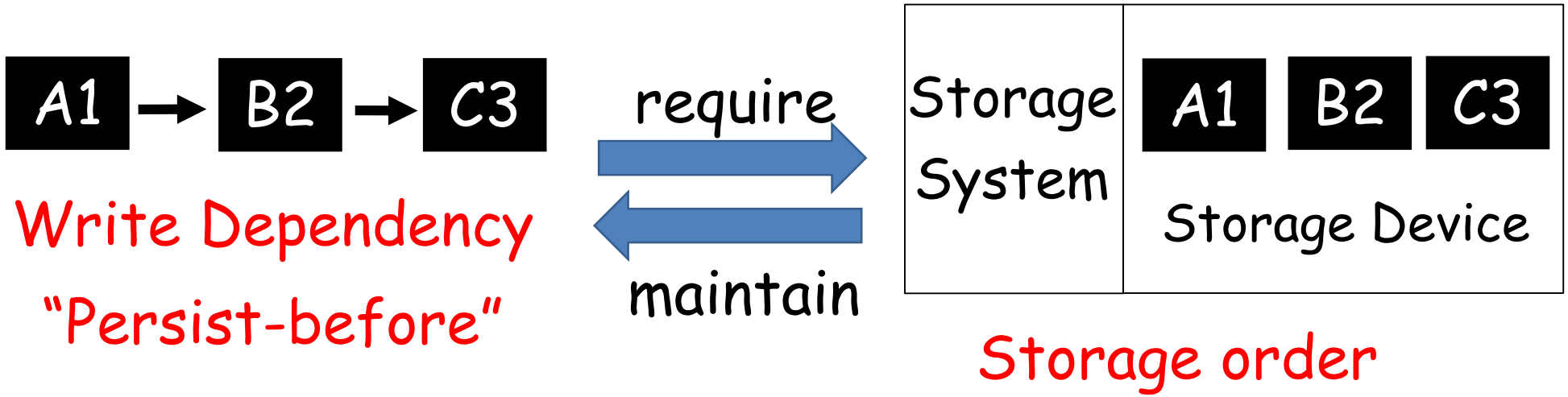
Multi-Channel Concurrency (>=32)

Multi-Device Concurrency (> =256)

Background: Write Dependency

File System Journaling | COW-based File System | Soft Updates | ……

Consistency



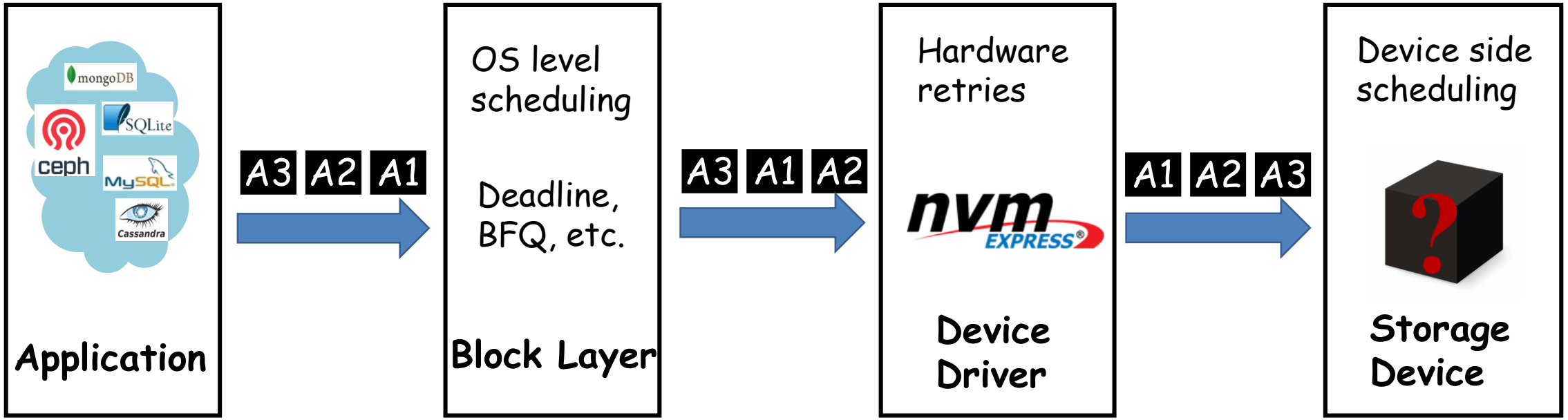
Write Dependency

"Persist-before"

Storage order

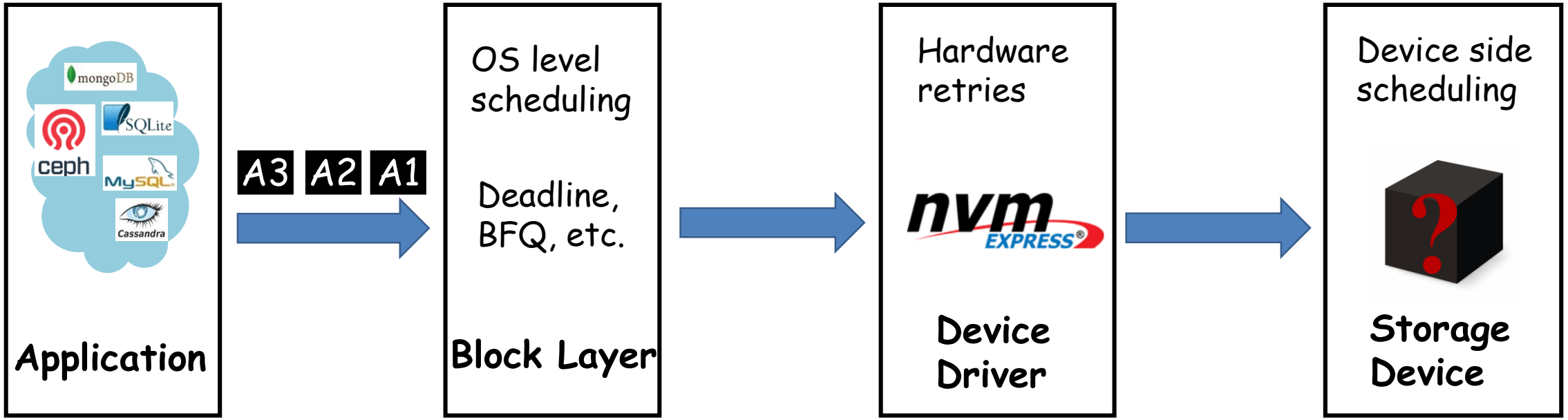
Background: Storage Order

Modern IO stack is Orderless.



Background: Storage Order

To enforce storage order, current IO stack should process only one set of orderless IOs at a time.



Serialization ✖ **Concurrency**

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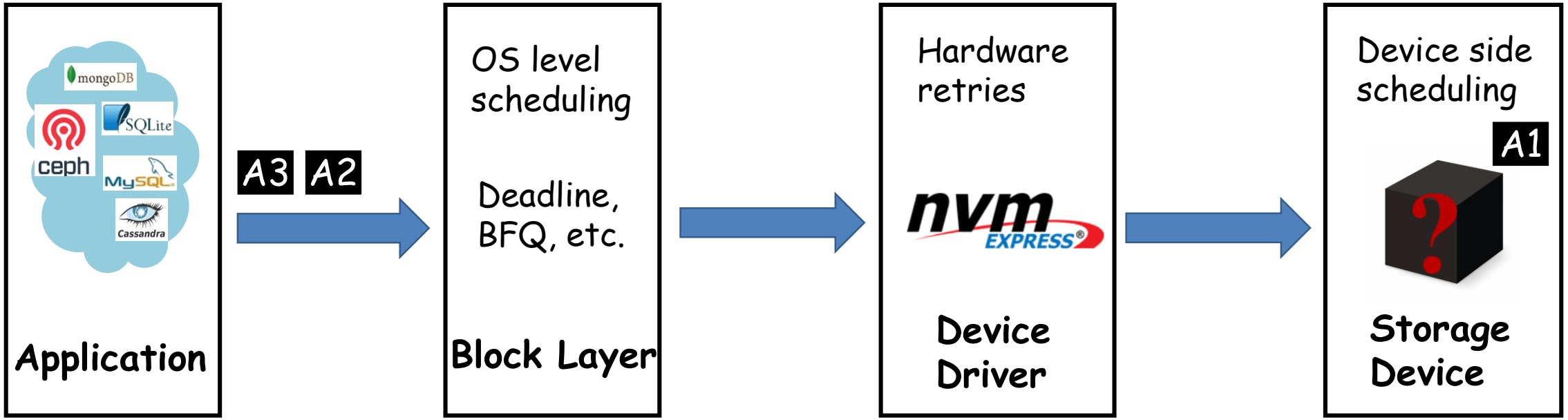

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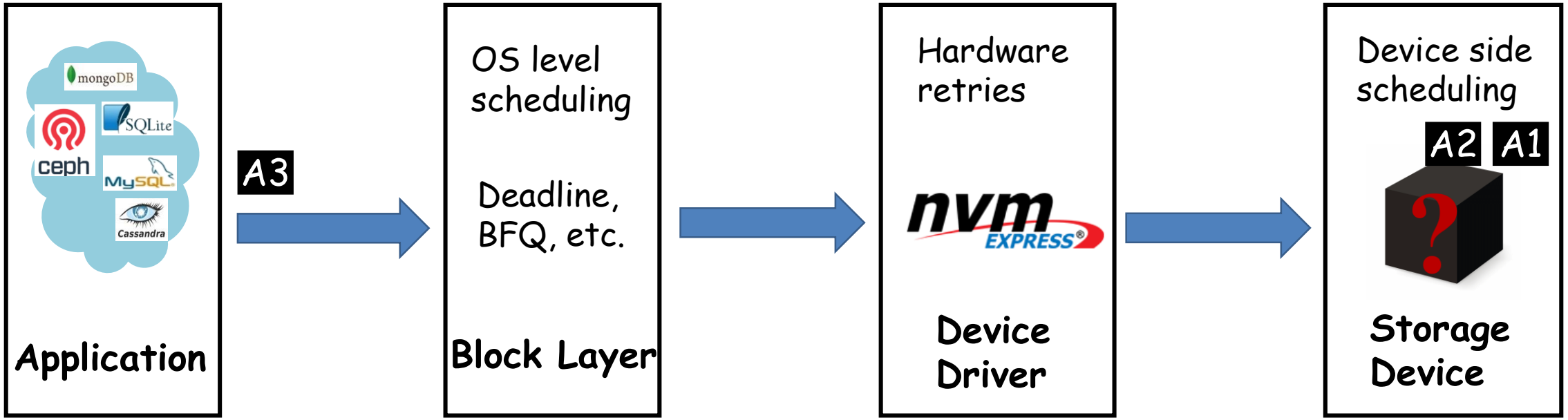

