Understanding the Robustness of SSDs under Power Fault

Mai Zheng
Feng Qin
The Ohio State University

Joseph Tucek
Mark Lillibridge
HP Labs

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- a “truly revolutionary and disruptive” technology

- Great performance 🙂
- Low power consumption 🙂

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- *** behavior in adverse conditions ?

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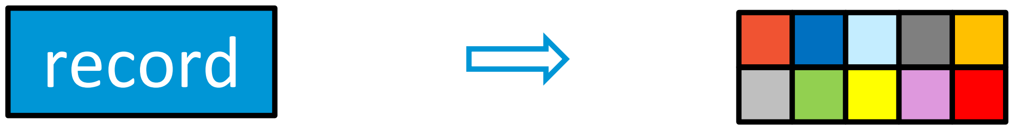
Potential Failures

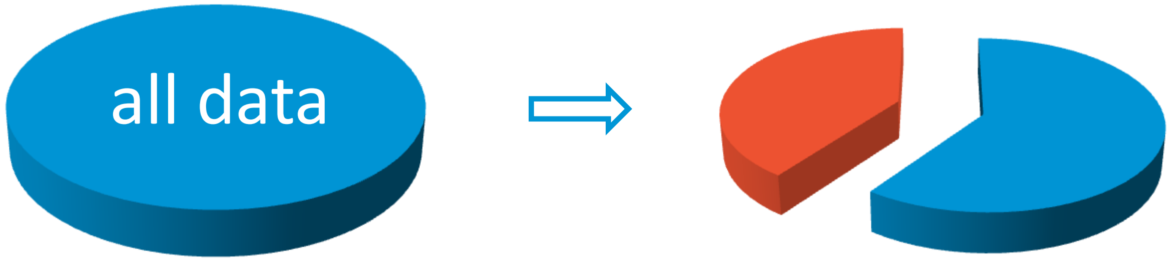
Simple Failures

before power fault after power fault

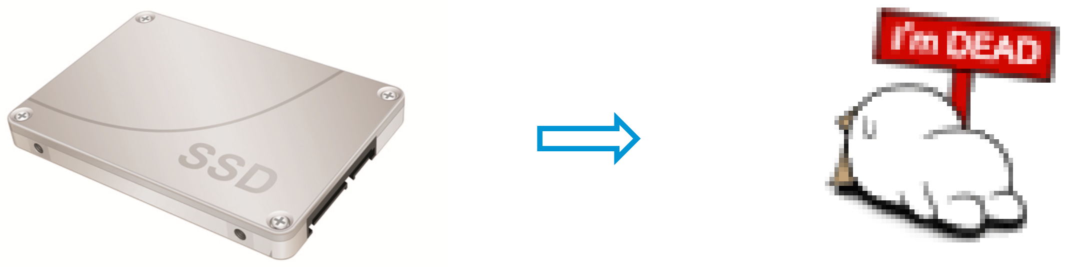
