PMA: A Persistent Memory Allocator with High Efficiency and Crash Consistency Guarantee

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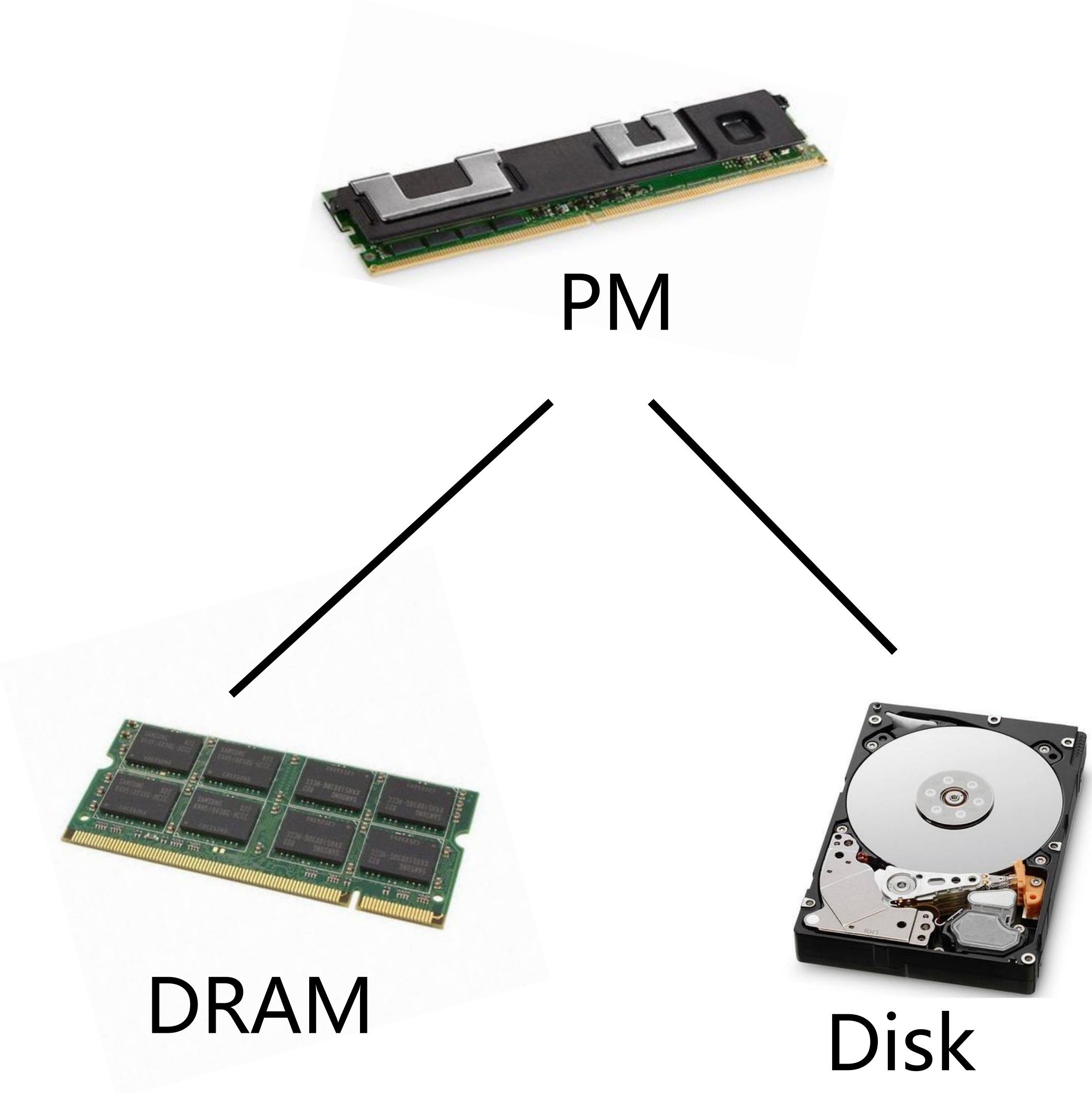
Persistent Memory

- ➢Persistent memory (PM)
  - ✓ Persistency
  - ✓ Byte-addressability
  - ✓ Near-DRAM latency
  - ✓ Large capacity

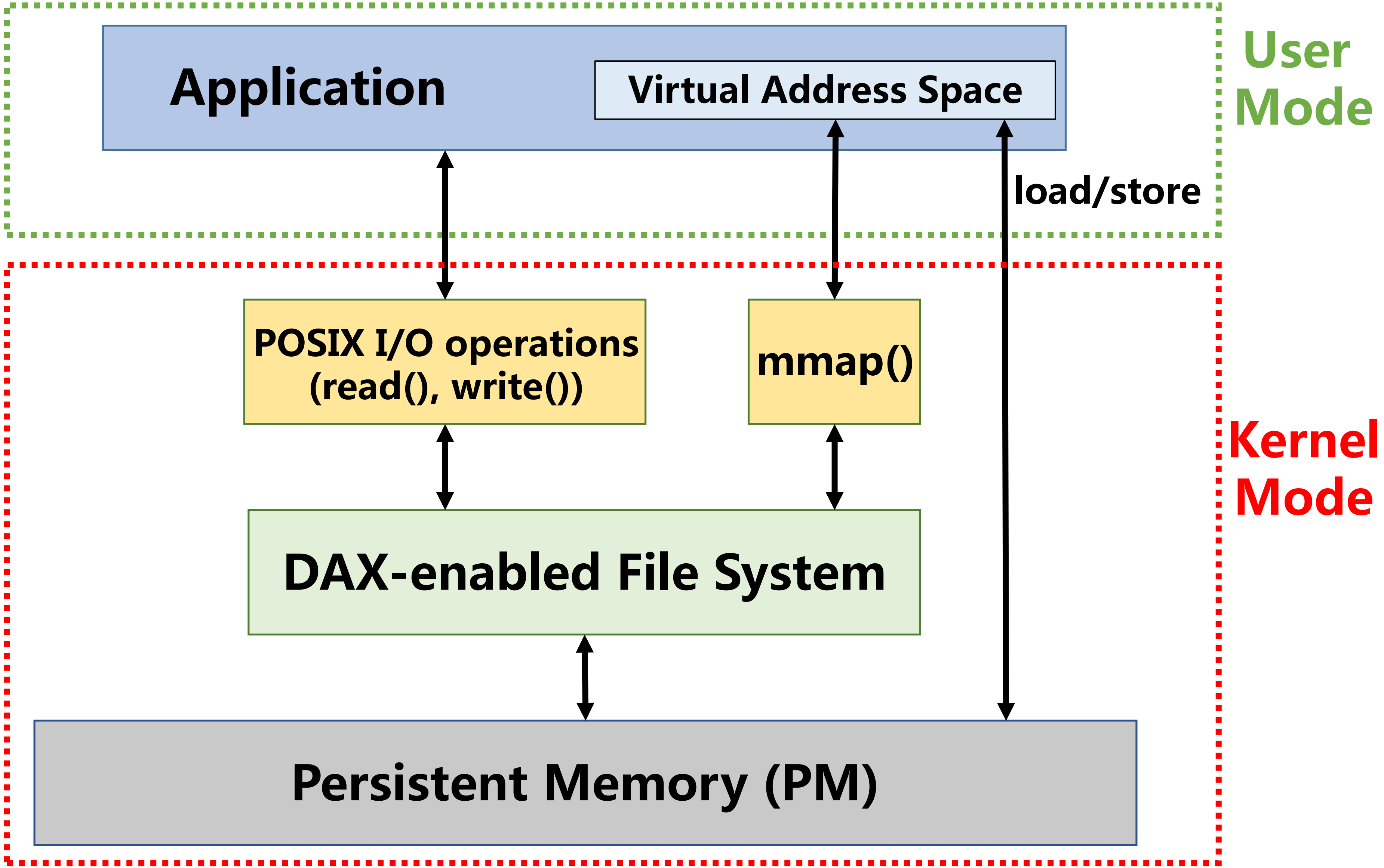


PM

DRAM

Disk

Direct Access (DAX)



Memory Allocator

➢Functionality

- Dynamically allocate/reclaim memory space for working threads
- Reduce memory fragmentations
- Avoid false sharing among multiple working threads

➢Existing DRAM allocator

- Hoard[1]
- Jemalloc[2]
- Tcmalloc[3]

[1] E. D. Berger, K. S. McKinley, R. D. Blumofe and P. R. Wilson, “Hoard: A Scalable Memory Allocator for Multithreaded Applications,” in ASPLOS, 2000

[2] J. Evans, “A Scalable Concurrent malloc(3) Implementation for FreeBSD,” in BSDCan, 2006.

[3] Google. TCMalloc: Thread-Caching Malloc. https://google.github.io/tcmalloc/

Memory Allocator

Why can’t DRAM allocators be employed by PM?

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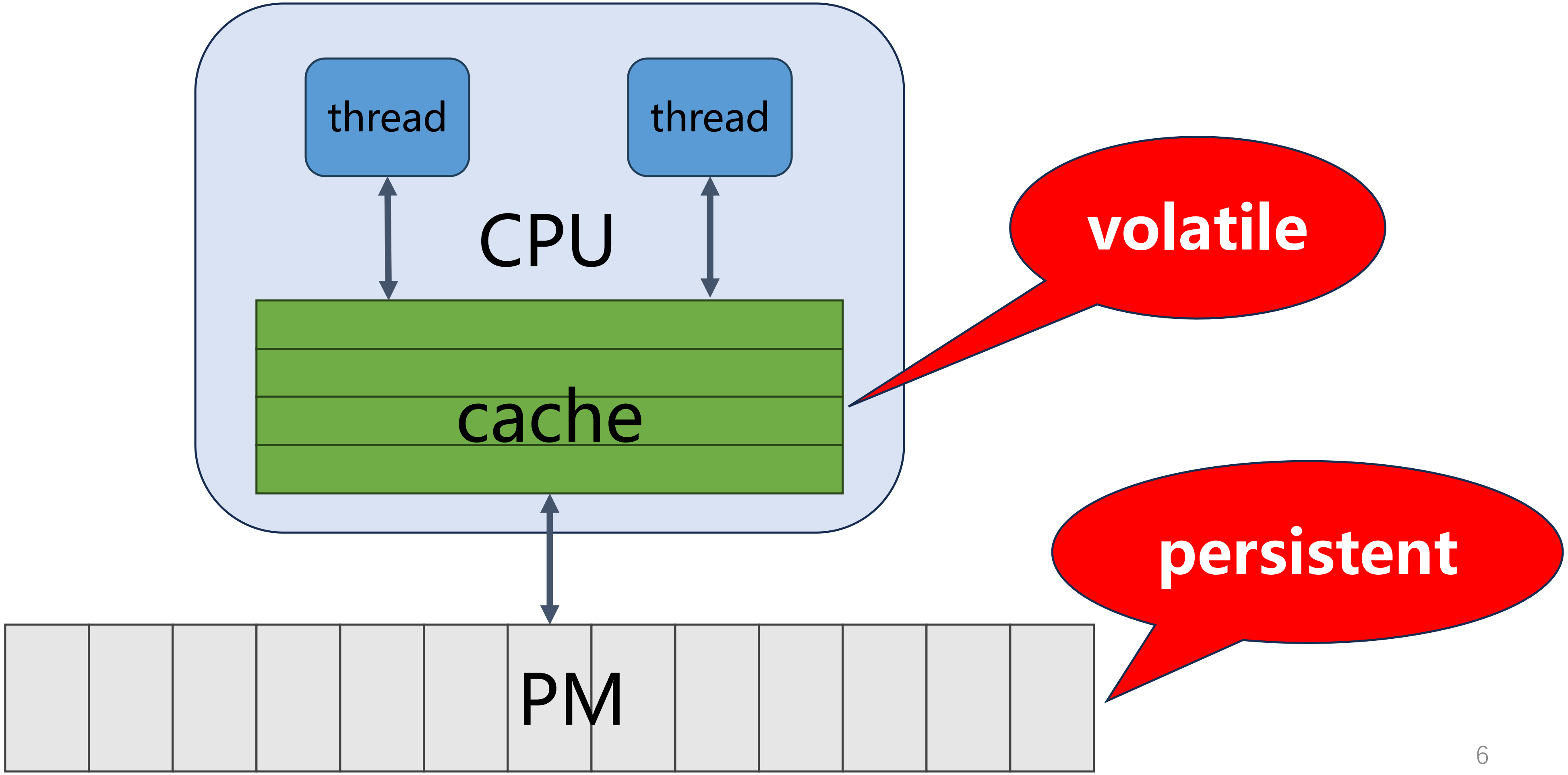