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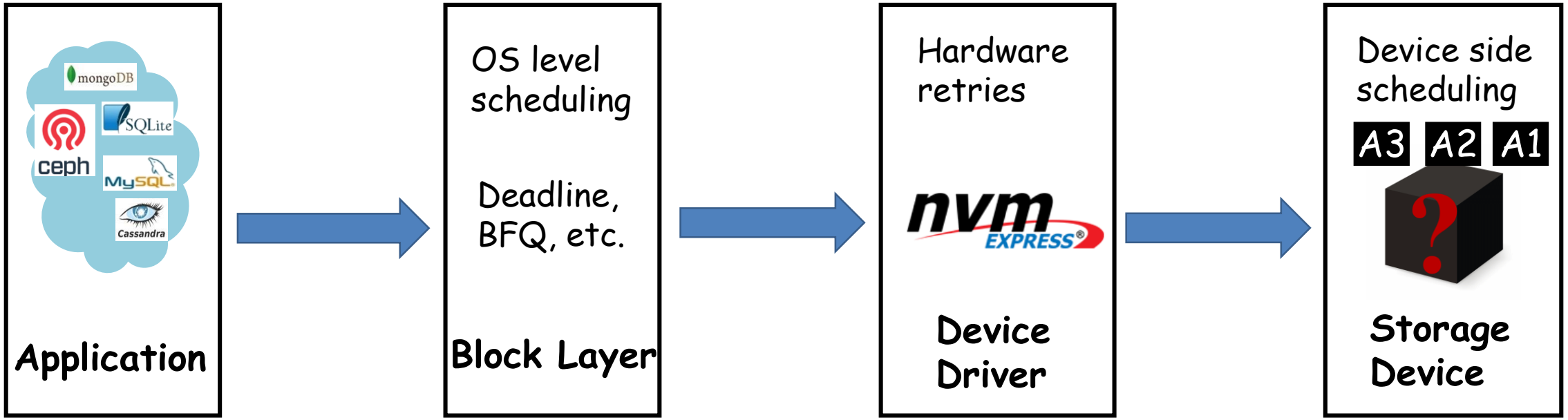
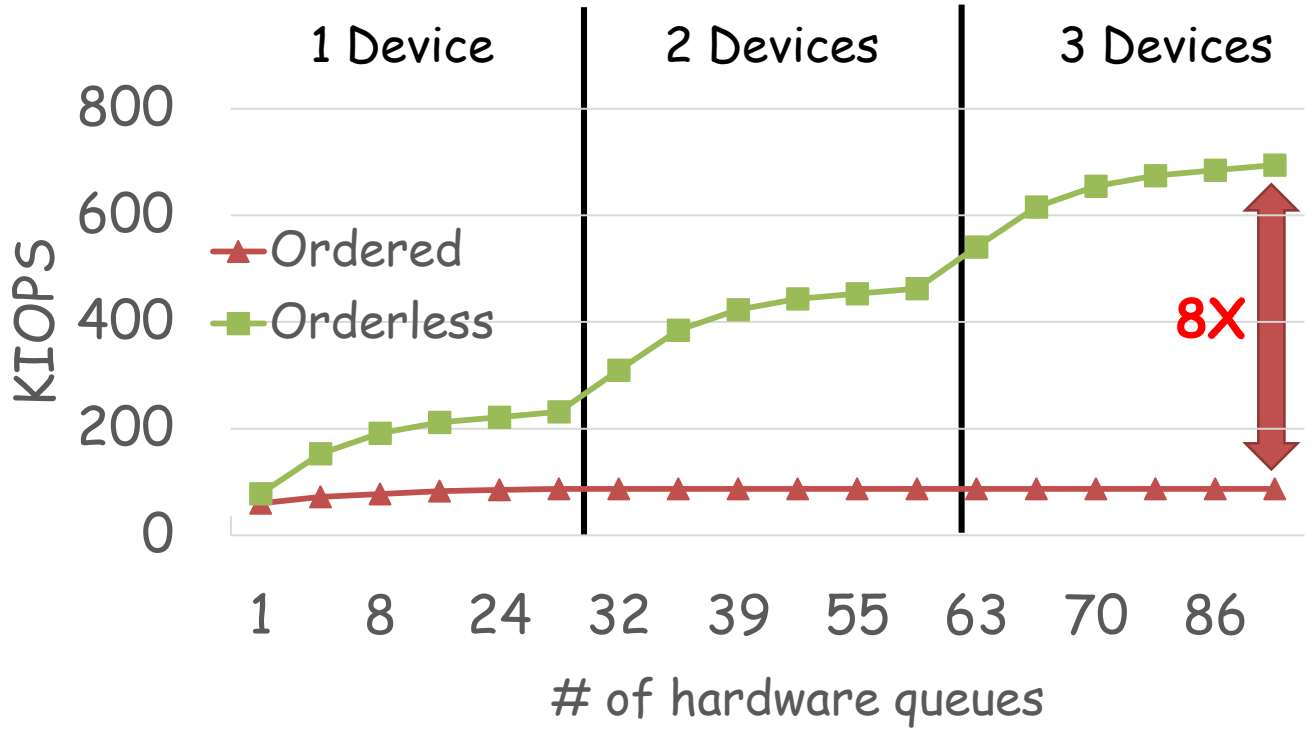


Serialization ✖ **Concurrency**

Motivation



Test tool: fio

IO size: 4 KB

Threads: up to 4

Test SSD: Intel 750

Ordered writes -> Hard to grow!

Orderless writes-> Full bandwidth!

2. Design

Can we and how to achieve storage order with full bandwidth?

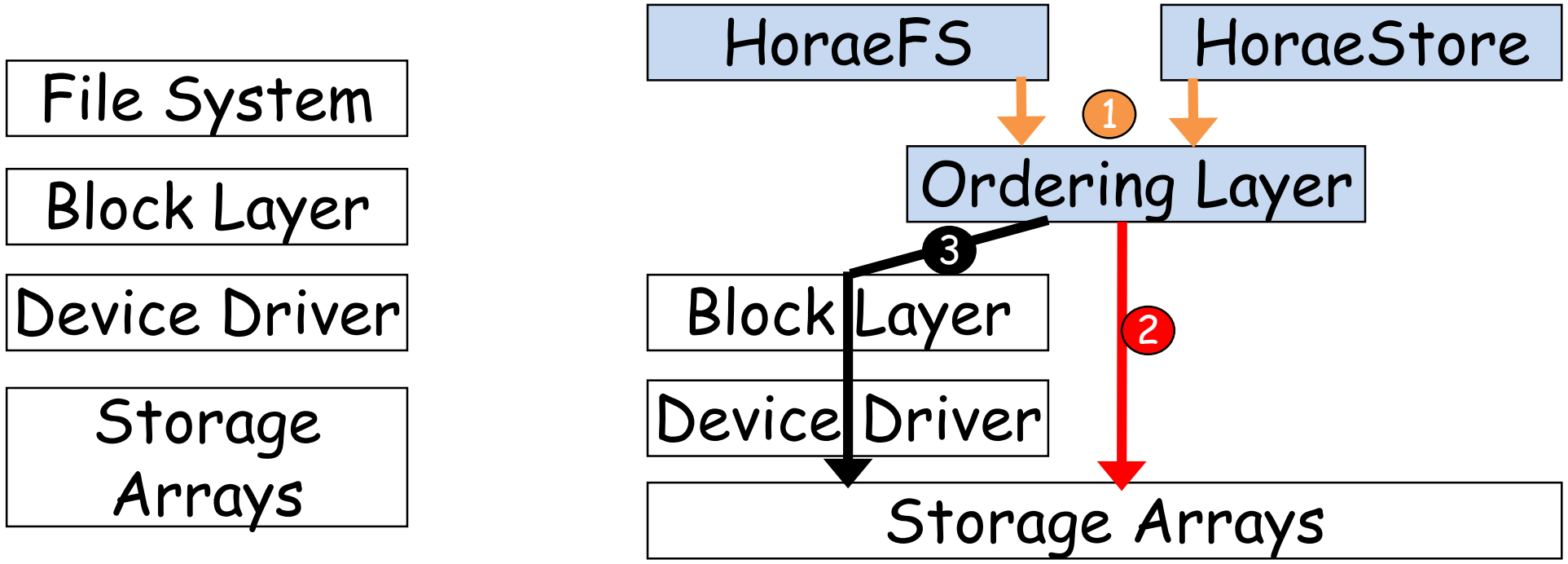
Yes, with Horae.

Horae IO stack Overview

Key idea: Split the IO stack into an ordered control path ❷ and an orderless data path ❸

Full bandwidth

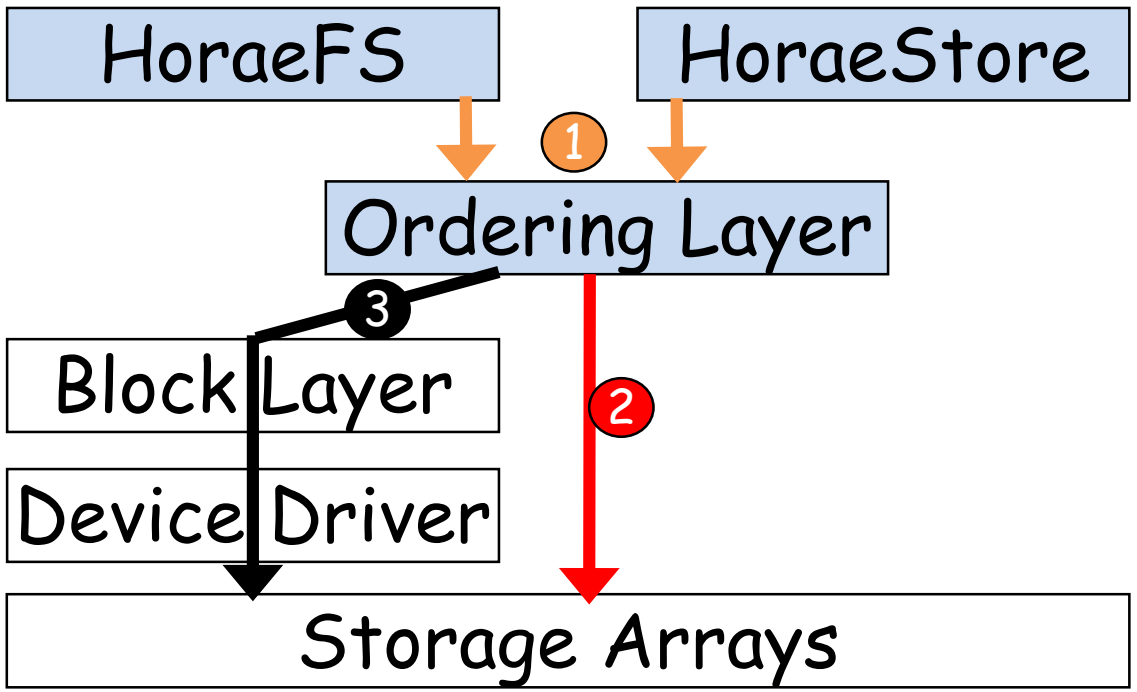
Storage order



Linux IO Stack

Horae IO Stack

Horae's Key Design



Horae IO Stack

Key idea: 2

Dedicated Control Path

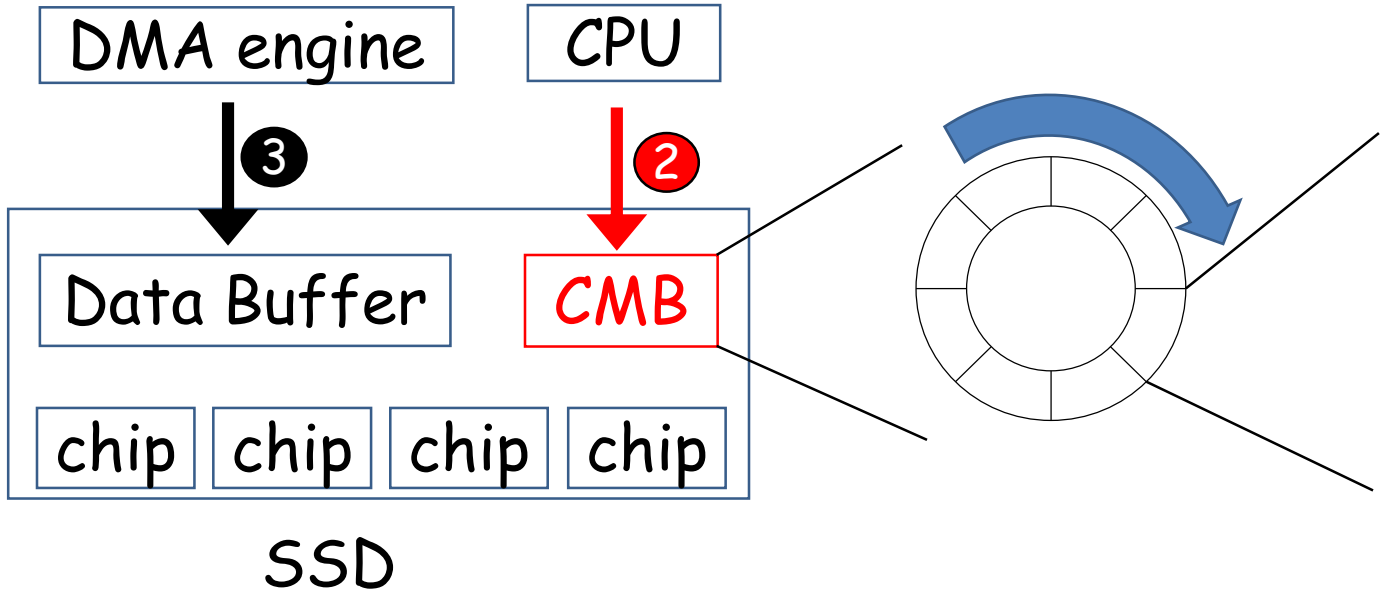
Opportunities:

