RubbleDB: CPU-Efficient Replication with NVMe-oF

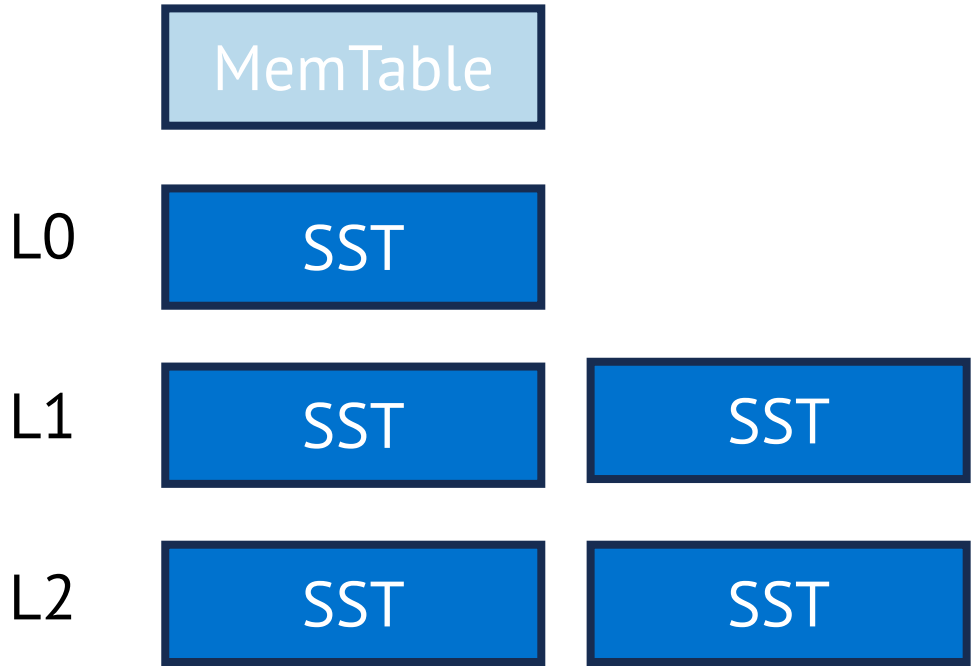
Haoyu Li[1], Sheng Jiang[1], Chen Chen[1], Ashwini Raina[2], Xingyu Zhu[1], Changxu Luo[1], Asaf Cidon[1]

[1]*Columbia University,* [2]*Princeton University*

USENIX ATC '23

CPU: the bottleneck in key-value stores

Compactions in log-structured merge trees (LSM) is CPU expensive



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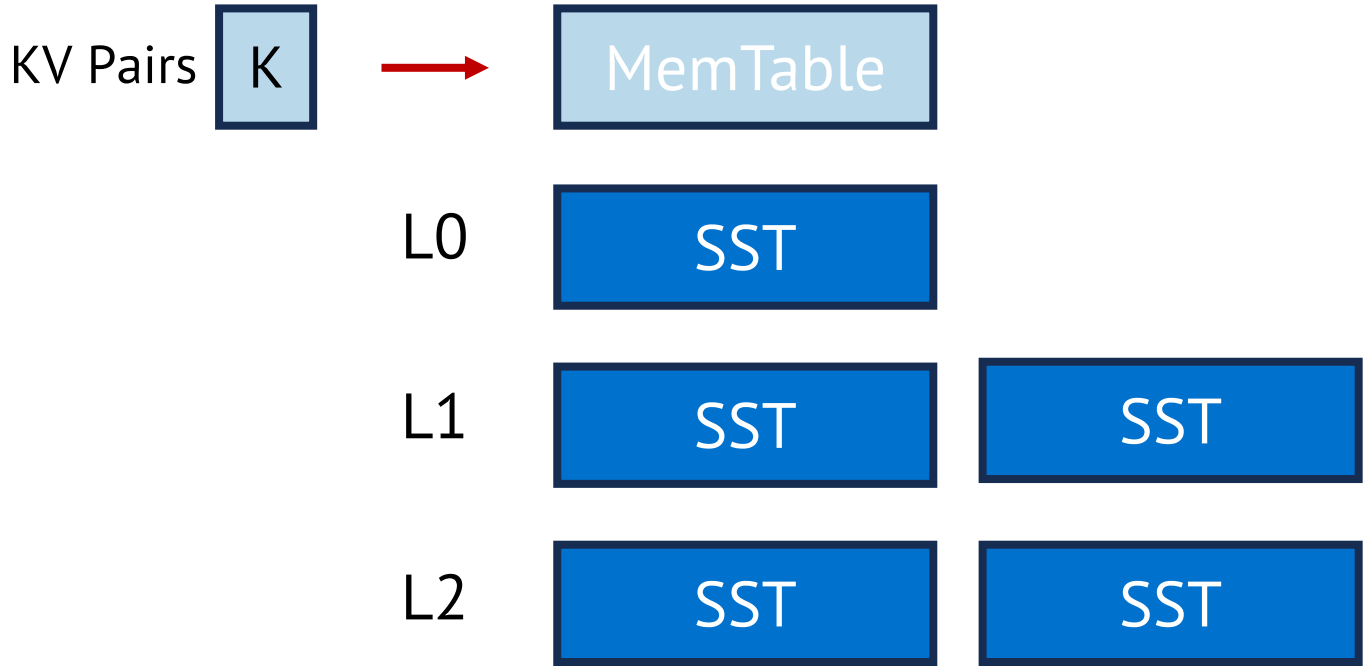

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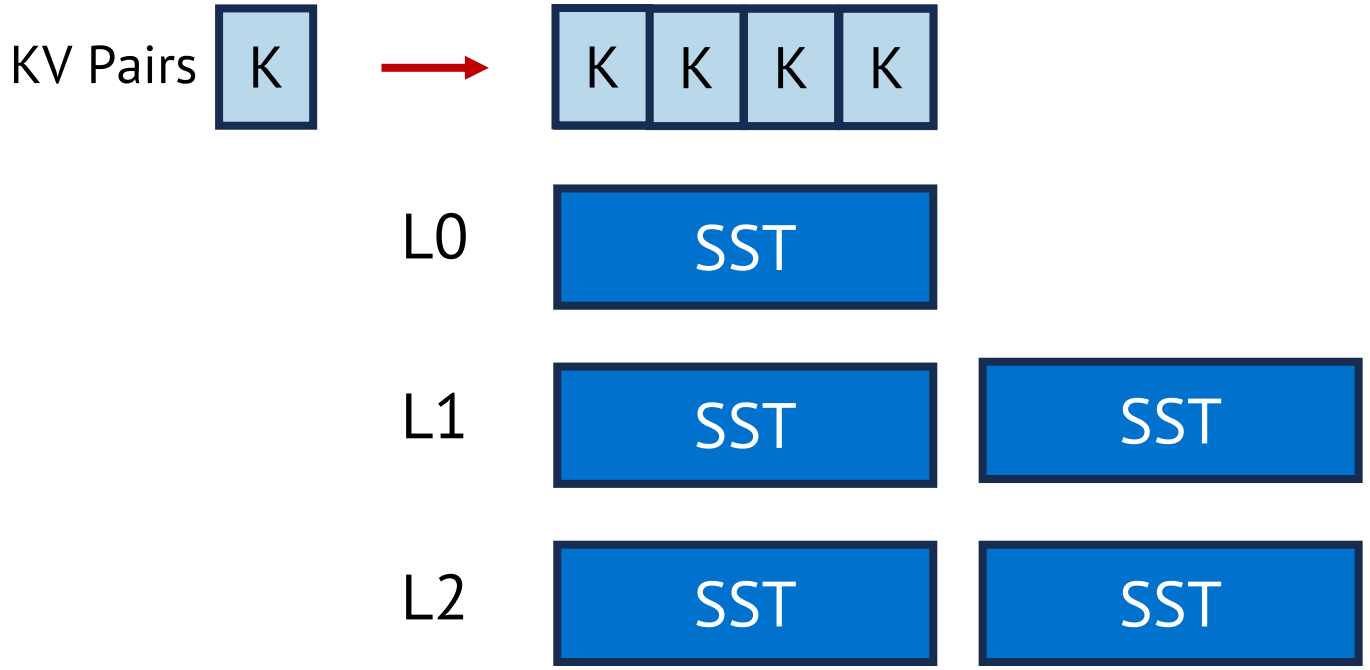

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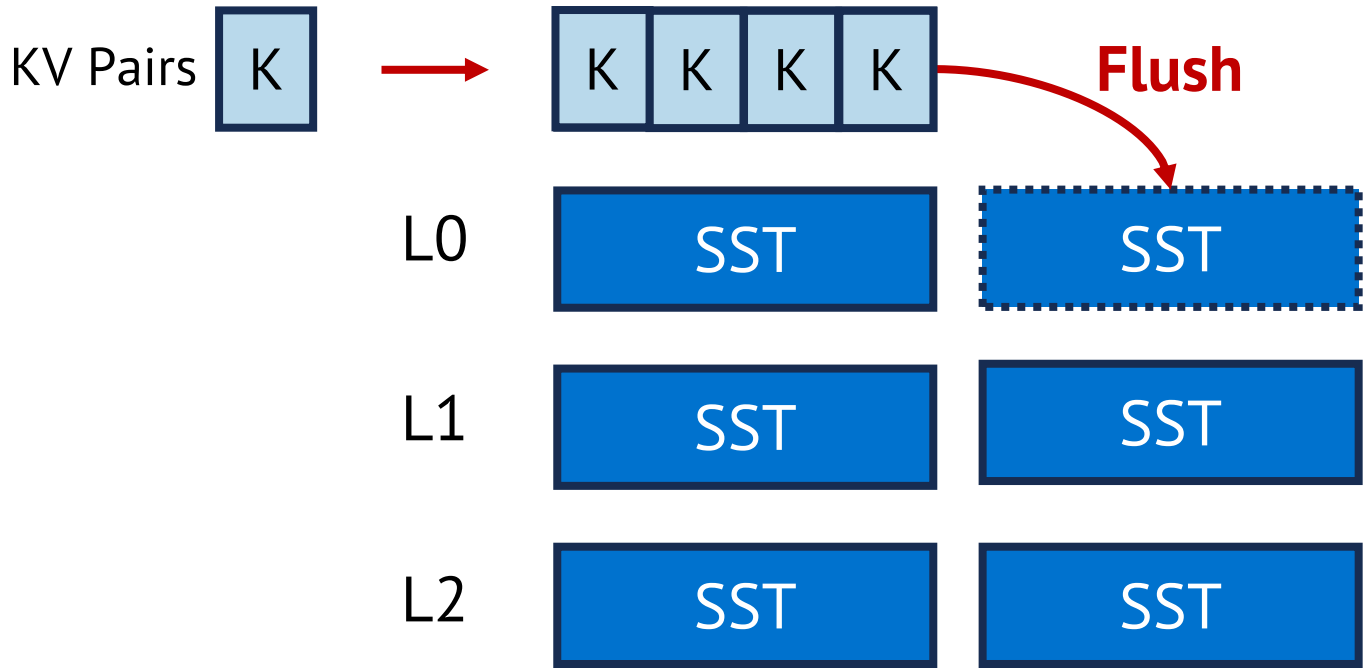

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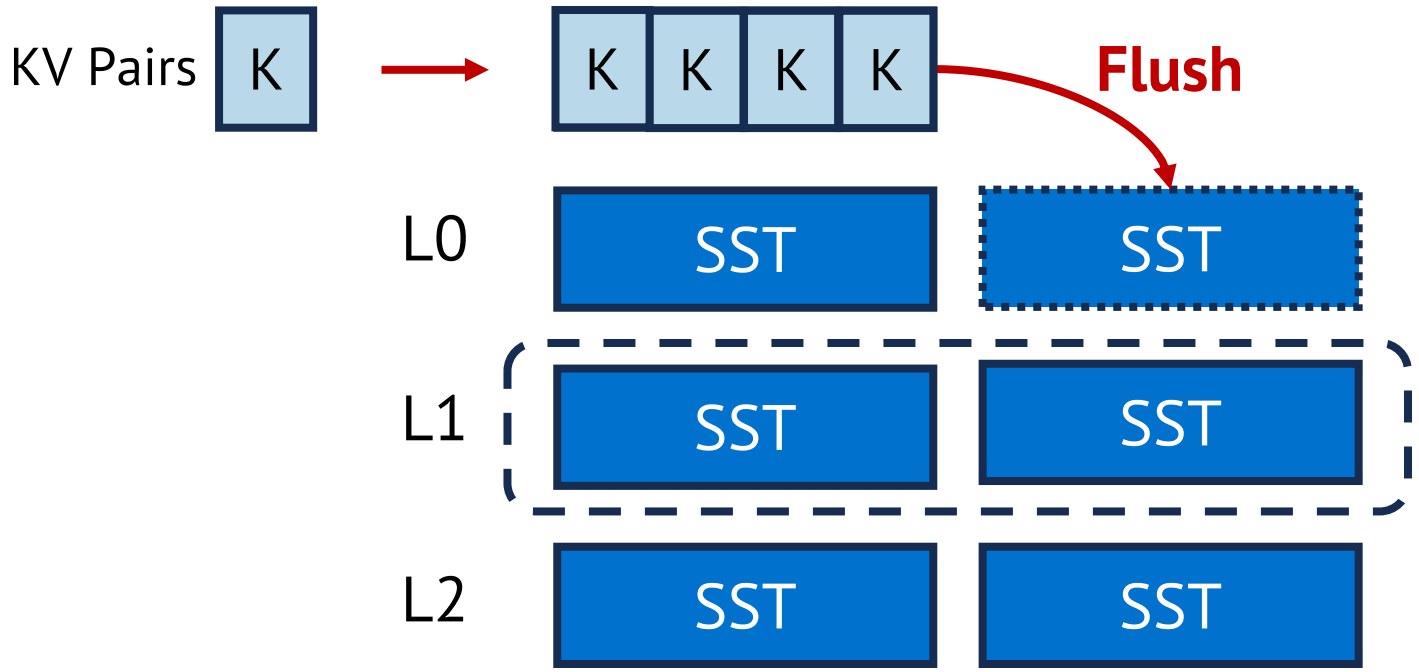