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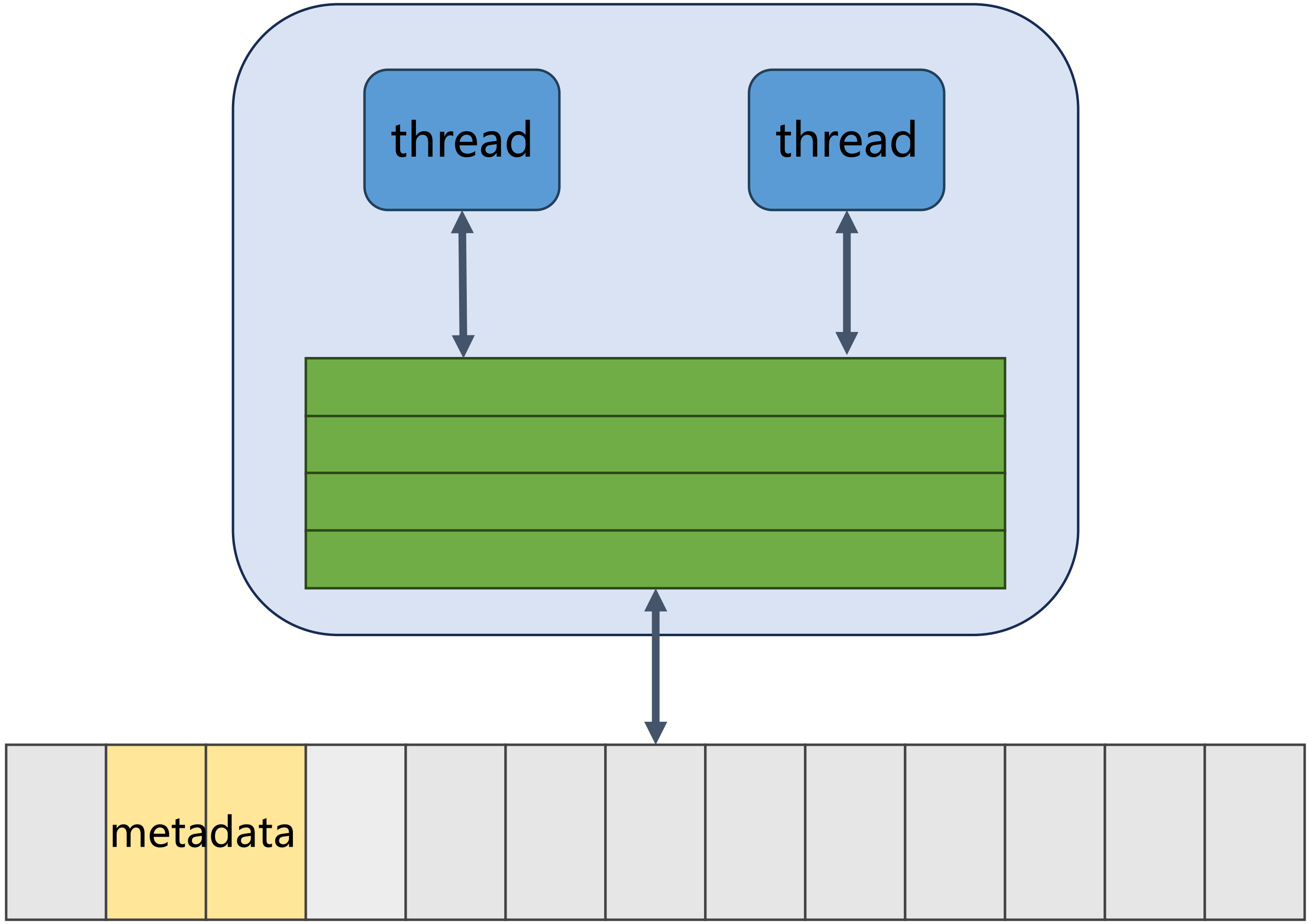

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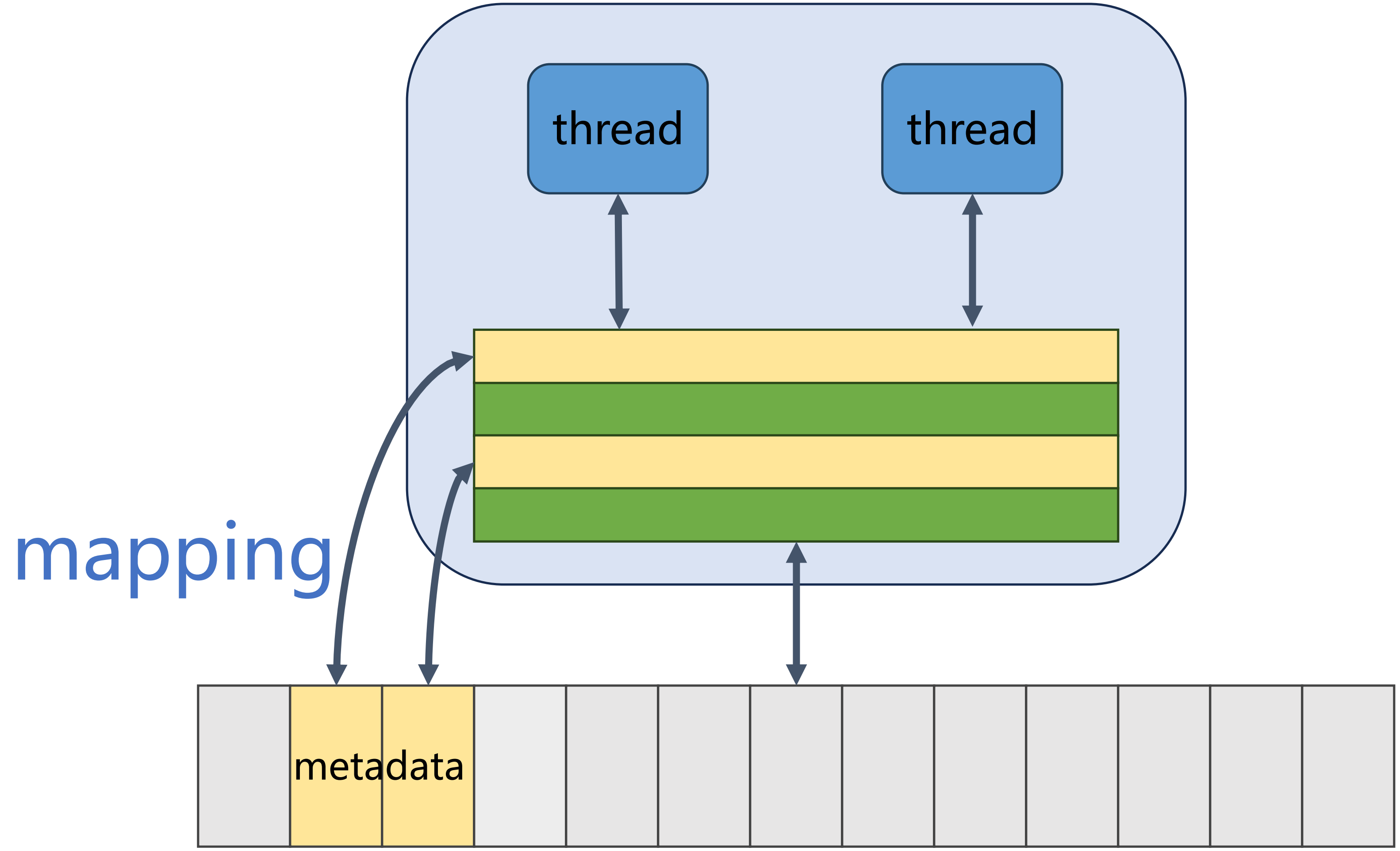

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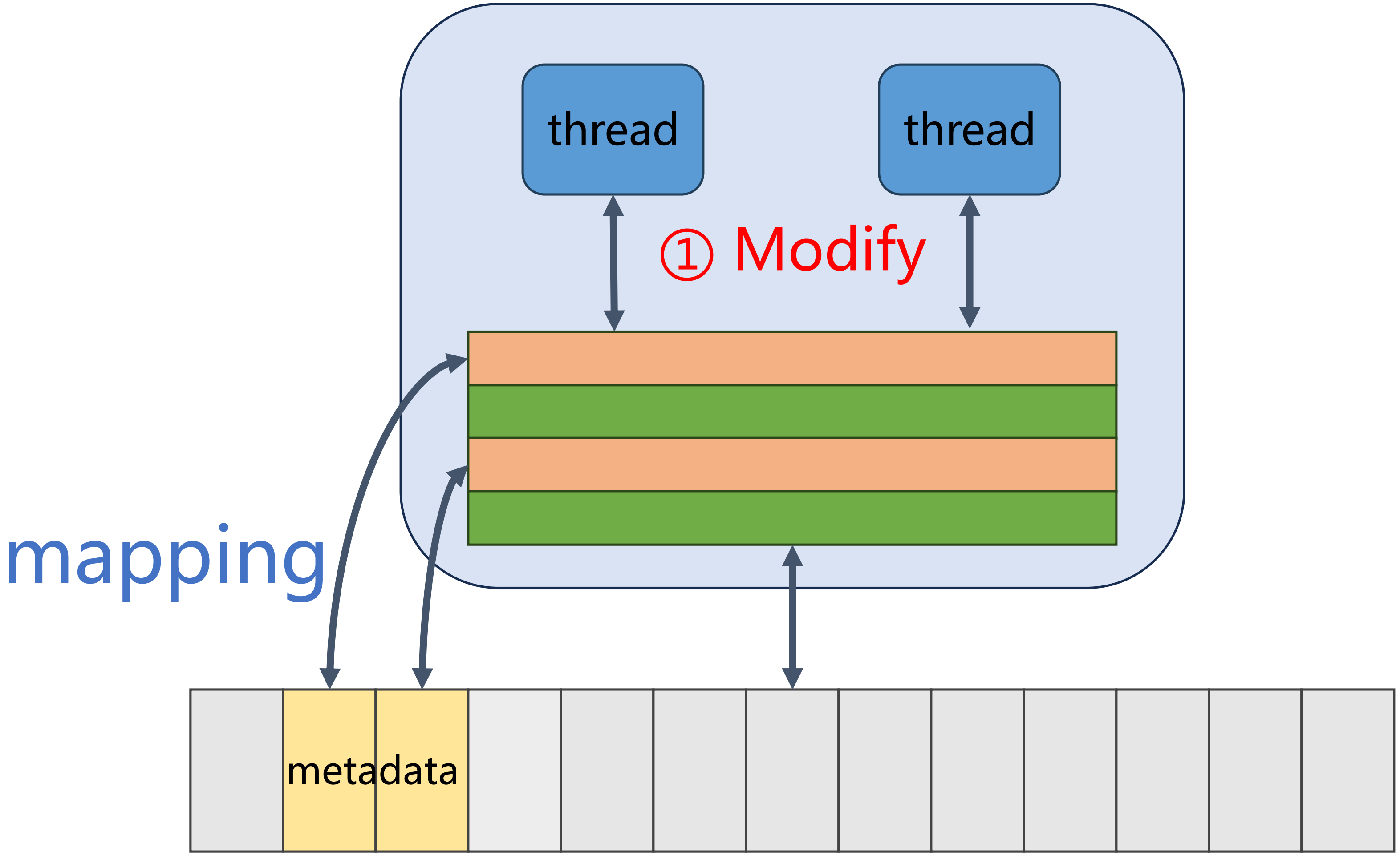

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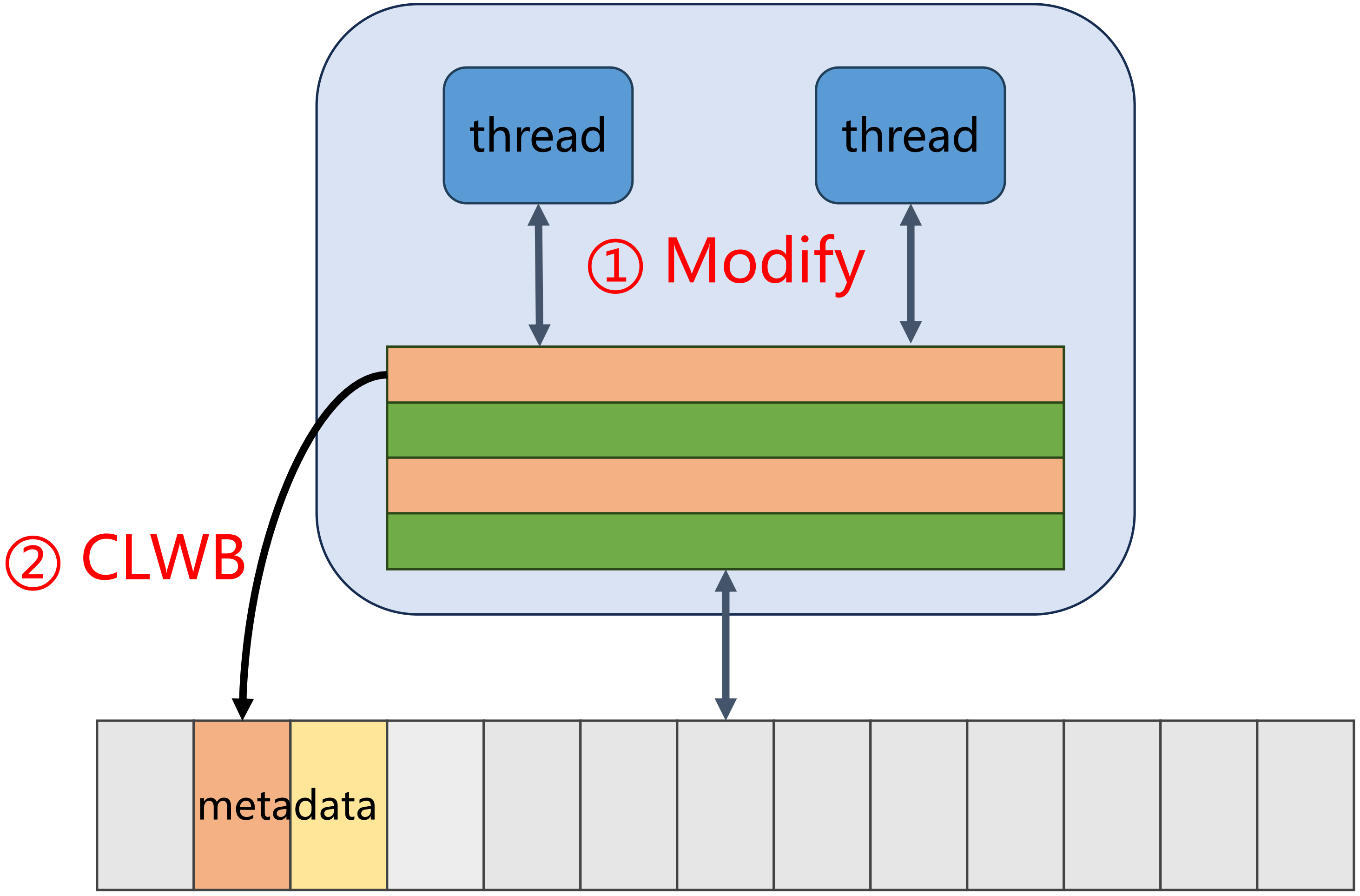