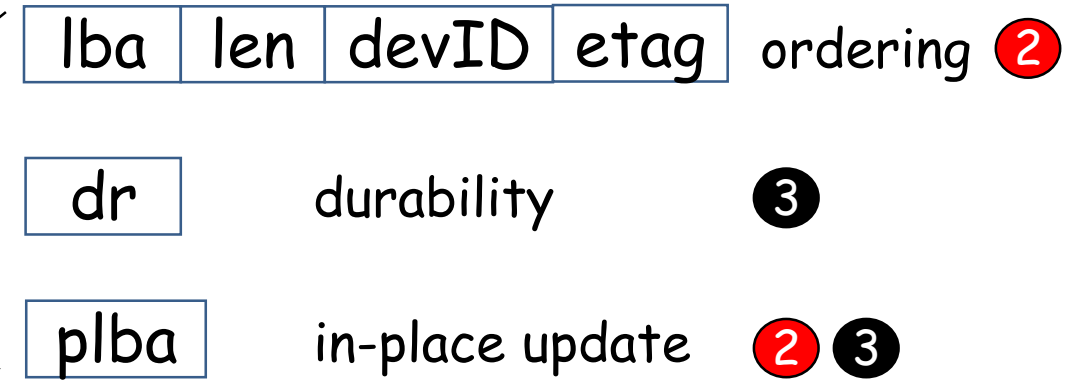
- Parallelizing durability commands 3
- Parallelizing in-place updates 2 3

Use cases: 1

- File System: HoraeFS
- Object Store: HoraeStore

Dedicated Control Path





CMB (persistent Controller Memory Buffer) In NVMe spec.

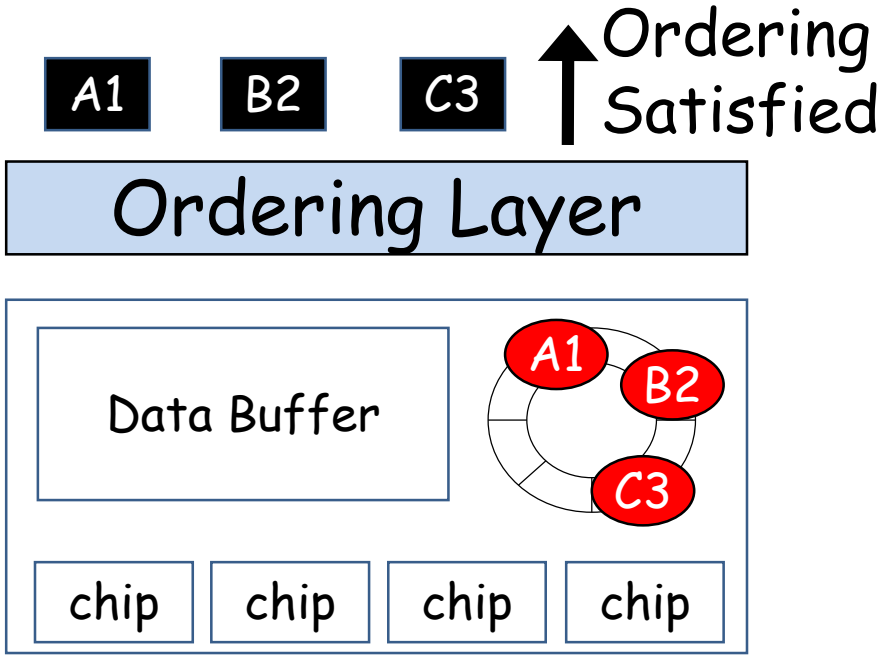
Circular Ordering Queue

16-Byte Ordering Metadata, persist latency ~0.5us

A1

Dedicated Control Path

Use the ordering metadata to provide ordering guarantee during normal execution and crash recovery.



(a) Normal execution

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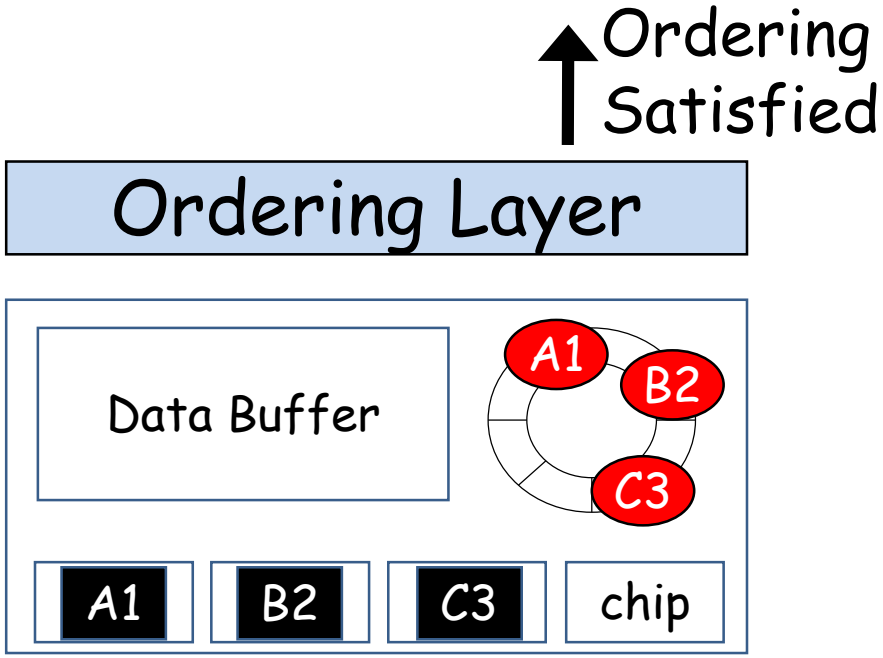

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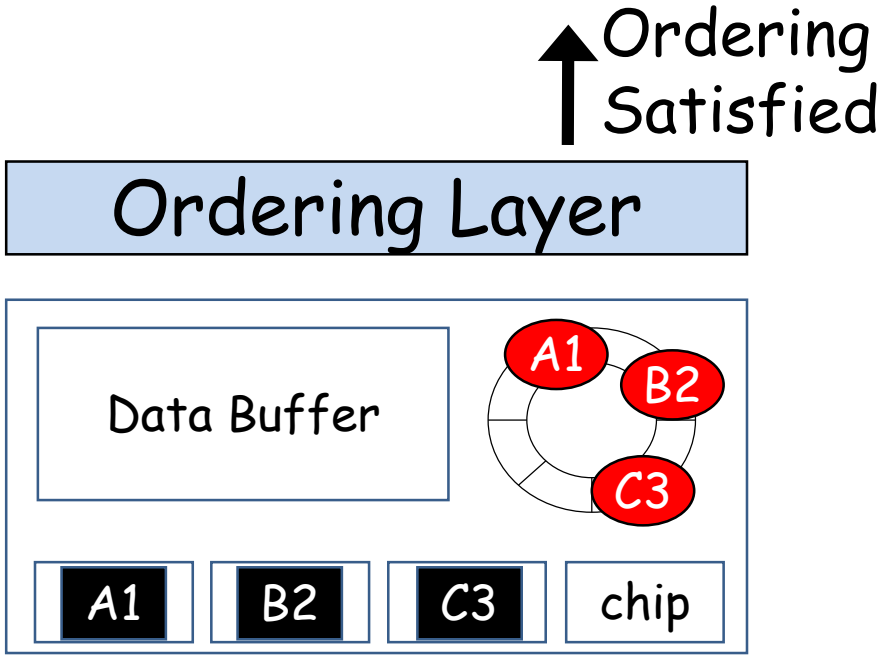

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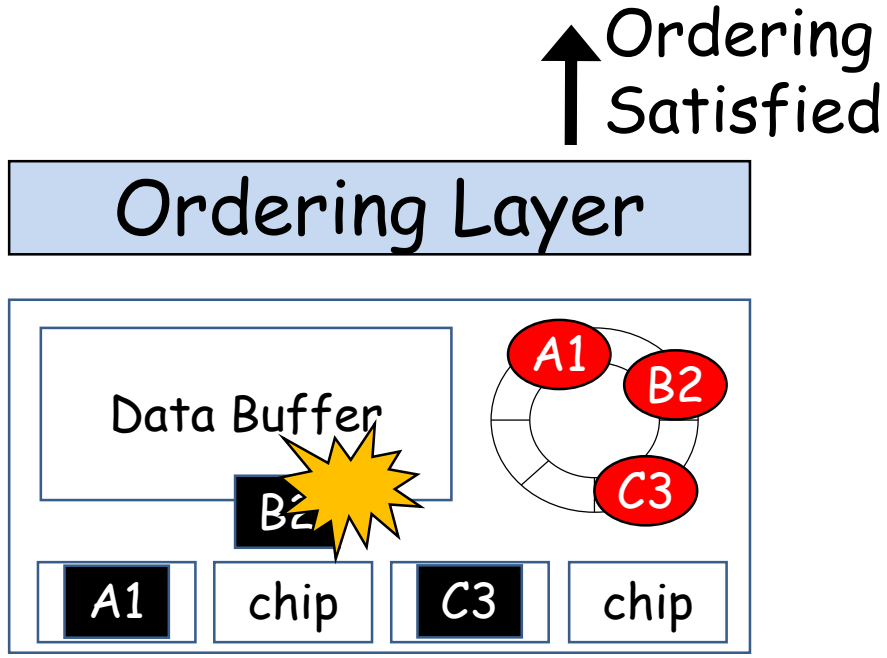

(b) Crash recovery

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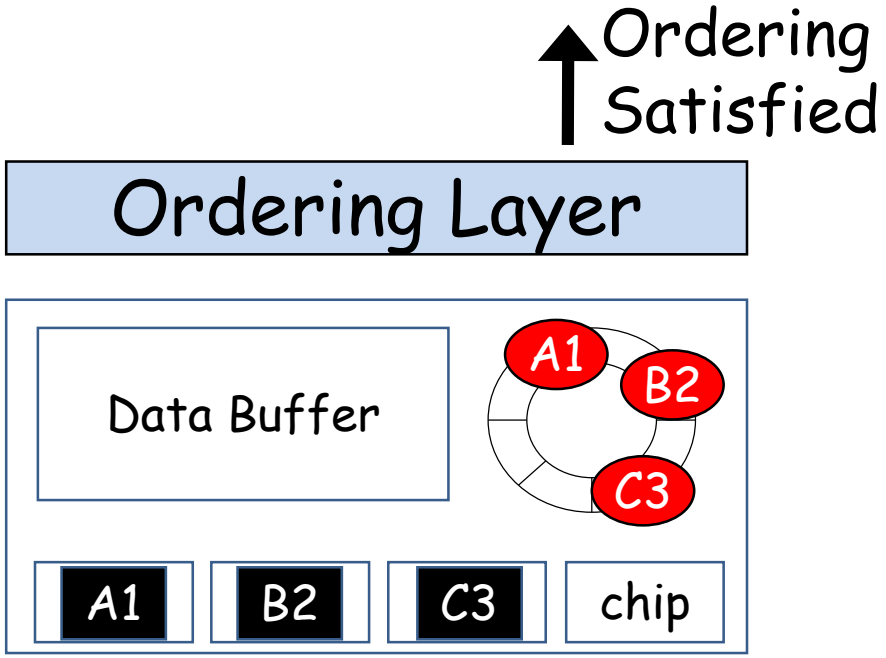