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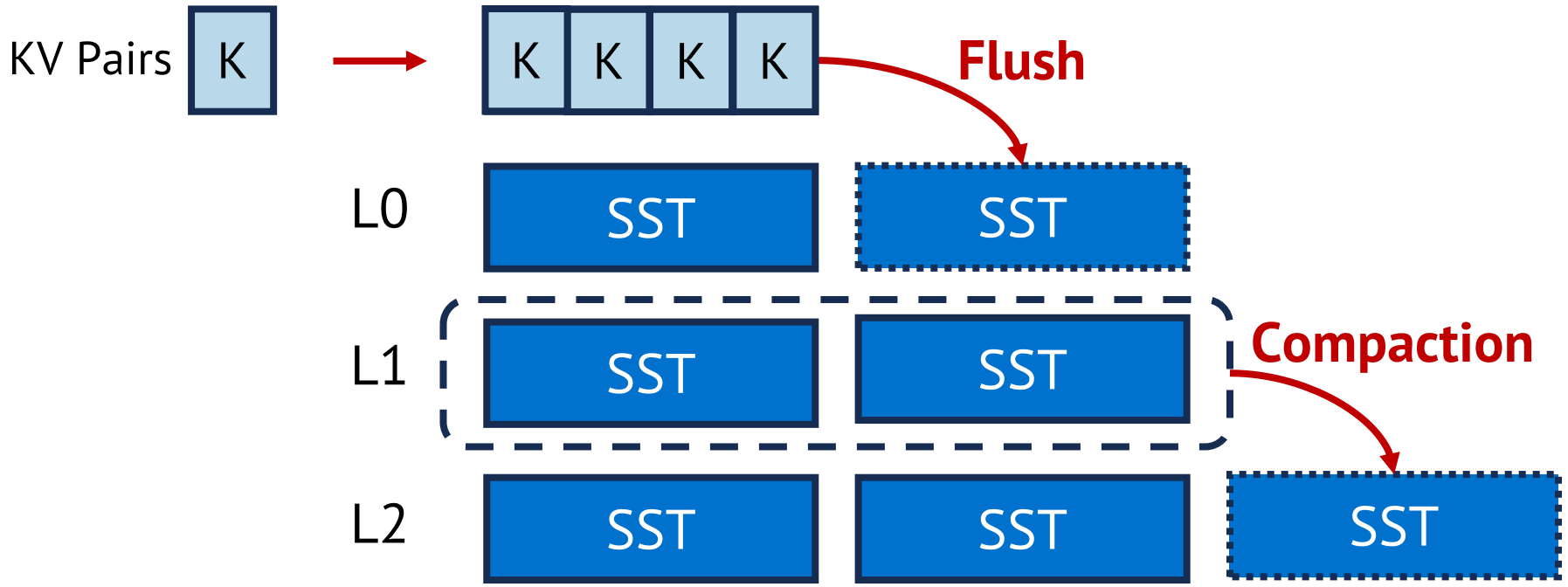

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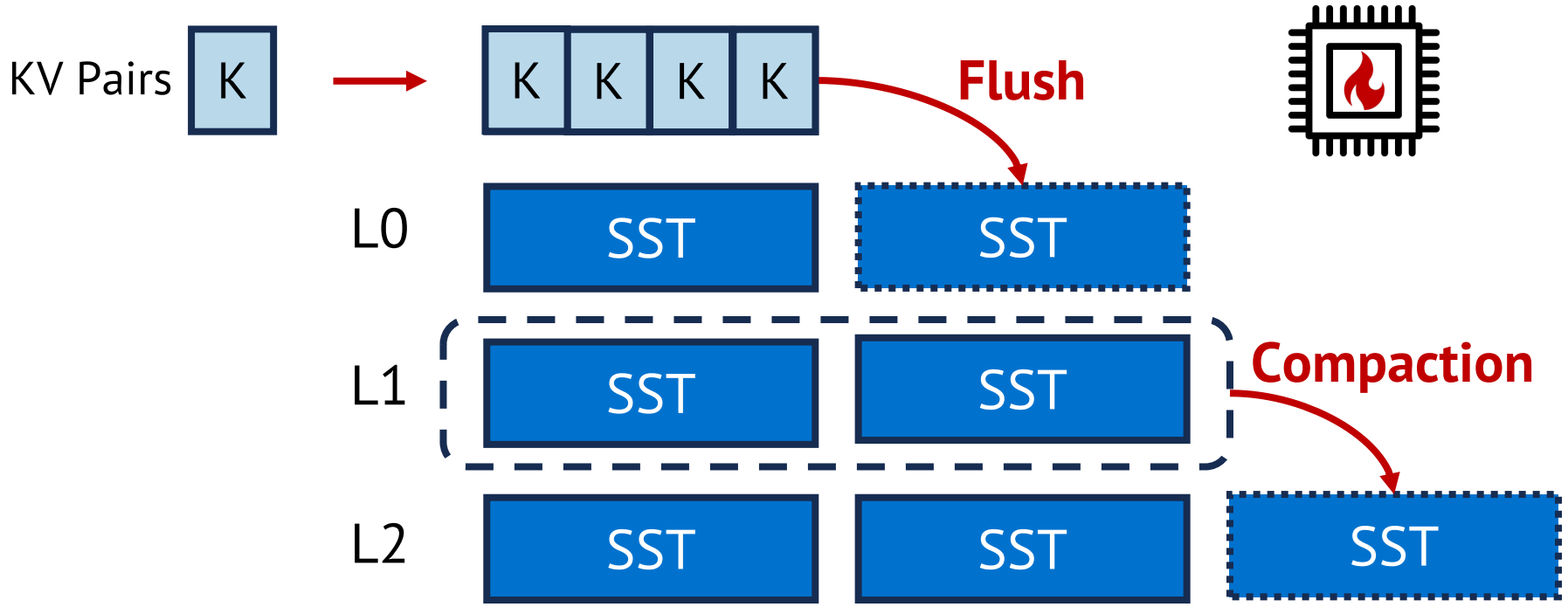
CPU: the bottleneck in key-value stores

Compactions in log-structured merge trees (LSM) is CPU expensive

- Up to 72% of the total CPU time*!



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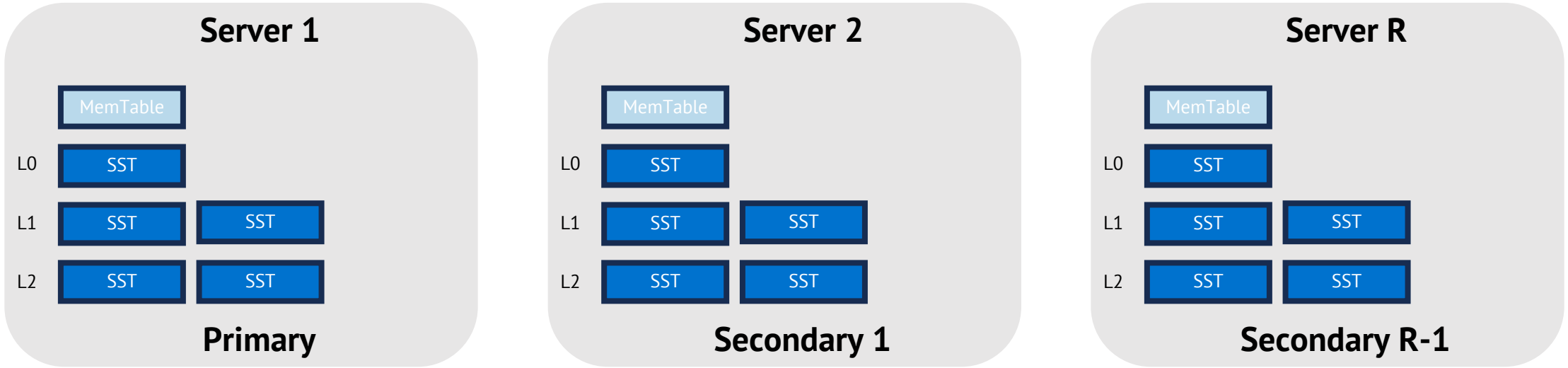
Compactions in replicated LSM trees

Redundant compactions happen in each replica

- e.g., CockroachDB, ZippyDB, Cassandra, and etc.



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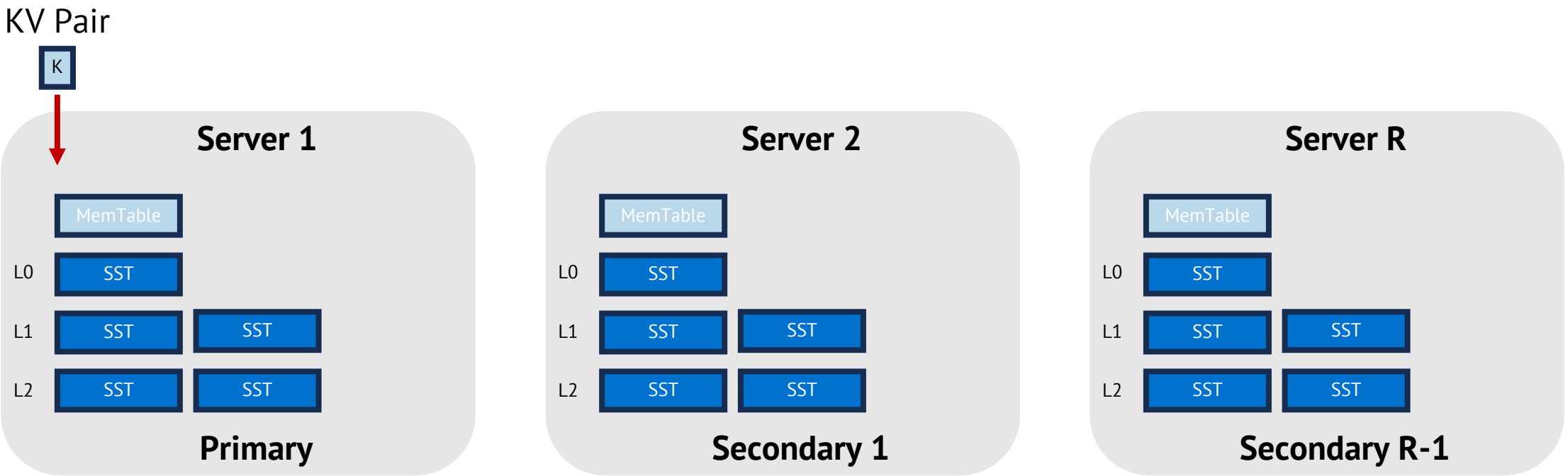

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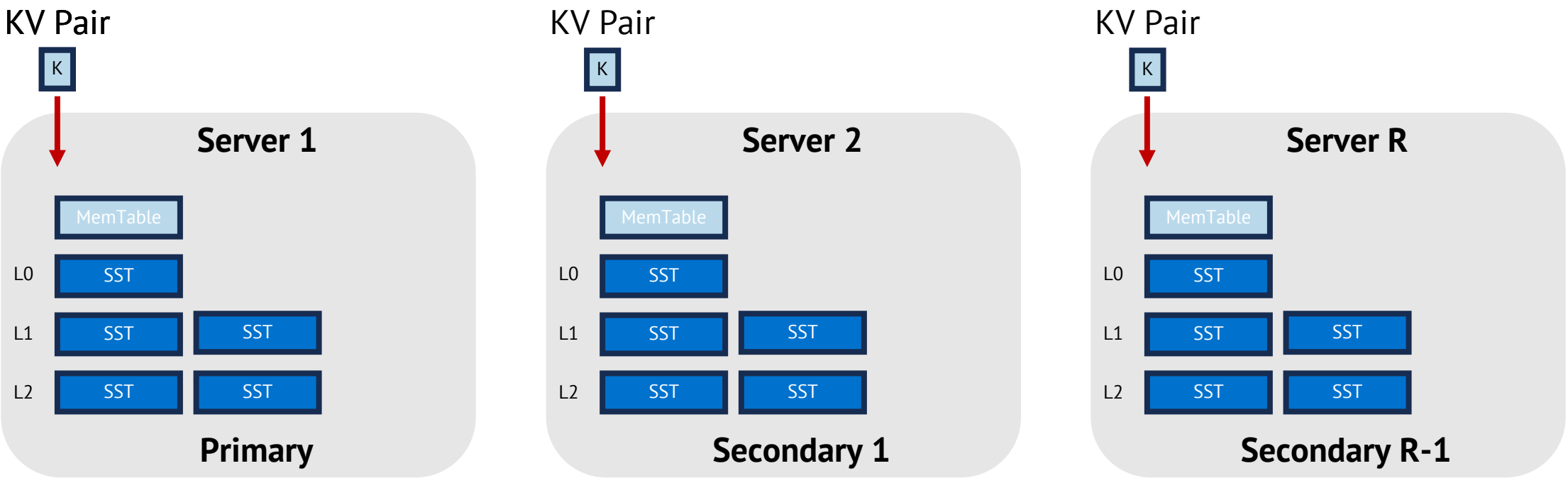

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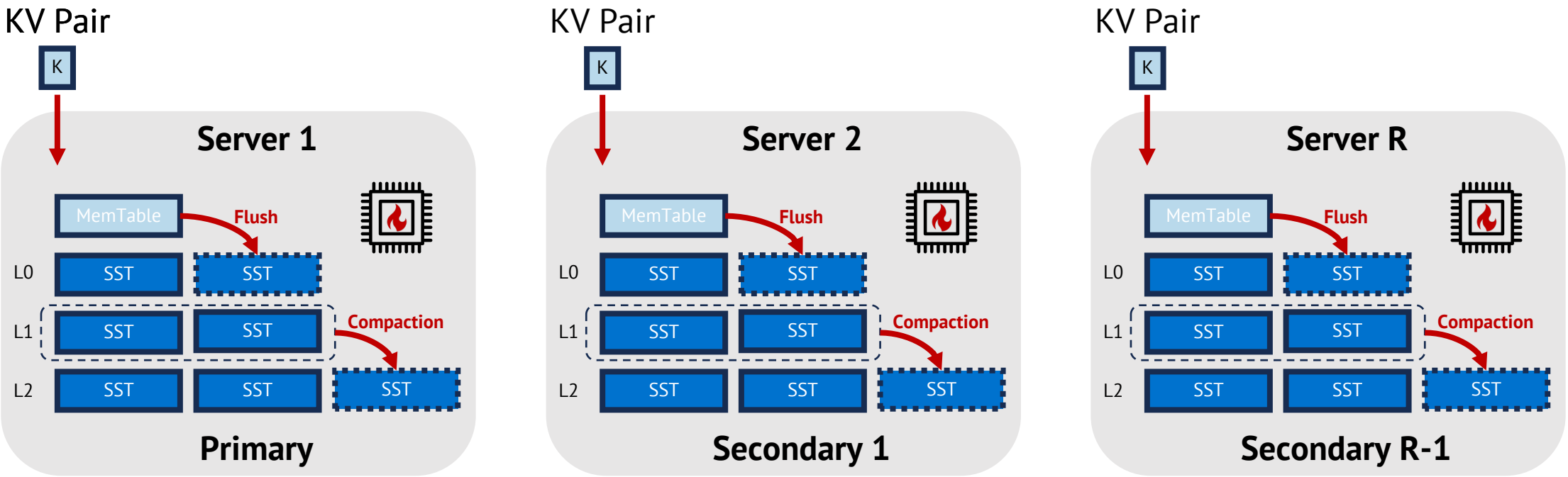

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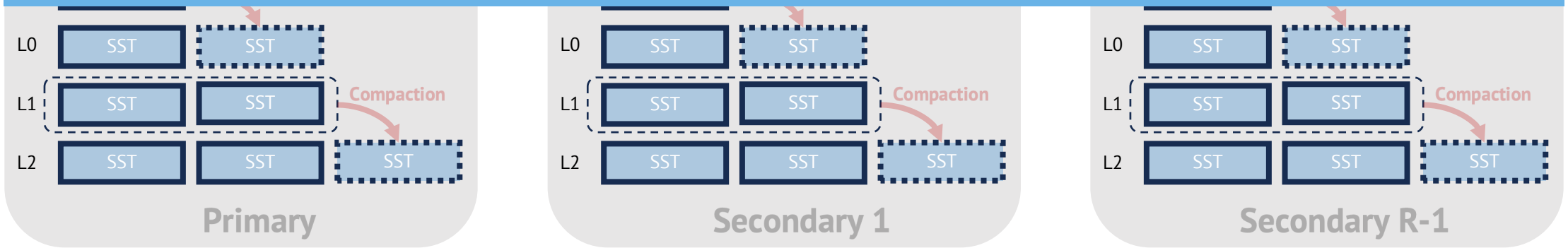
Can we remove redundant compactions?