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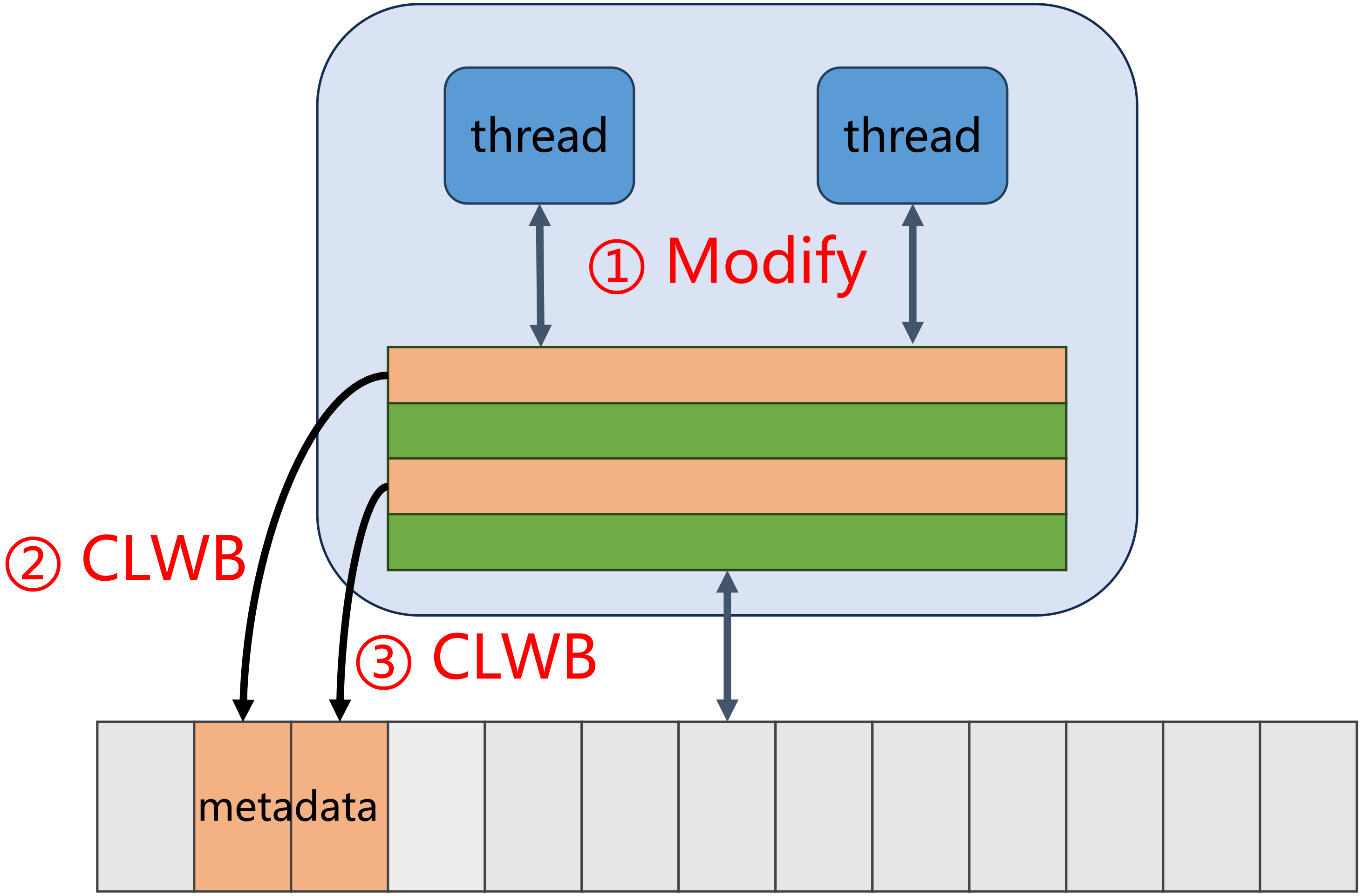

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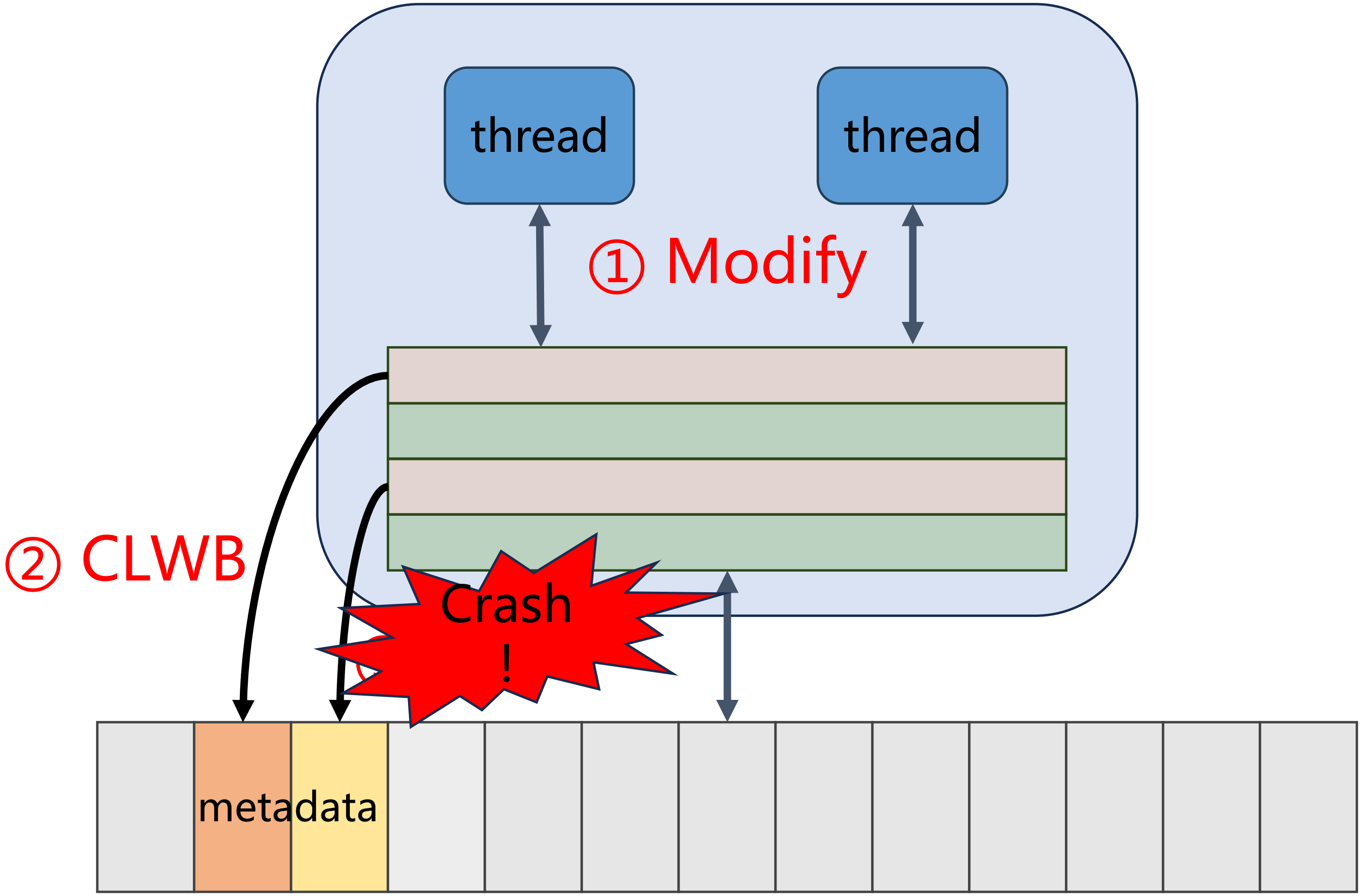

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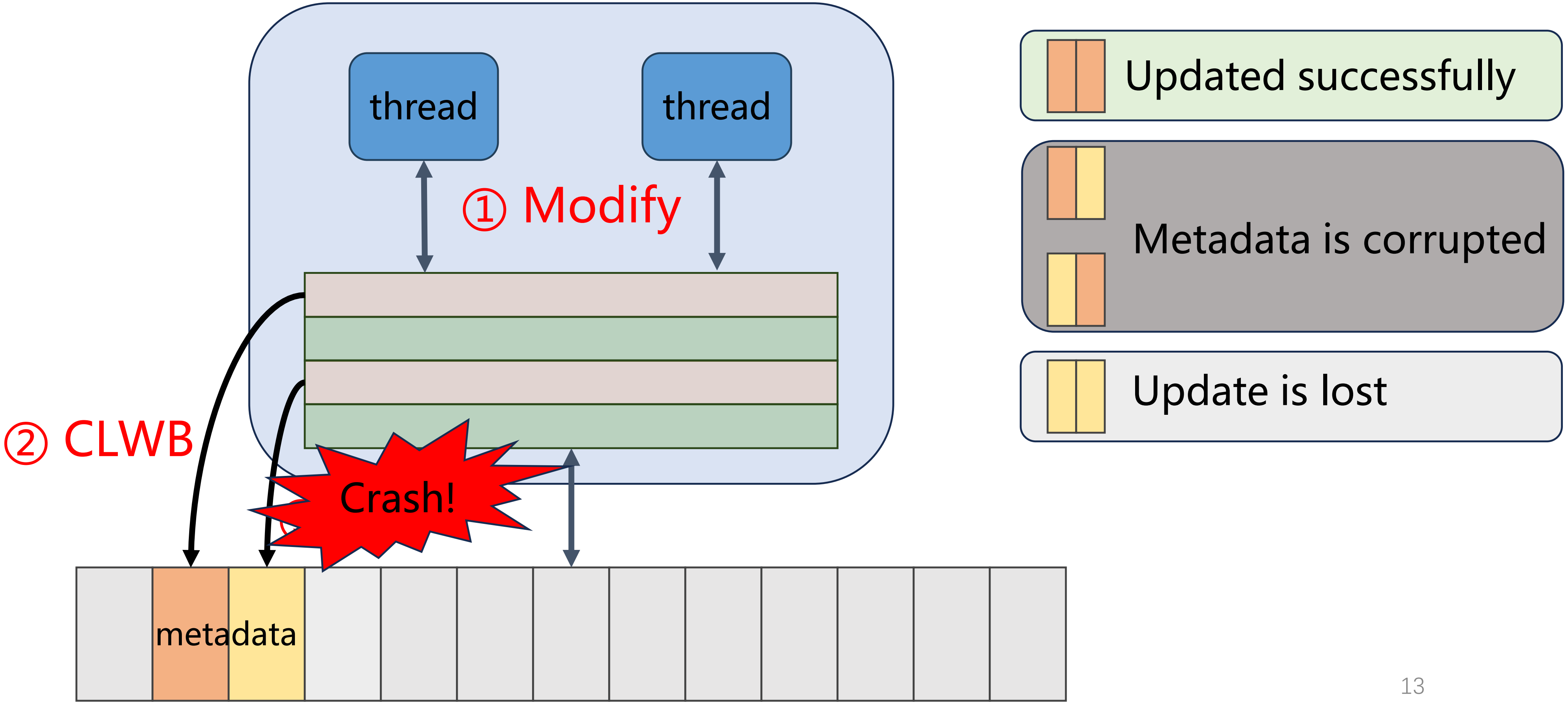
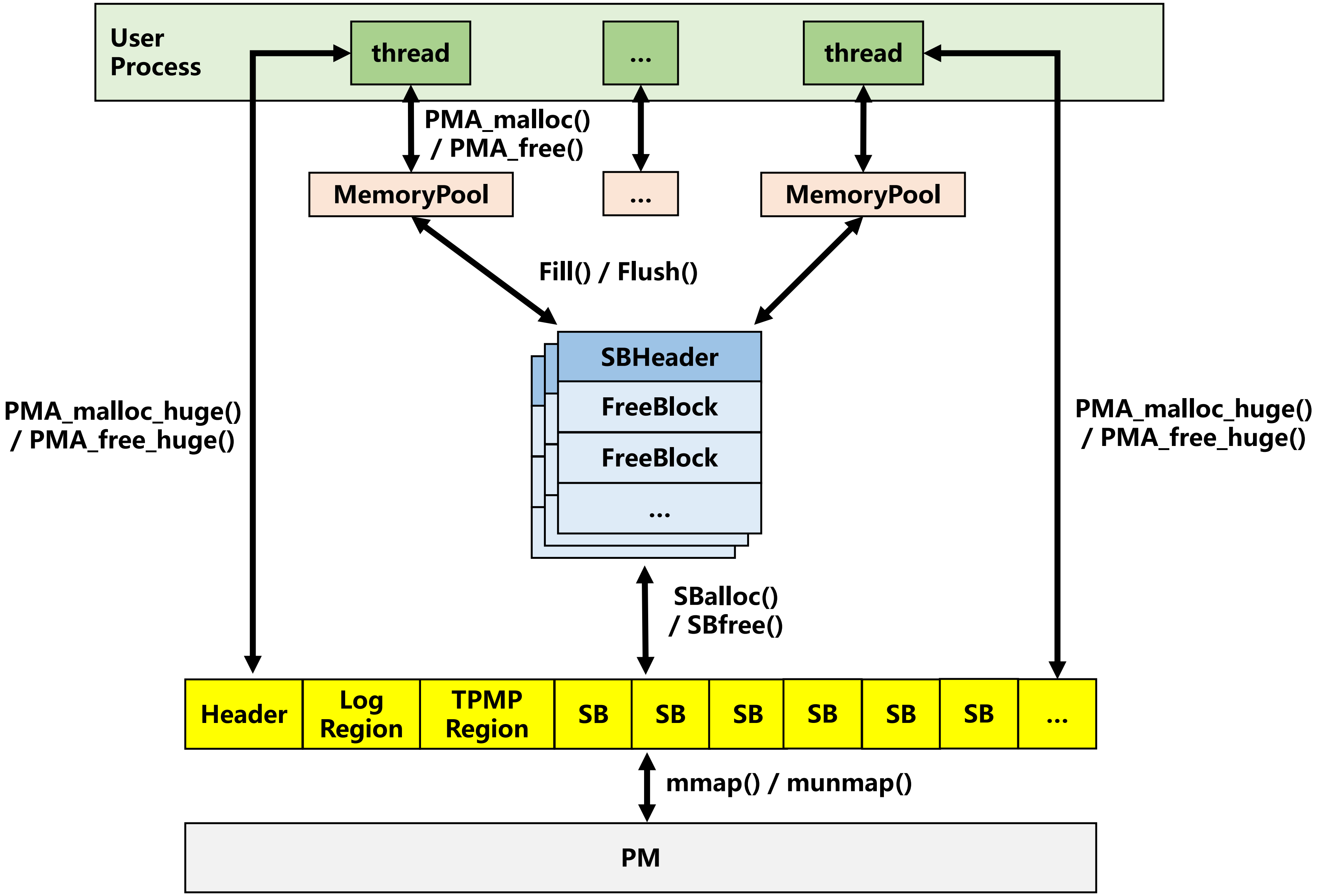