- Bit Corruption



- Metadata Corruption

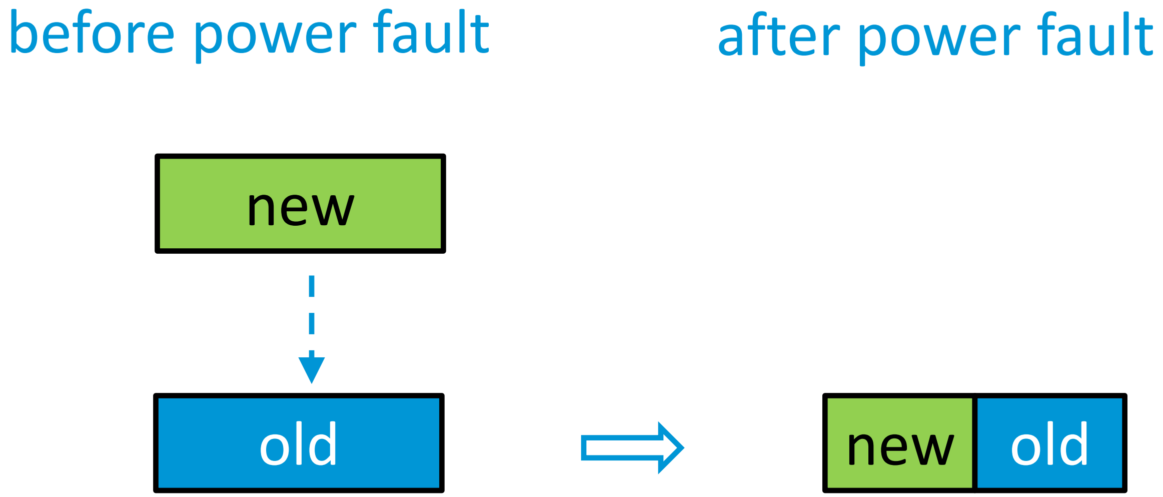


- Dead Device

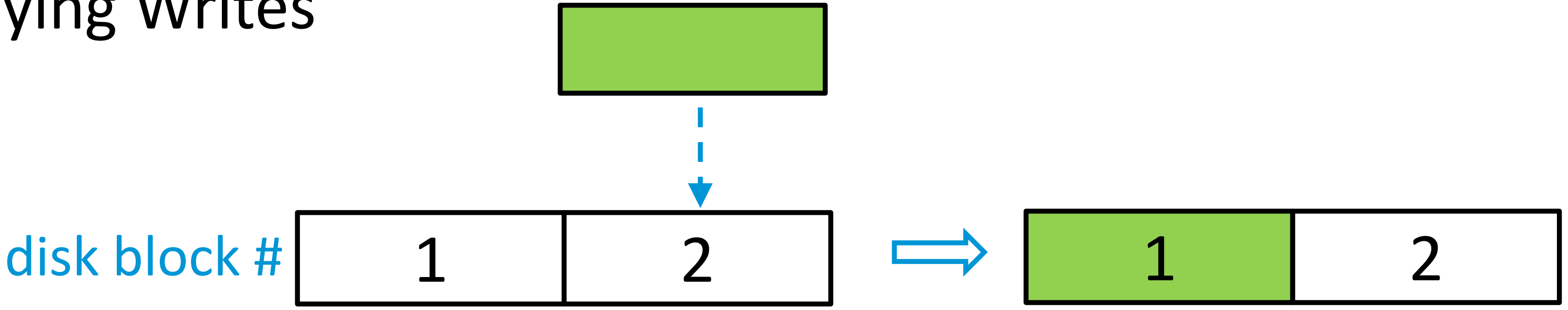


Simple Failures

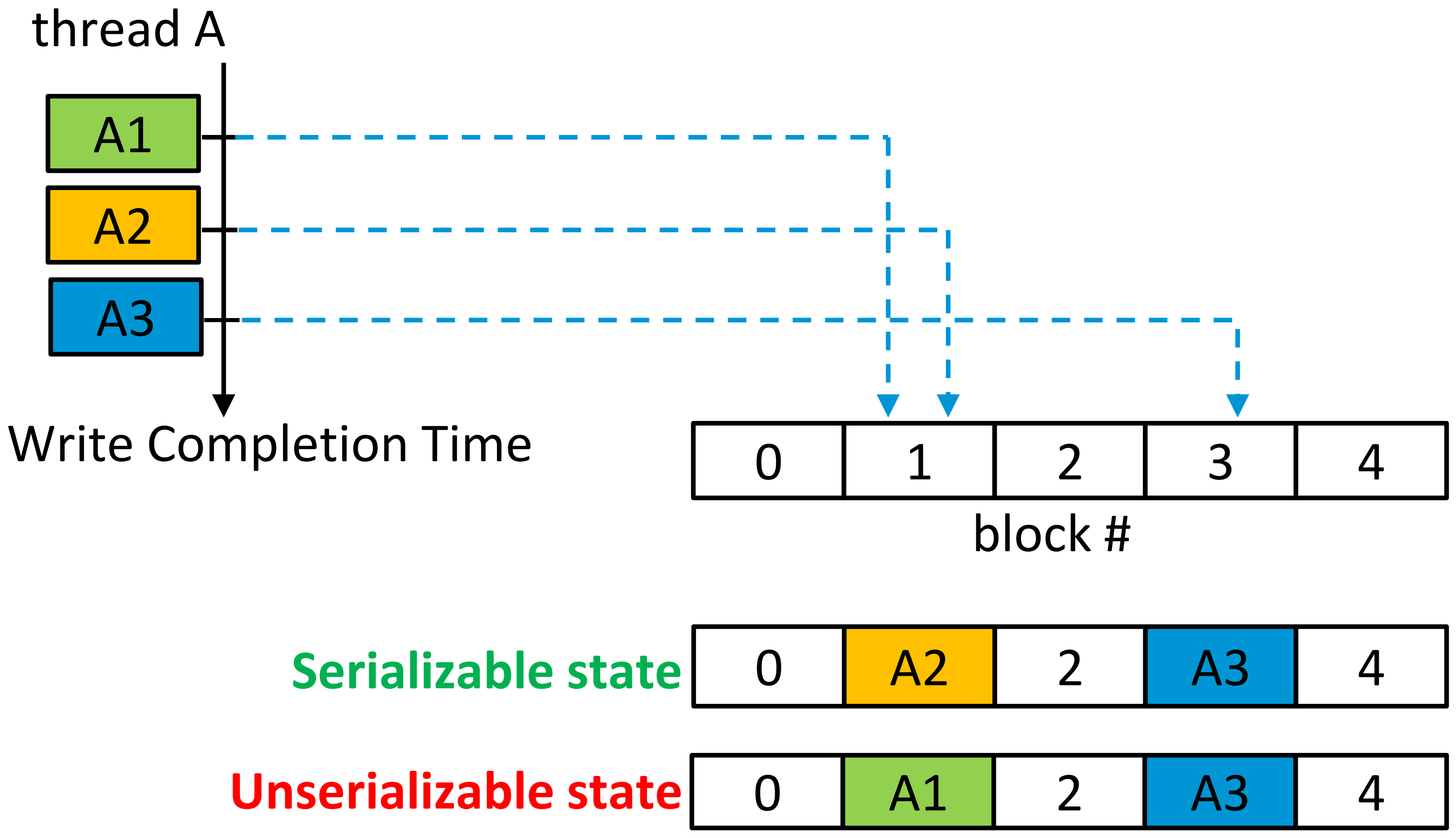
- Shorn Writes



- Flying Writes

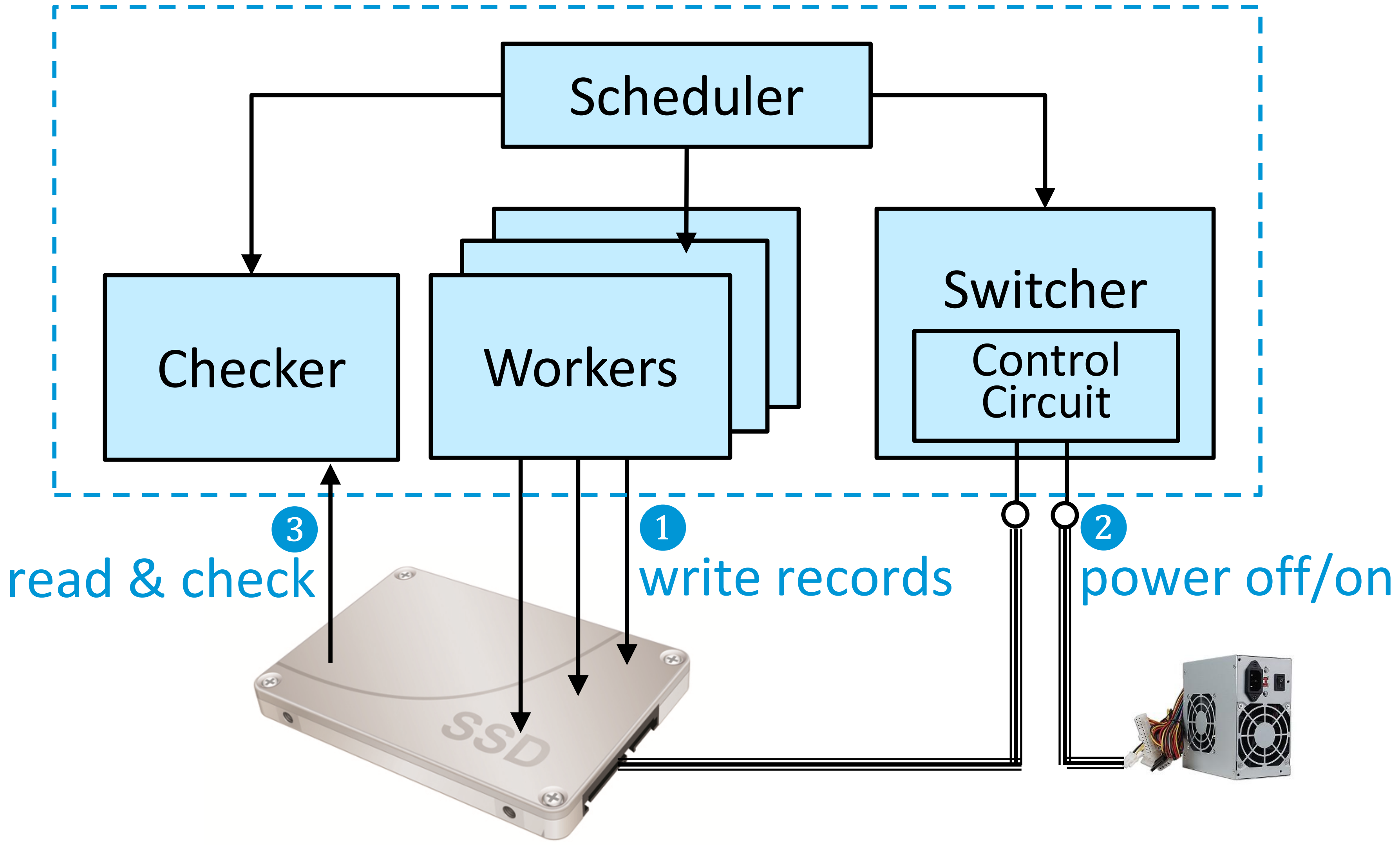


Complex Failure: Unserializable Writes

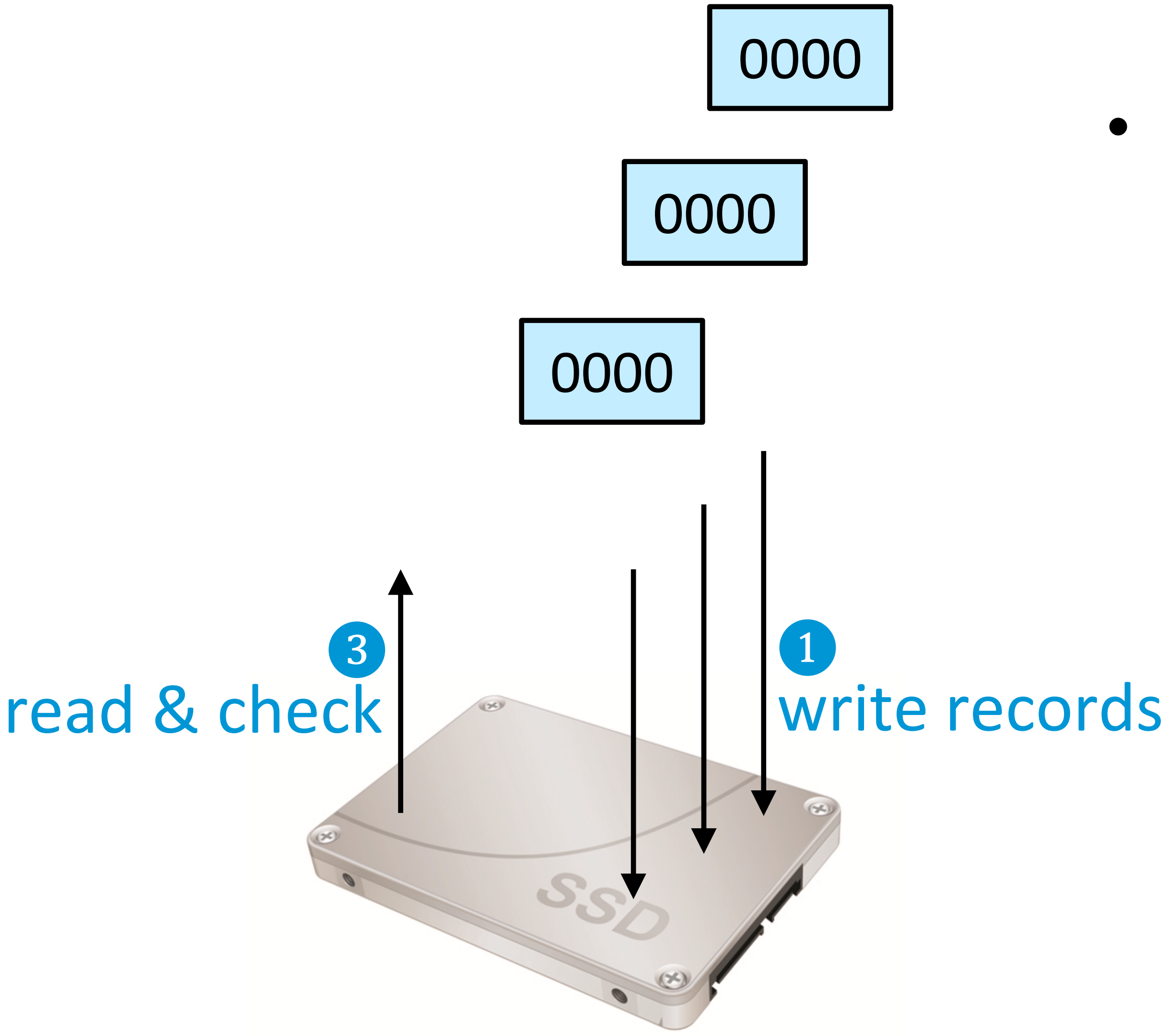


Testing Framework

Design

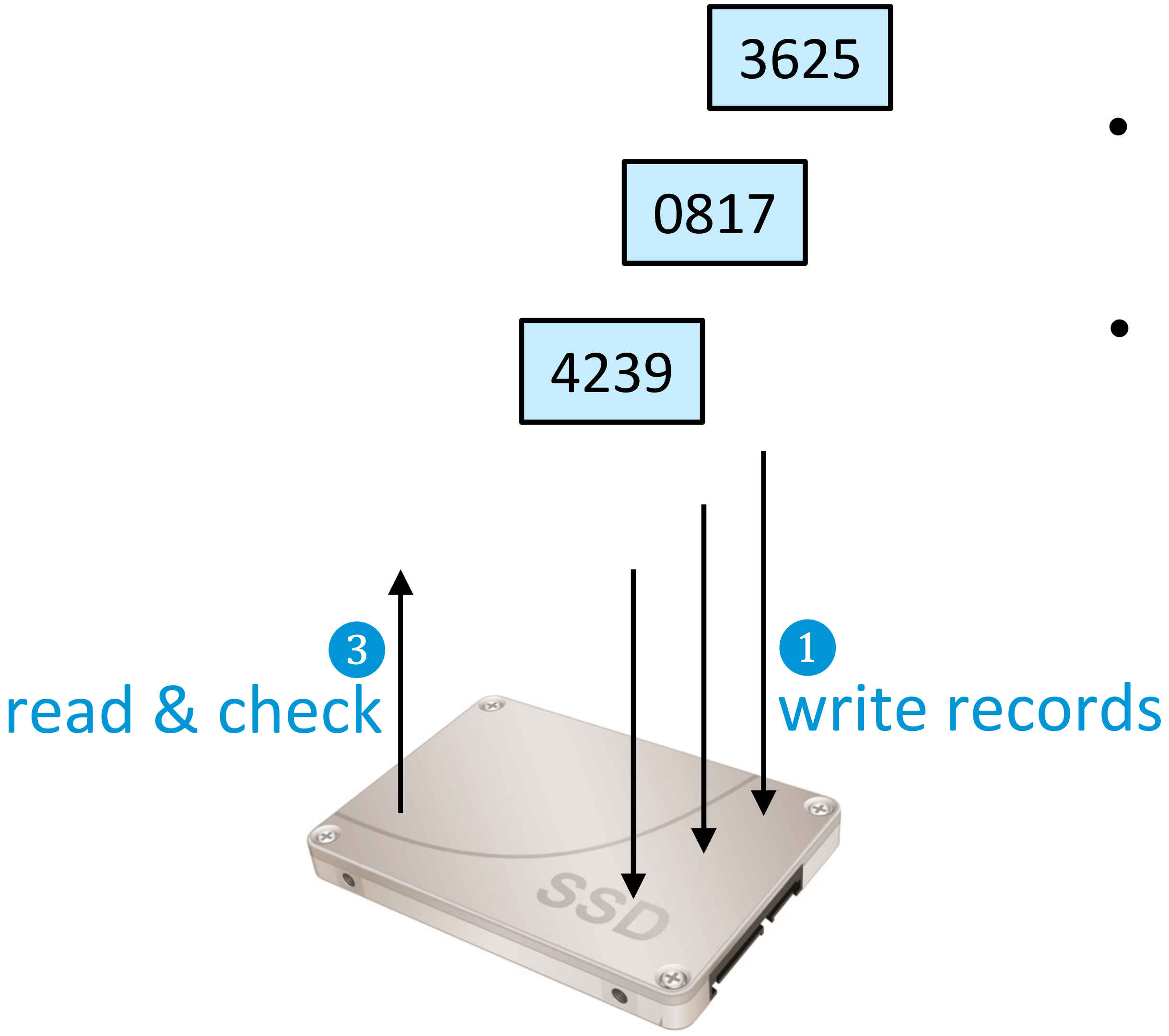

Scheduler
Checker
Workers
Switcher
Control Circuit
3
read & check
1
write records
2
power off/on
SSD

What to Write?



- all 0's ? ☹

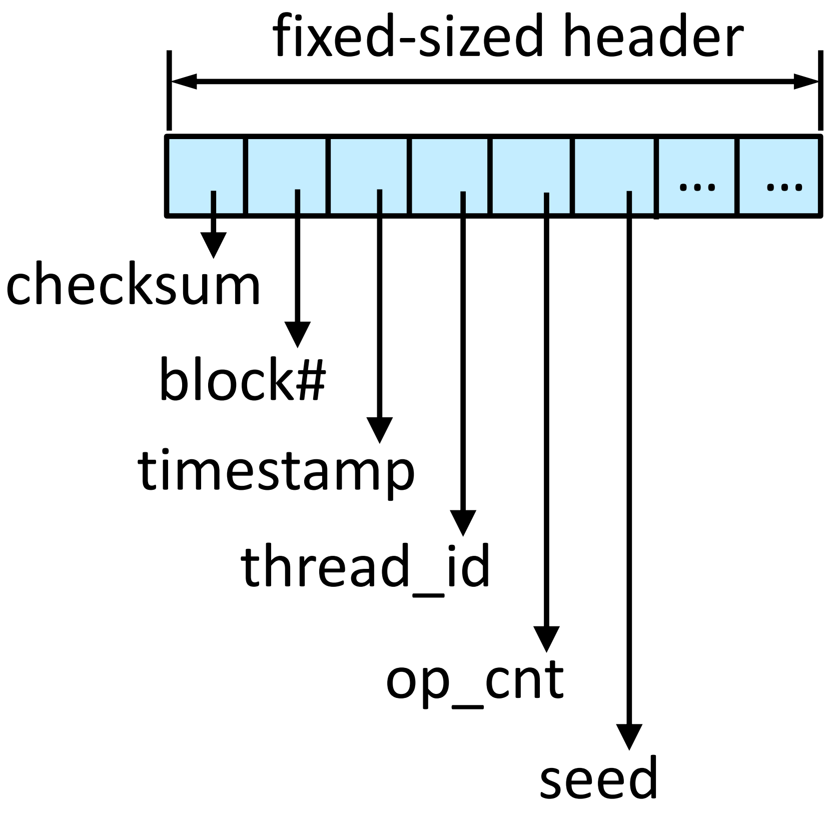
What to Write?