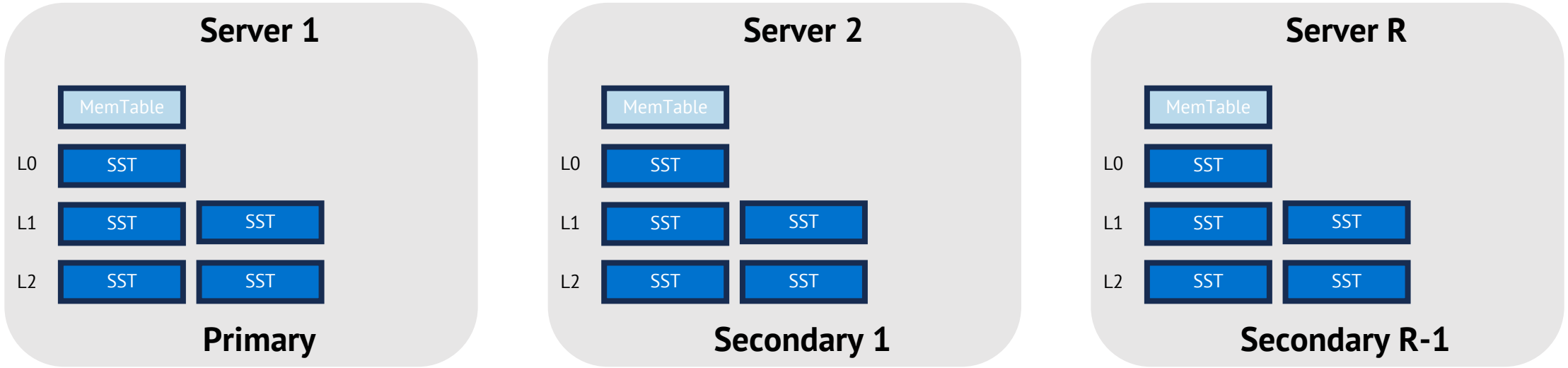


This Talk

Redundant compactions can be eliminated

RubbleDB makes it practical to share compaction results with NVMe-oF

How to remove redundant compactions?



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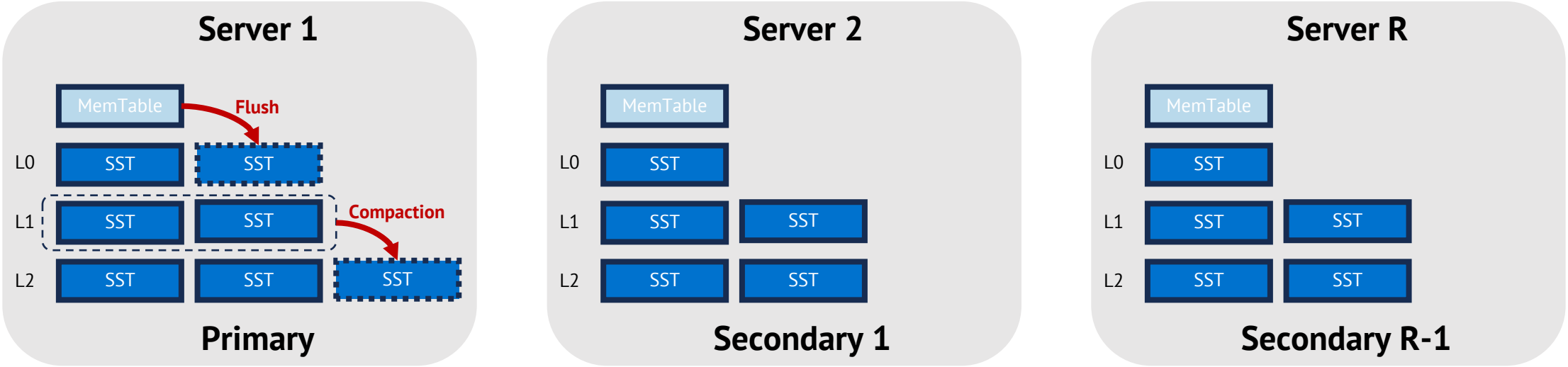

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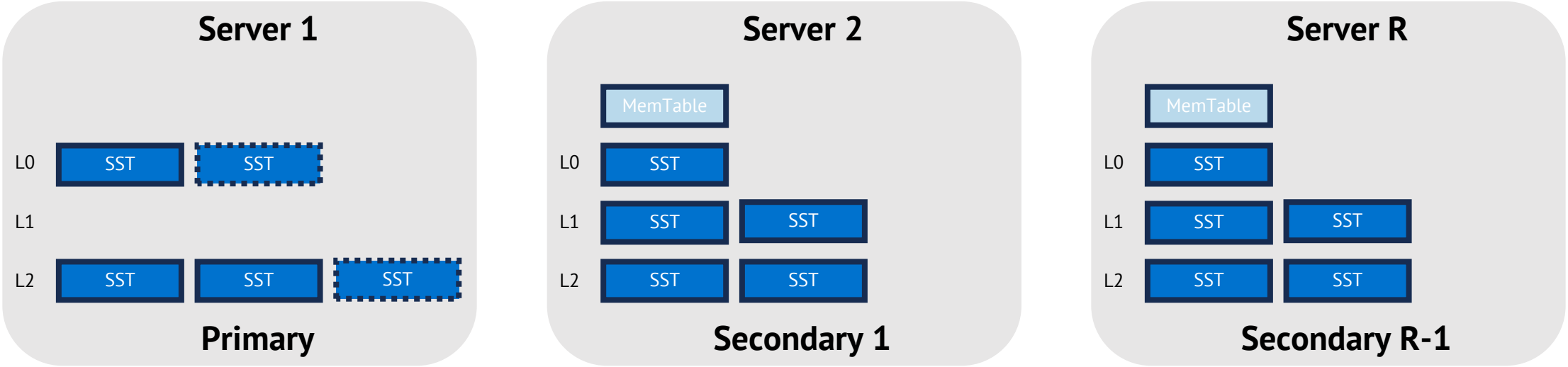

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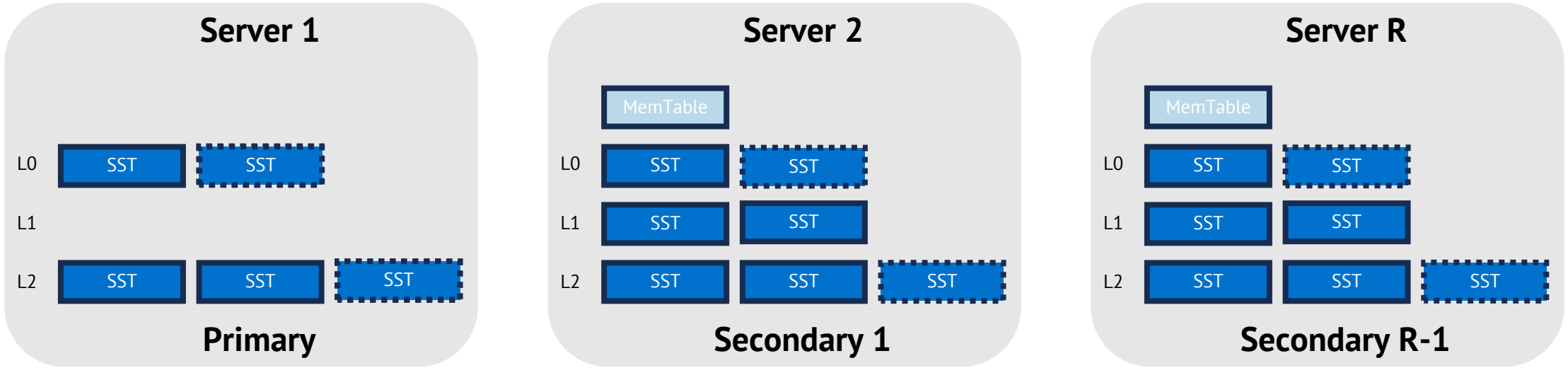

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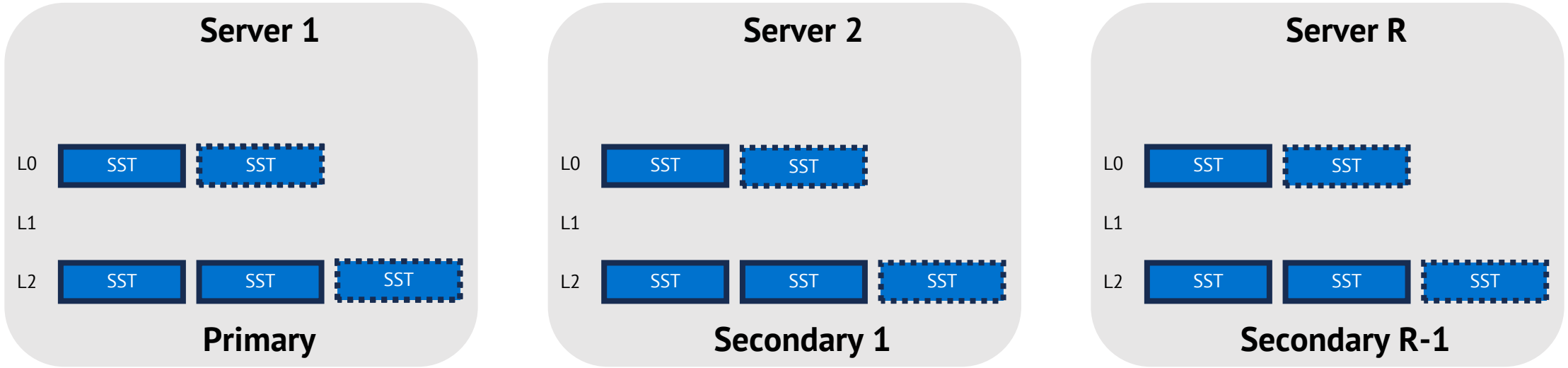

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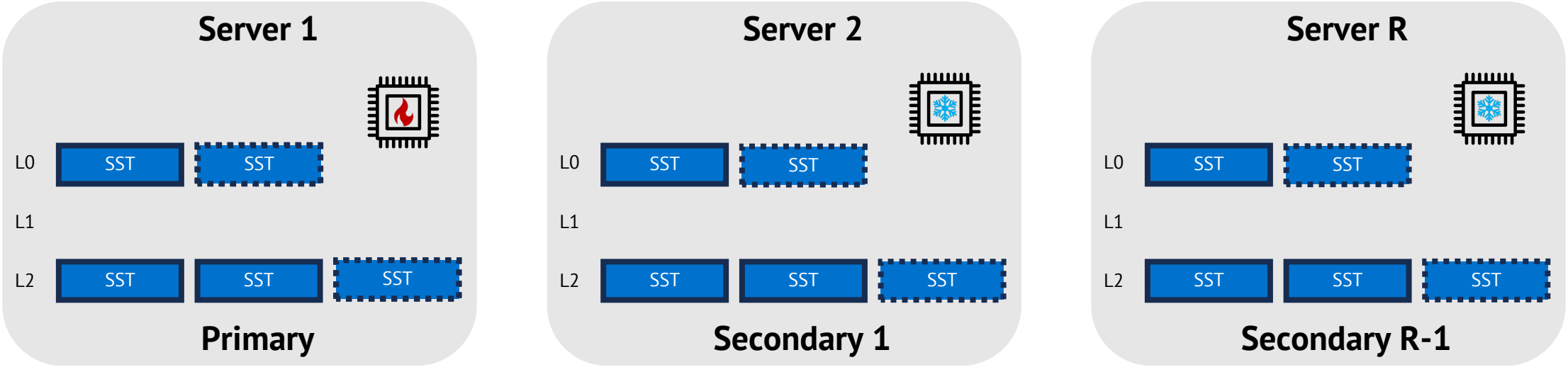
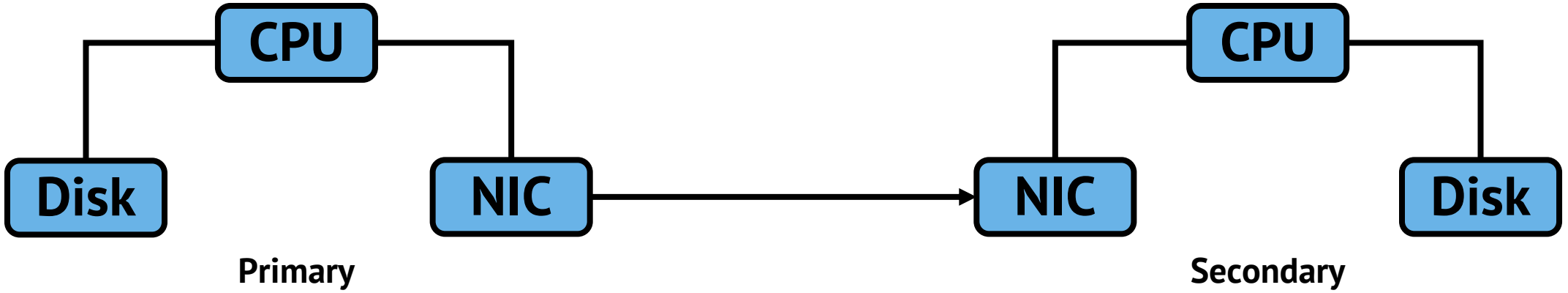
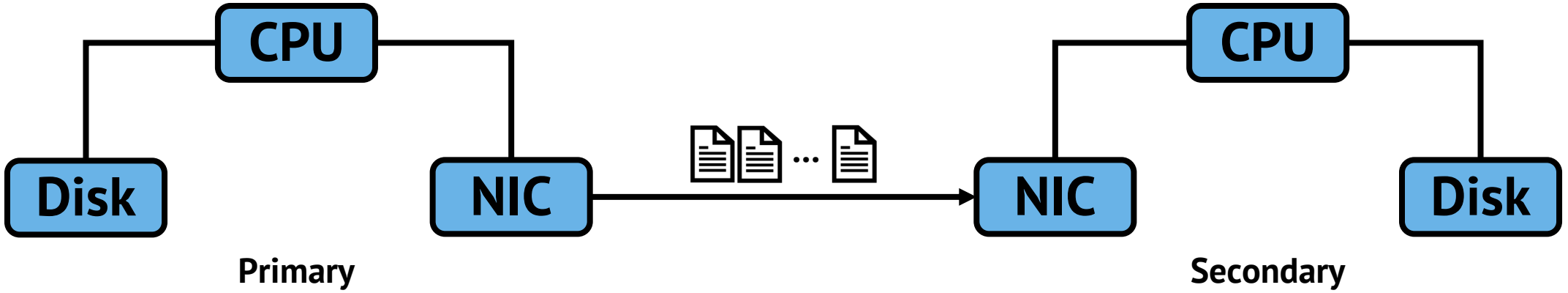