PMA: Overview



PMA: Size Class

- Predefine some standard size classes
    - E.g. {8, 10, 12, 14, 16, 20, 24, 28, 32, …, 8192}

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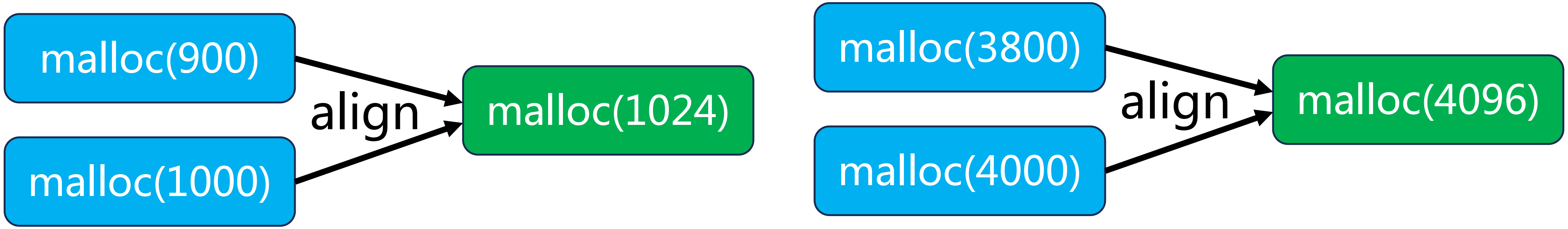

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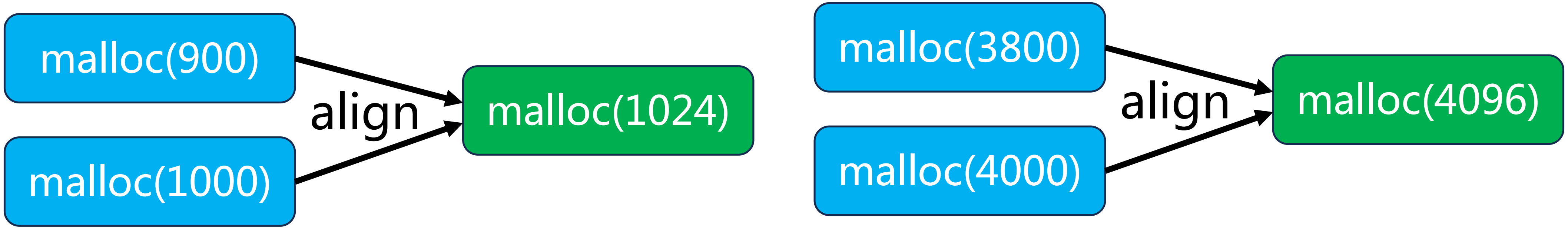


malloc(900)

malloc(1000)

align

malloc(1024)

malloc(3800)

malloc(4000)

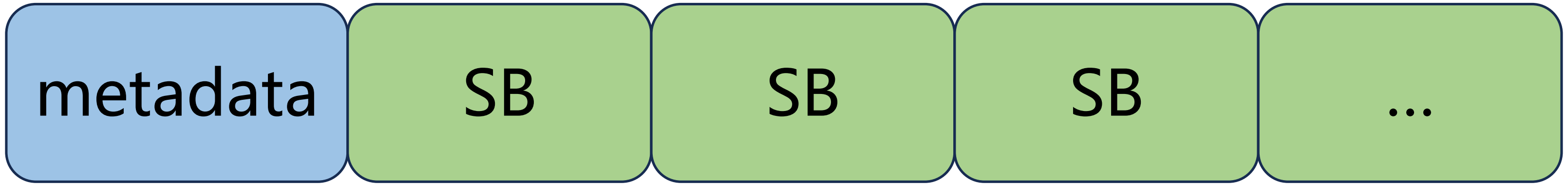
align

malloc(4096)

- Fragmentation rate ≤ 20% [1]

[1] R. Leite and R. Rocha, “A Modern and Competitive Lock-Free Dynamic Memory Allocator,” in VECPAR, 2018

PMA: Super Block



metadata SB SB SB …

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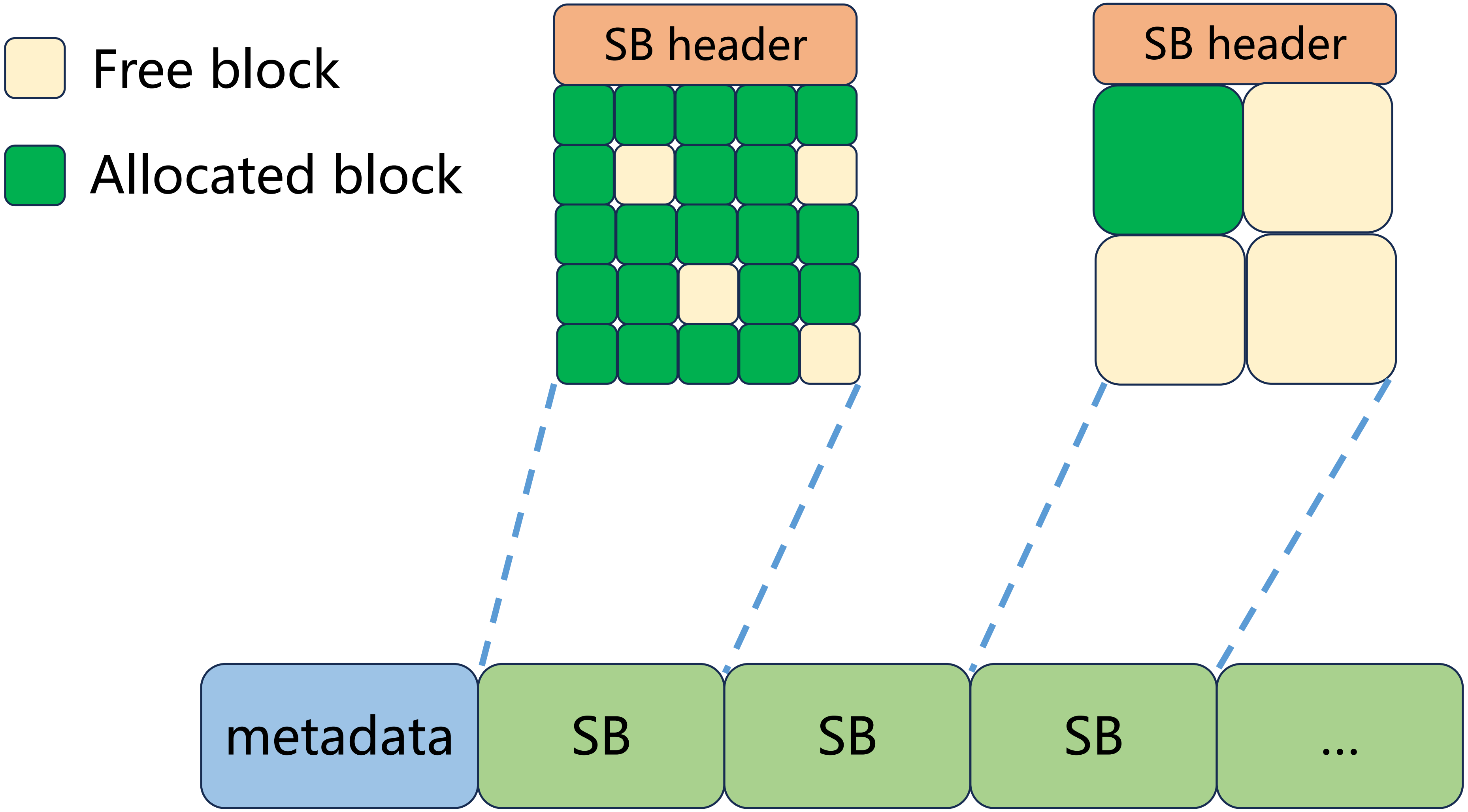

□ Free block

🟩 Allocated block

SB header

SB header

metadata

SB

SB

SB

...