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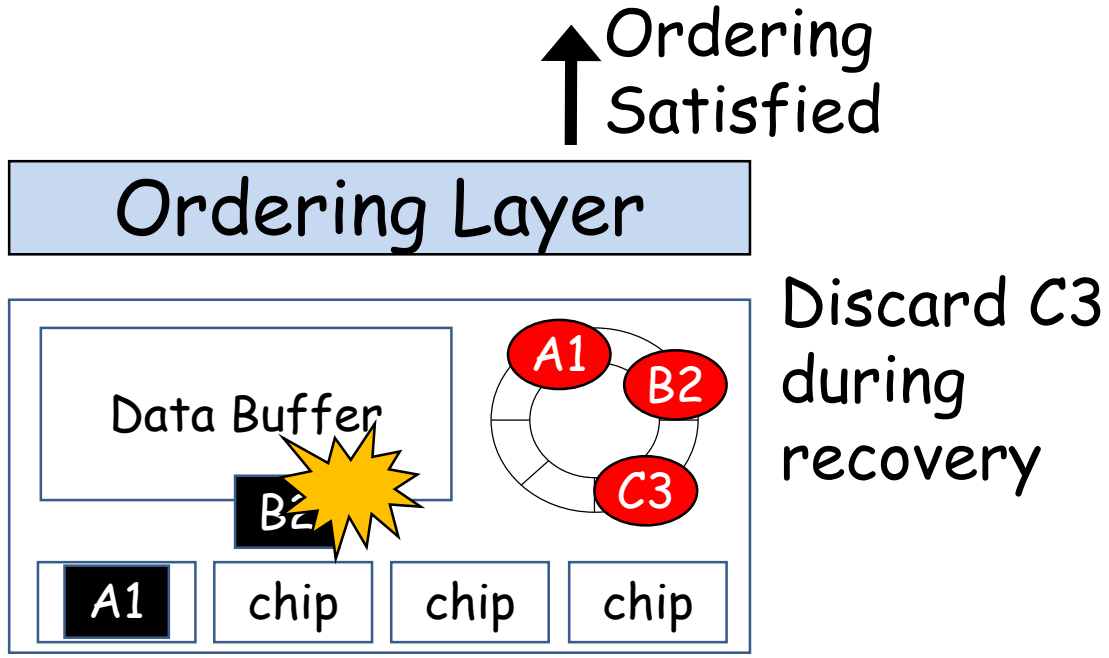

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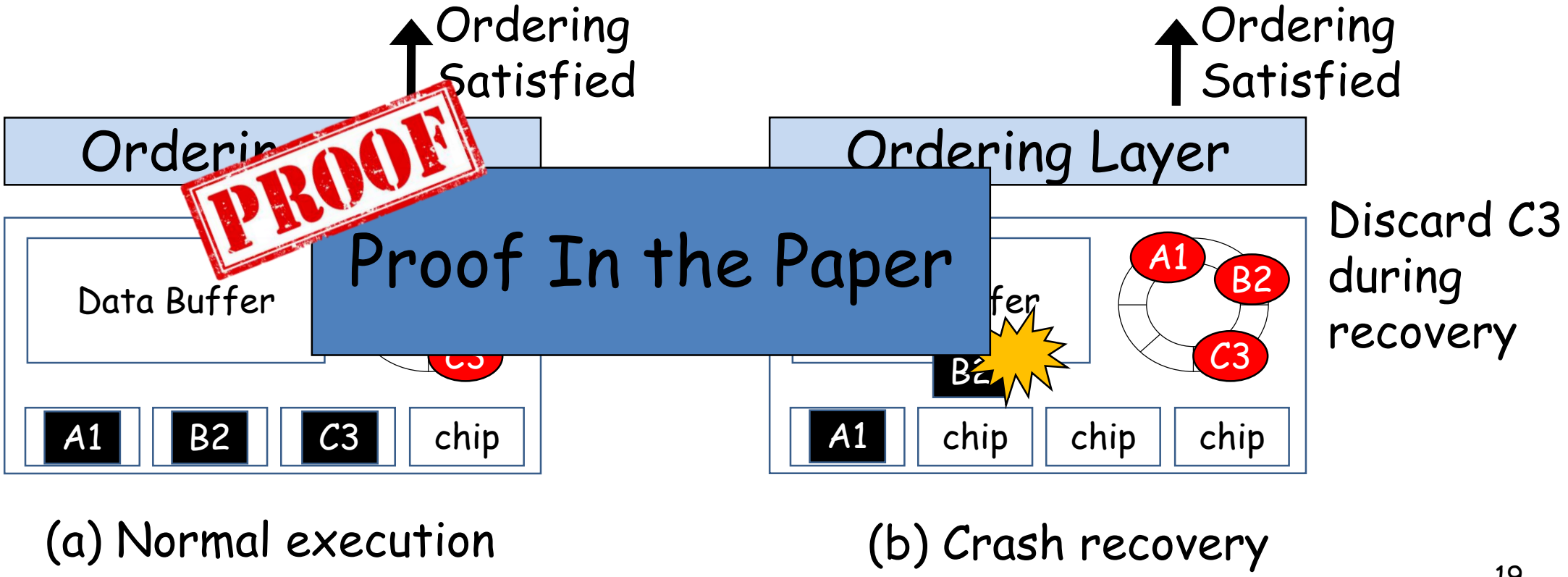

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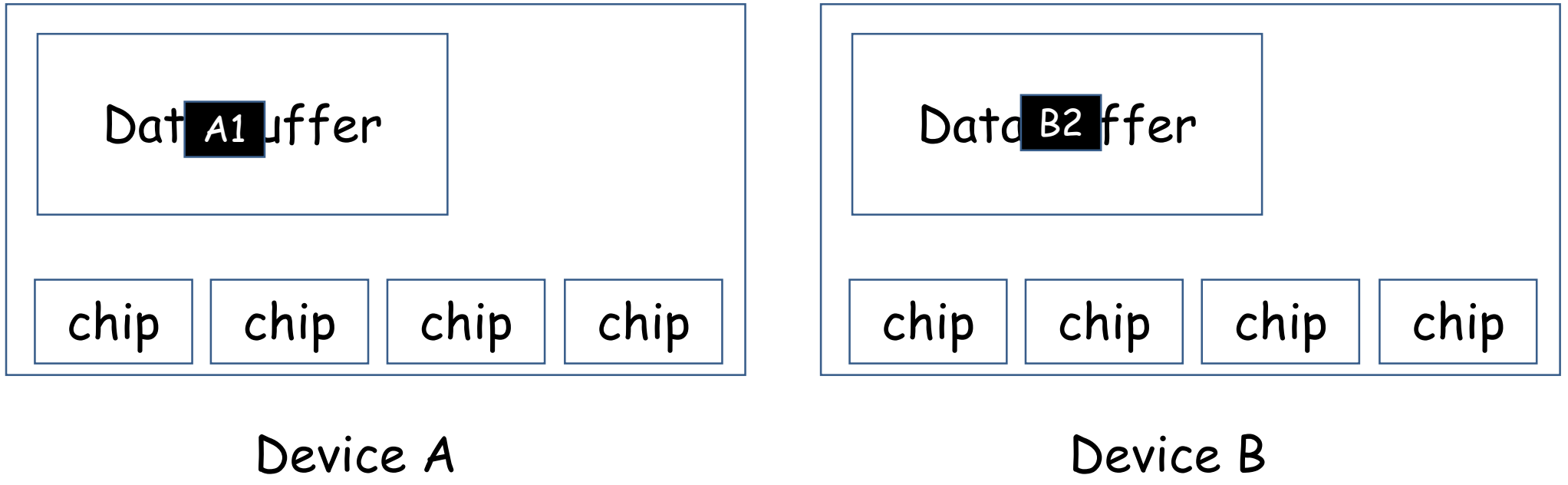
Classic Durability Guarantee

- Linux uses FLUSH command to synchronously and serially drain out the possibly volatile data buffer in each device.



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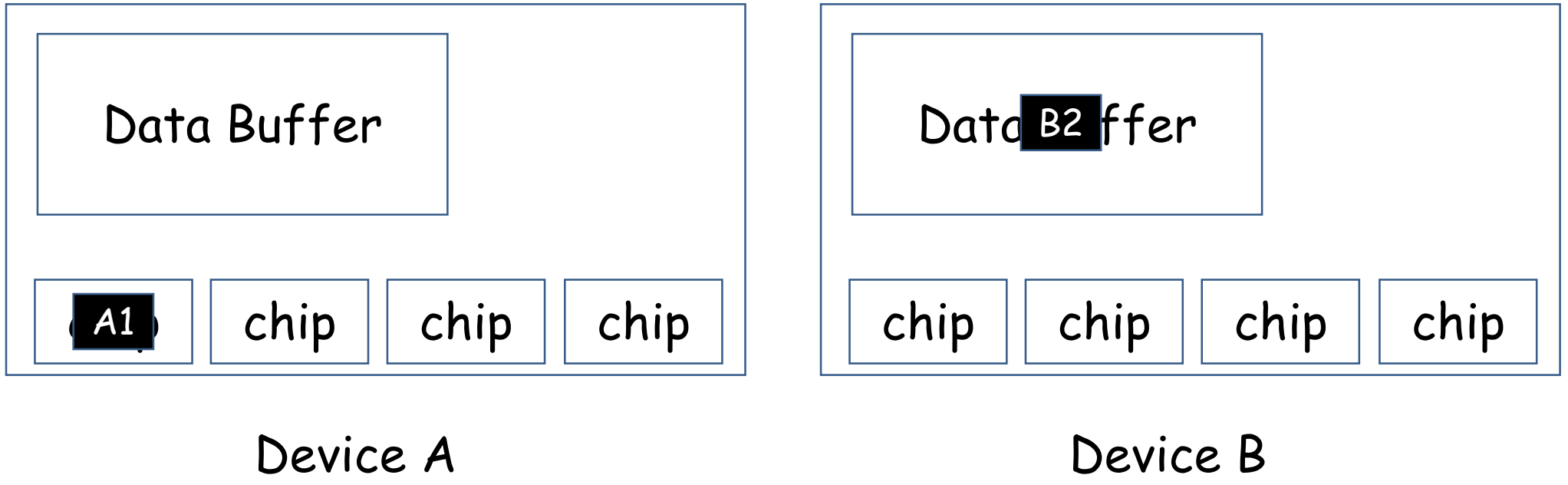