Challenges of sharing SST files



Challenges of sharing SST files

- Heavy network traffic
  - Luckily datacenter network is often underutilized[1][2]



[1] Alibaba Cluster Trace 2018.
[2] Building an elastic query engine on disaggregated storage. (NSDI 20)

Challenges of sharing SST files

- Heavy network traffic
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- CPU involvement on the secondary
  - After receiving the data, the secondary writes it to the local disk

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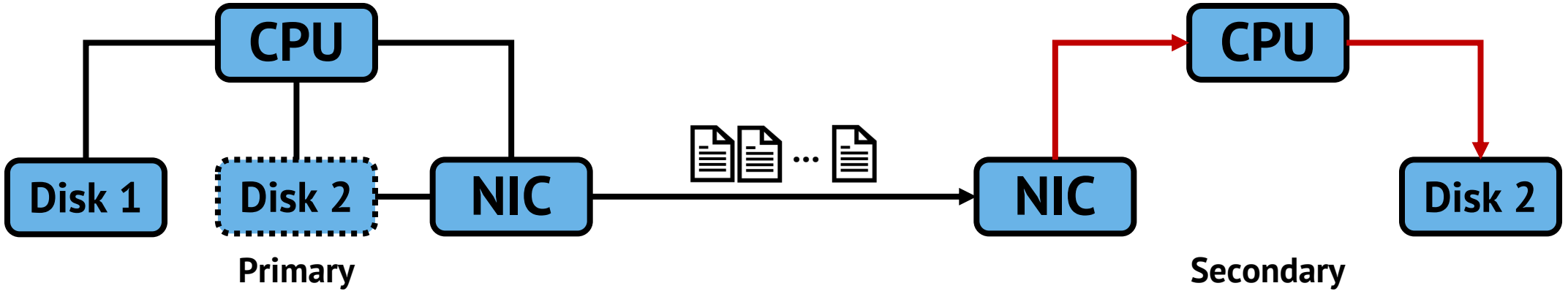
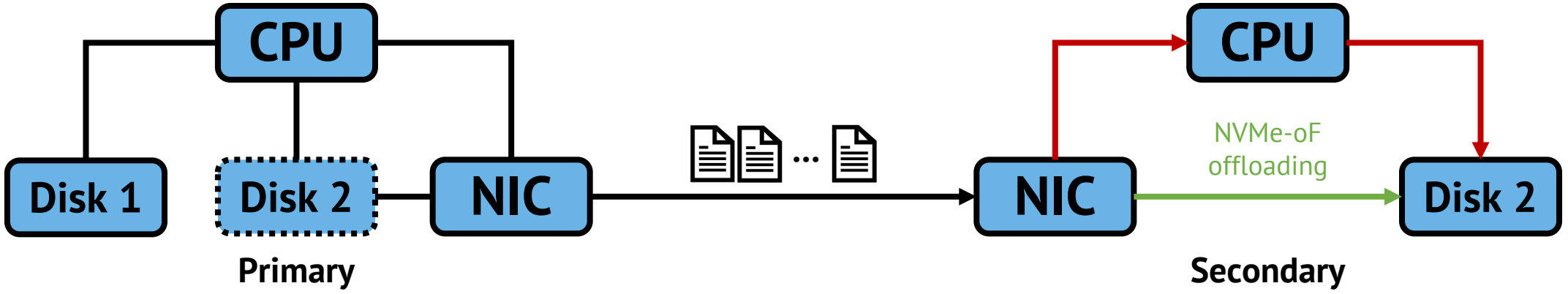
An attractive opportunity: NVMe-oF

- Non-Volatile Memory Express over Fabric
- Mount a remote disk as a local file system over RDMA or TCP



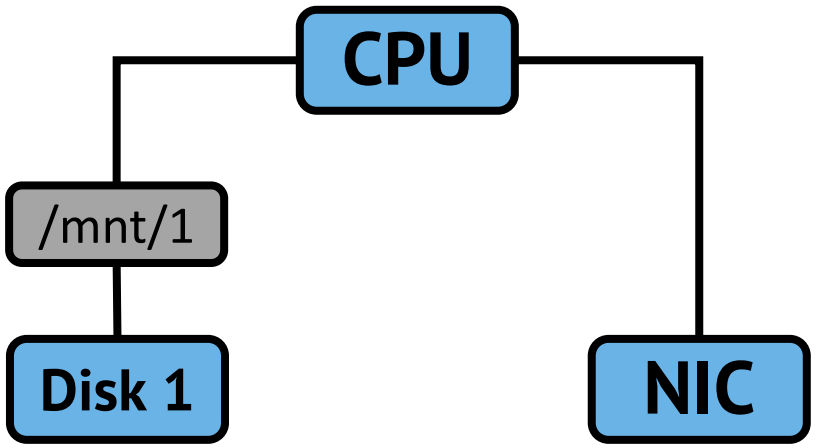
An attractive opportunity: NVMe-oF

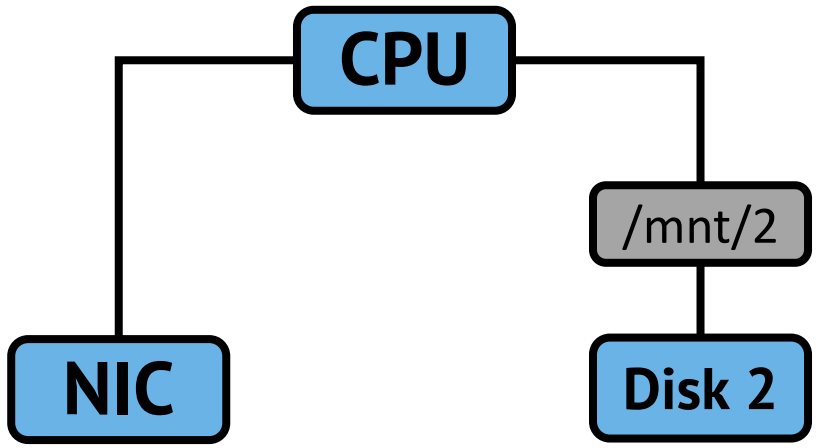
- Non-Volatile Memory Express over Fabric
- Mount a remote disk as a local file system over RDMA or TCP
- Zero CPU involvement on remote target
  - Commodity NICs support NVMe-oF target offloading



The challenge: NVMe-oF bypasses the remote filesystem

Secondaries cannot see incoming SST files





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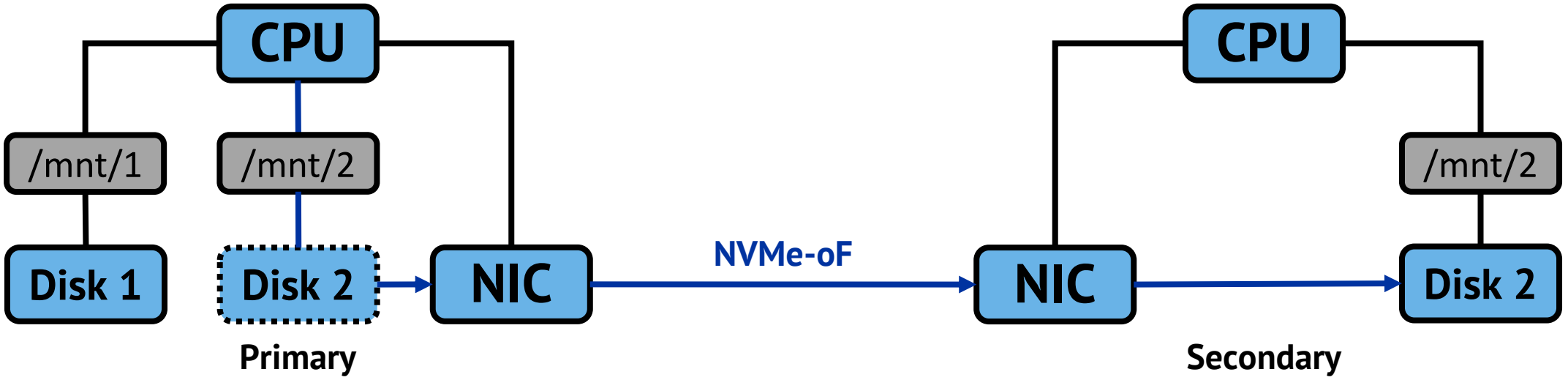

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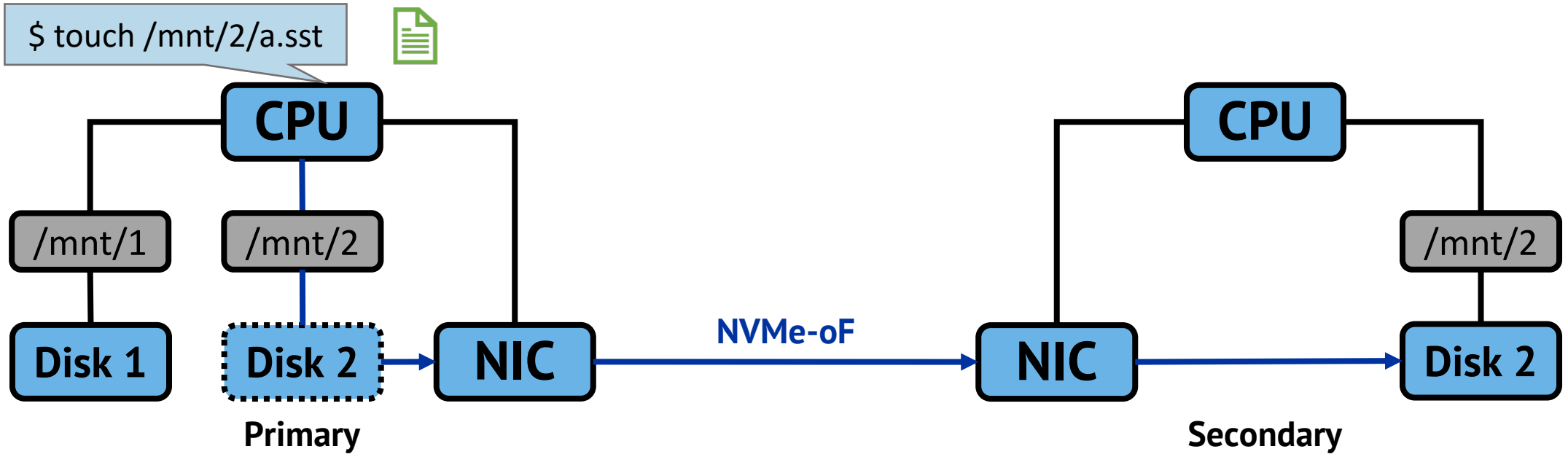

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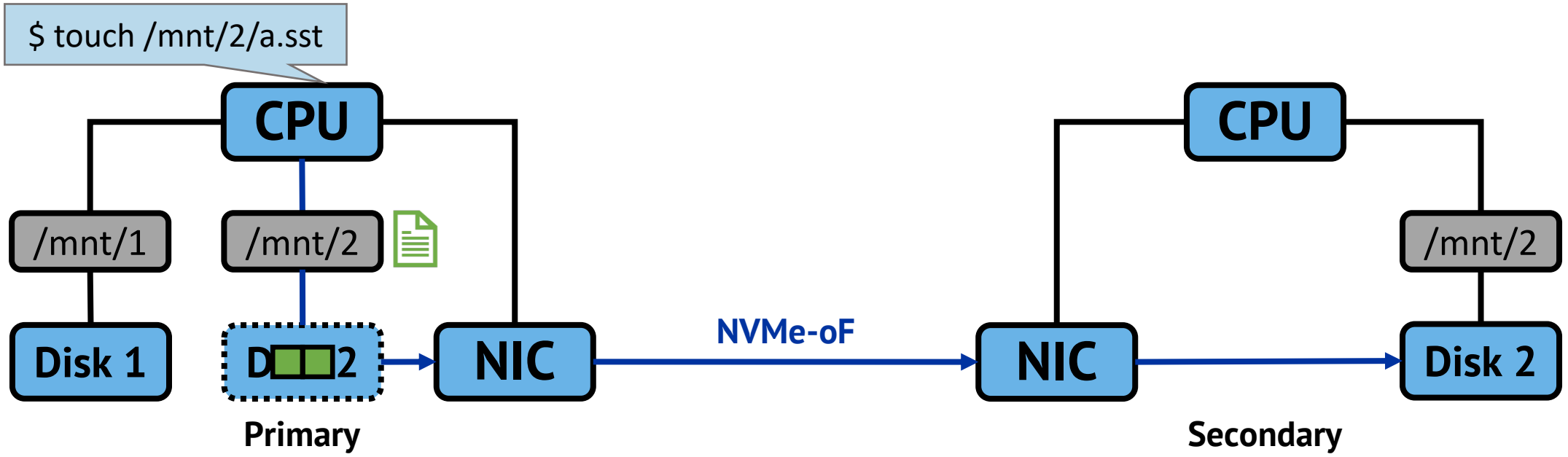