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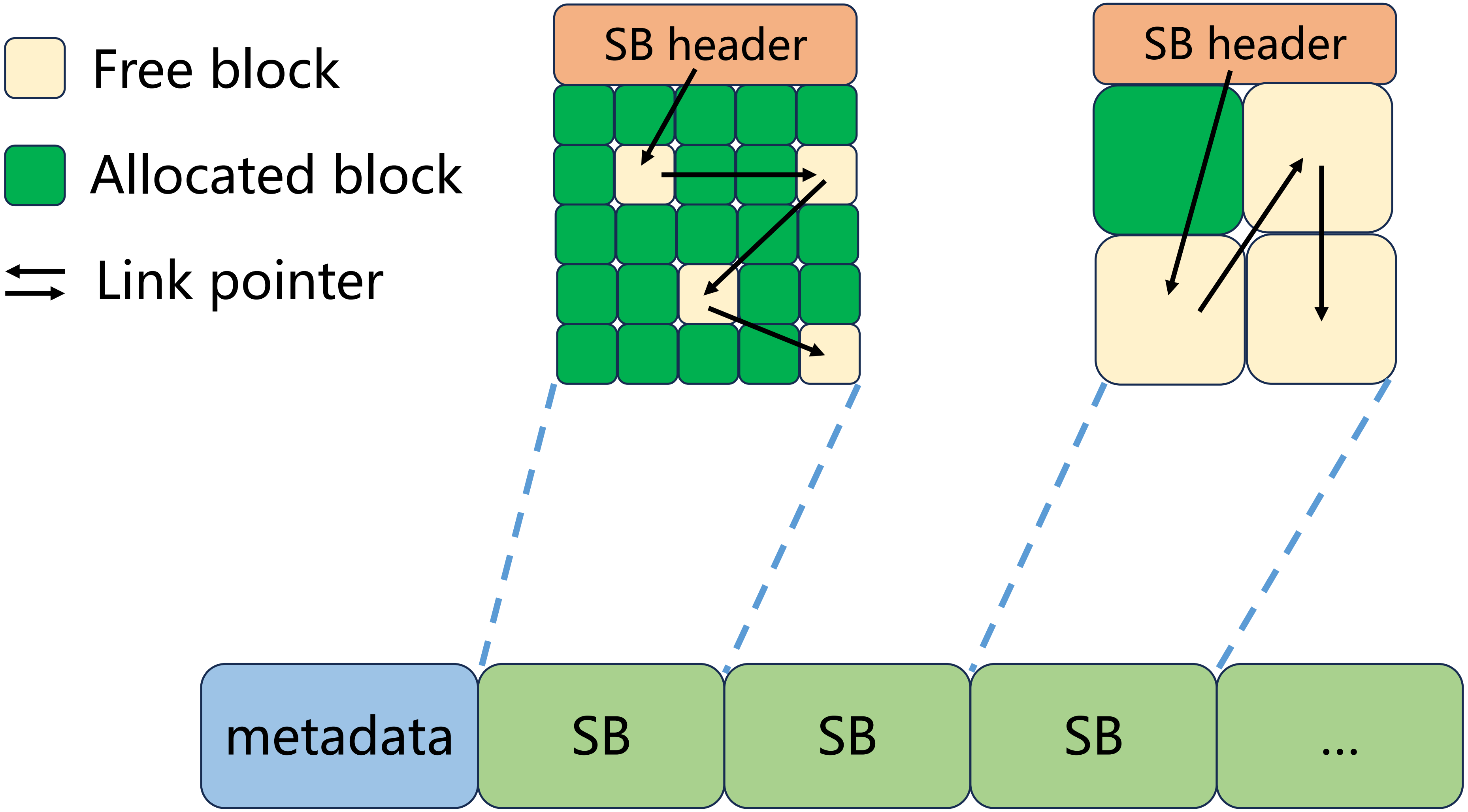

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⇆ Link pointer

SB header

SB header

metadata

SB

SB

SB

…

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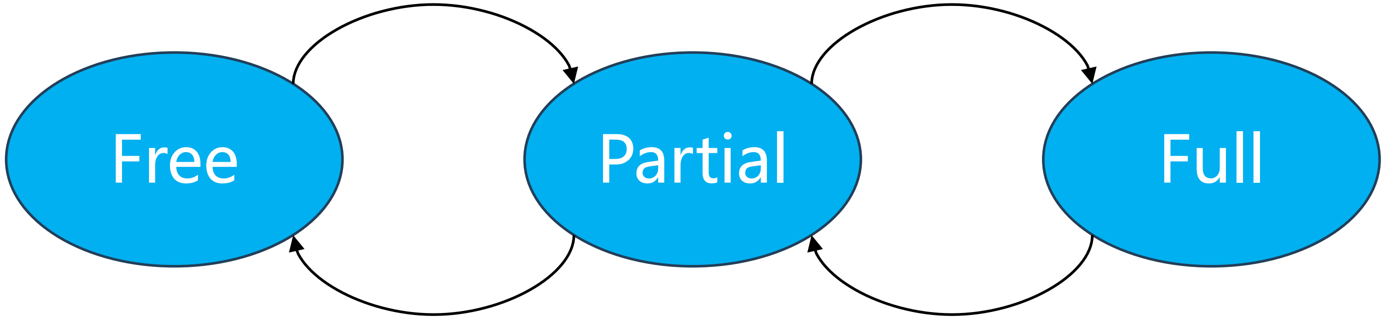

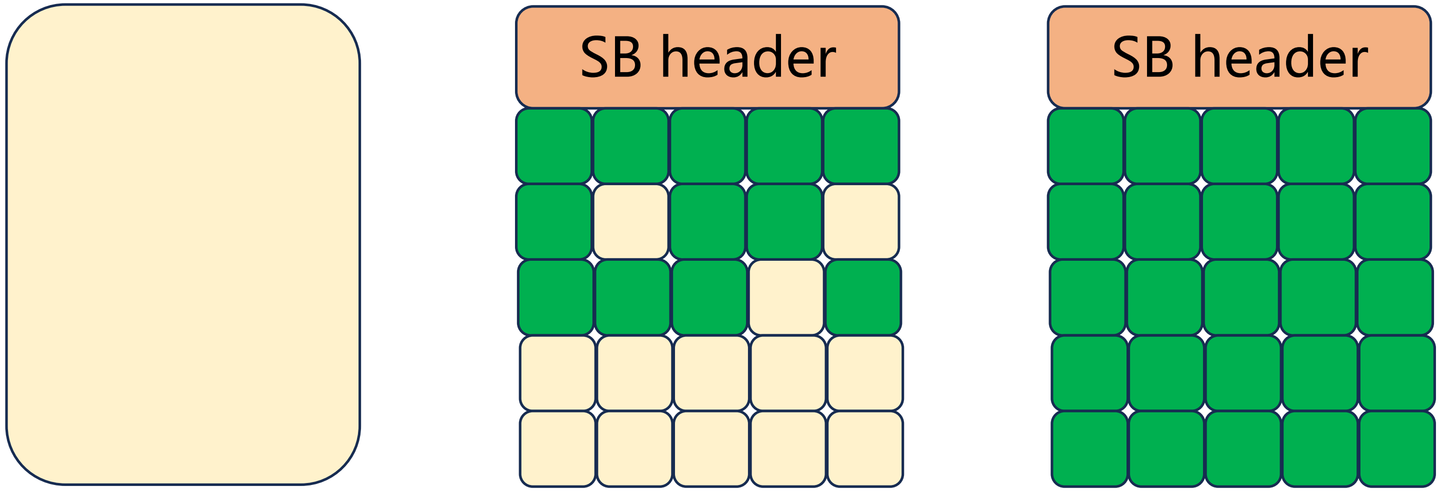

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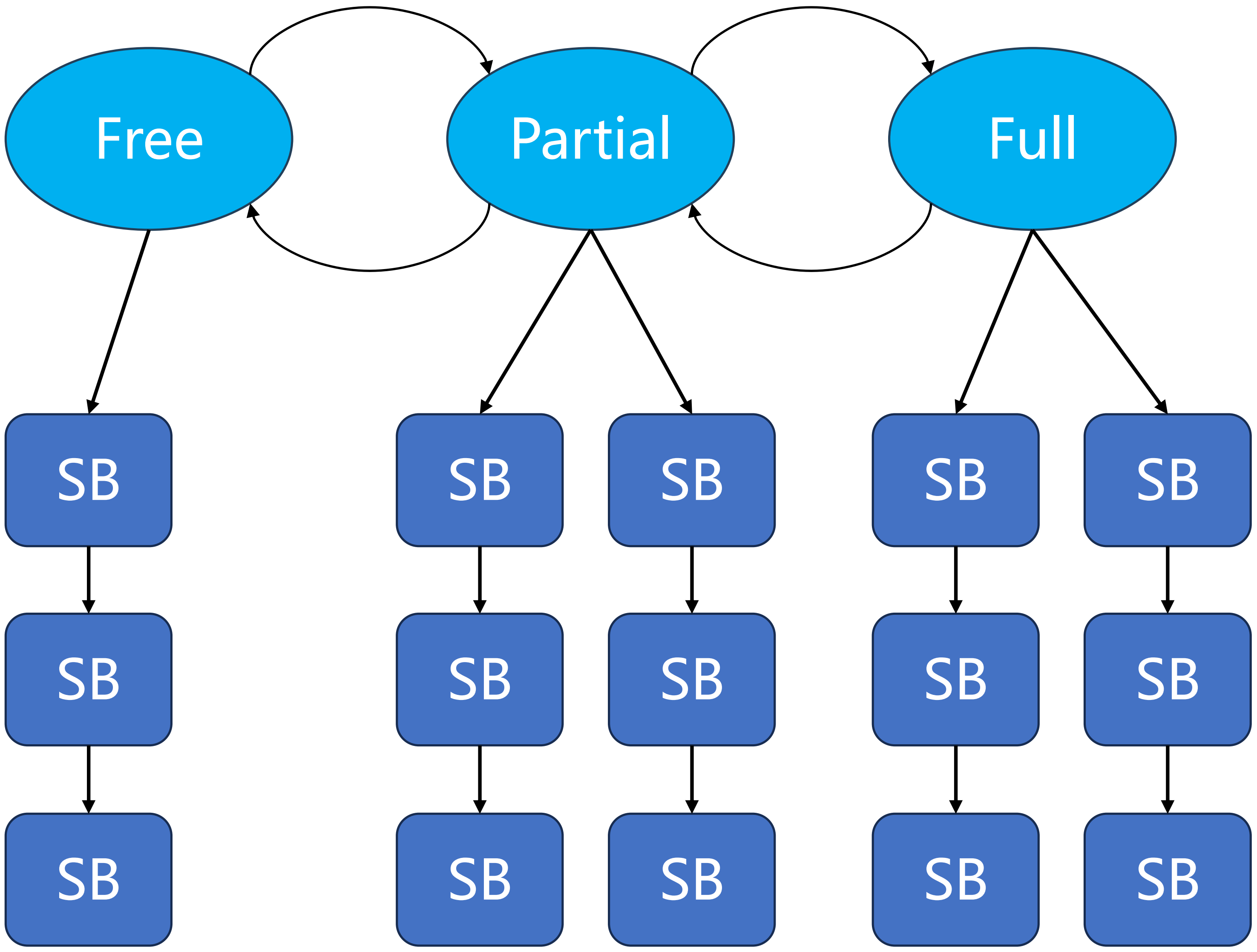
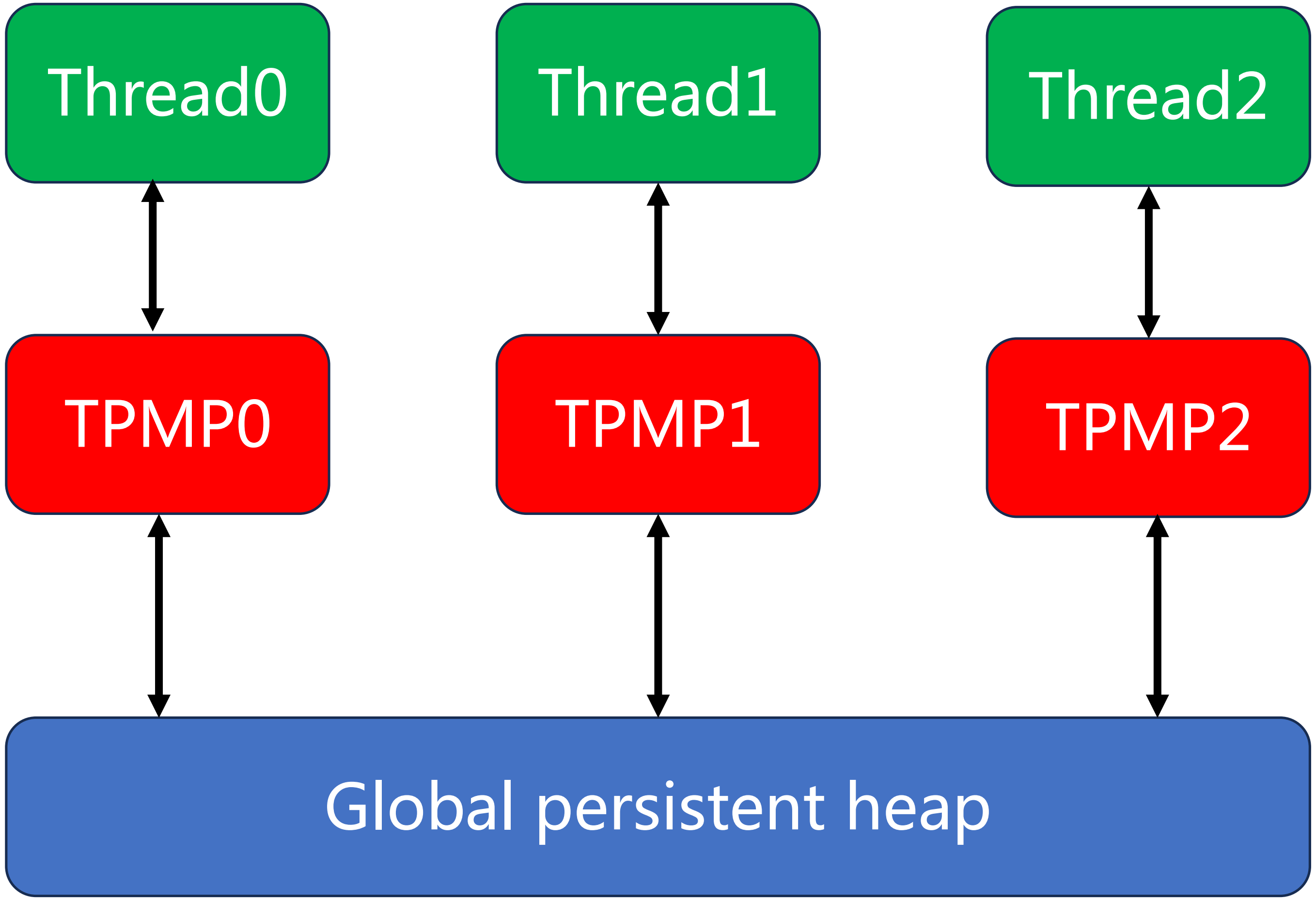