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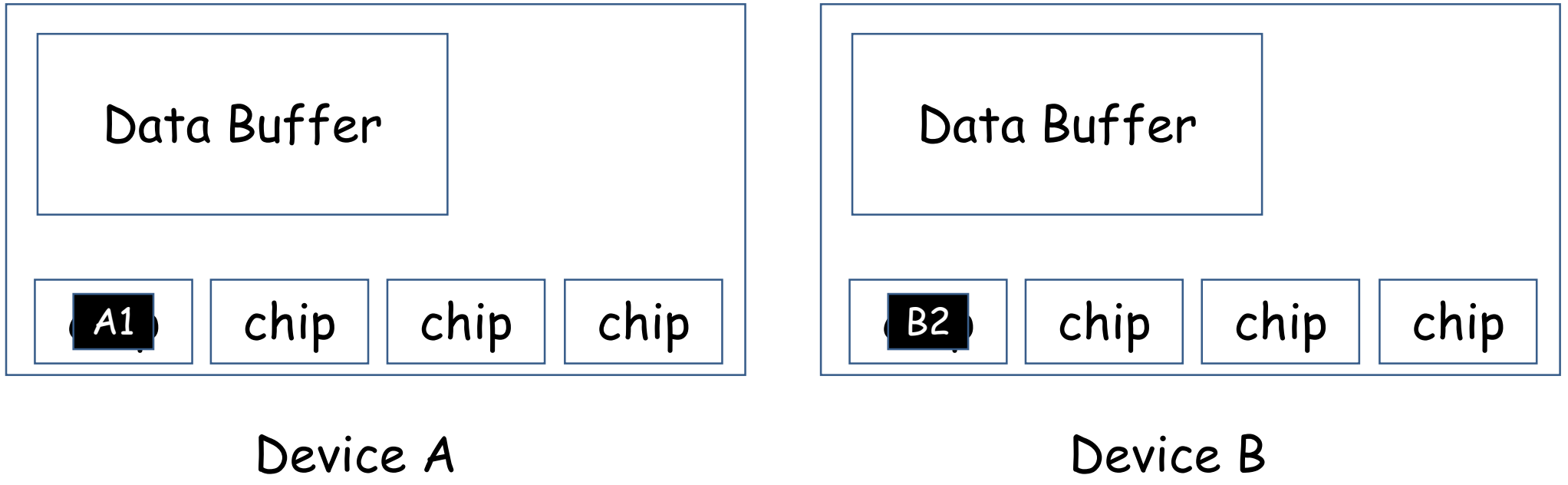
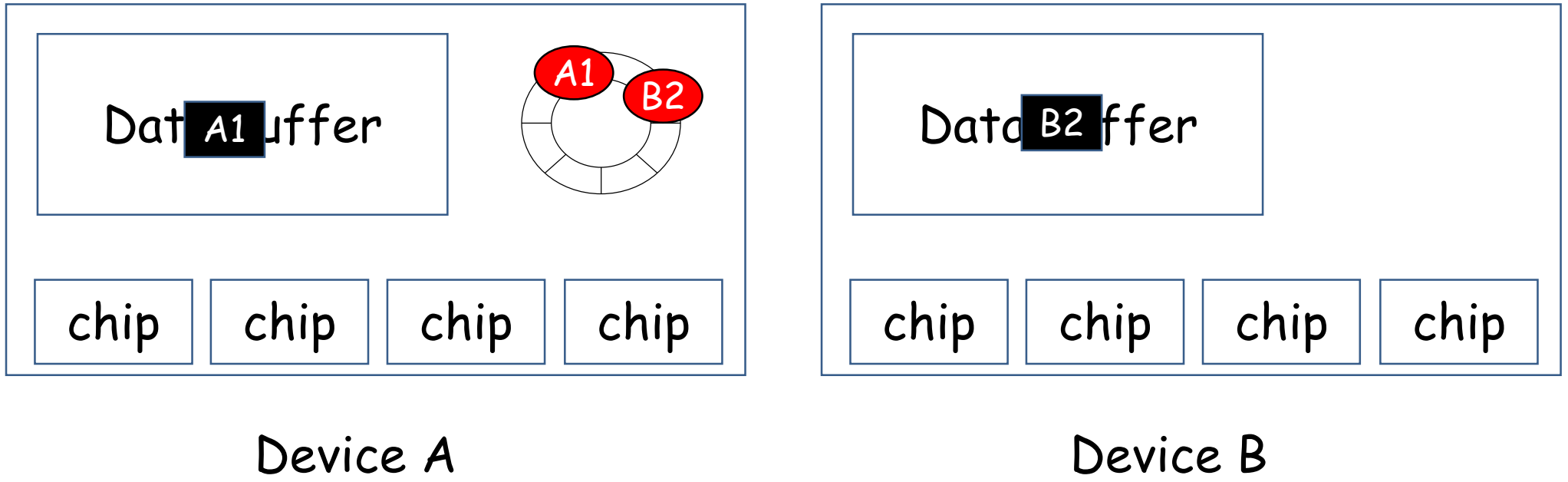


Horae's Durability Guarantee

- Horae introduces joint FLUSH to perform parallel FLUSHes in separate devices.



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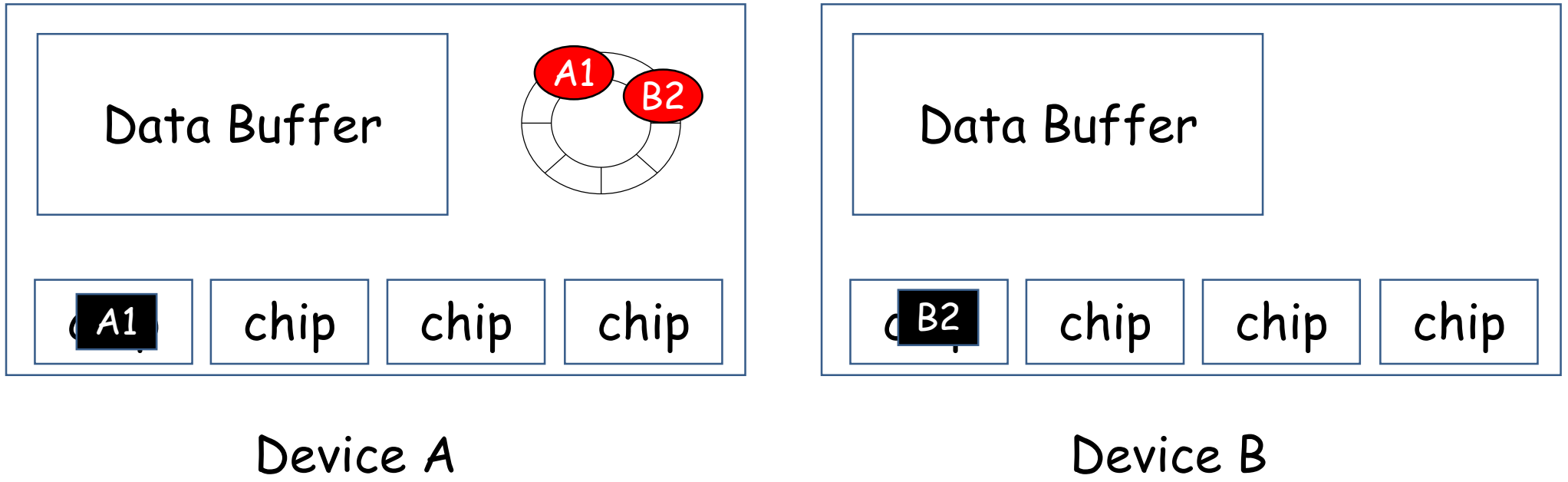
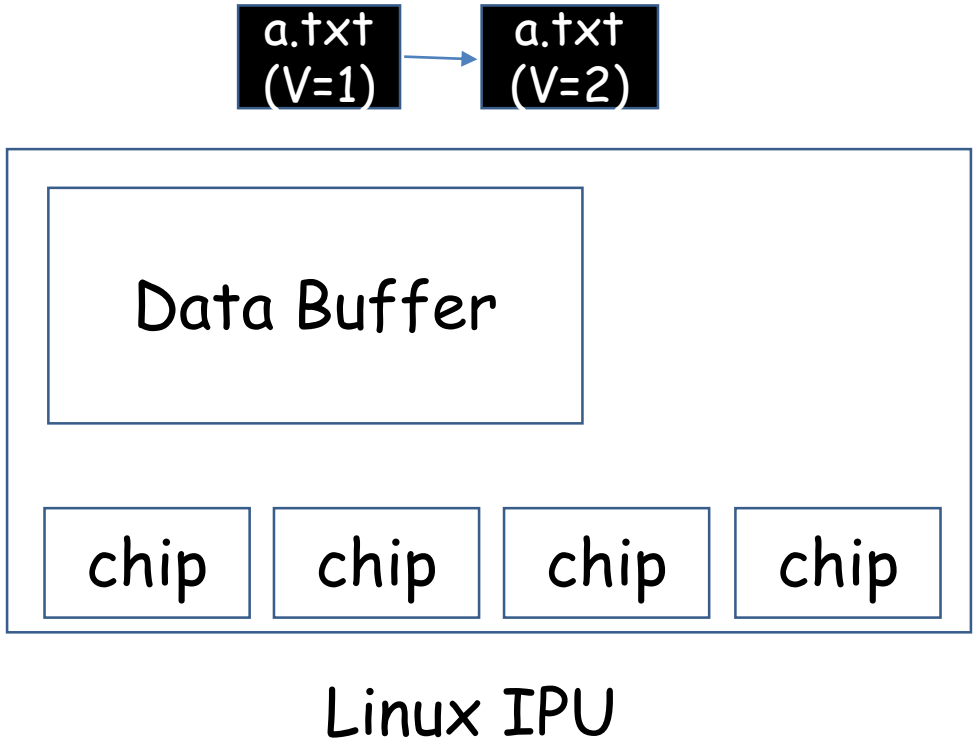


Parallelizing In-Place Updates

- Classic IO stacks serialize in-place updates.



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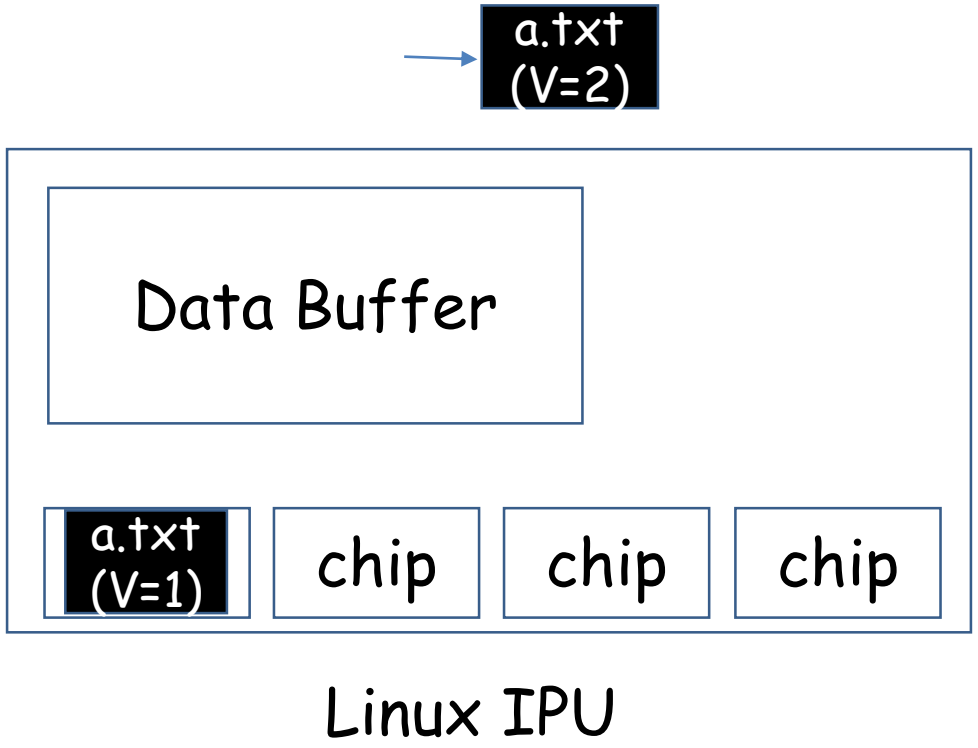

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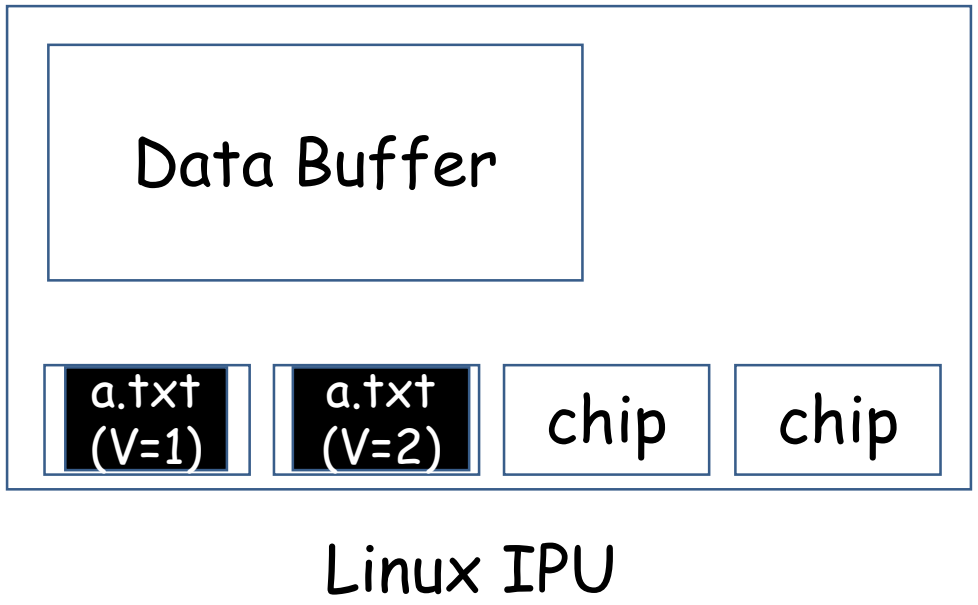