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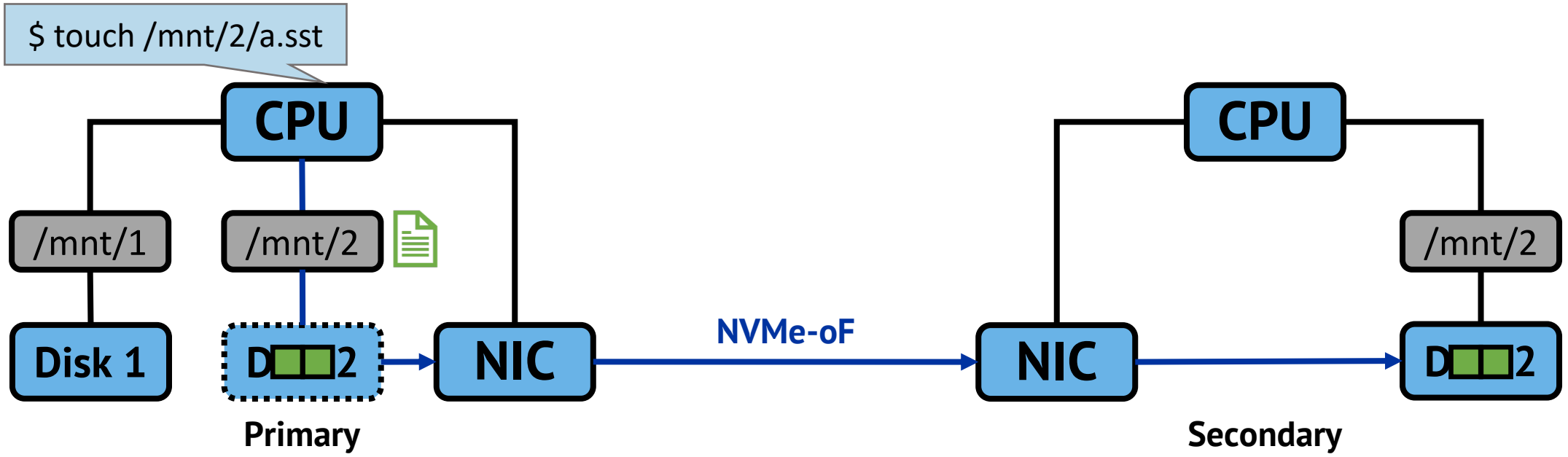

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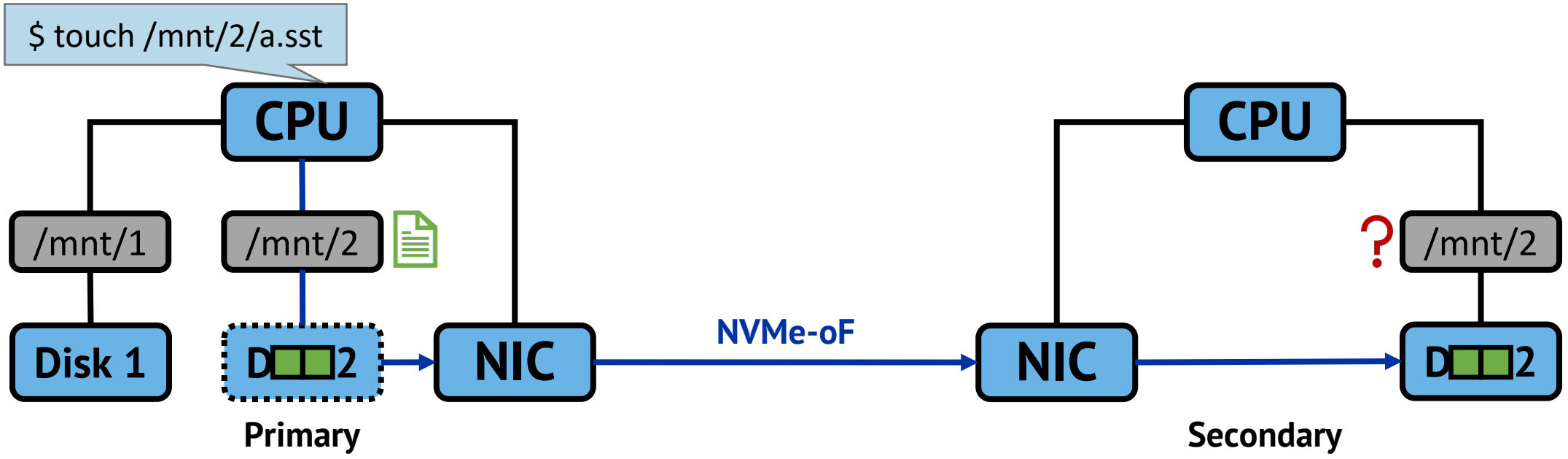

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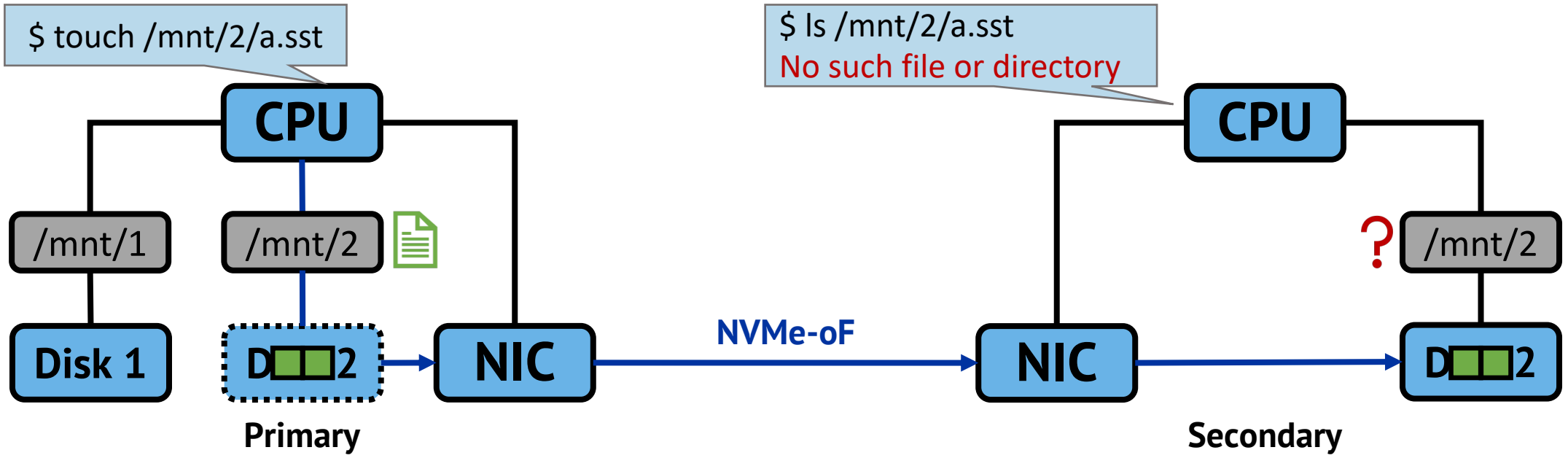

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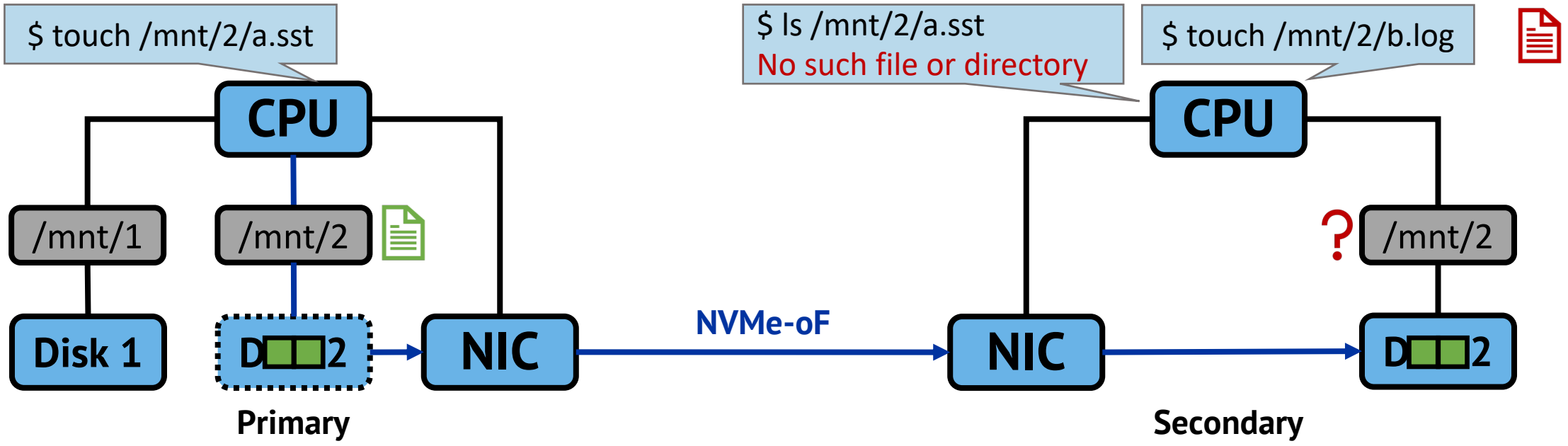

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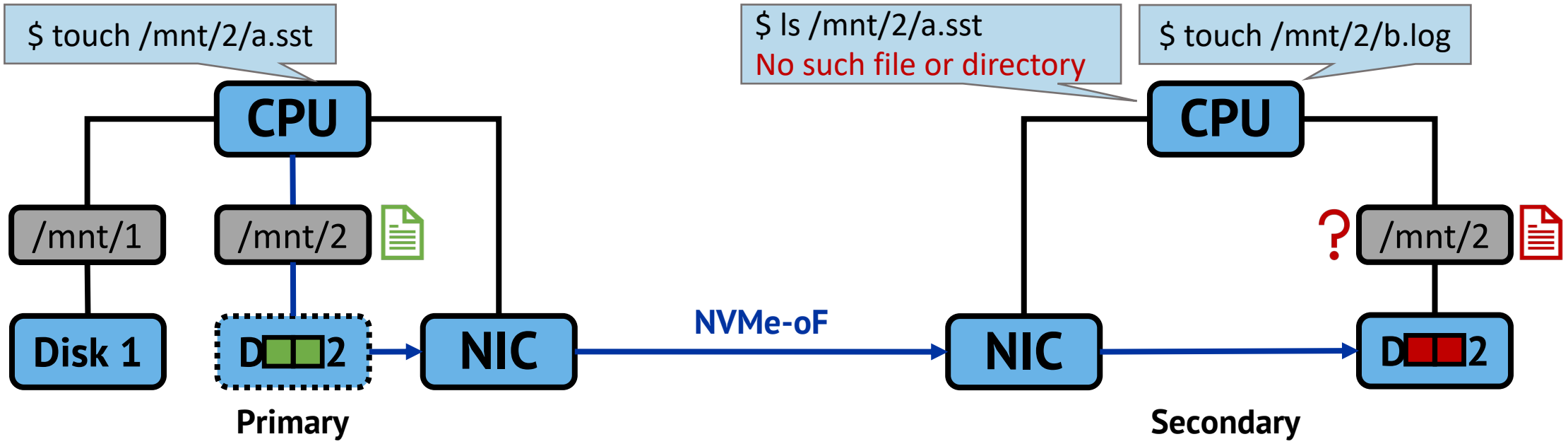

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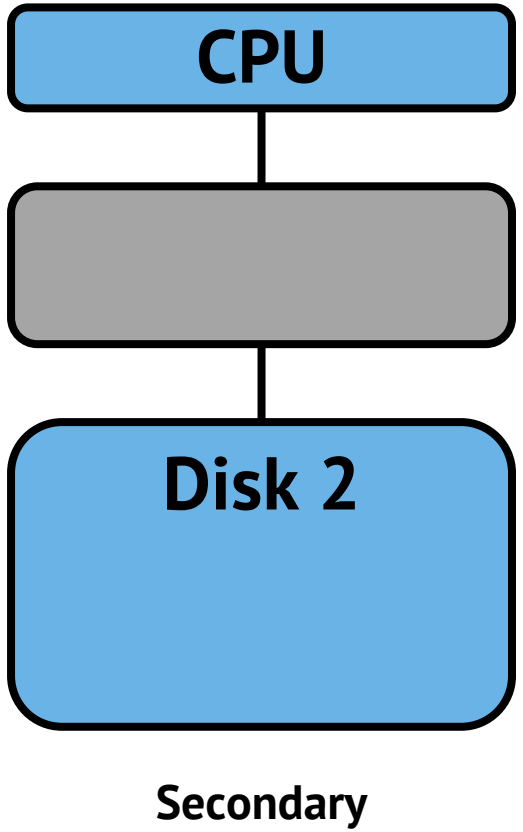

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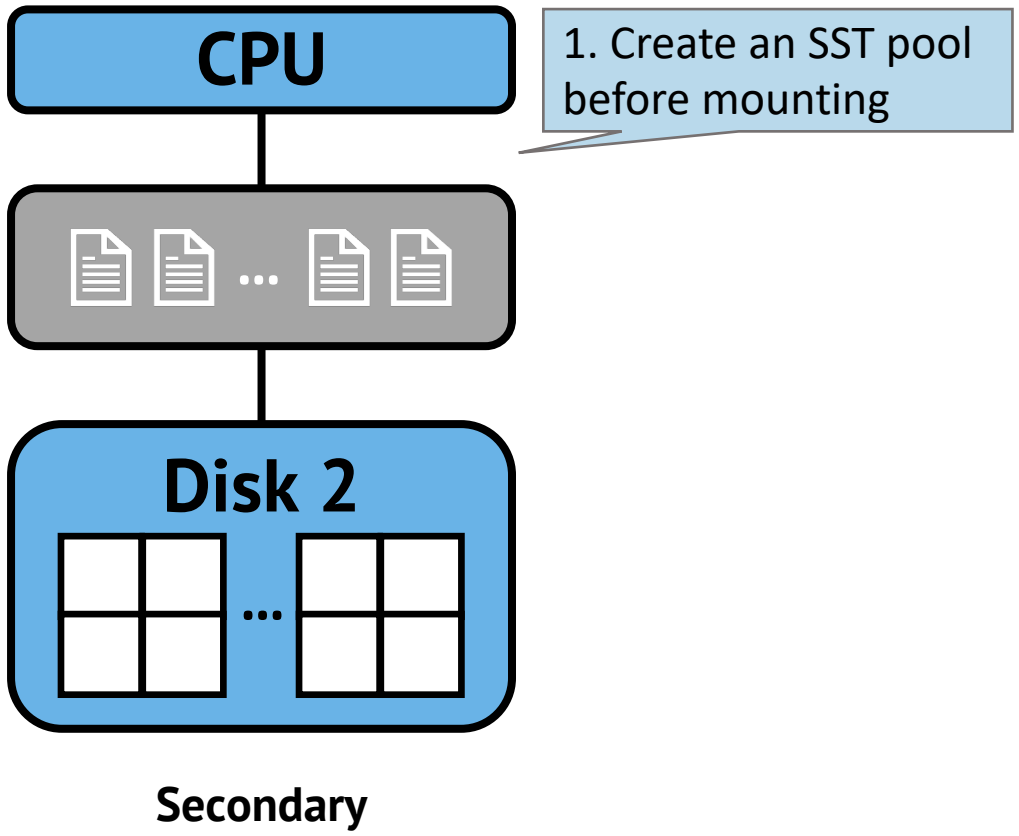