PMA: Thread-Private Memory Pool



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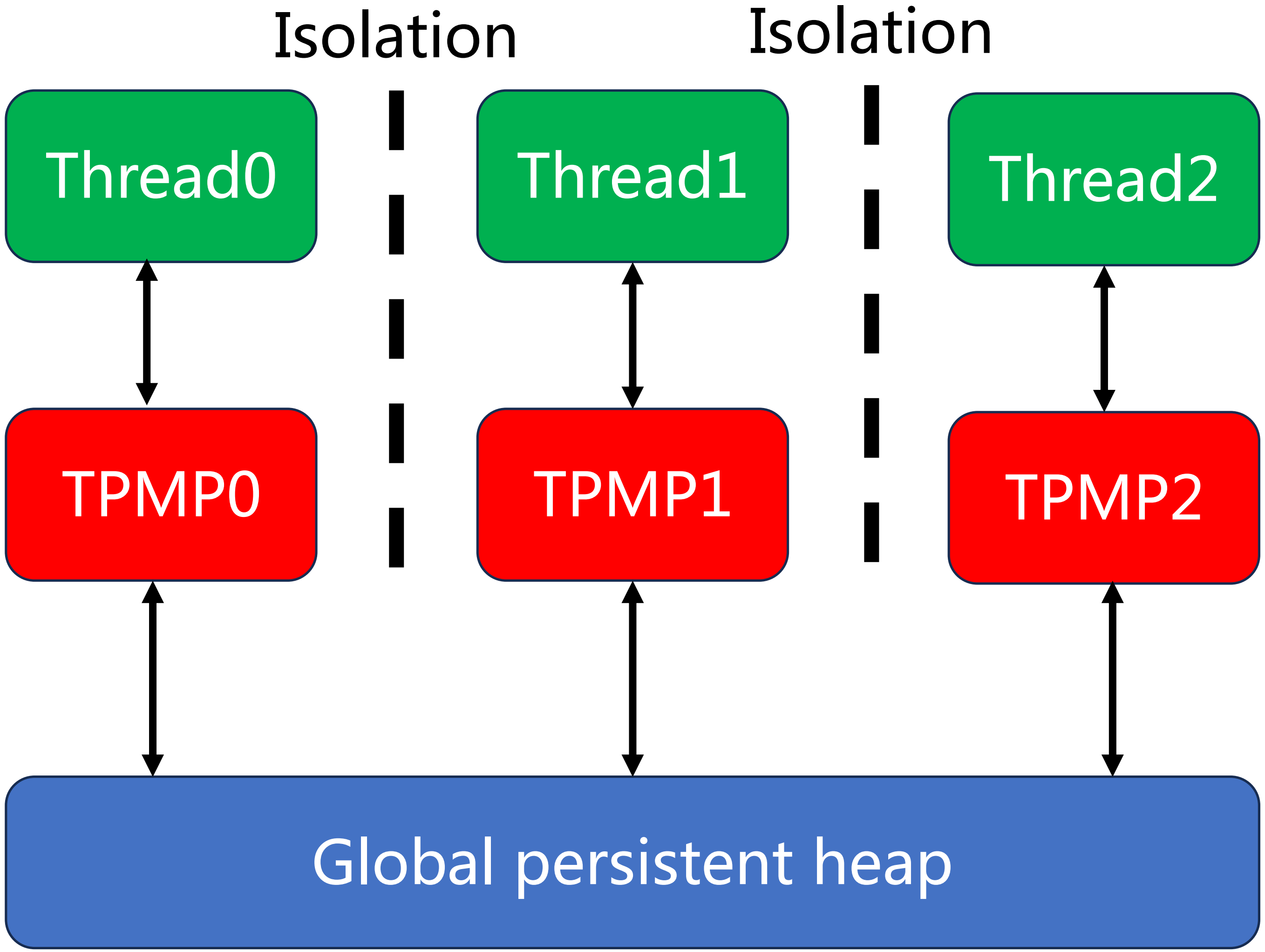

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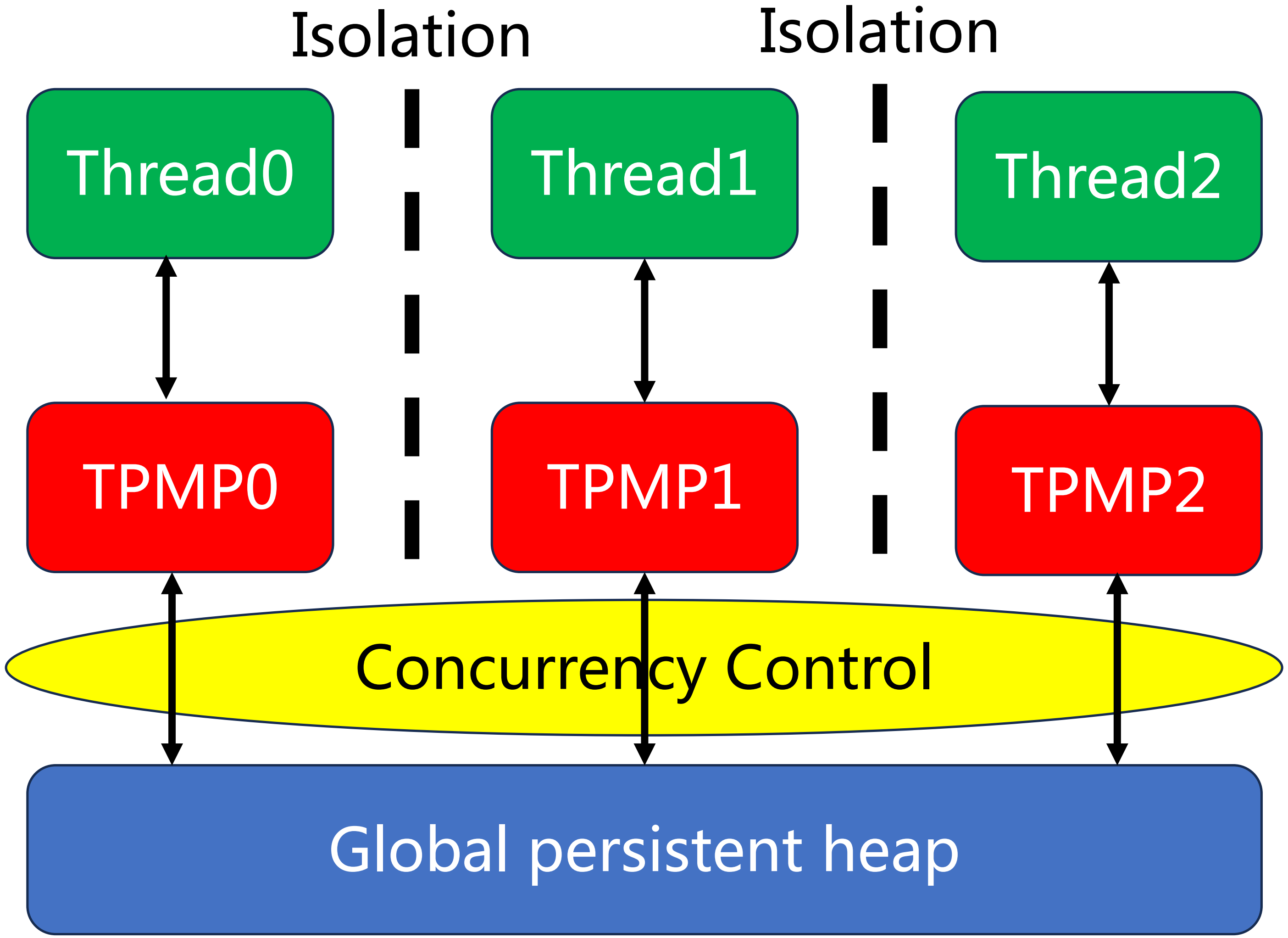

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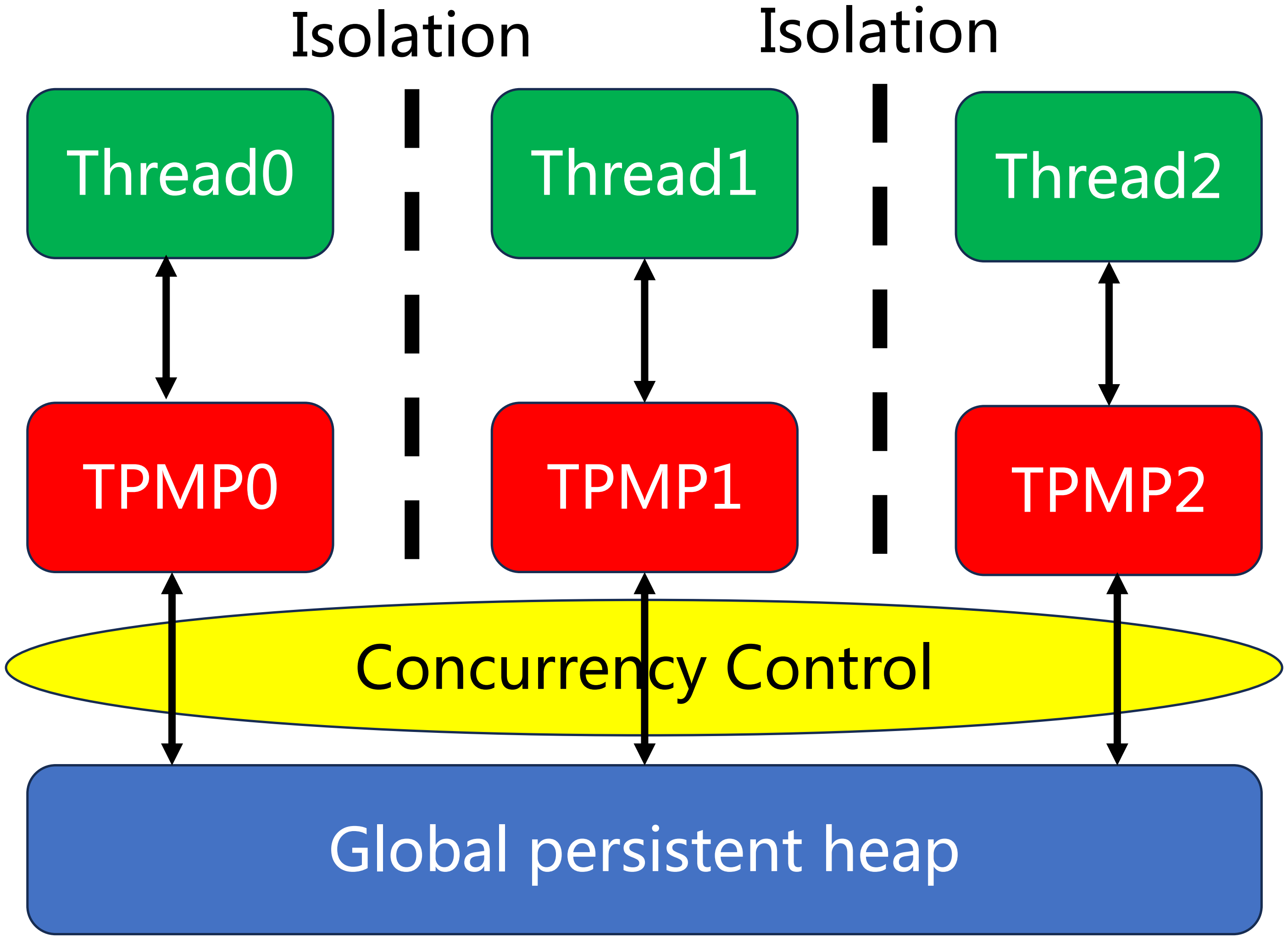
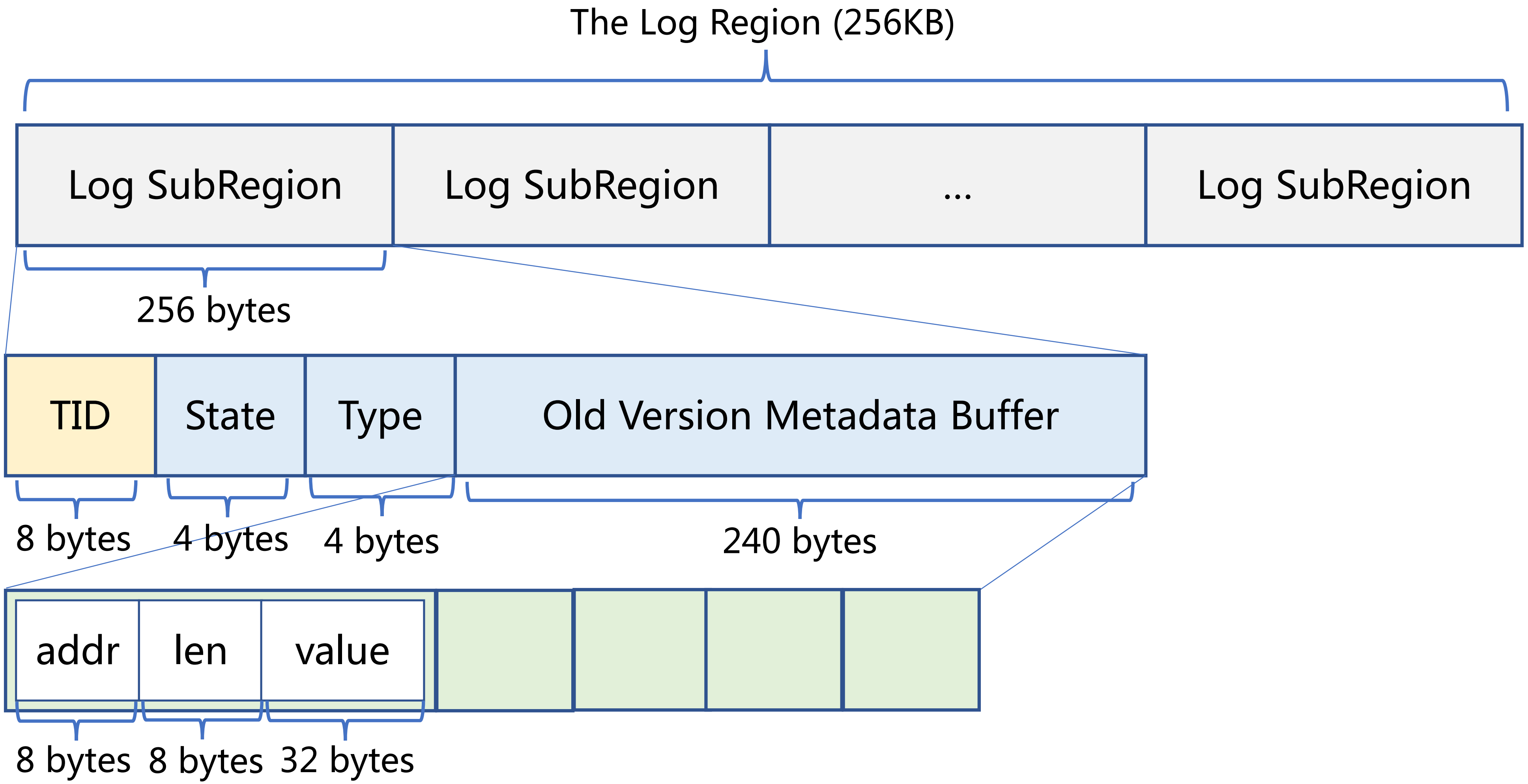