- all 0’s ? ☹
- random numbers? ☹

Special Record Format

- allows detecting all 6 types of failures



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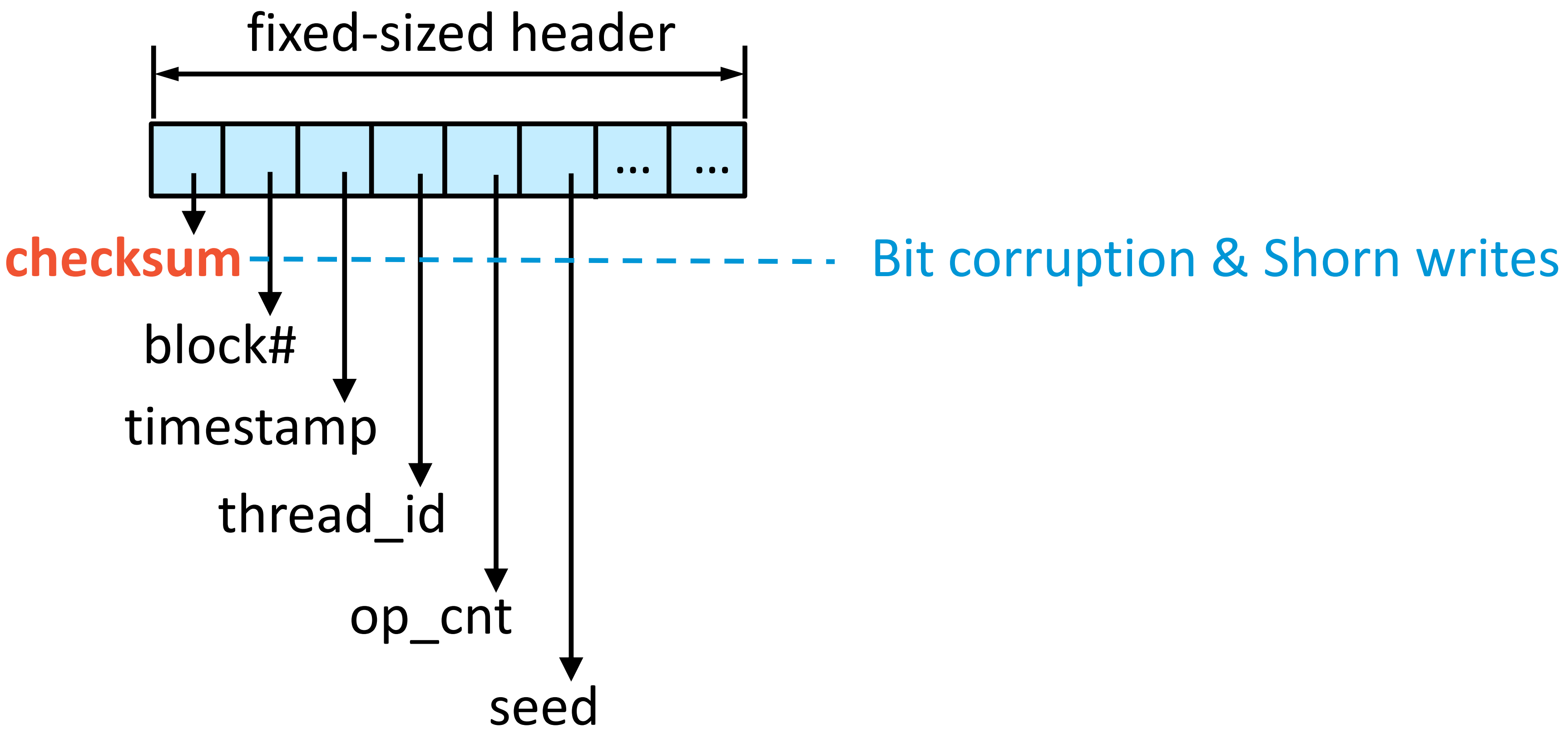

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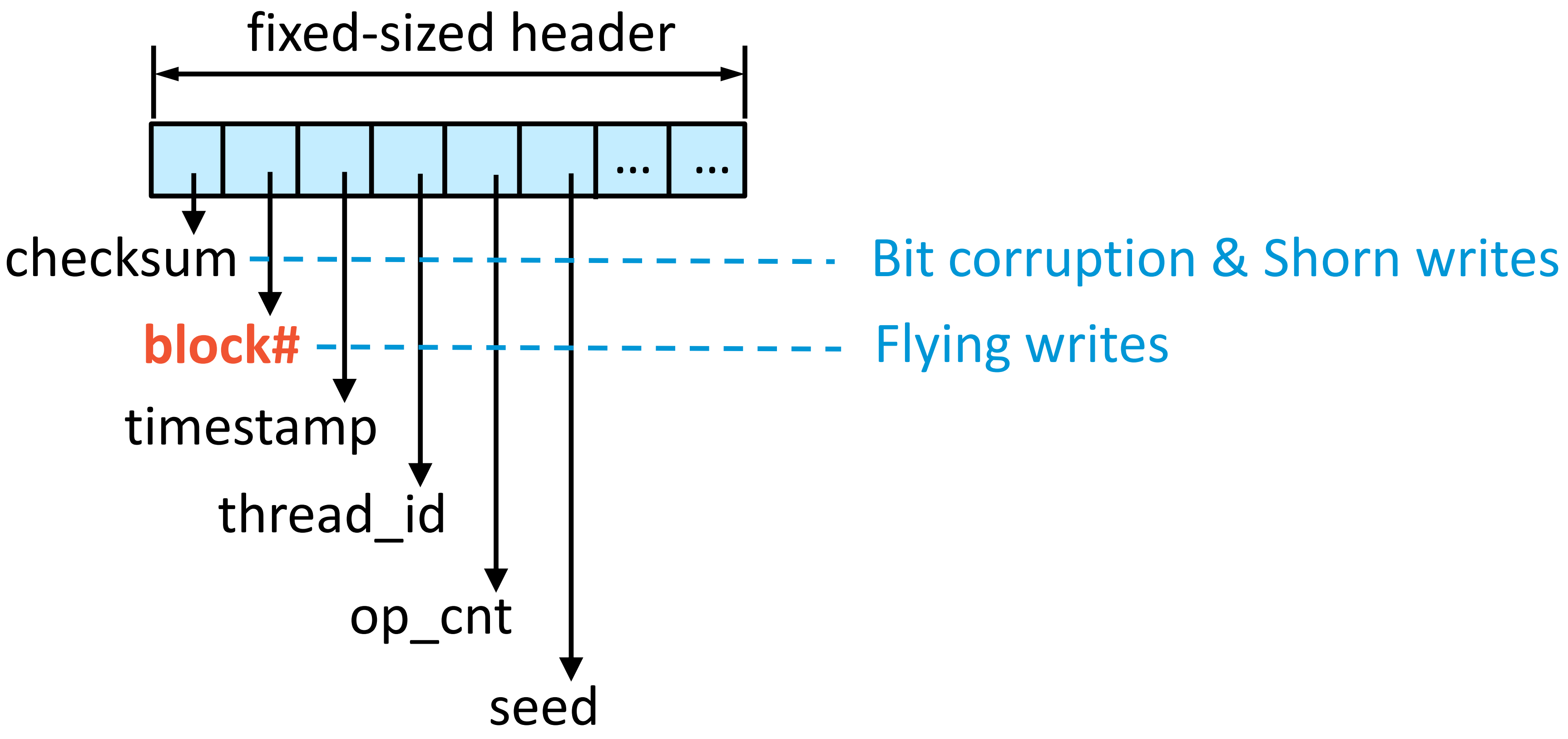

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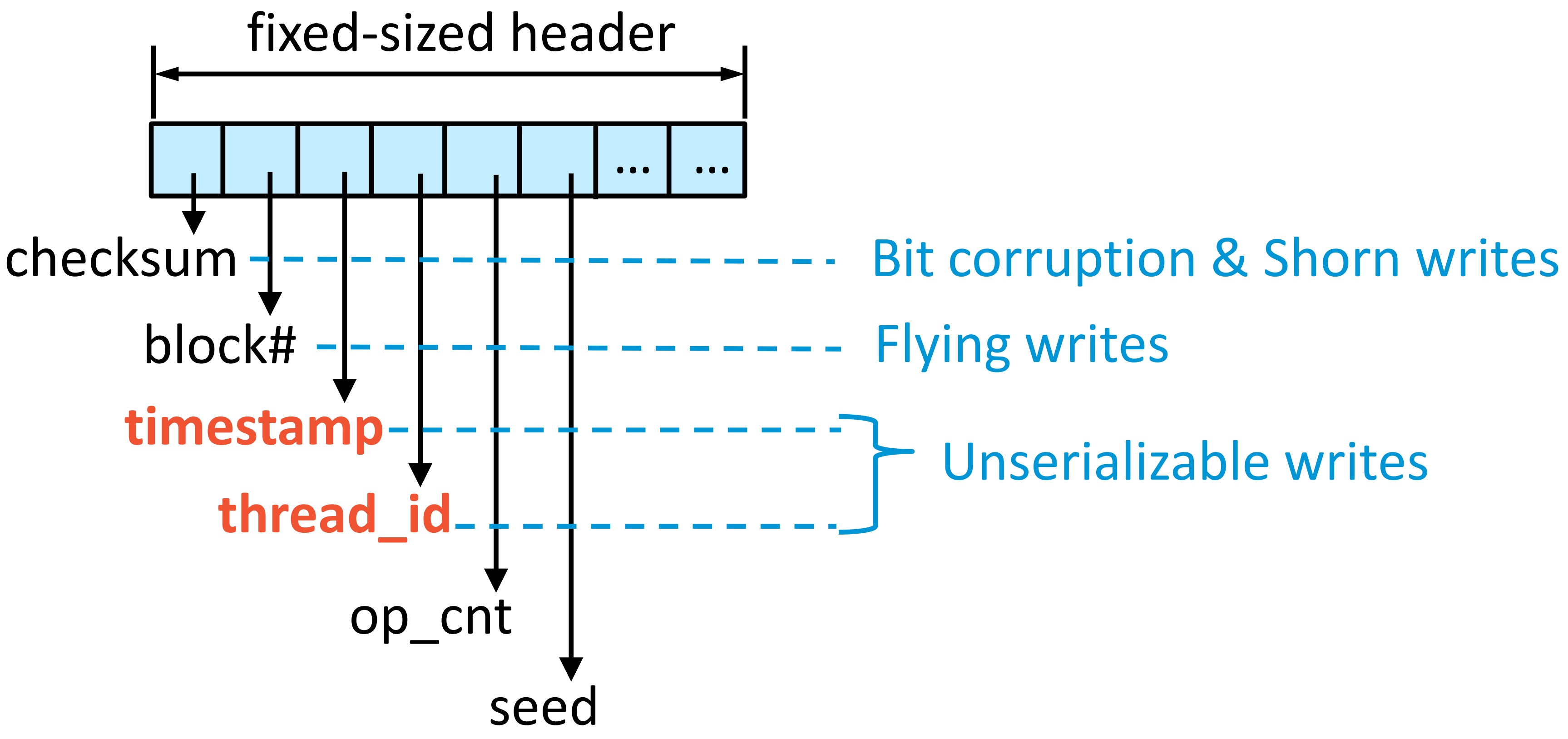