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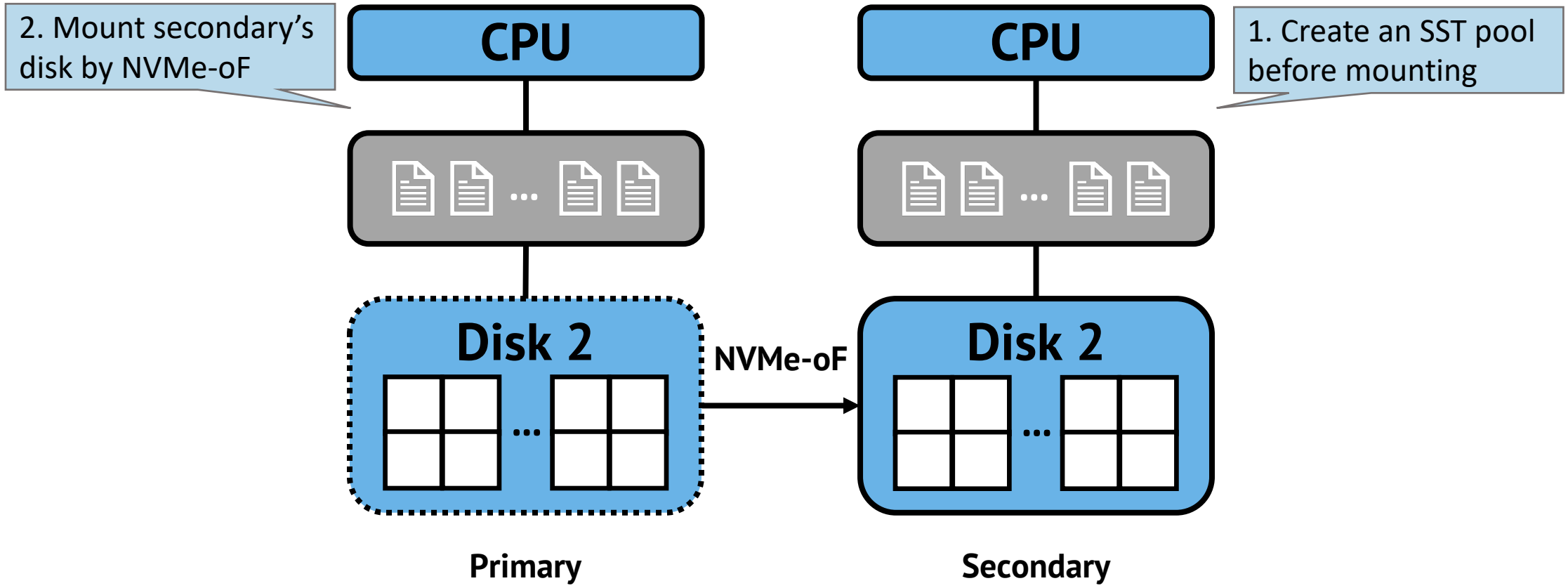

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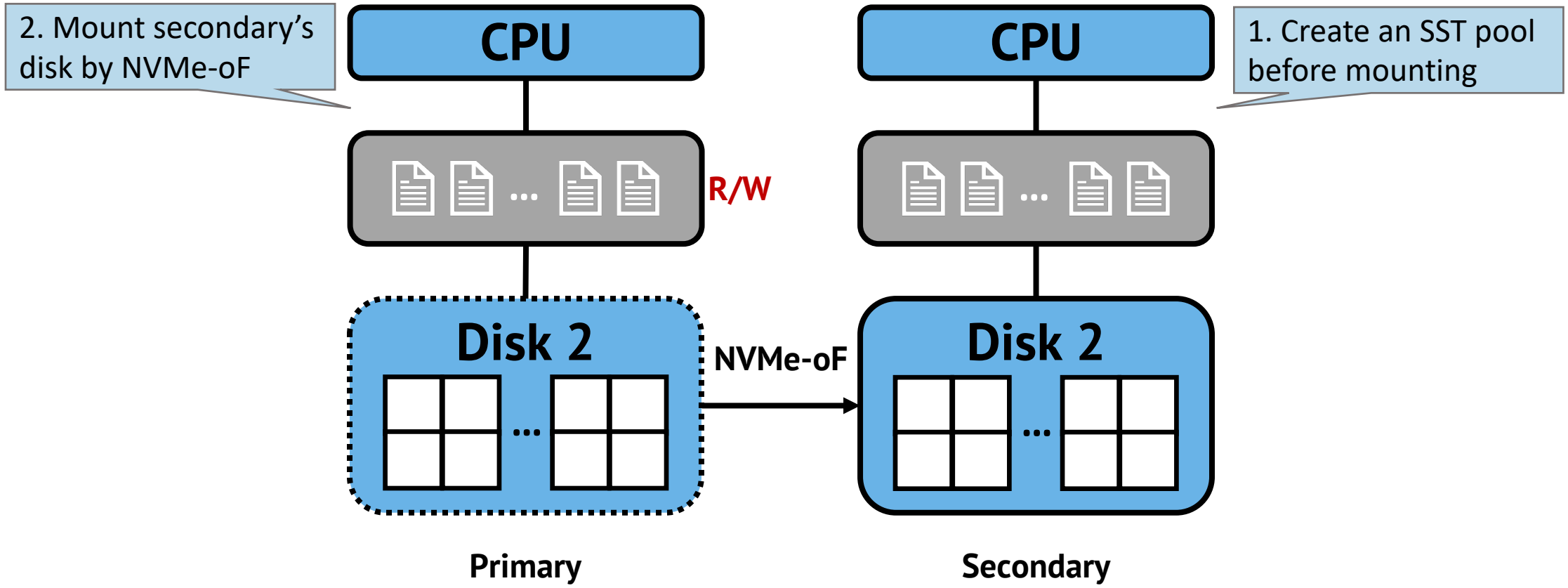

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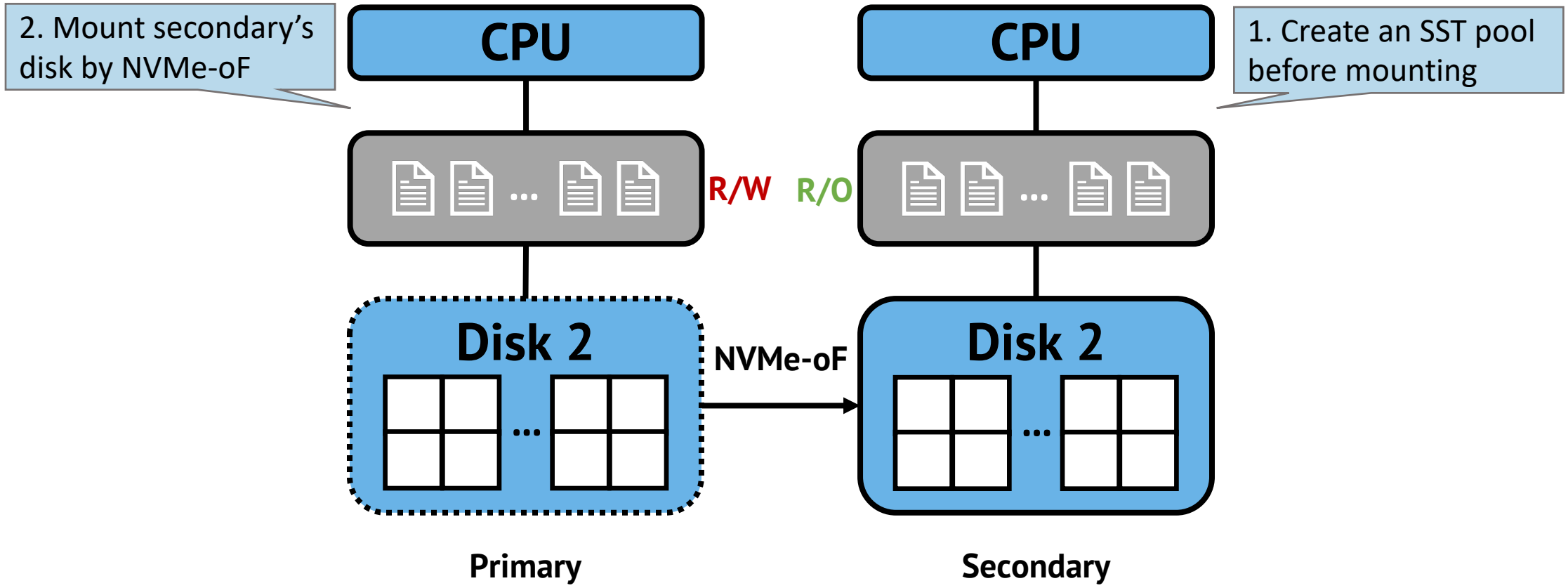

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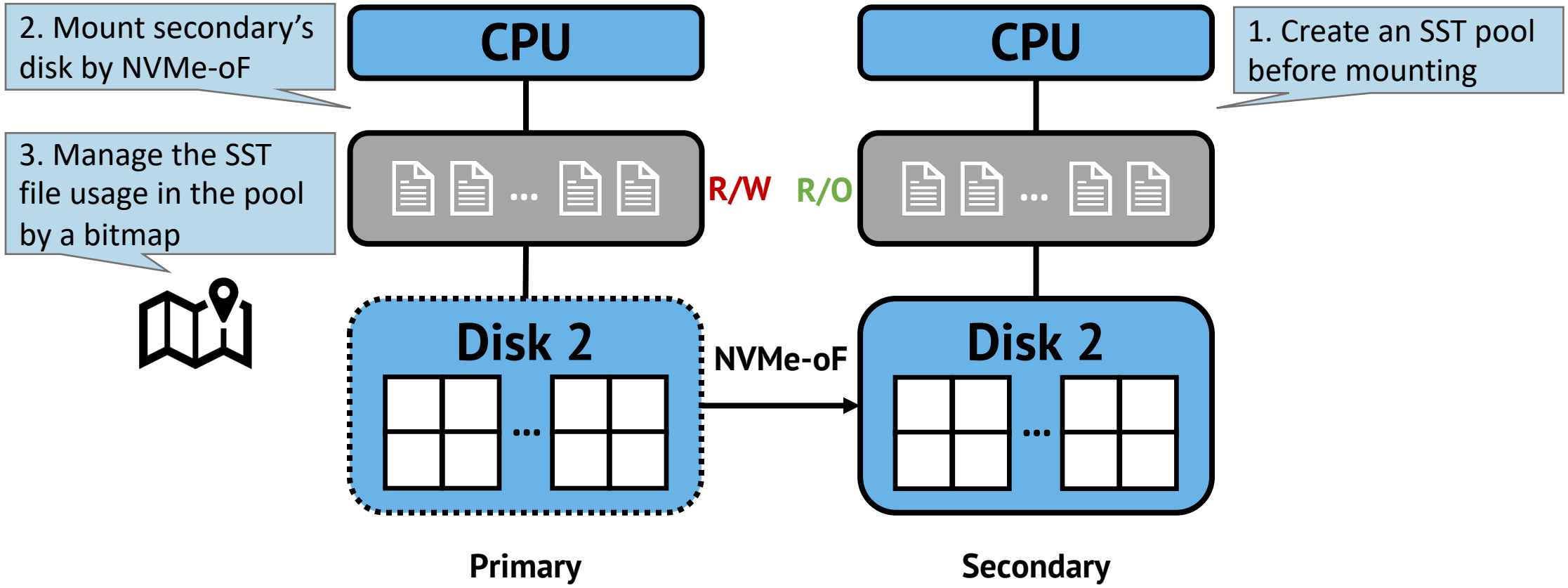

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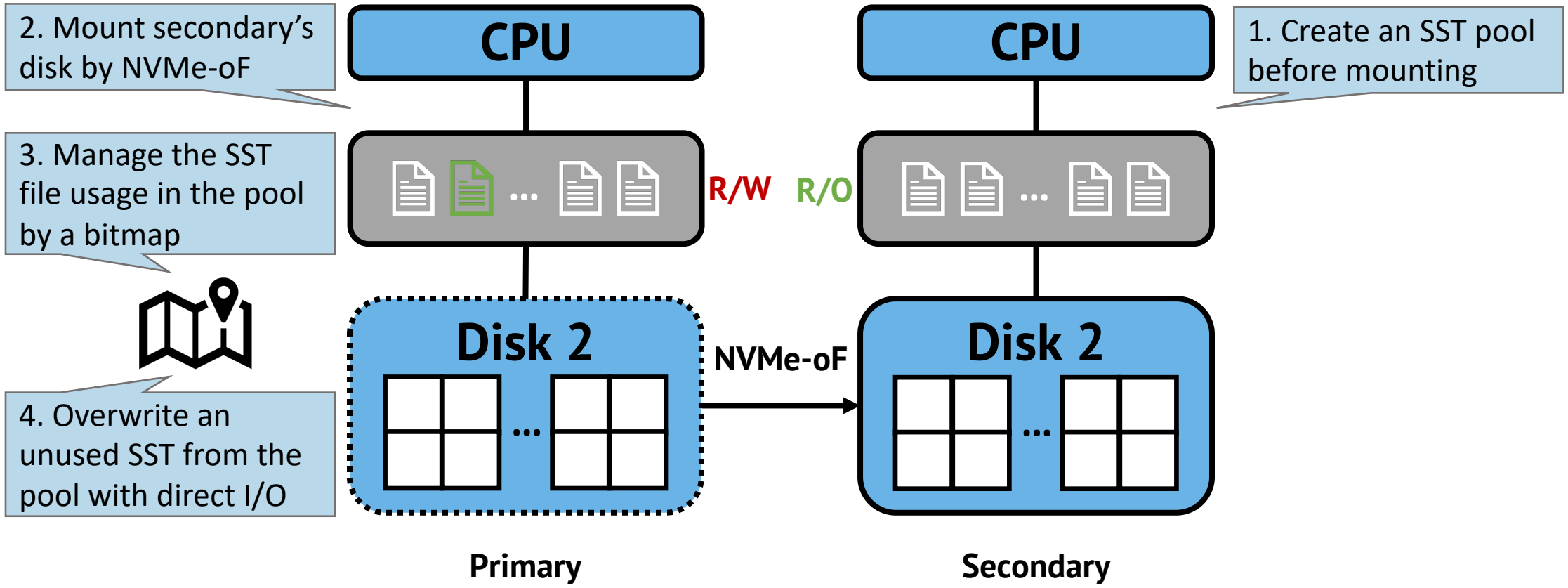