Over 99% of allocation requests can be served by the TPMP!

PMA: Crash Consistency

- ➢Transactions in PMA
  - ✓ Moving a SB from one list to another
  - ✓ Filling a TPMP with a SB or vice versa
  - ✓ Allocating/Reclaiming a memory block from a TPMP

PMA: Crash Consistency



Performance Evaluation

➢ Testbed

- ✓ 2 × Intel Xeon Gold 6230R @2.10GHz (26 cores)
- ✓ 6 × 128GB Intel Optane DC PMM 100 Series

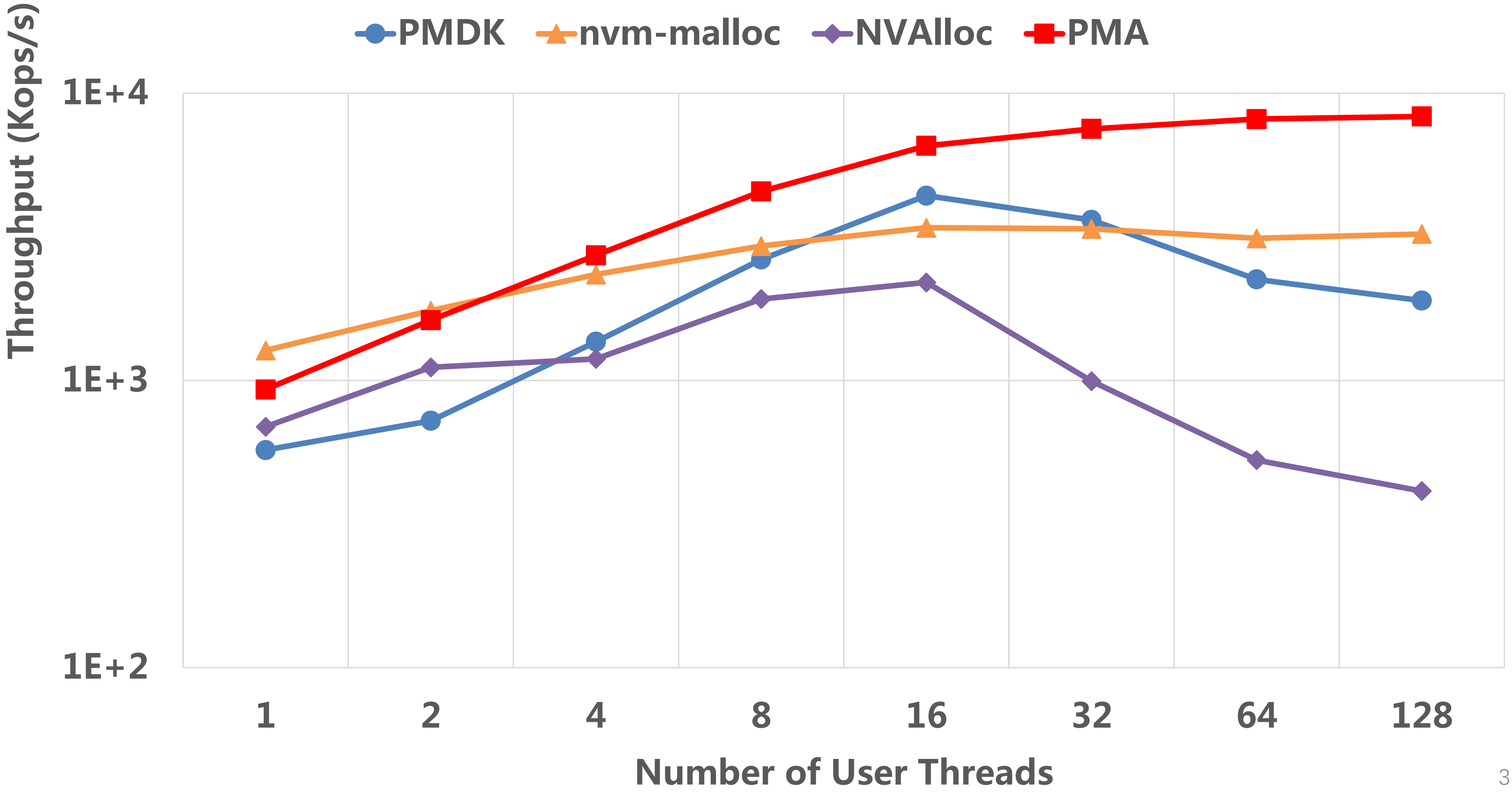
➢ Workload

- ✓ Allocating and reclaiming 10^6 memory blocks of 64 bytes
- ✓ Repeating for 10^3 iterations

➢ Competitors

✓	PMDK	[Intel]
✓	nvm_malloc	[VLDB 2015]
✓	NVAlloc-log	[ASPLOS 2022]

Performance Evaluation



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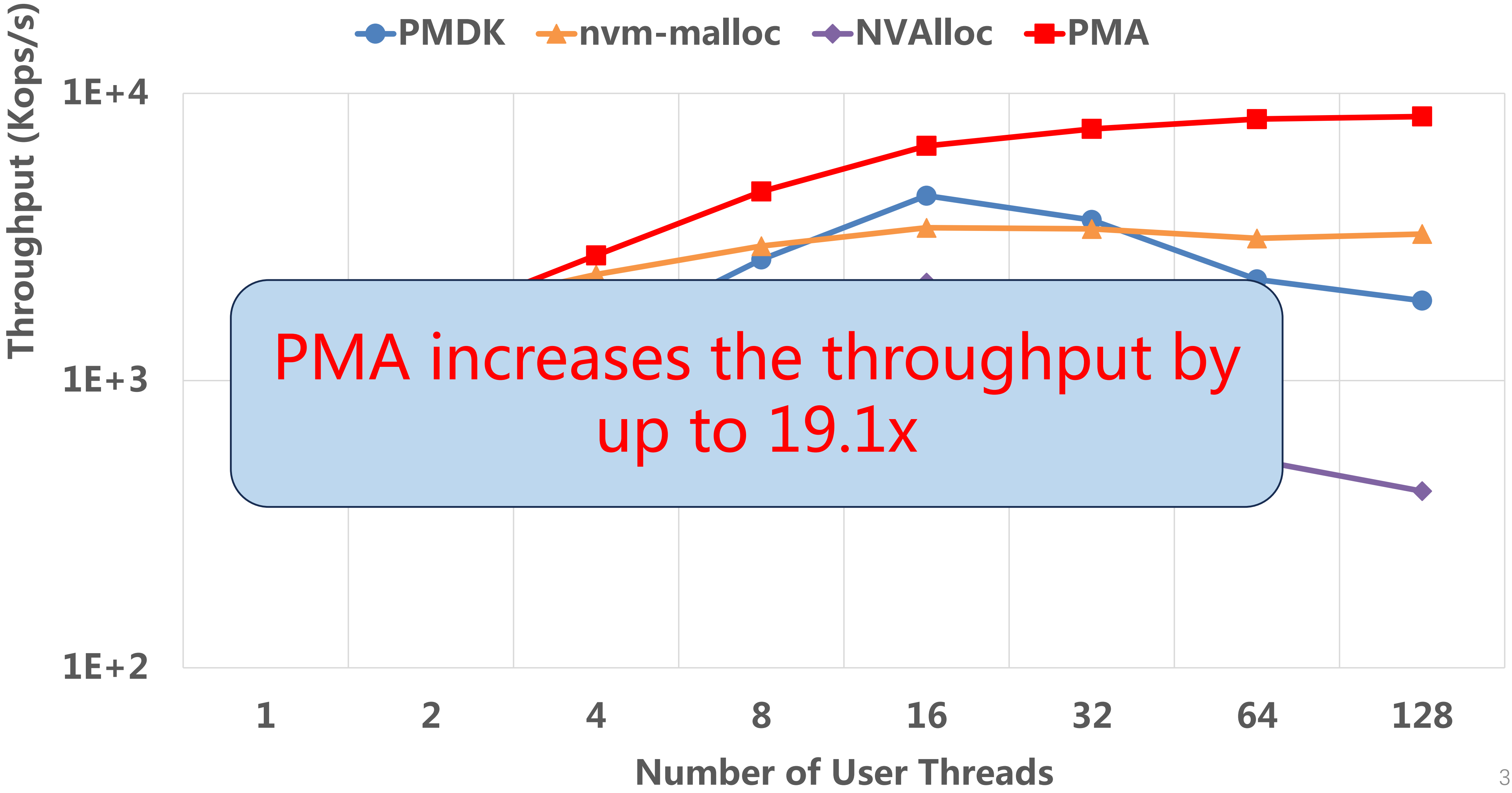

PMA increases the throughput by up to 19.1x

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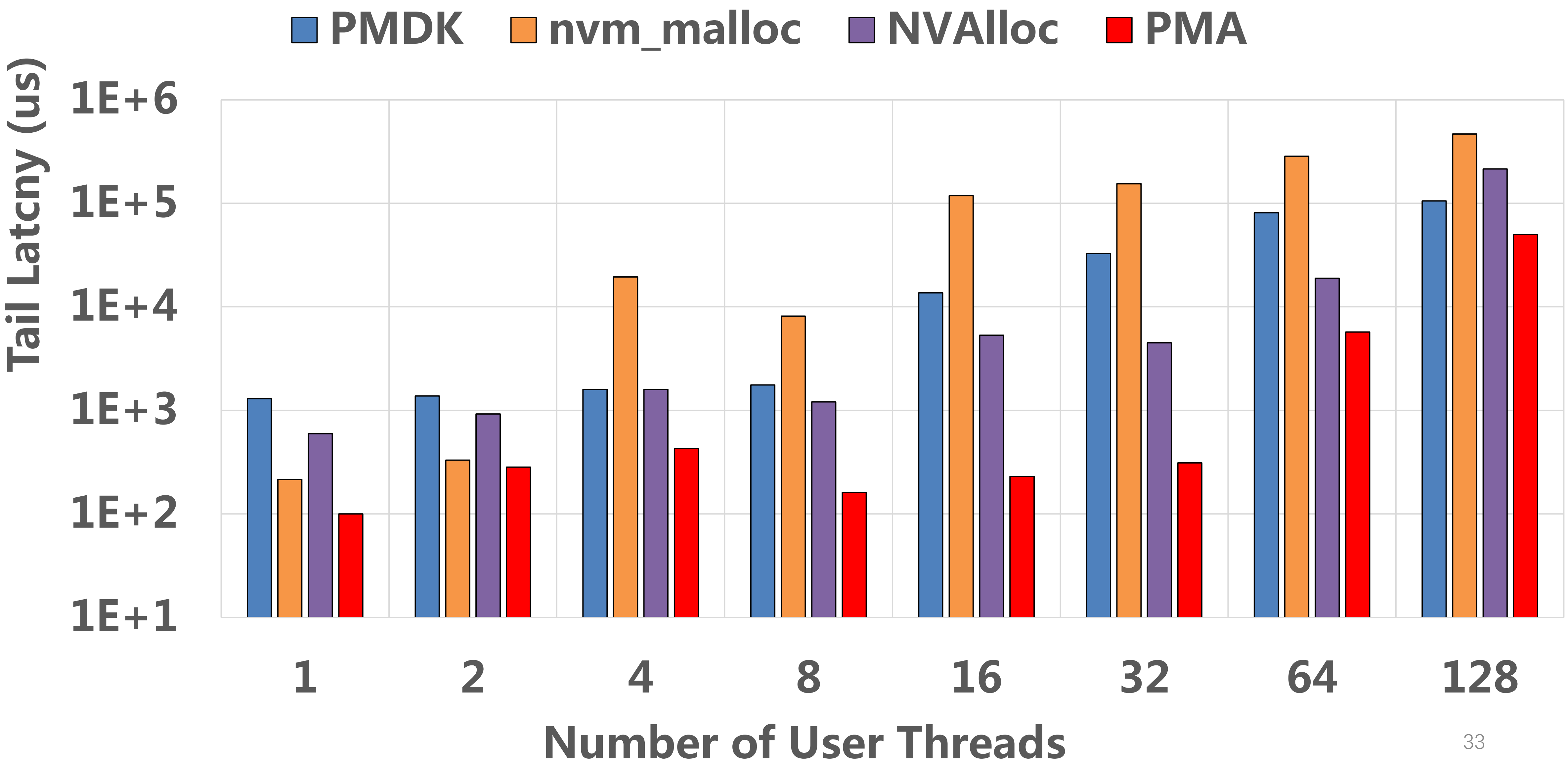