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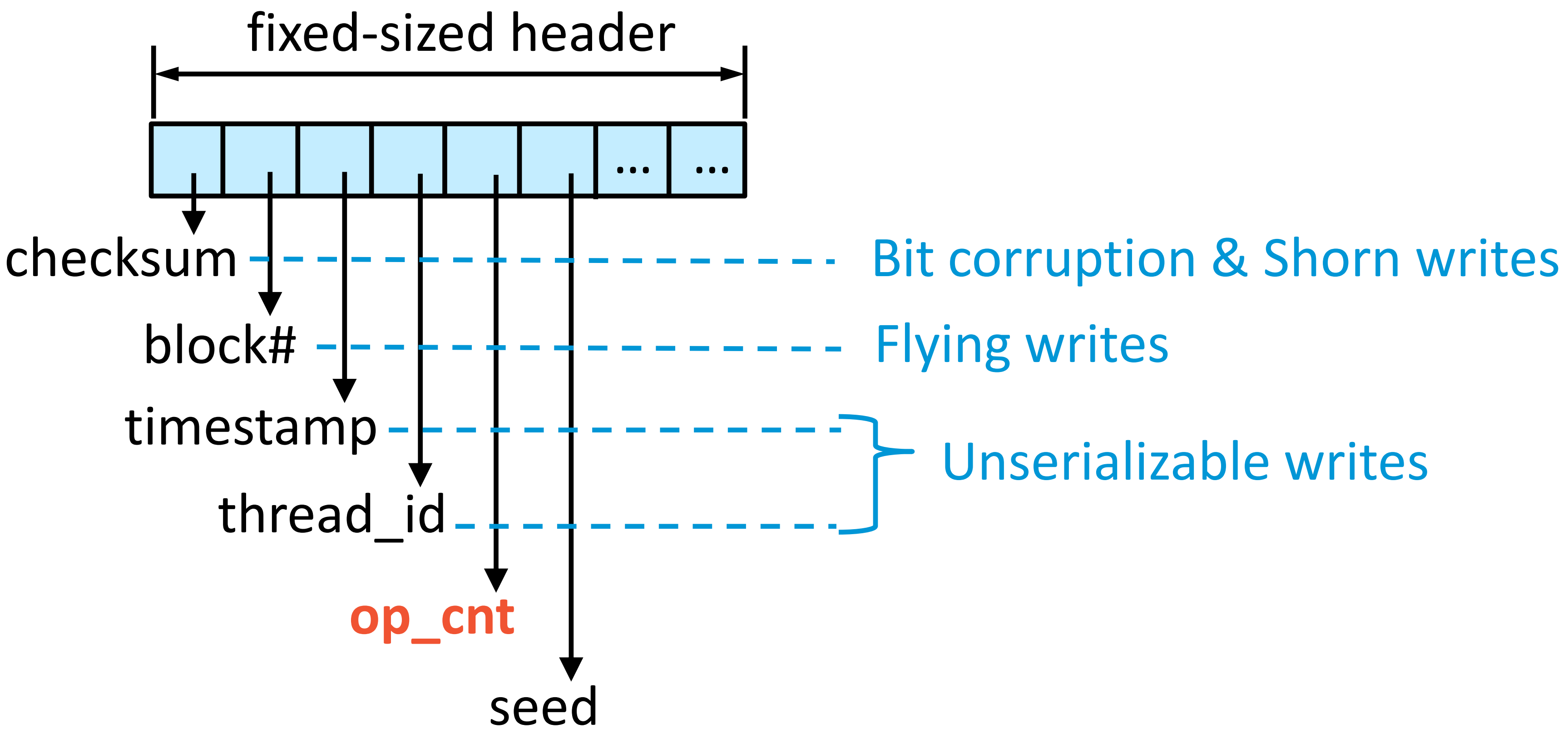

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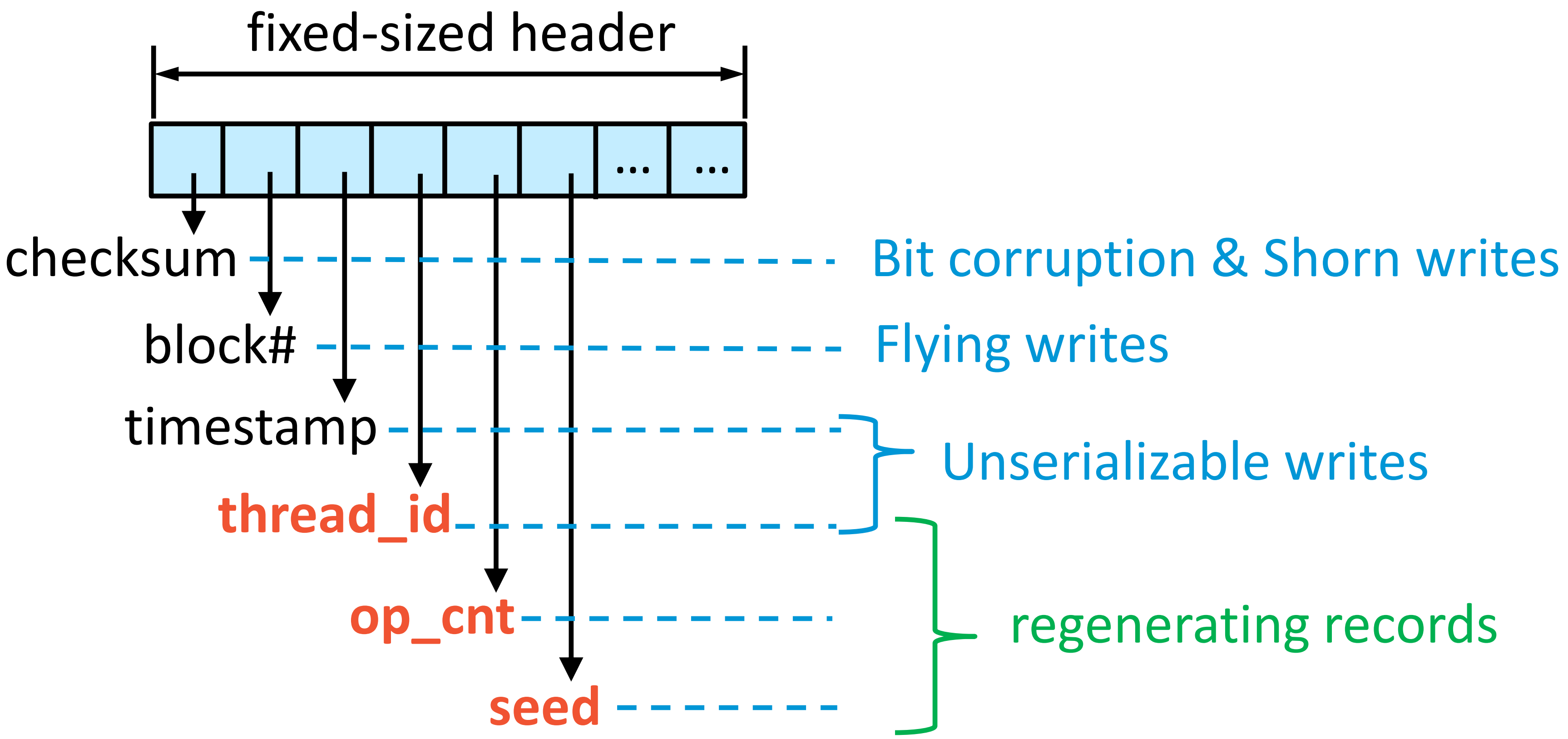

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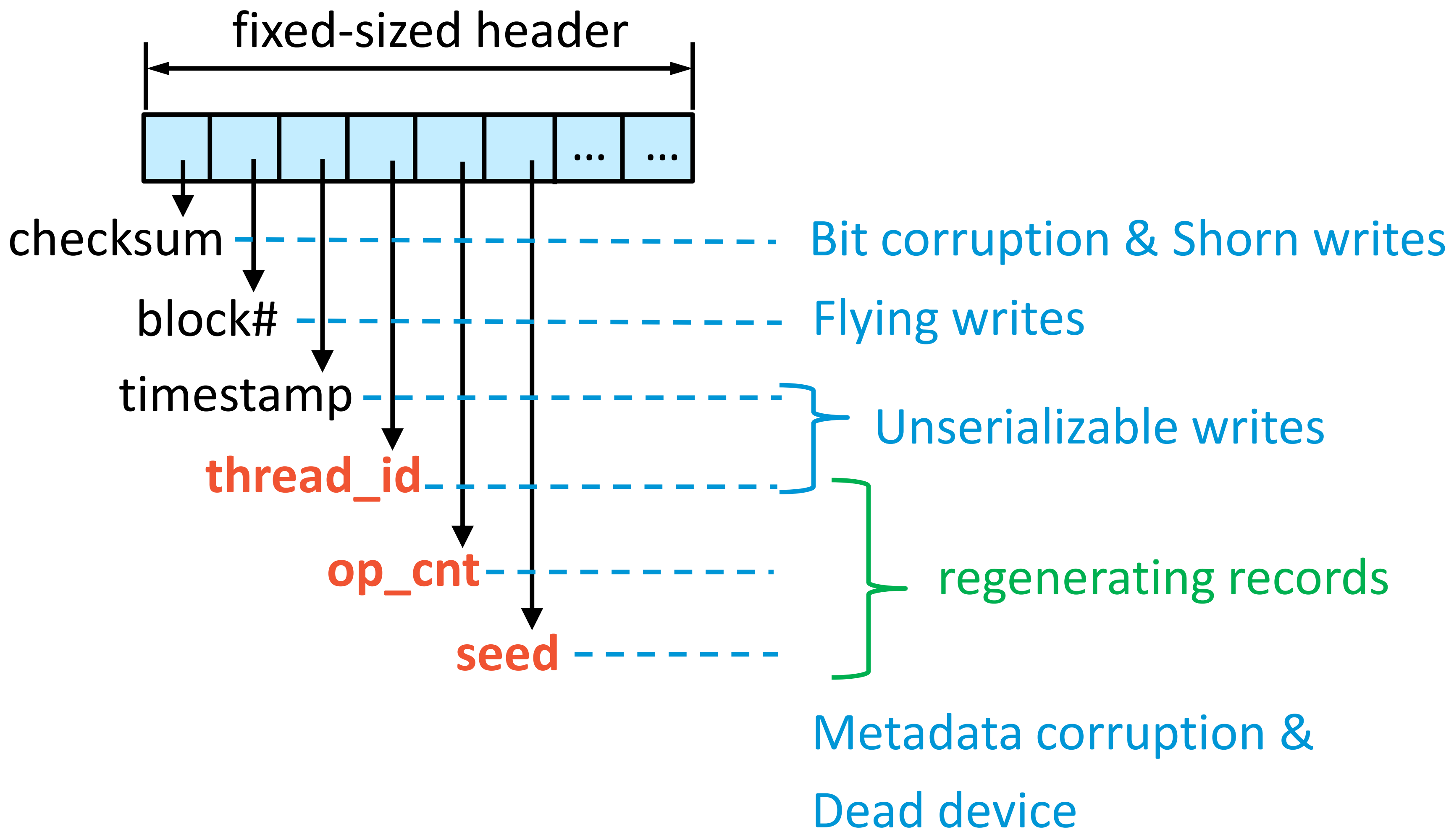