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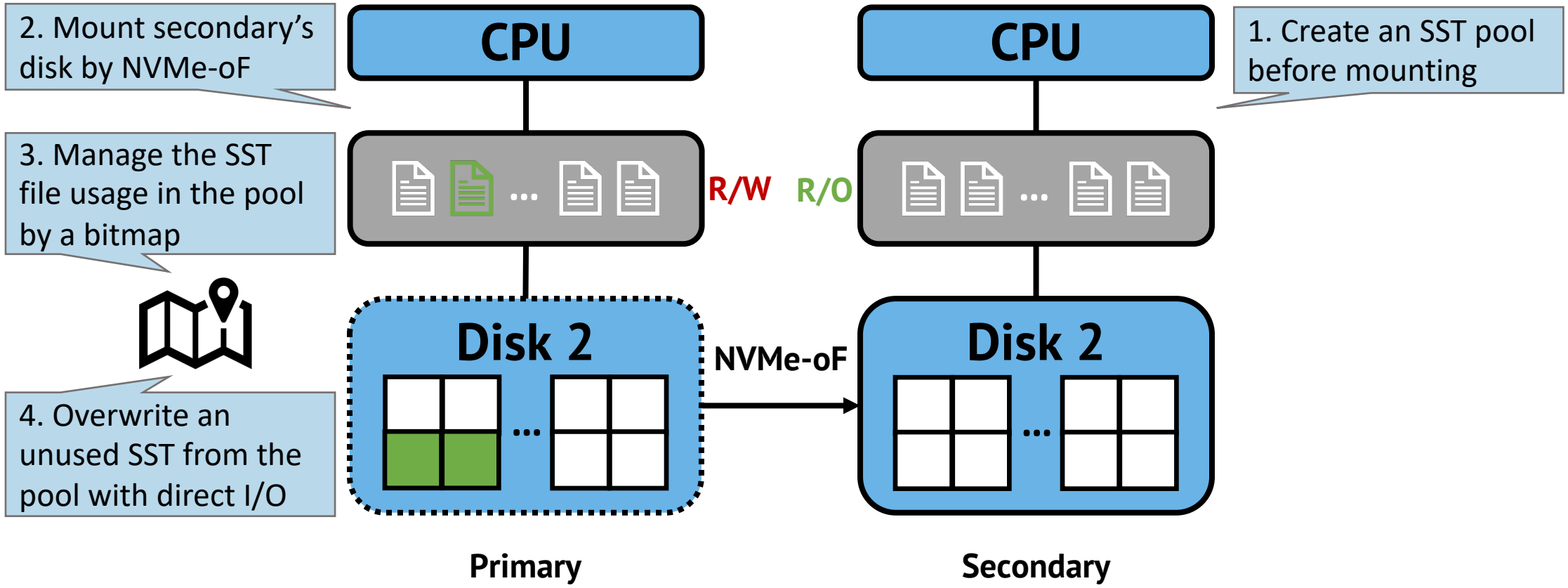

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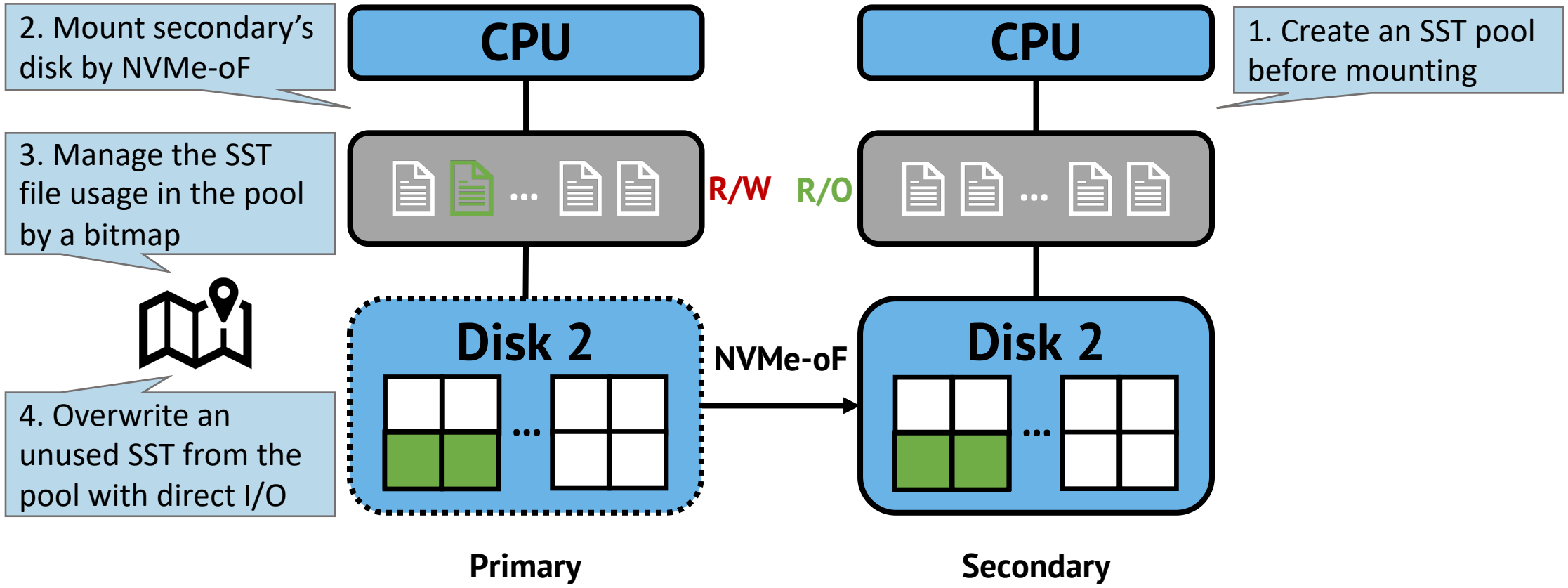

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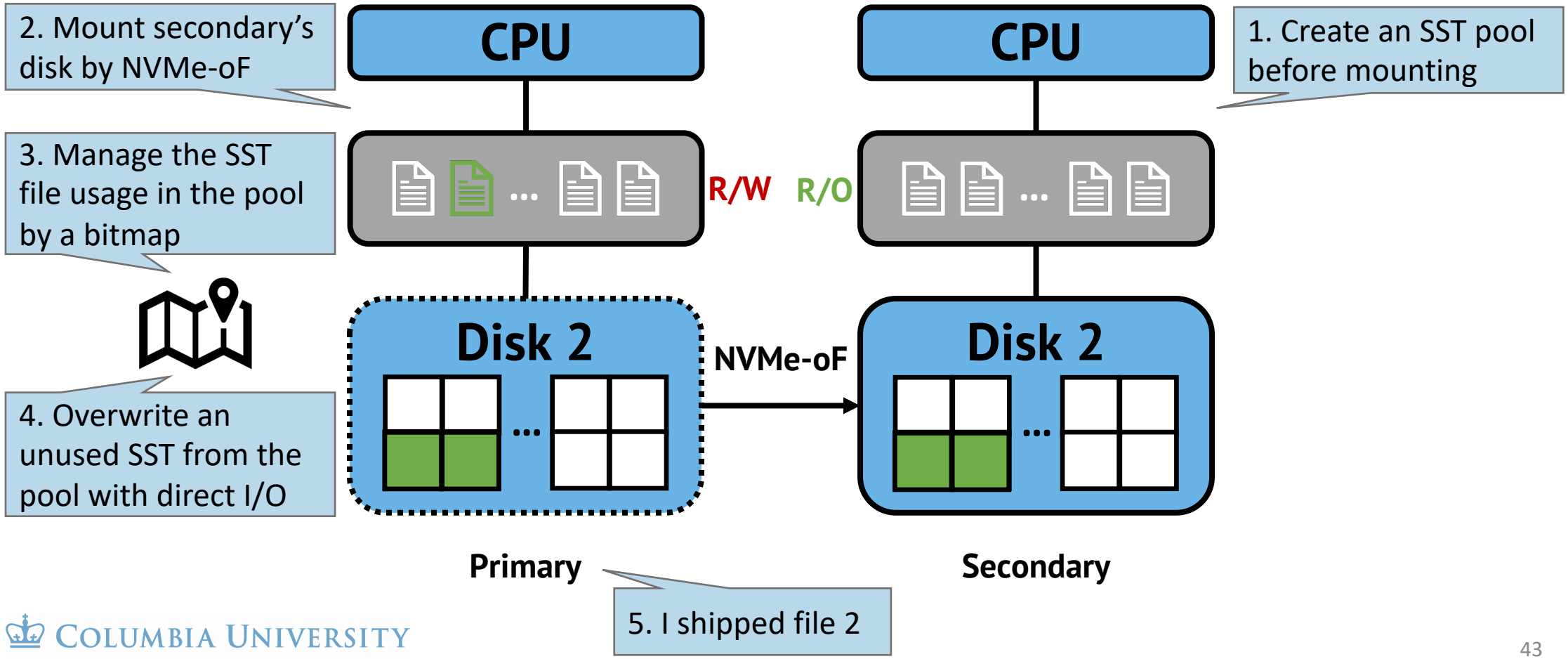

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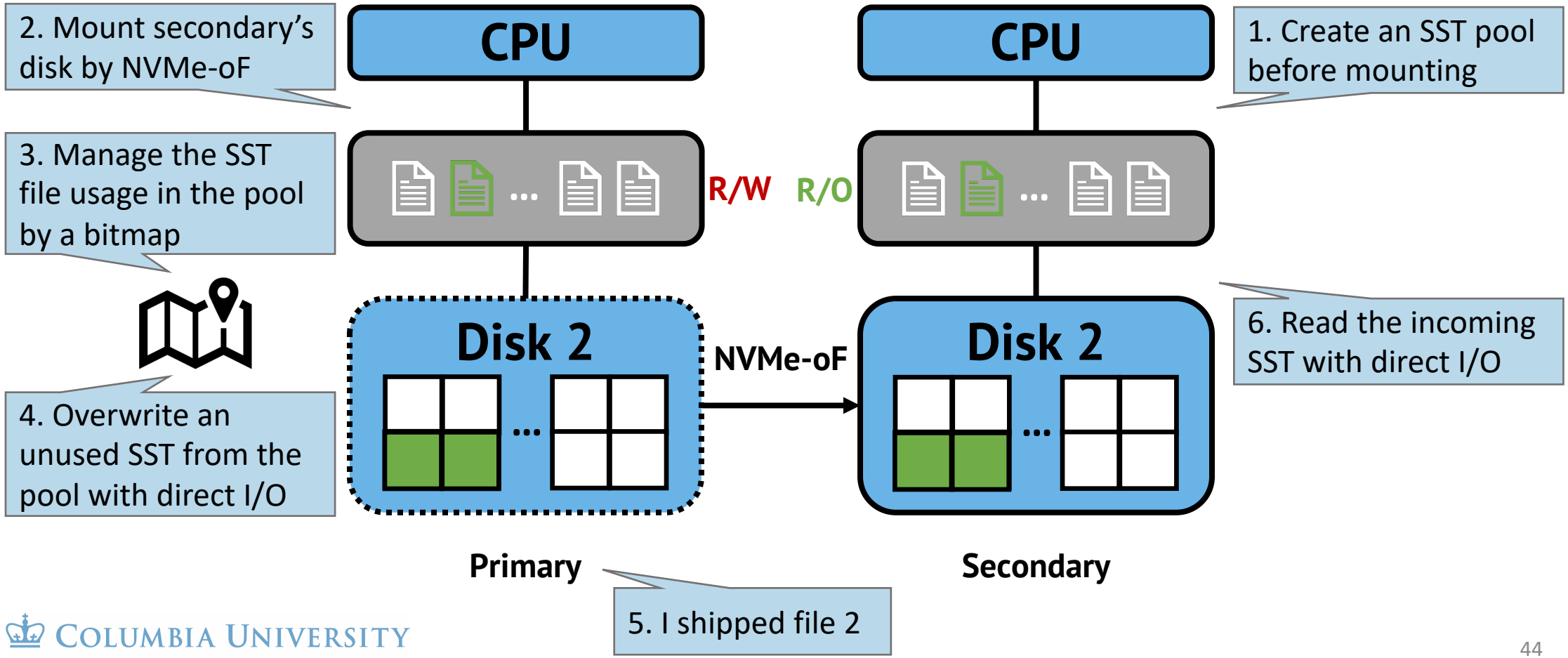

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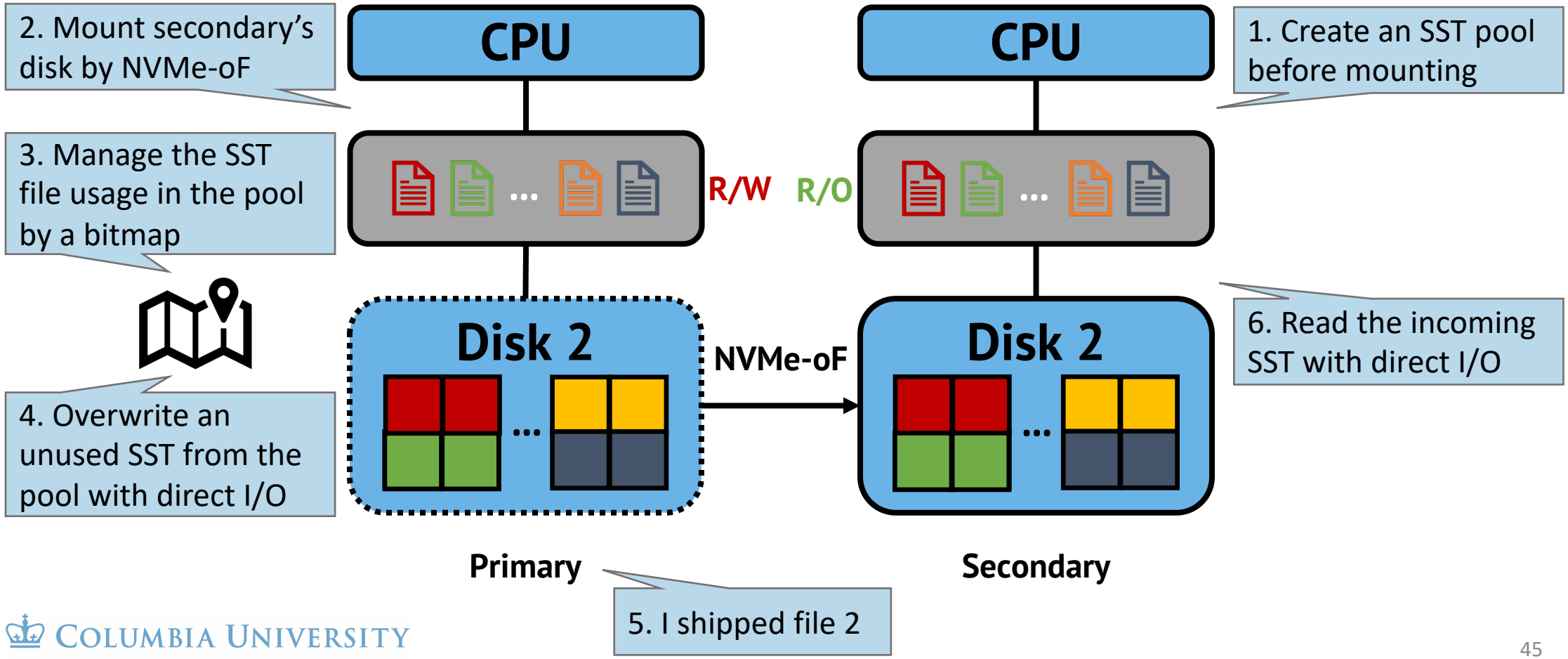