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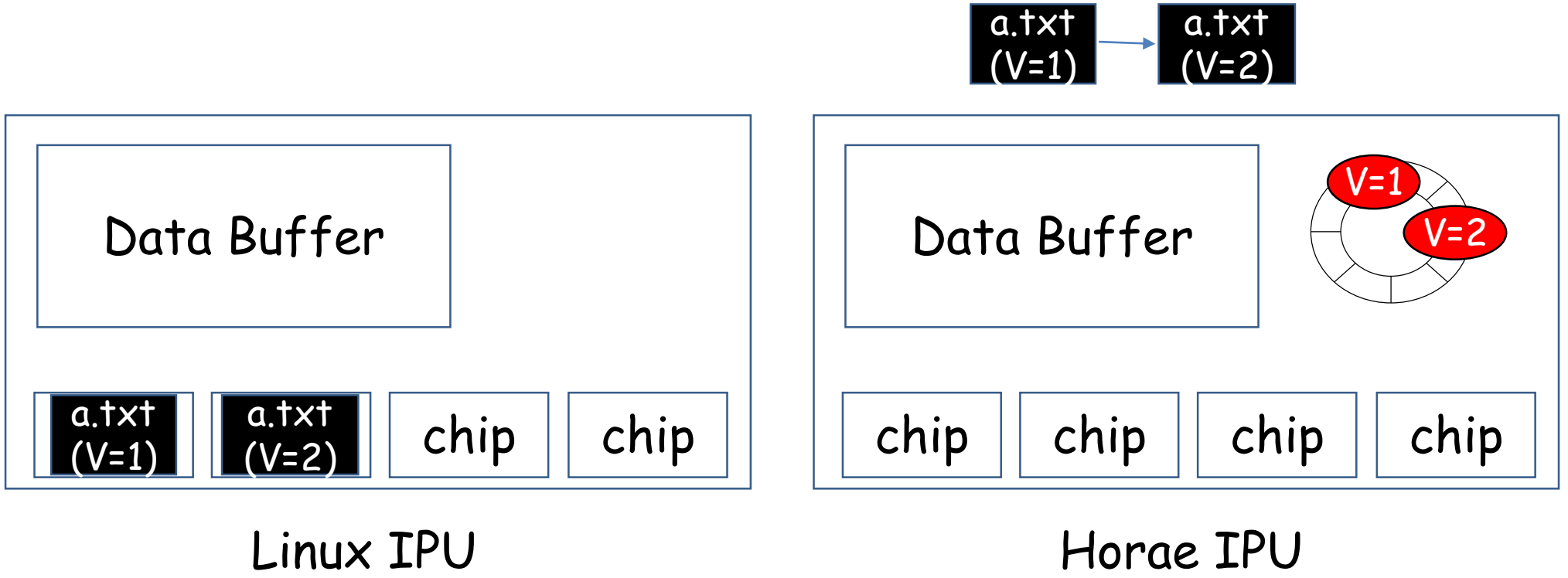

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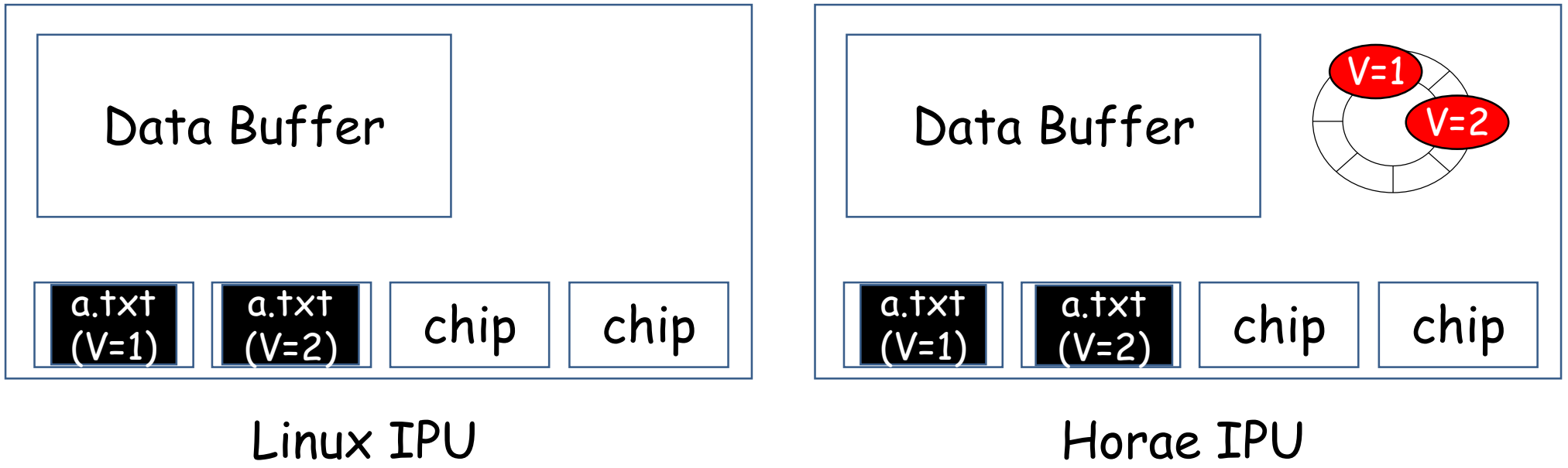
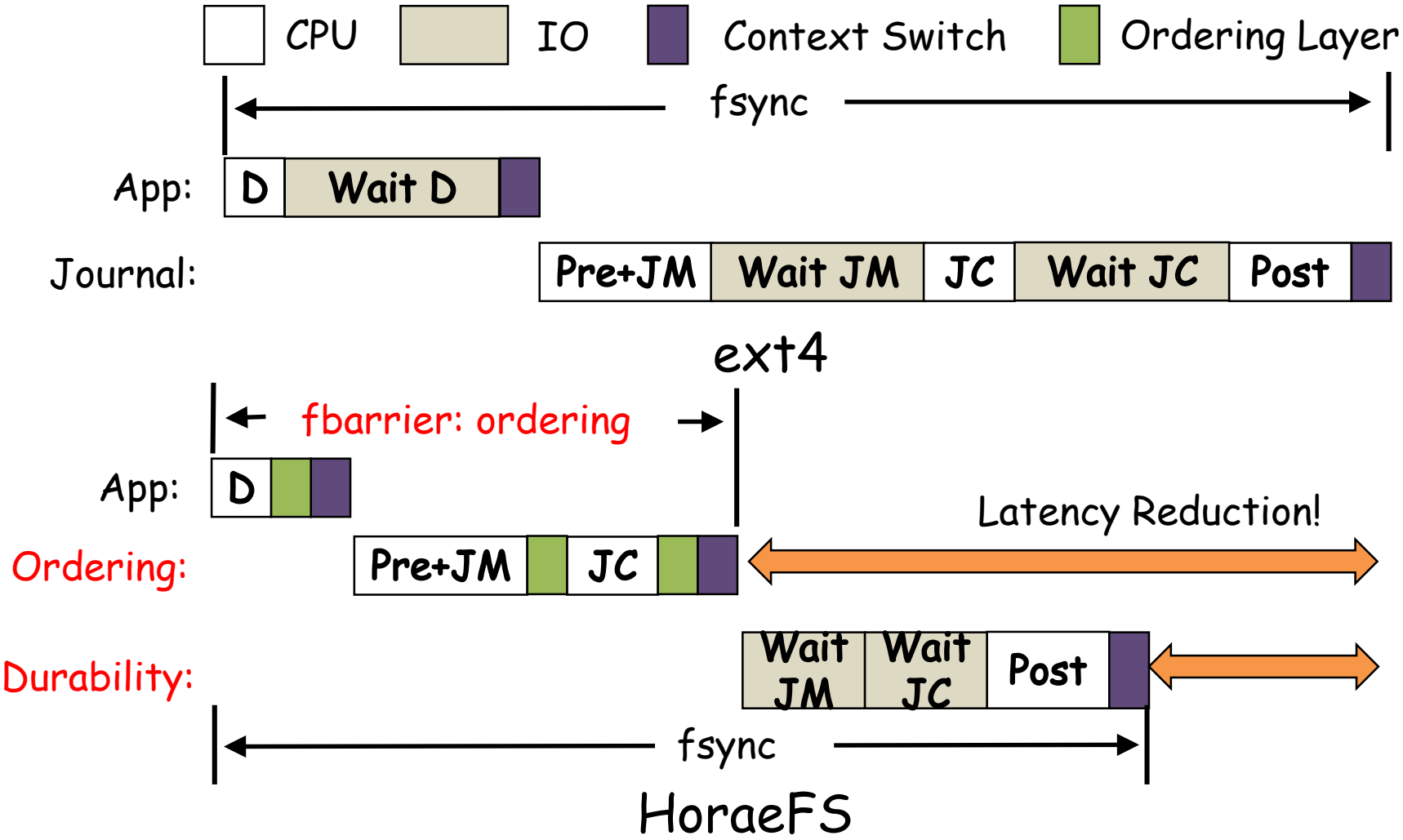


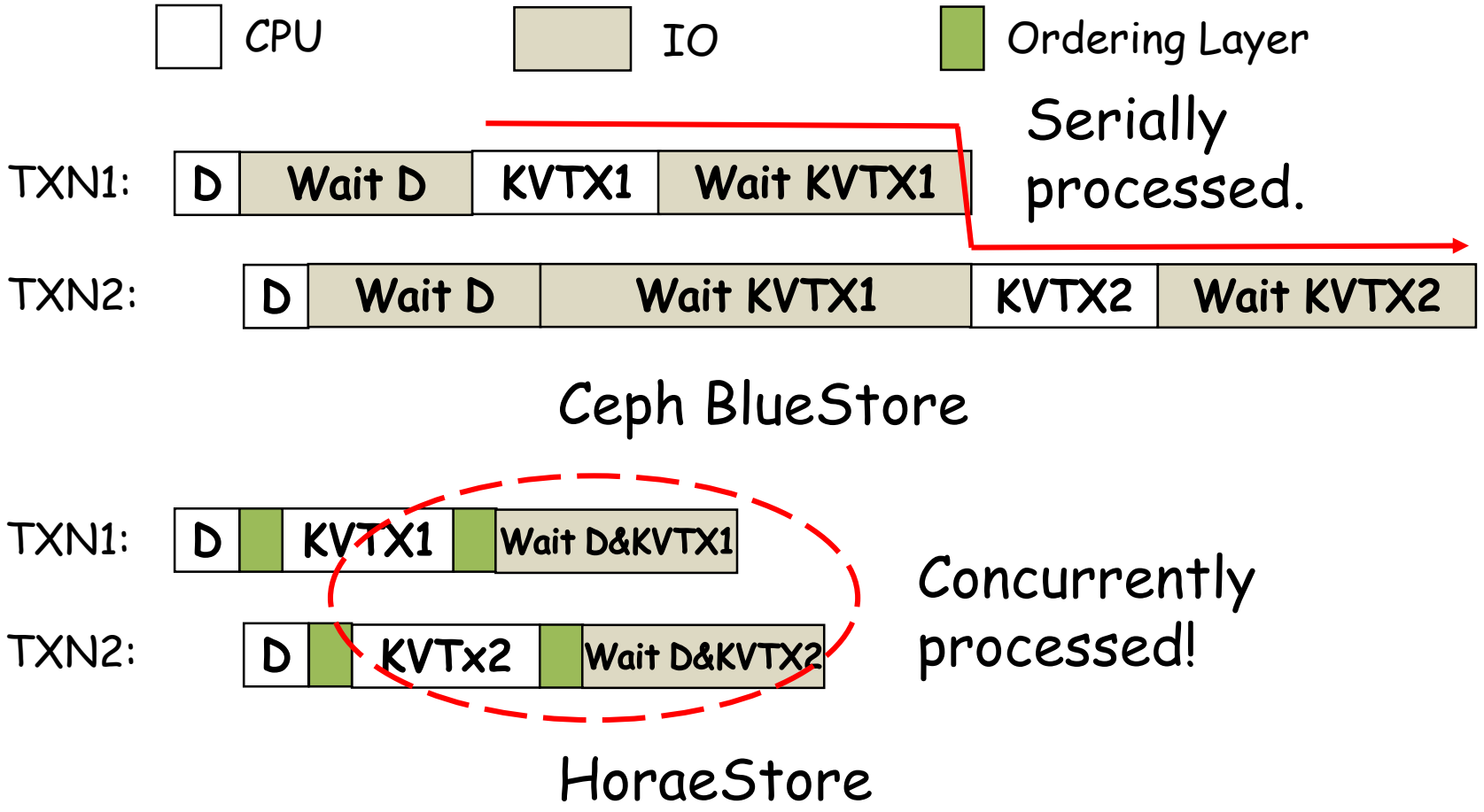
Use Case 1: HoraeFS

separate ordering logic from durability logic



Use Case 2: HoraeStore

parallelize dependent transactions



3. Evaluation

Test layer

Application
File System
Block Device
Storage

Benchmarks

- OLTP-insert, dbbench, objectbench
- FIO allocating write
- FIO random overwrite