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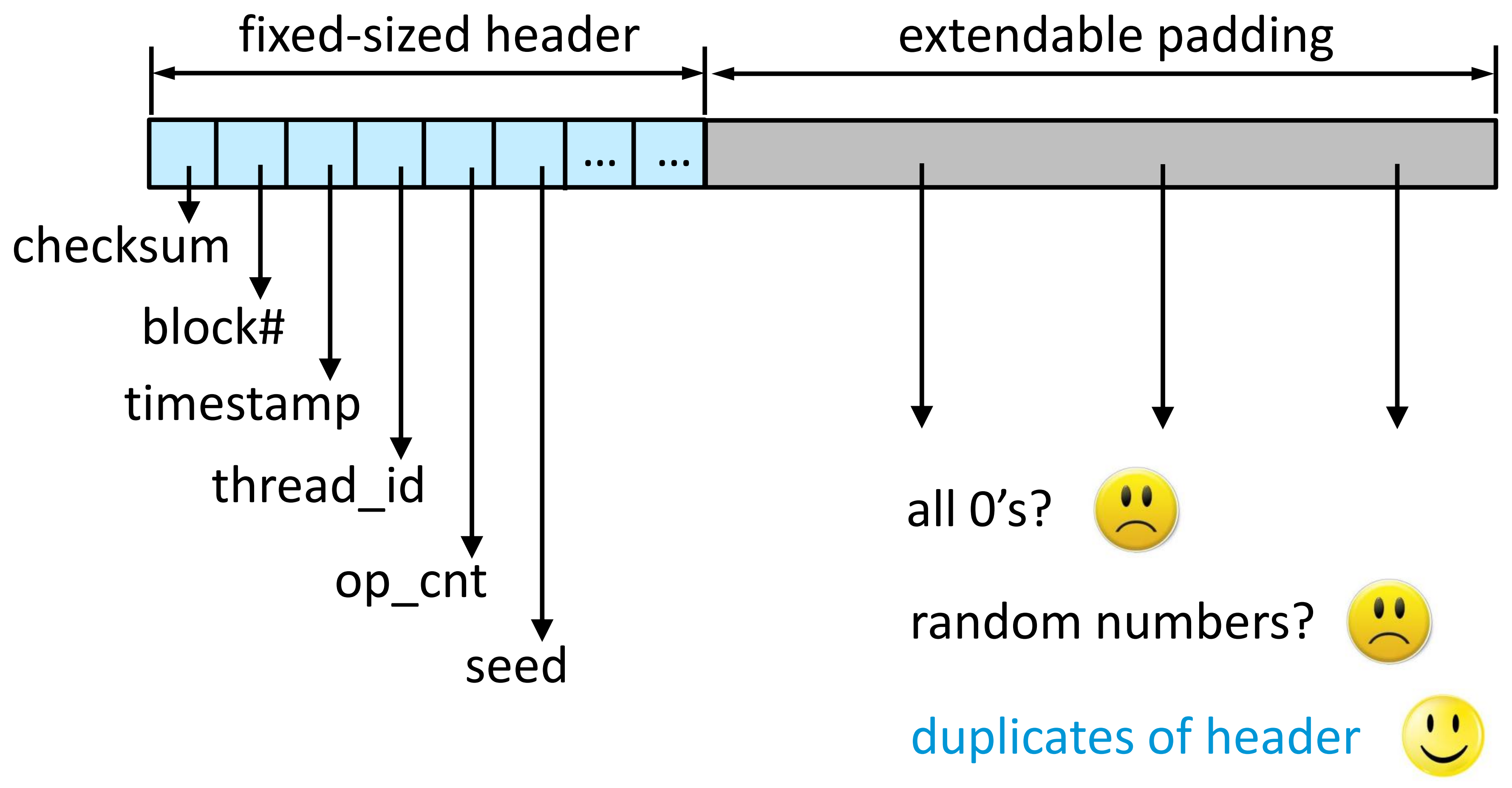
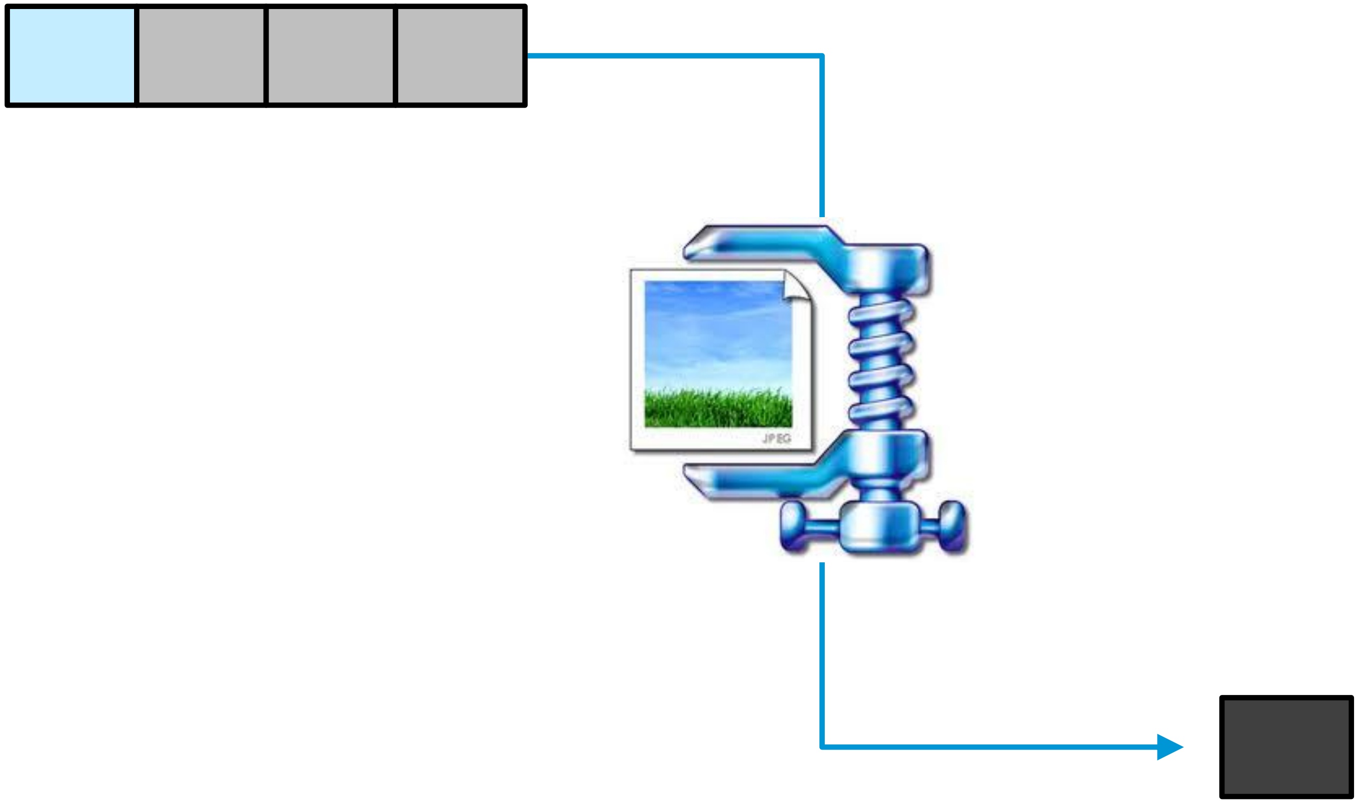
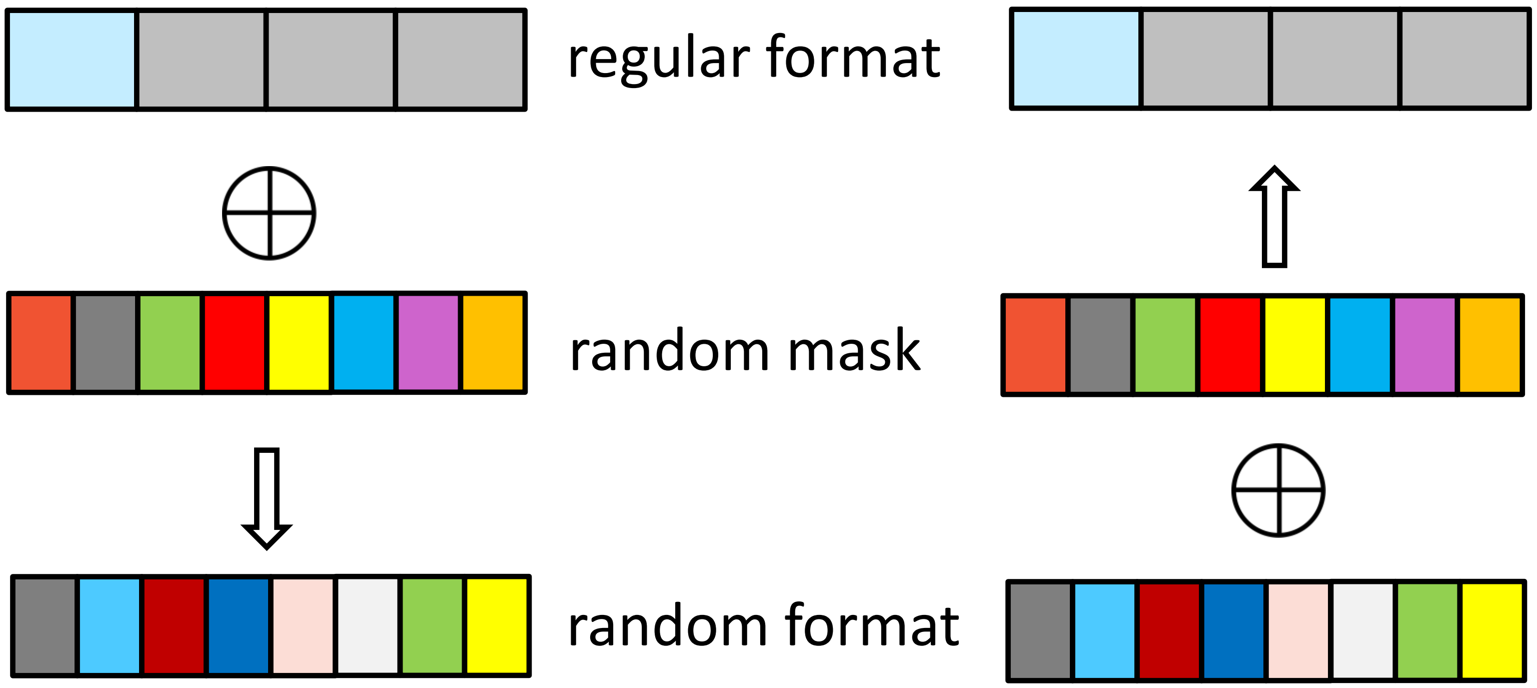


Advanced FTL: Compression



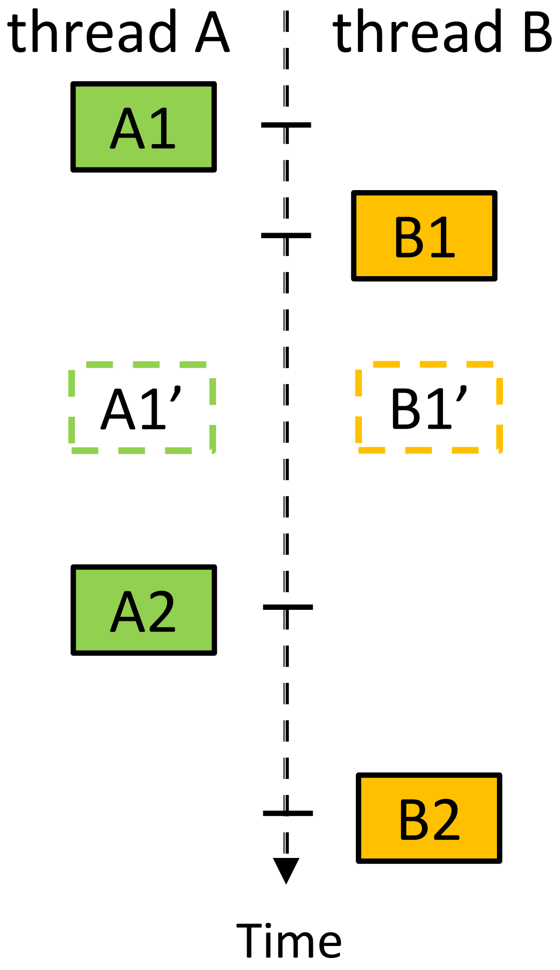
Randomization of Record Content

- avoid interference of compression



Deriving Completion-time Partial Order

- a key step of unserializable writes detection



🟩 A1 : generating time of 1st record of A

▨ A1' : completion time of writing 1st record of A

Deriving Completion-time Partial Order

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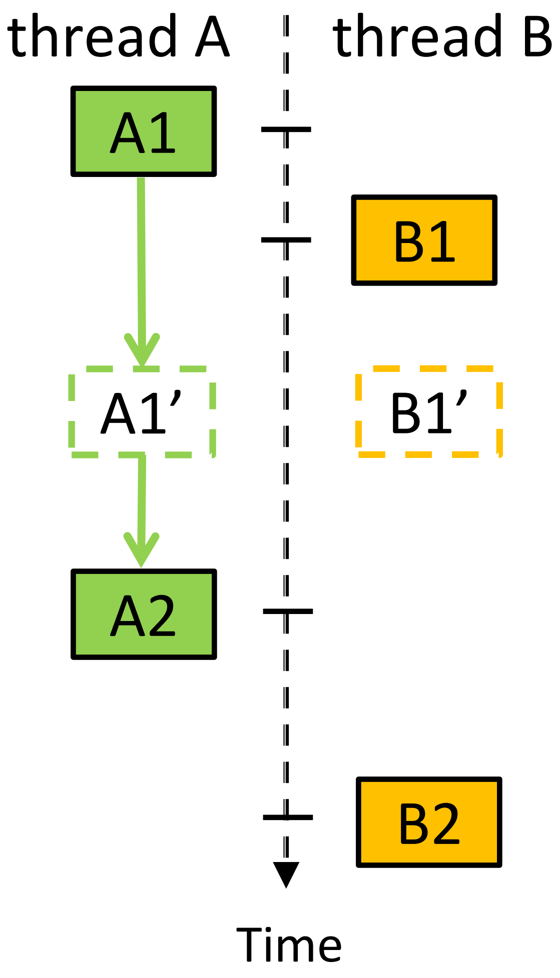