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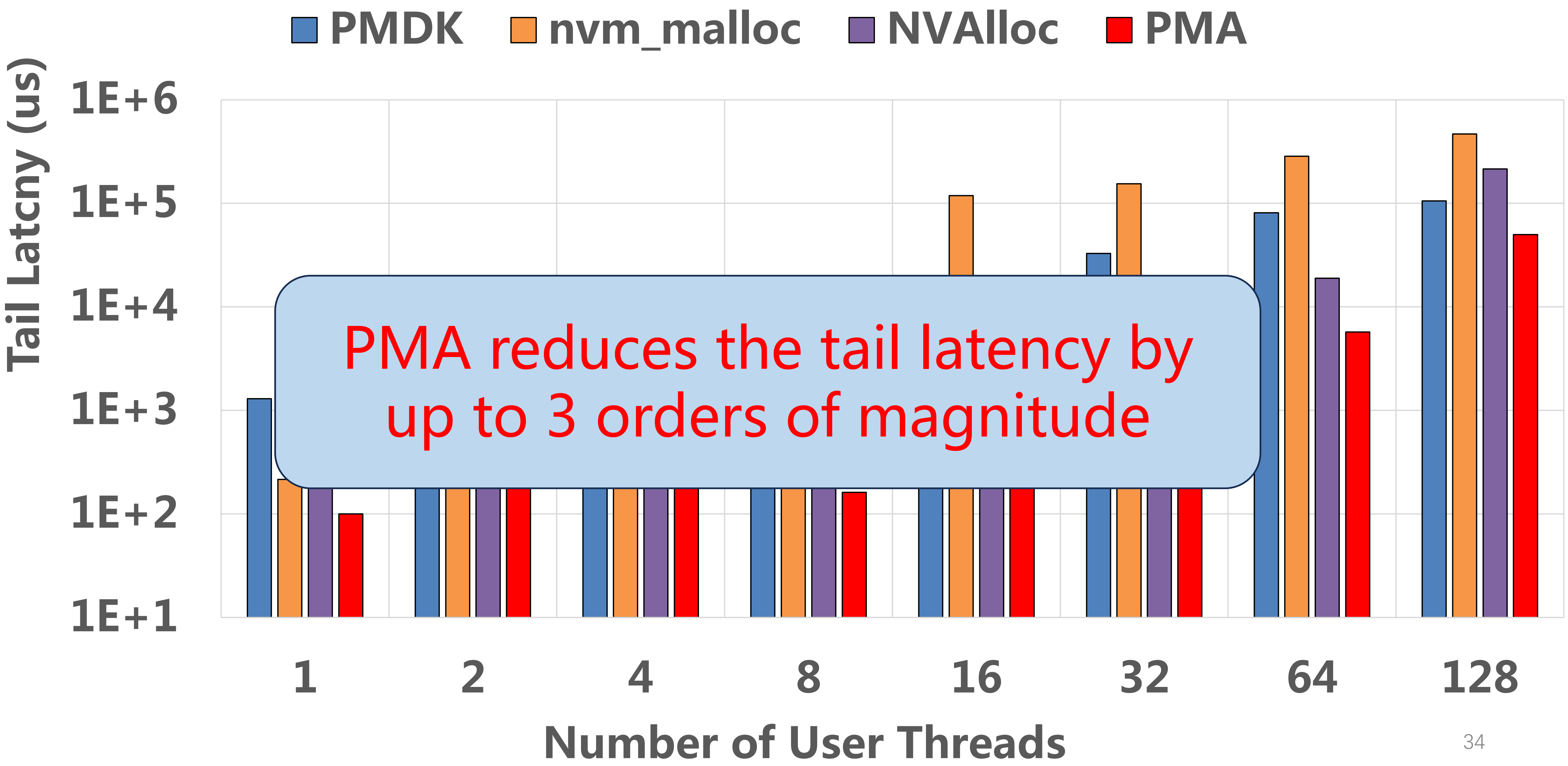

PMA reduces the tail latency by up to 3 orders of magnitude

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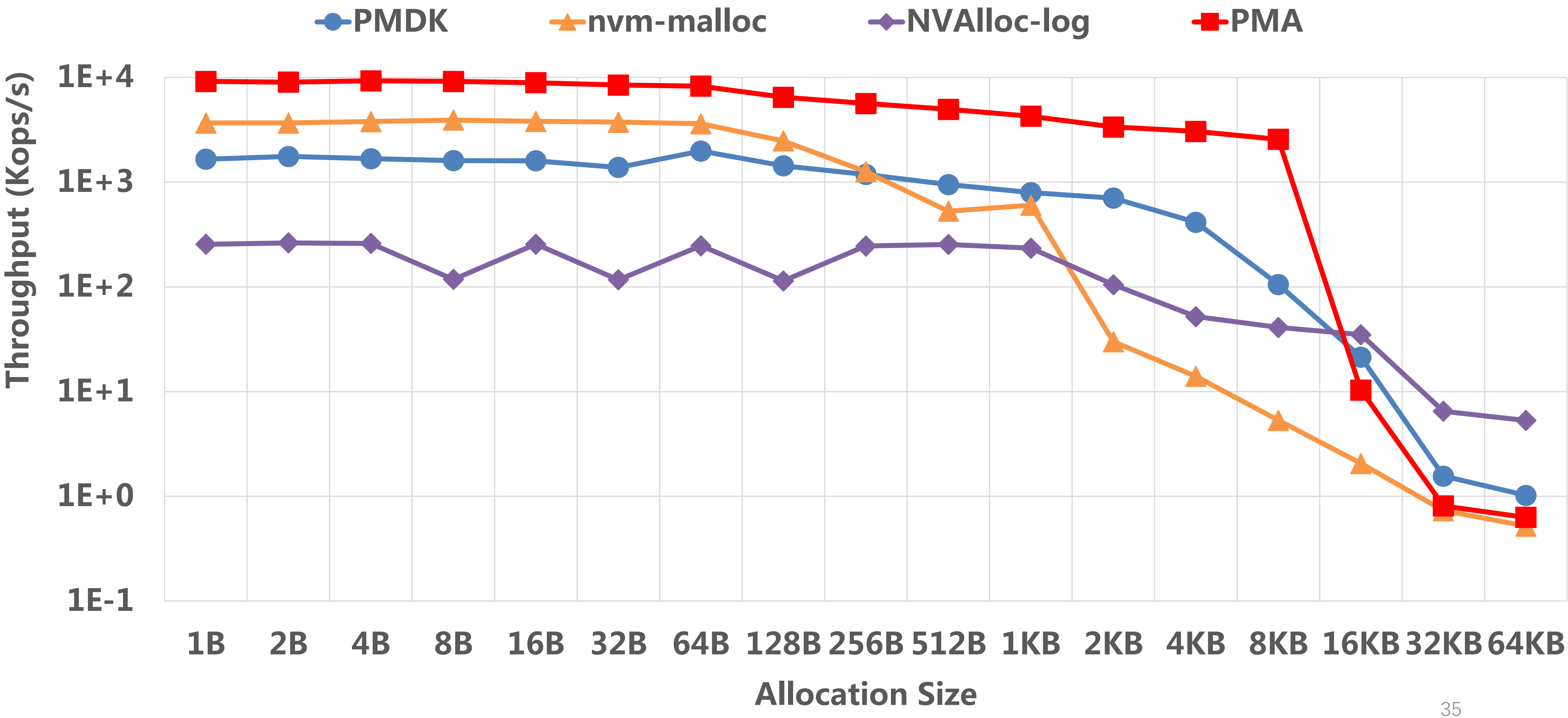

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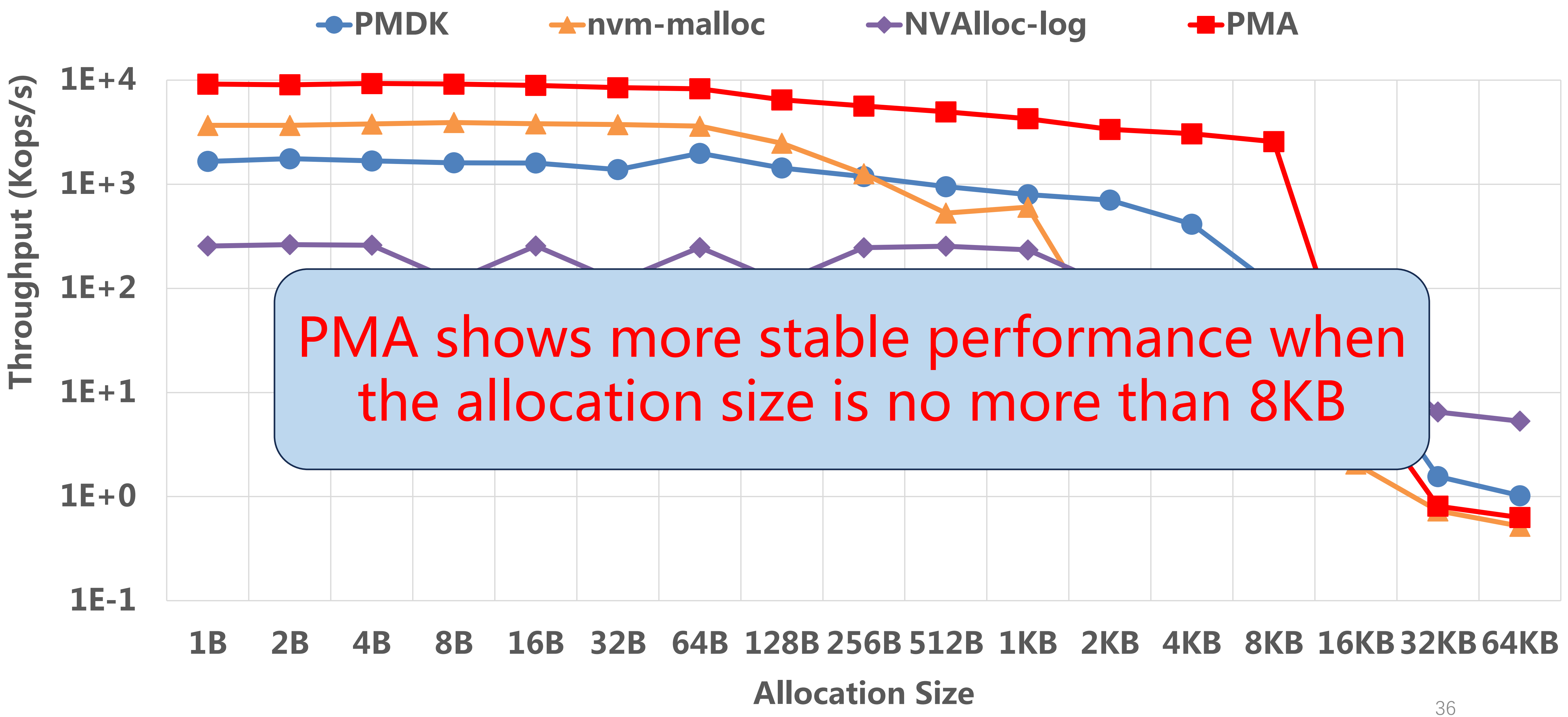

PMA shows more stable performance when the allocation size is no more than 8KB

Conclusion

- DRAM allocators cannot be used for PM due to crash consistency issues

- PMA: a high-performance and crash-consistent allocator for PM
  - ✓ Two-level memory management
  - ✓ Thread-private memory pool
  - ✓ Lightweight write-ahead log

- 3.4x~19.1x higher throughput and orders of magnitude lower tail latency

Thanks!

Q&A

https://github.com/HUSTxyxiang/PMA/

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