Hardware

- Lower-end SATA SSD A: Samsung 860 Pro
- Medium-end NVMe SSD B: Intel 750 (consumer-grade)
- High-end NVMe SSD C: Intel DC P3700 (datacenter-grade)

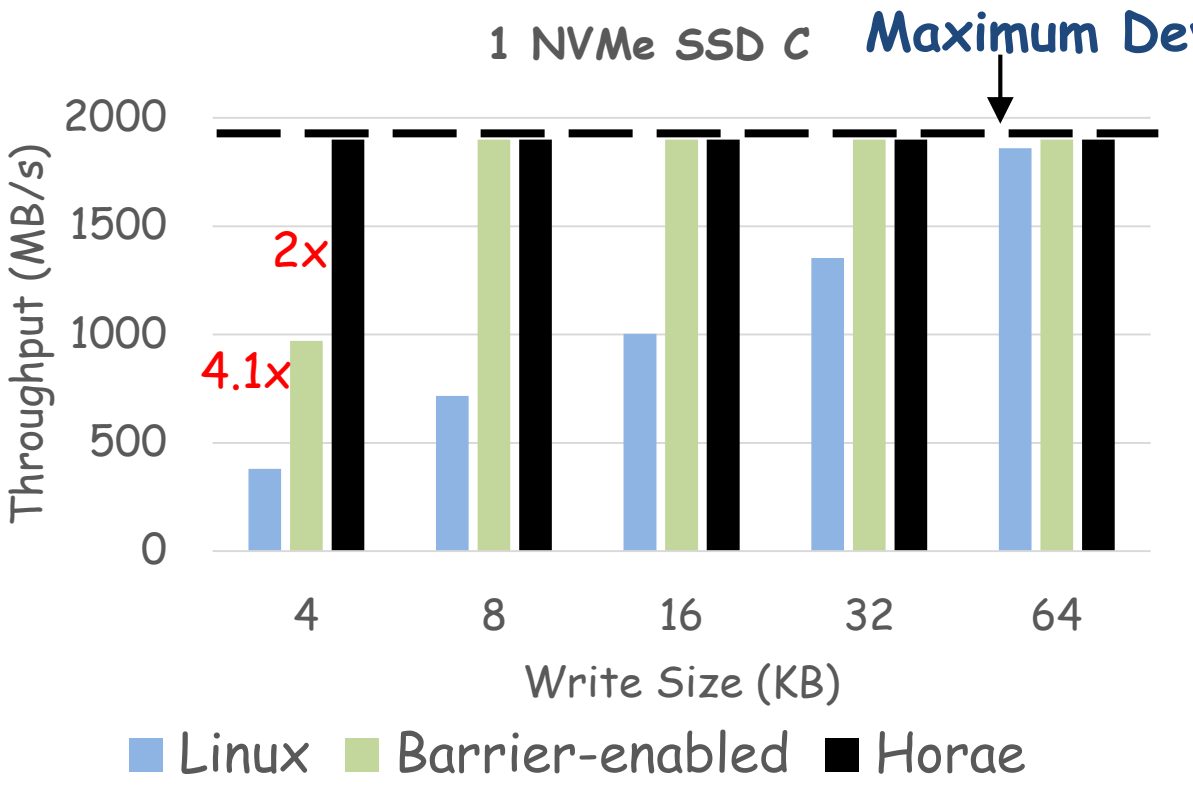
Compared systems

- Linux VS. Barrier[1] VS. Horae

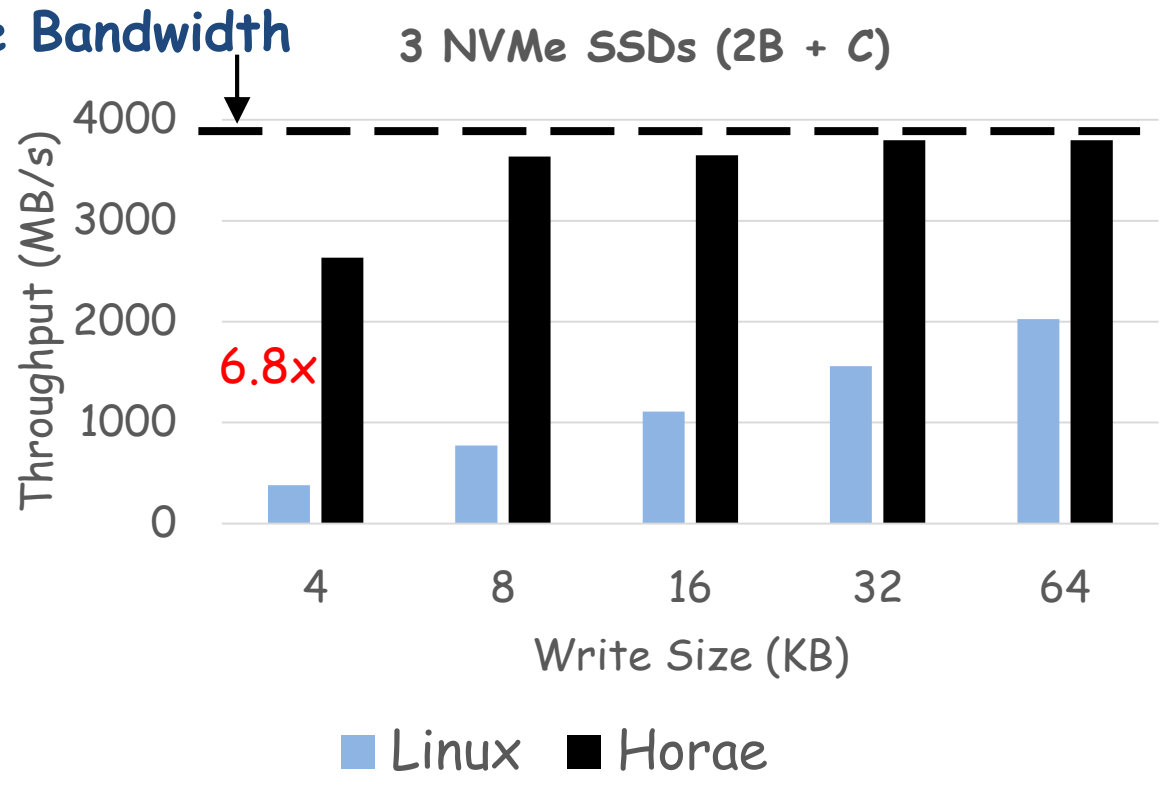
[1] Barrier-Enabled IO stack for Flash Storage, FAST'18

Block Device Performance

- **Single Device**



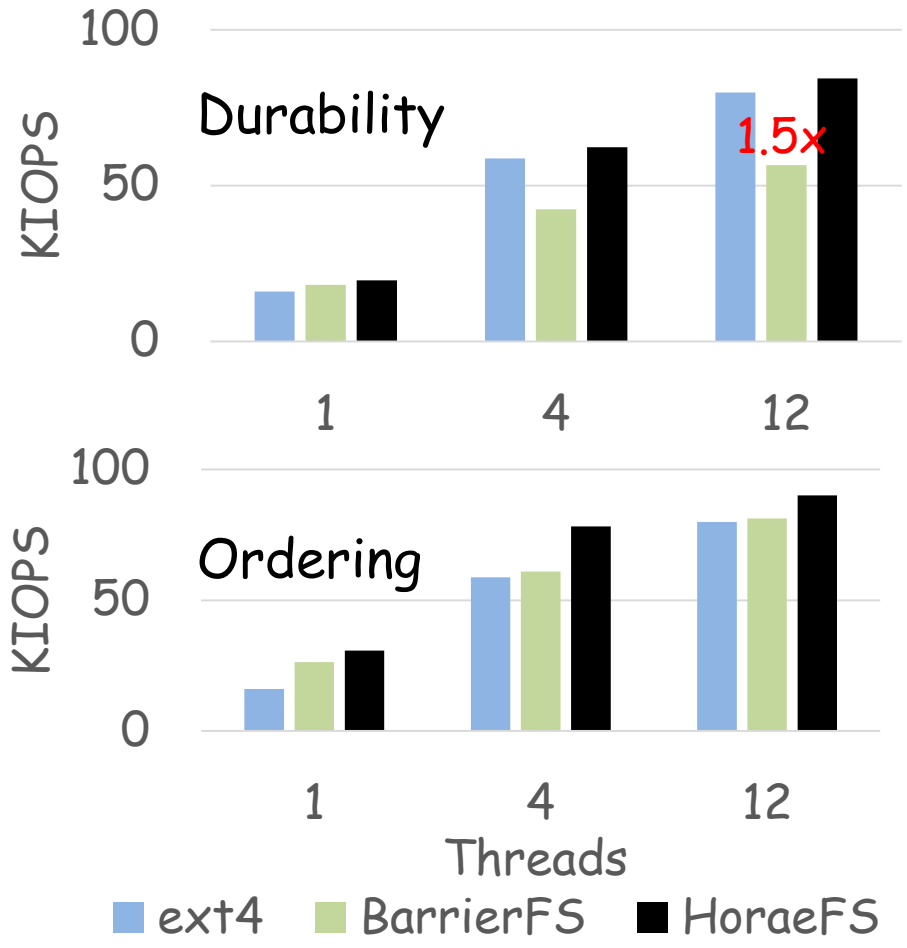
- **Multiple Devices**



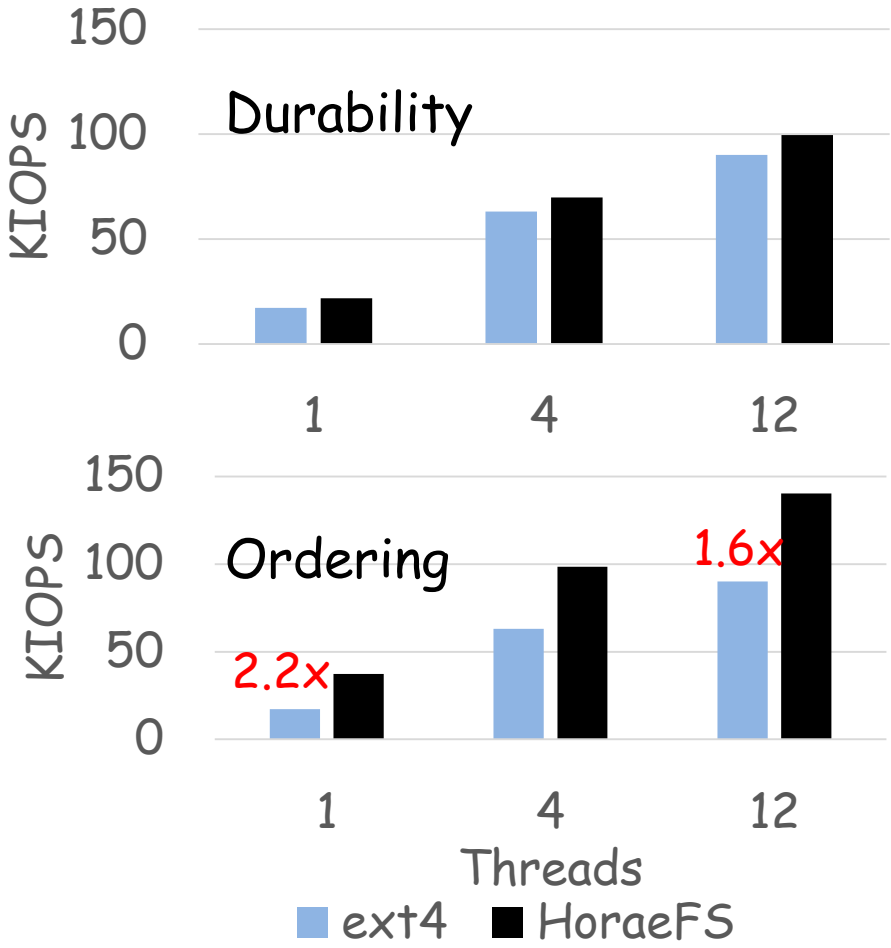
Separating the ordering control path is efficient.