Intra-thread:

A1 -> A1’ -> A2

Deriving Completion-time Partial Order

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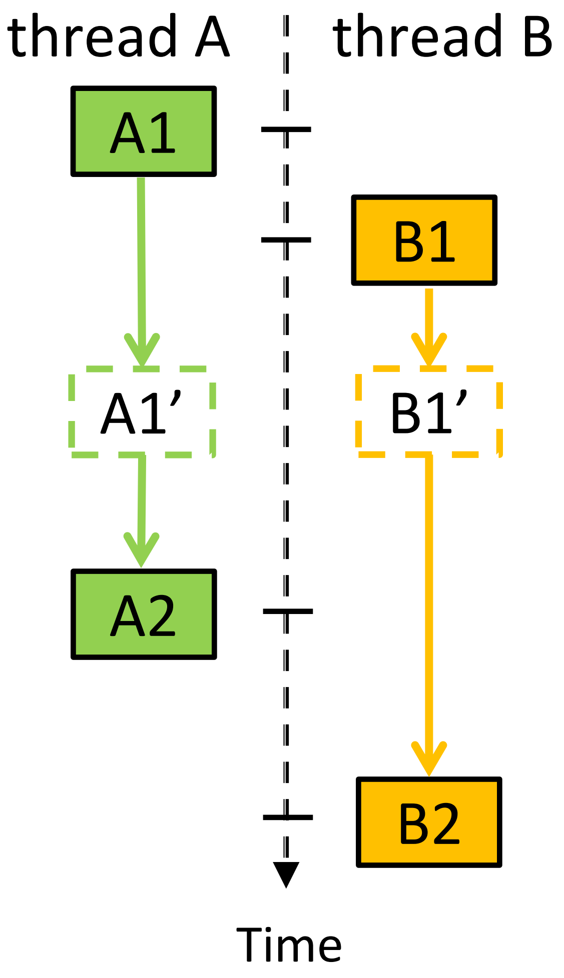

Intra-thread:

A1 -> A1’ -> A2

B1 -> B1’ -> B2

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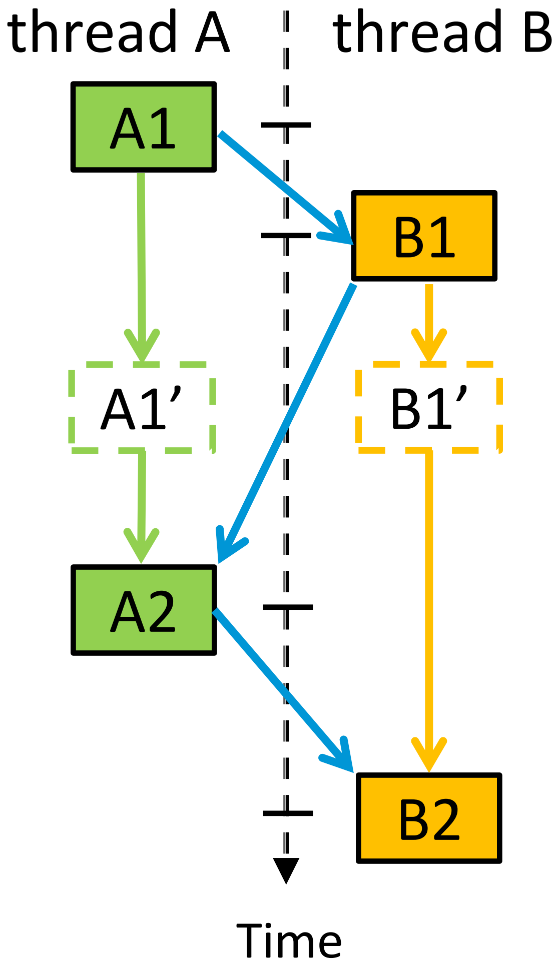

Intra-thread:

A1 -> A1’ -> A2

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Inter-thread:

A1 -> B1 -> A2 -> B2

Deriving Completion-time Partial Order

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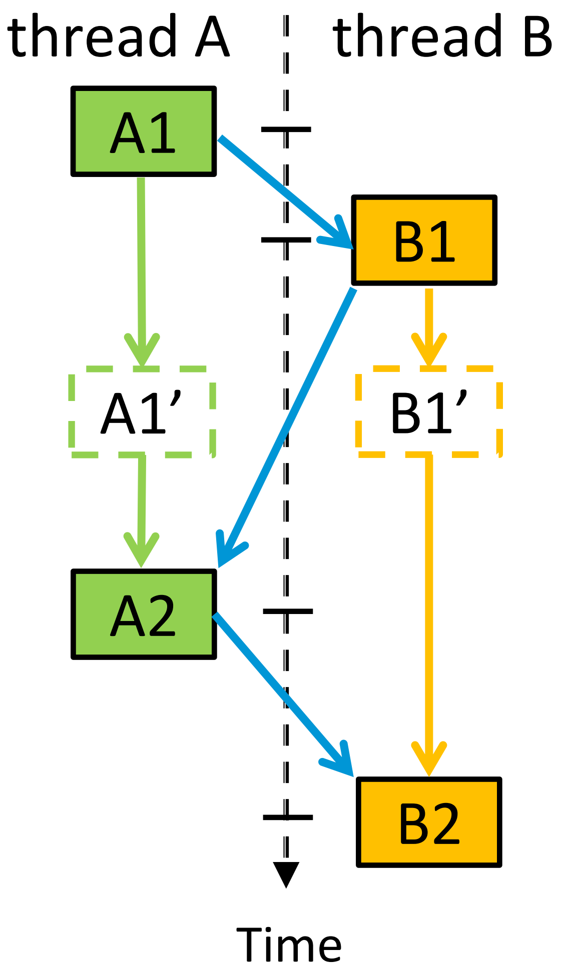


Intra-thread:

A1 -> A1’ -> A2

B1 -> B1’ -> B2

Inter-thread:

A1 -> B1 -> A2 -> B2

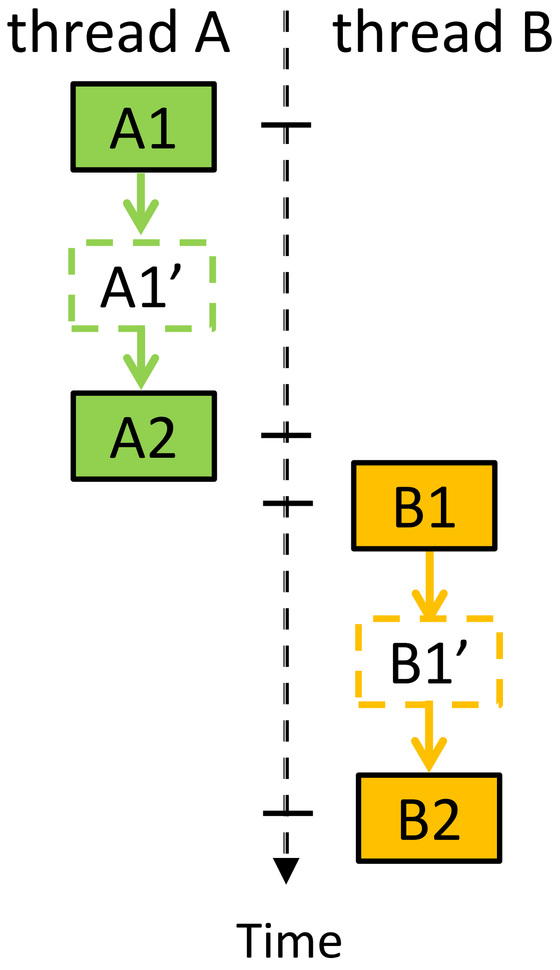
$\not\Rightarrow$ A1’ -> B1’ or

B1’ -> A1’

Conservatively report no errors

Deriving Completion-time Partial Order

- a key step of unserializable writes detection



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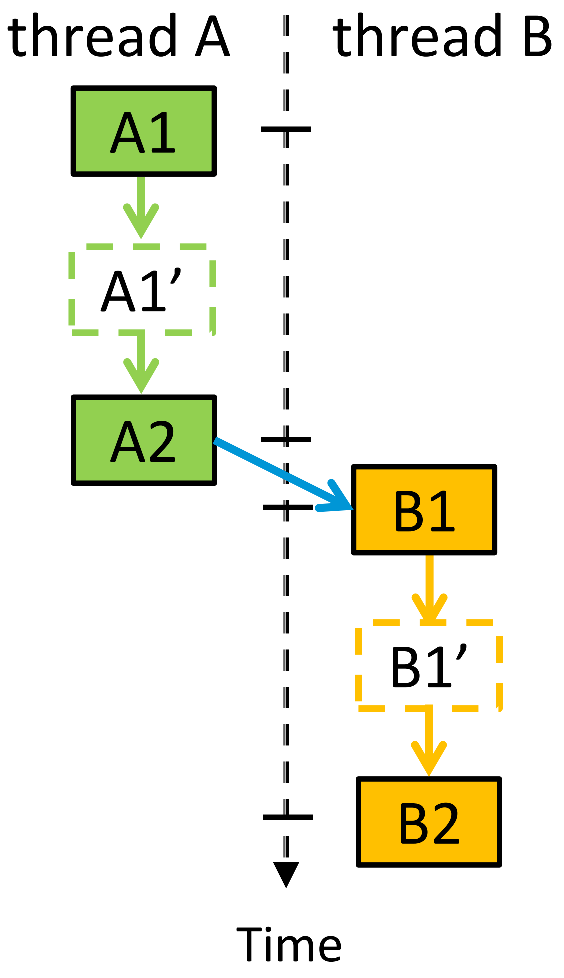

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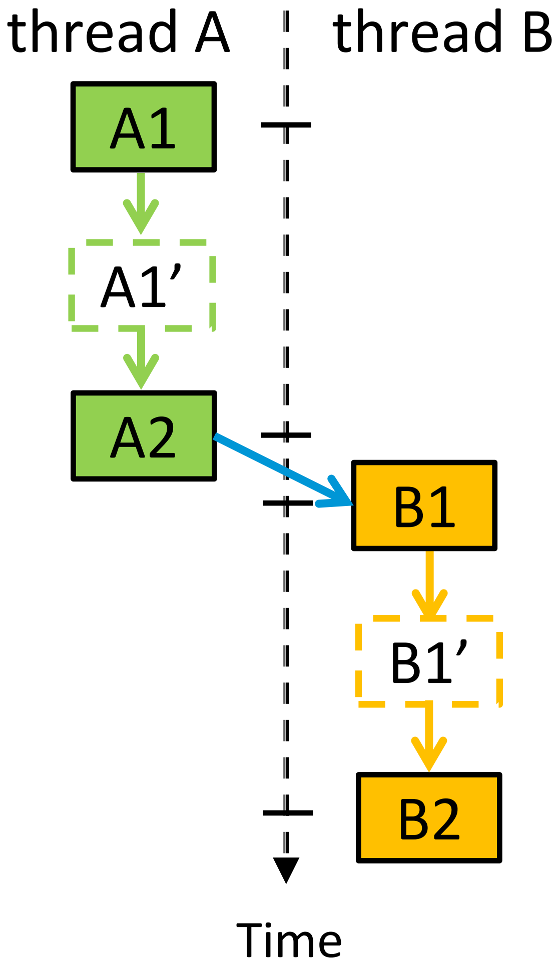


Intra-thread:

A1 -> A1’ -> A2

B1 -> B1’ -> B2

Inter-thread:

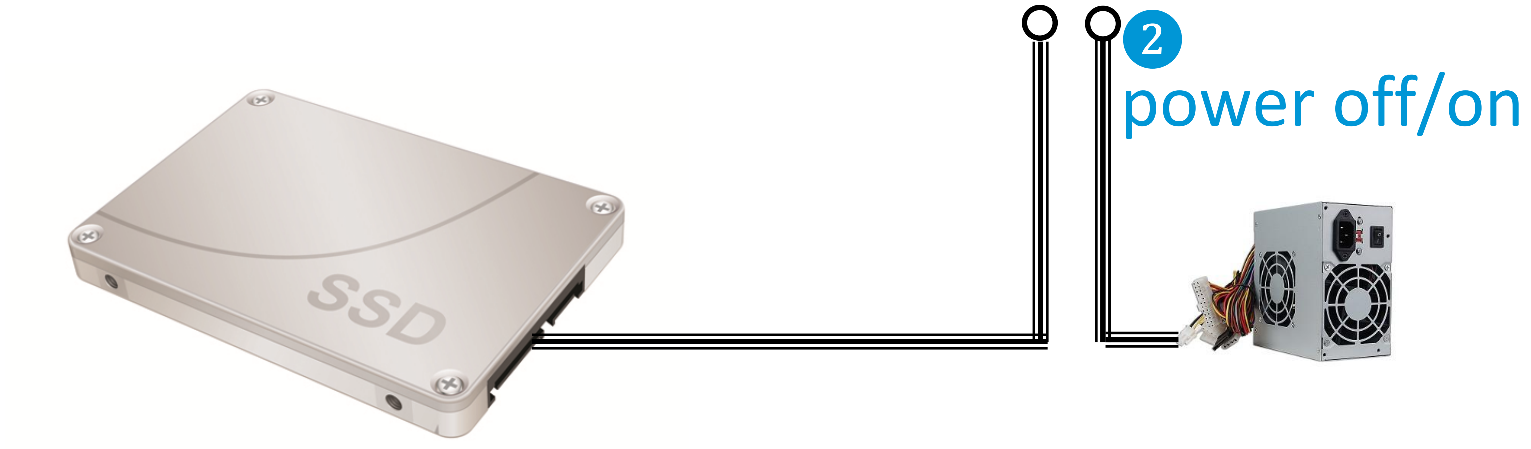
A2 -> B1

$\Rightarrow$ A1’ -> B1’

More details in our paper

& Golab *et al.* PODC’11

Power Fault Injection



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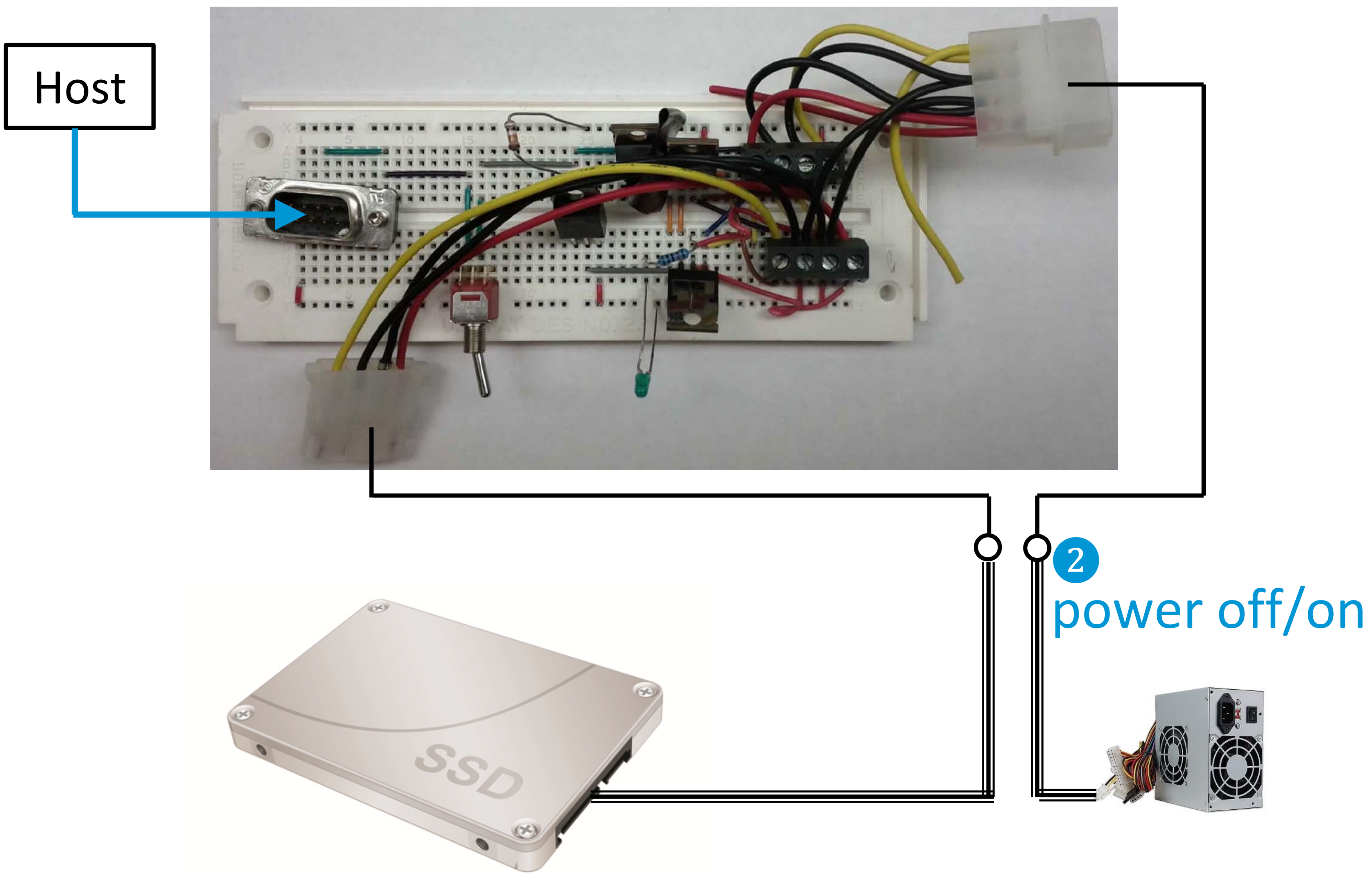


Results

Experimental Environment

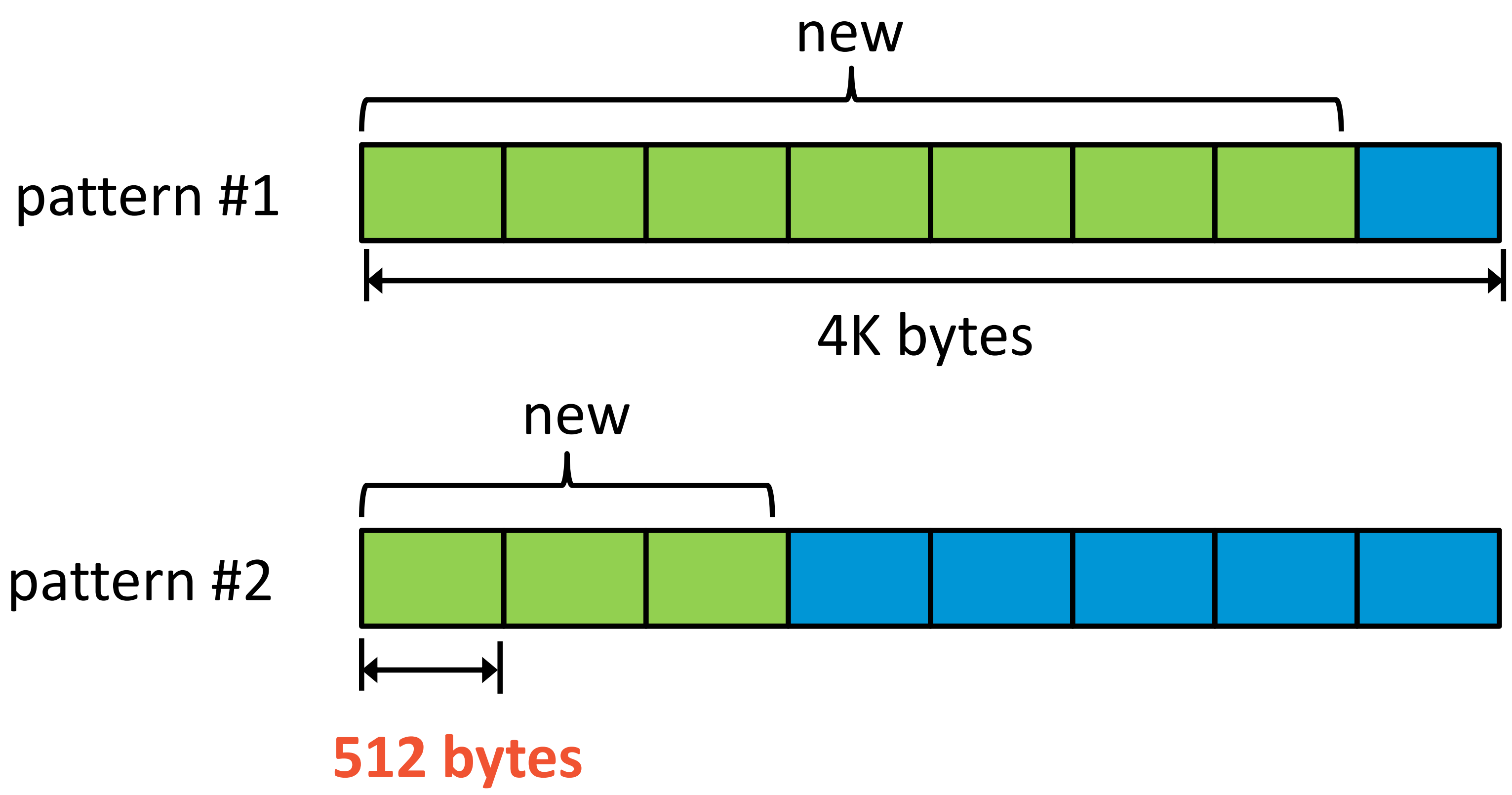
- Block Devices
  - 15 SSDs and 2 hard drives
  - SLC & MLC
  - Manufactured in 2009 – 2012
  - 4 have power-loss protection
  - Low-end to high-end ($0.63/GB - $6.50/GB)
- Host System
  - Debian 6.0 w/ 2.6.32 kernel
  - LSI Logic SAS controller
  - no filesystem on devices
  - Synchronized & Direct I/O (O_SYNC | O_DIRECT)