File System Performance

- 1 NVMe SSD (B)



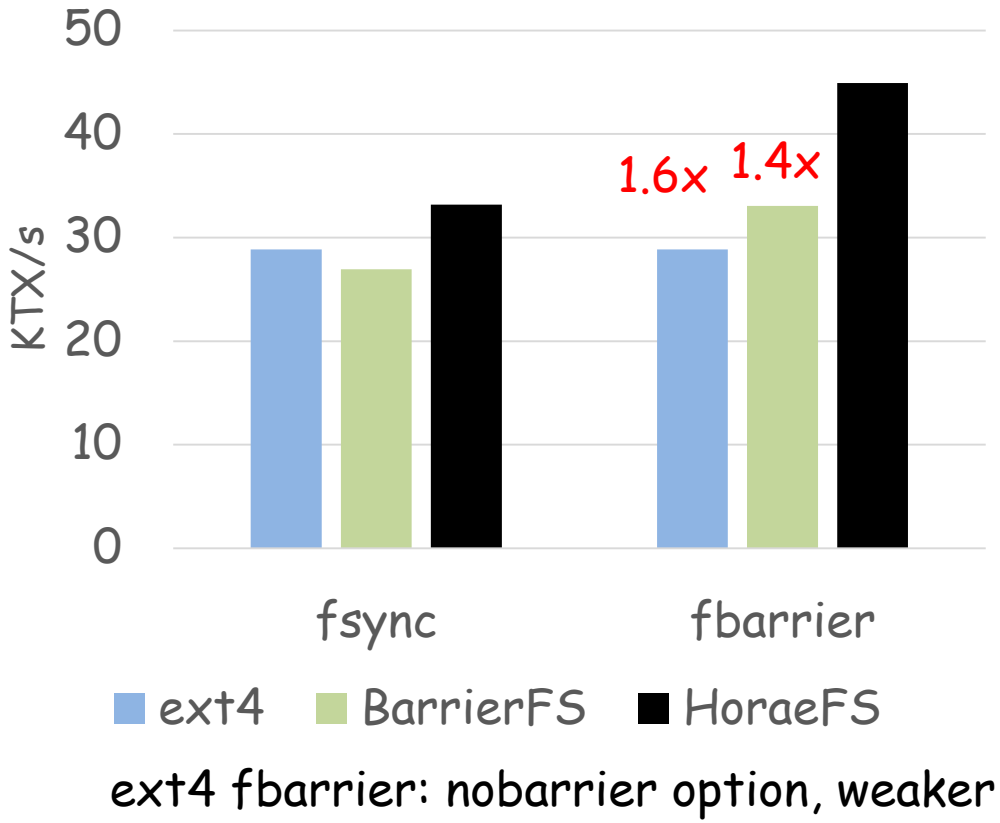
- 2 NVMe SSDs (B+C)



Parallelizing the data and journal processing is efficient.

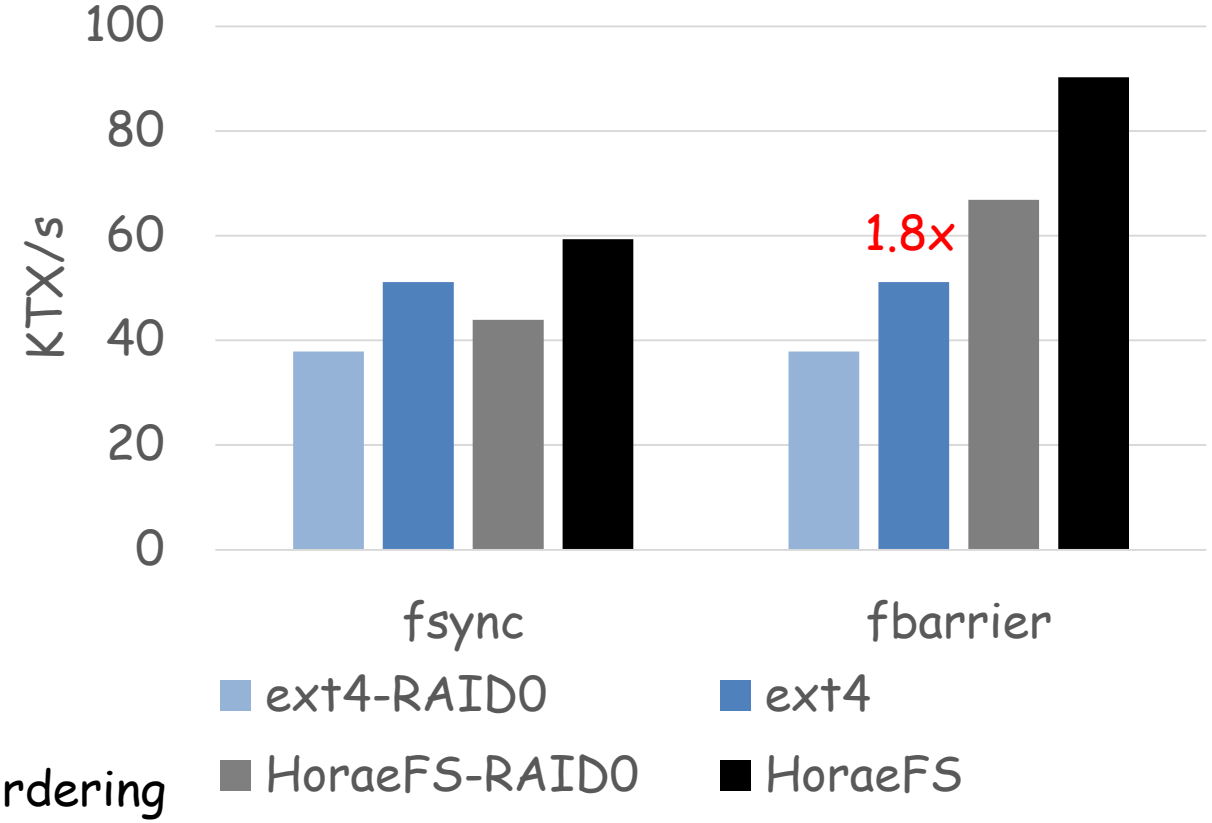
Application Performance-MySQL

- **Sole**



ext4 fbarrier: nobarrier option, weaker ordering

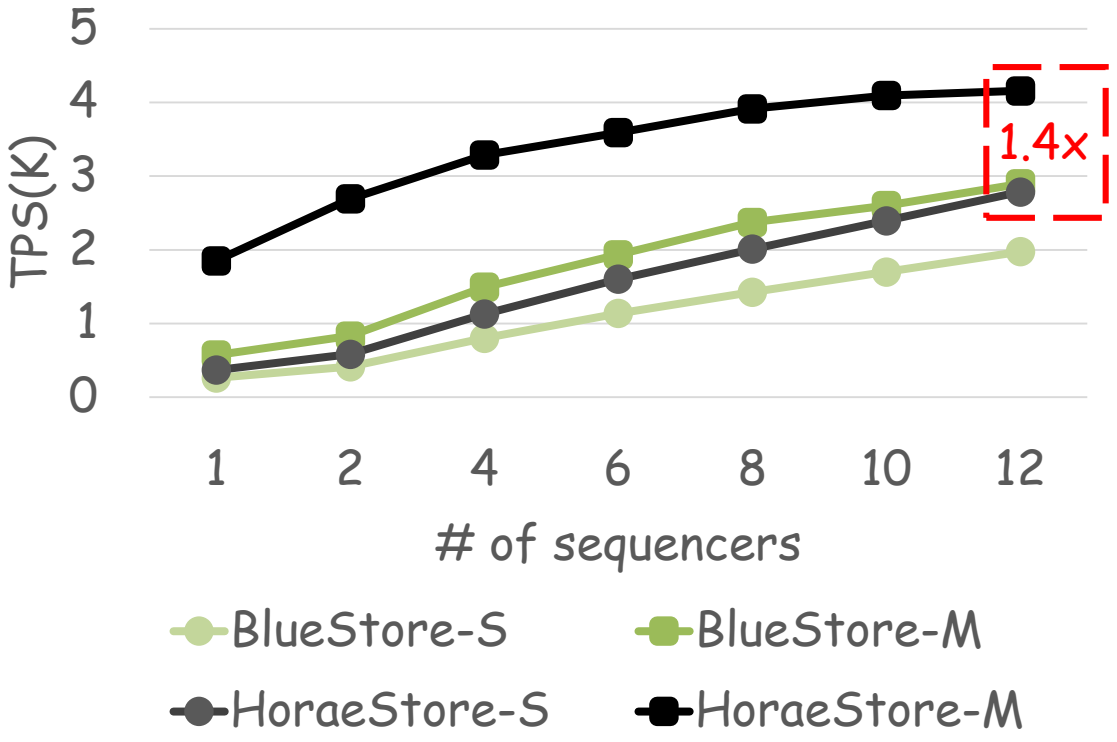
- **Separate redo log**



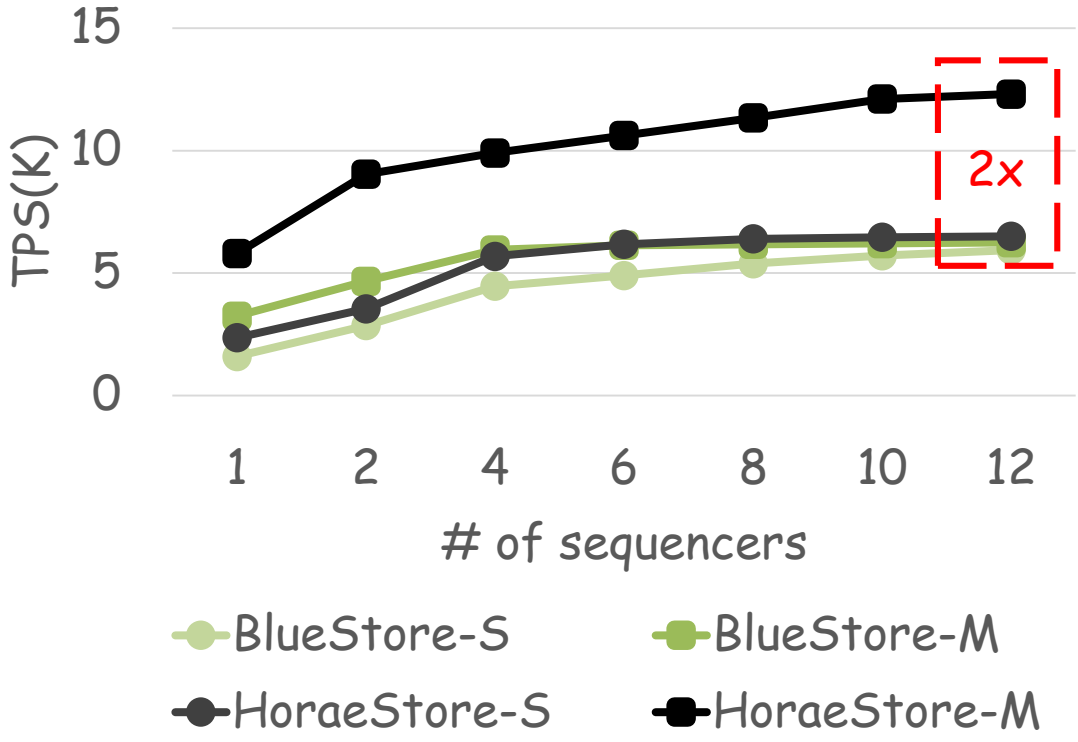
- Horae boosts MySQL performance by up to 1.8x
- HoraeFS-RAID0 < HoraeFS

Application Performance-HoraeStore

- **apply_transaction**



- **queue_transaction**



Sole: SSD A; Multiple: SSD A+B+C

HoraeStore outperforms BlueStore by up to 2x.

Conclusion

- The write dependency overhead becomes more severe with the scaling of storage concurrency.
- We re-architect IO stack with HORAE, providing a dedicated control path to reduce the write dependency overhead.
- Horae boosts file system level and application level performance by up to 2.2x and 2x.

Thank You!

Write Dependency Disentanglement with HORAE

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