Summary of Observations

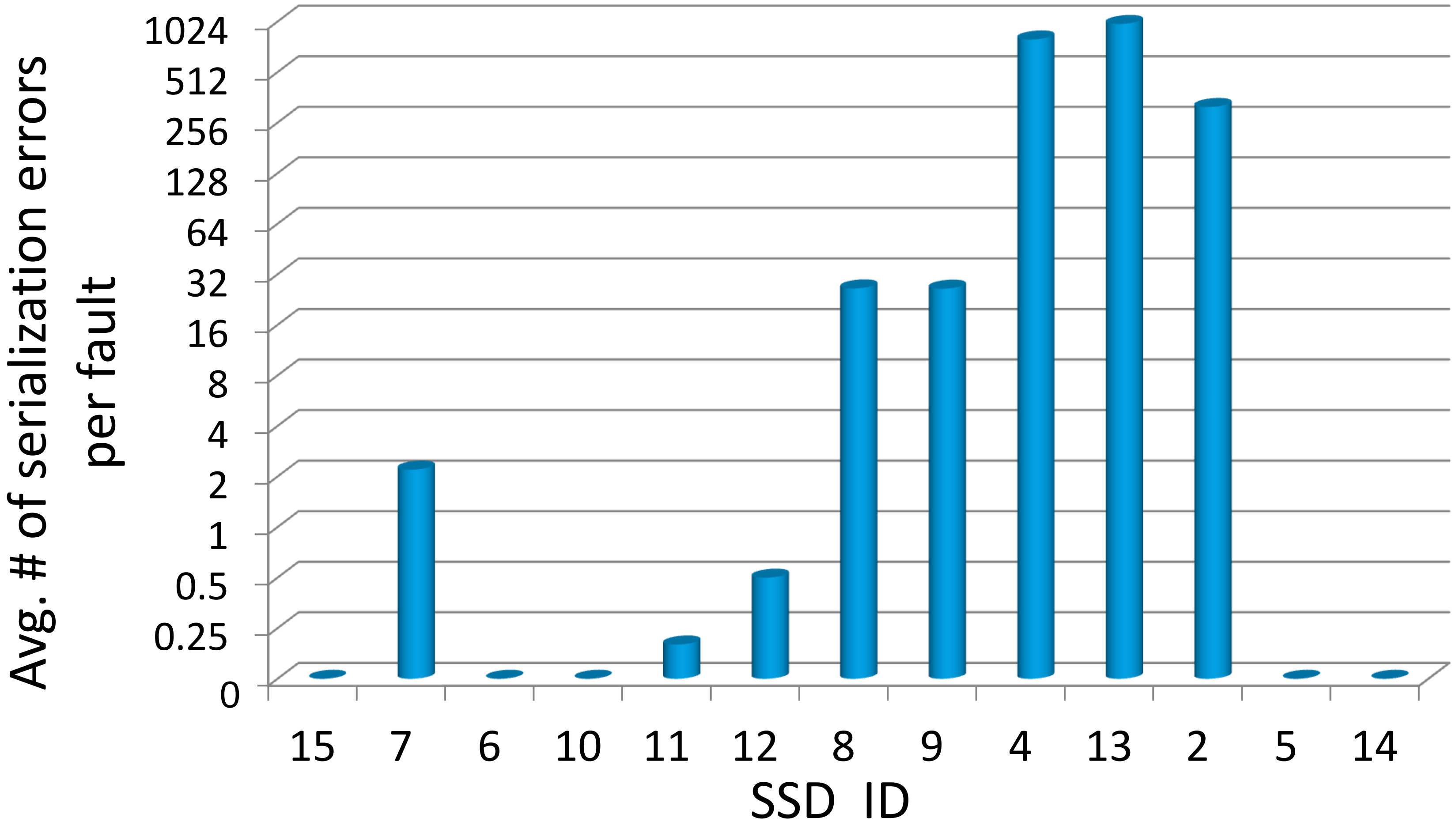
Failures	# of SSDs
Bit Corruption	3
Metadata Corruption	1
Dead Device	1
Shorn Writes	3
Flying Writes	0
Unserializable Writes	8
None	2

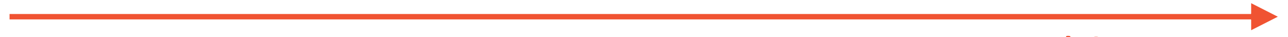
- 13 of 15 SSDs exhibit failure(s)
- 2 perfect SSDs
- 5 of 6 failures observed

Shorn Writes: Subpage Programming



Serialization Errors: Avg. Numbers Per Fault





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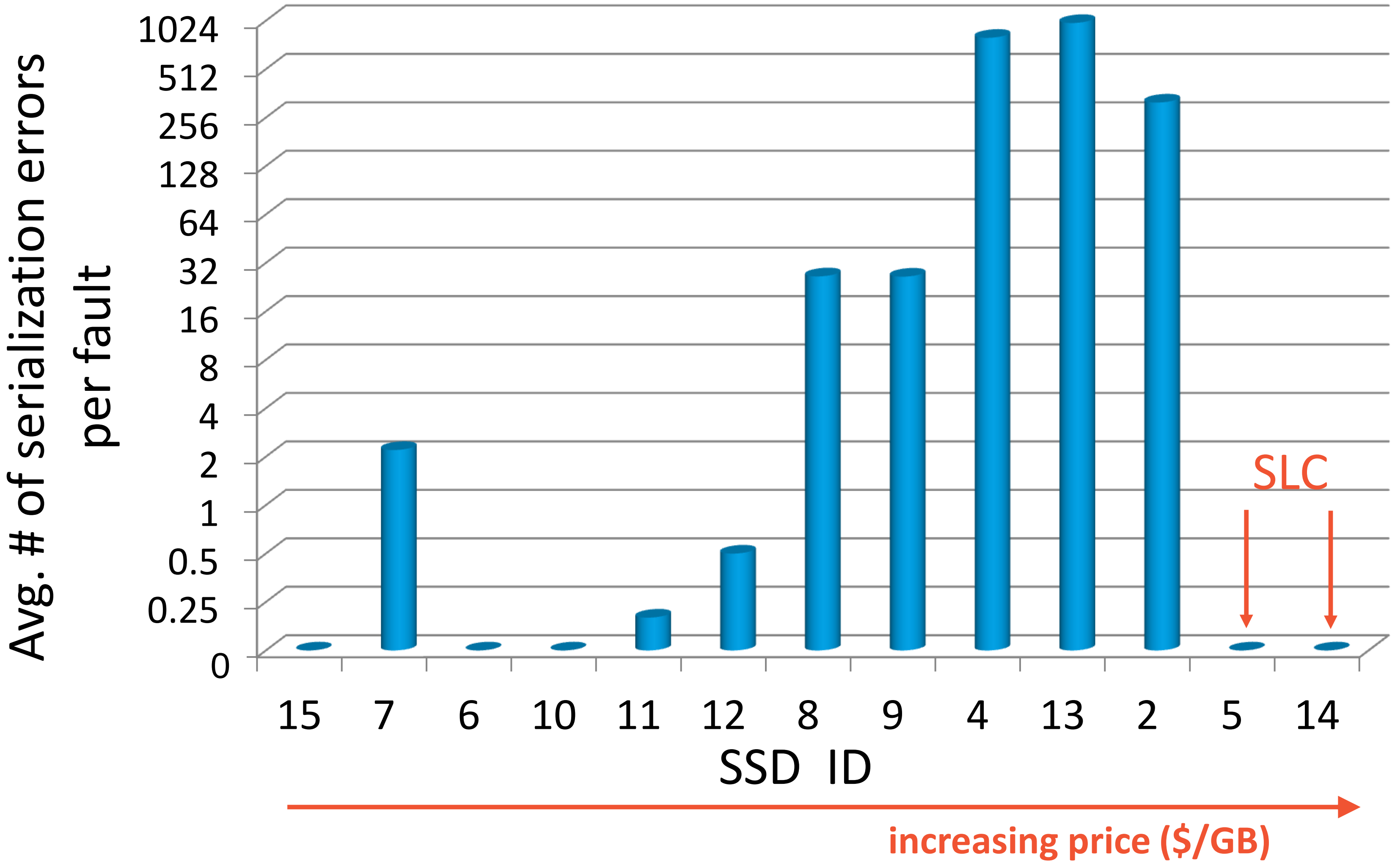
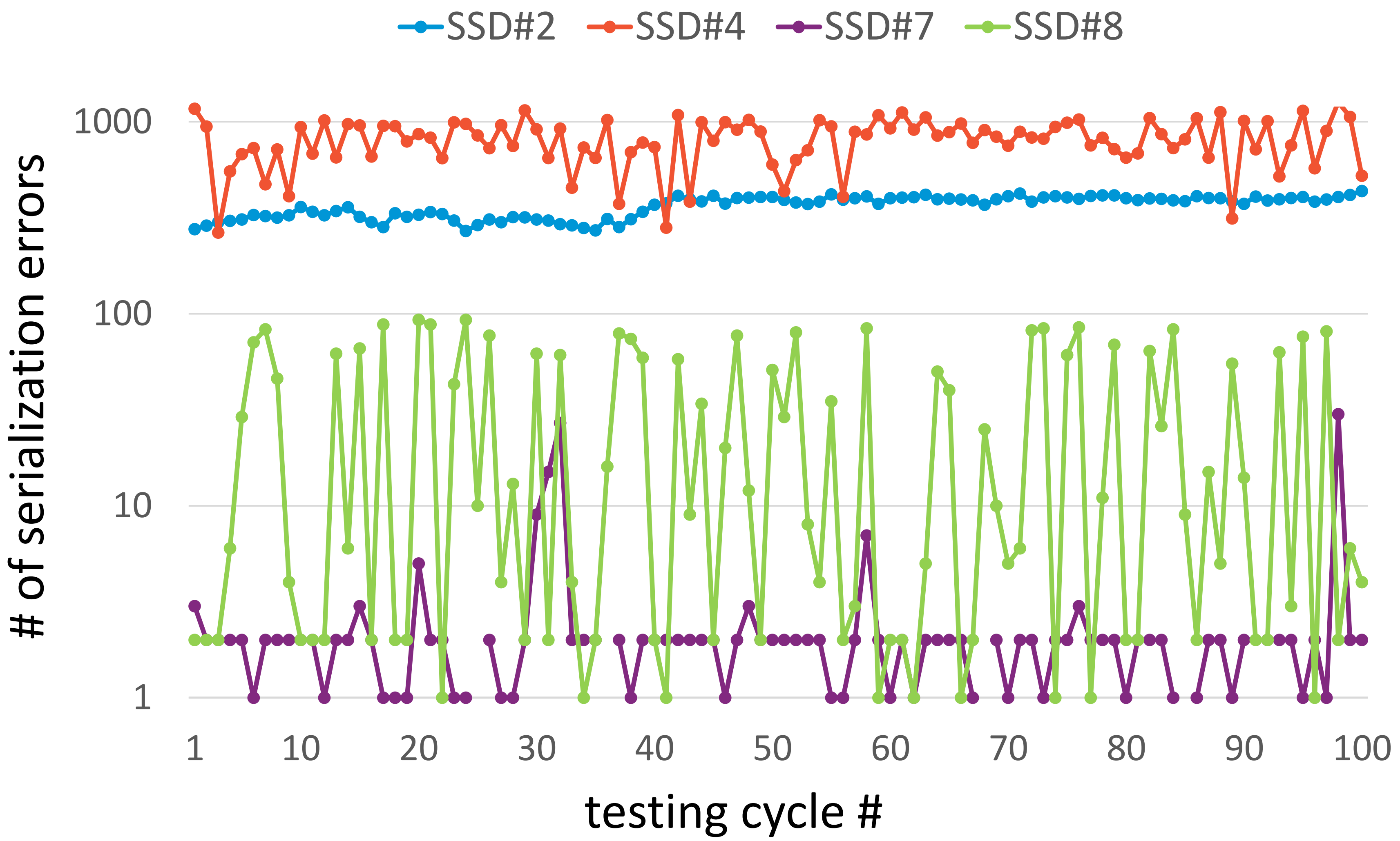
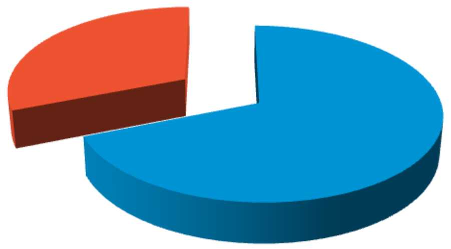


Serialization Errors: Patterns Over Time



Metadata Corruption

- 1 SSD
- 8 injected power faults
- lost 31% (72 GB) data



Dead Device

- 1 SSD
- 136 injected power faults
- can no long be detected by host

Conclusion

- An effective methodology to expose bugs in block devices under power fault
- Important implications to storage design
  - e.g. write ahead logging V.S. unserializable writes

Thank you!

Pristine Version of Our Paper can be Found at:

http://www.cse.ohio-state.edu/~zhengm/