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Primary' and secondaries' internal states are actually different

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MemTable 1

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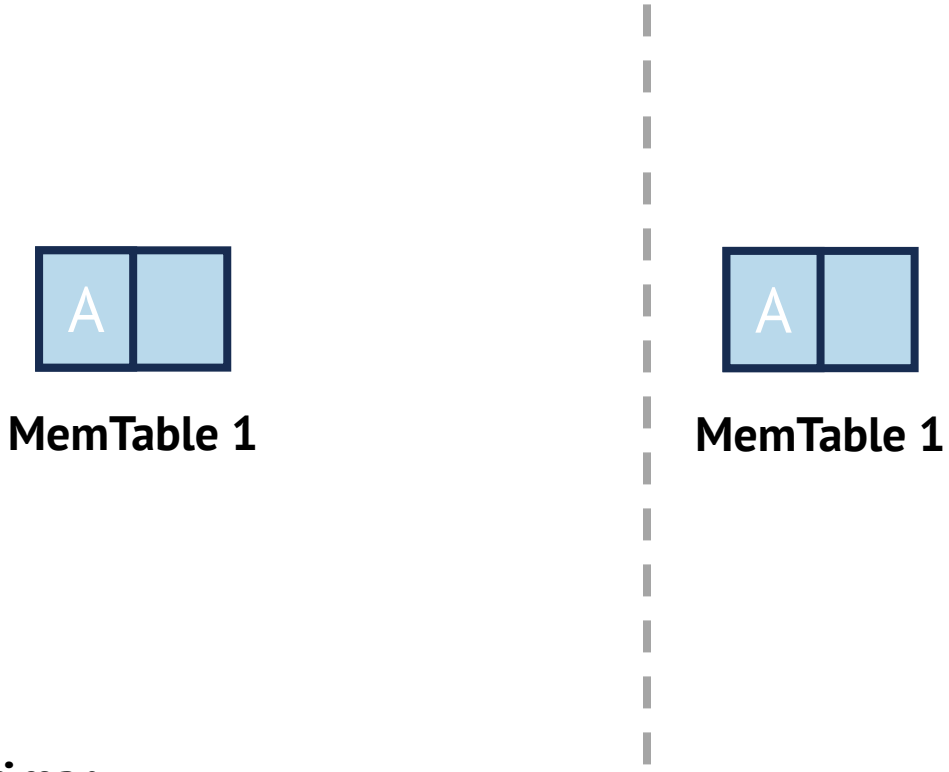

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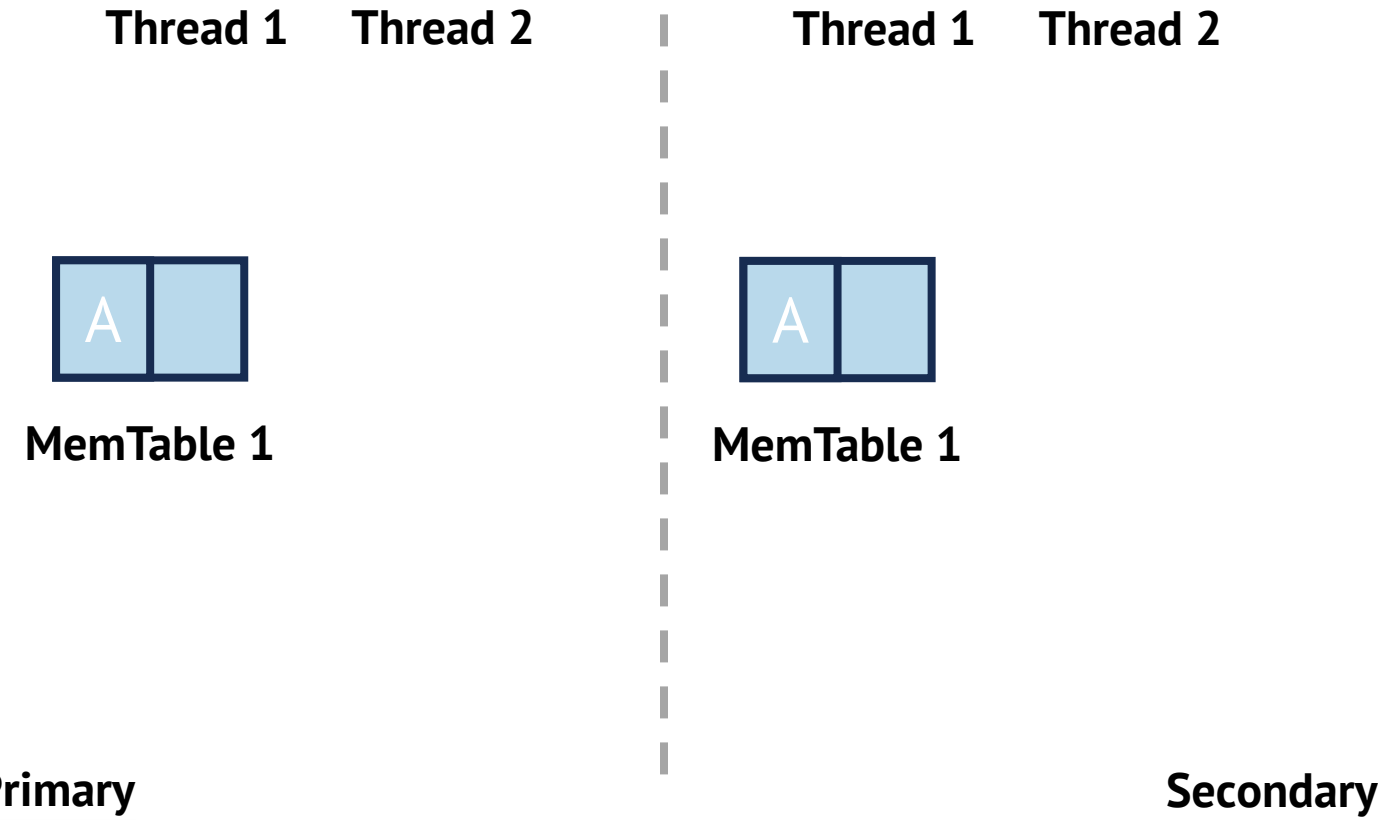

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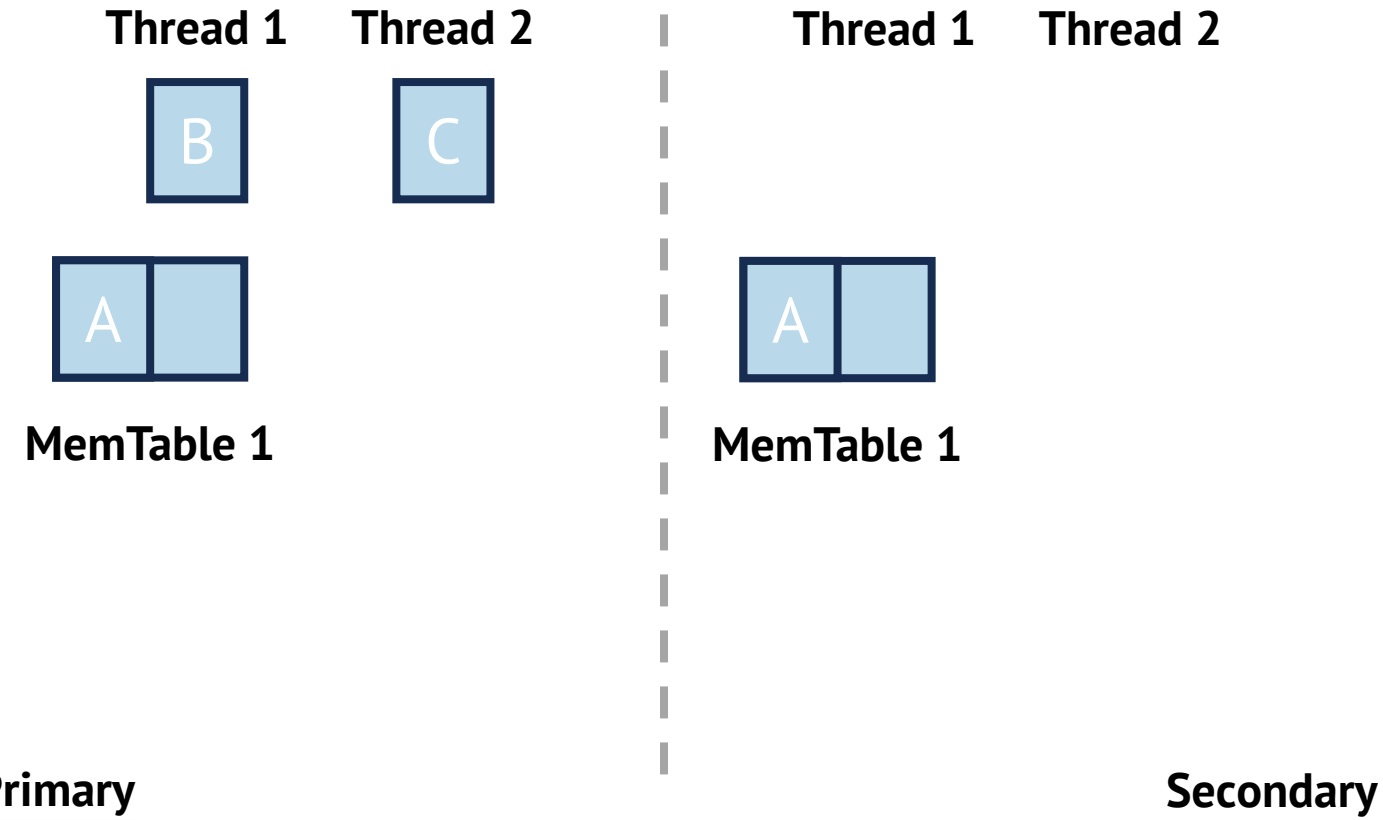

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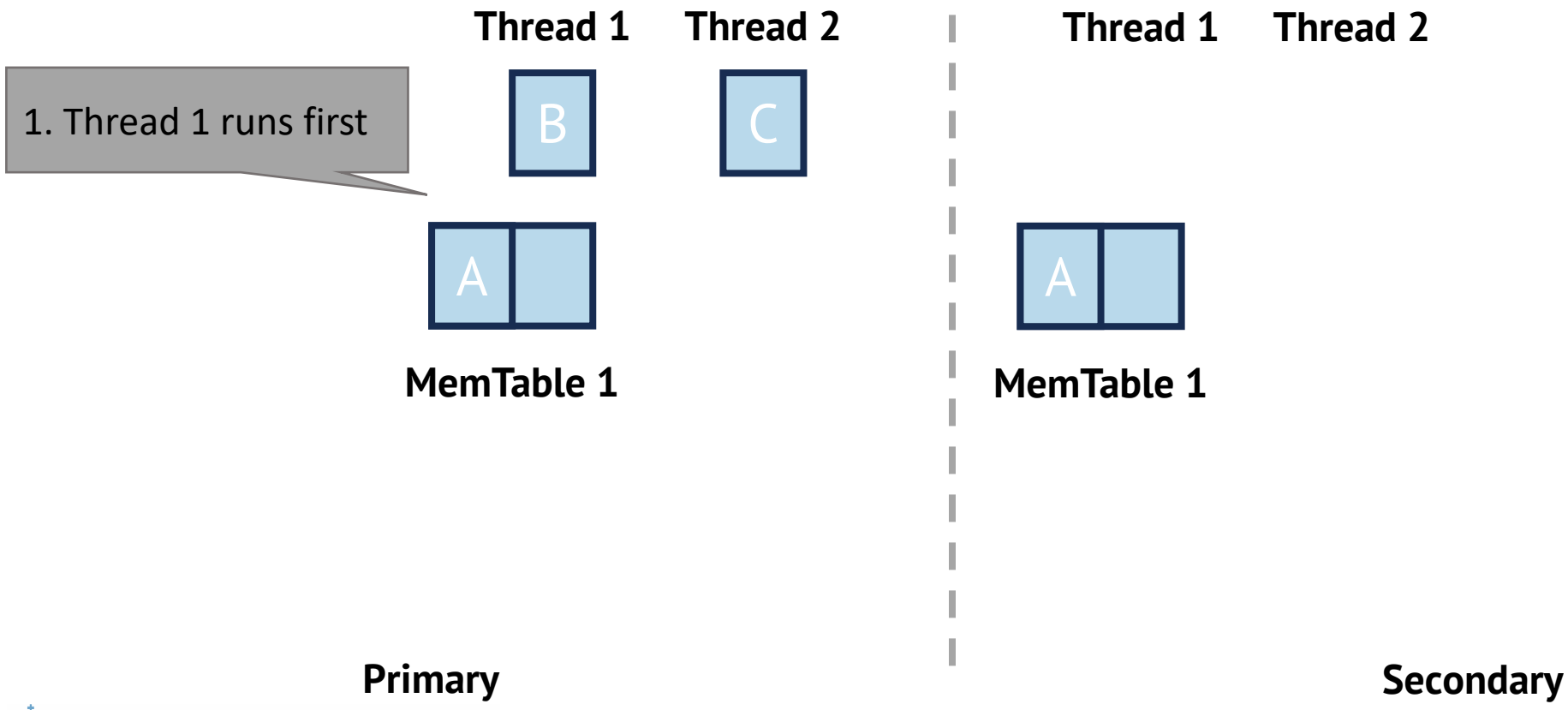

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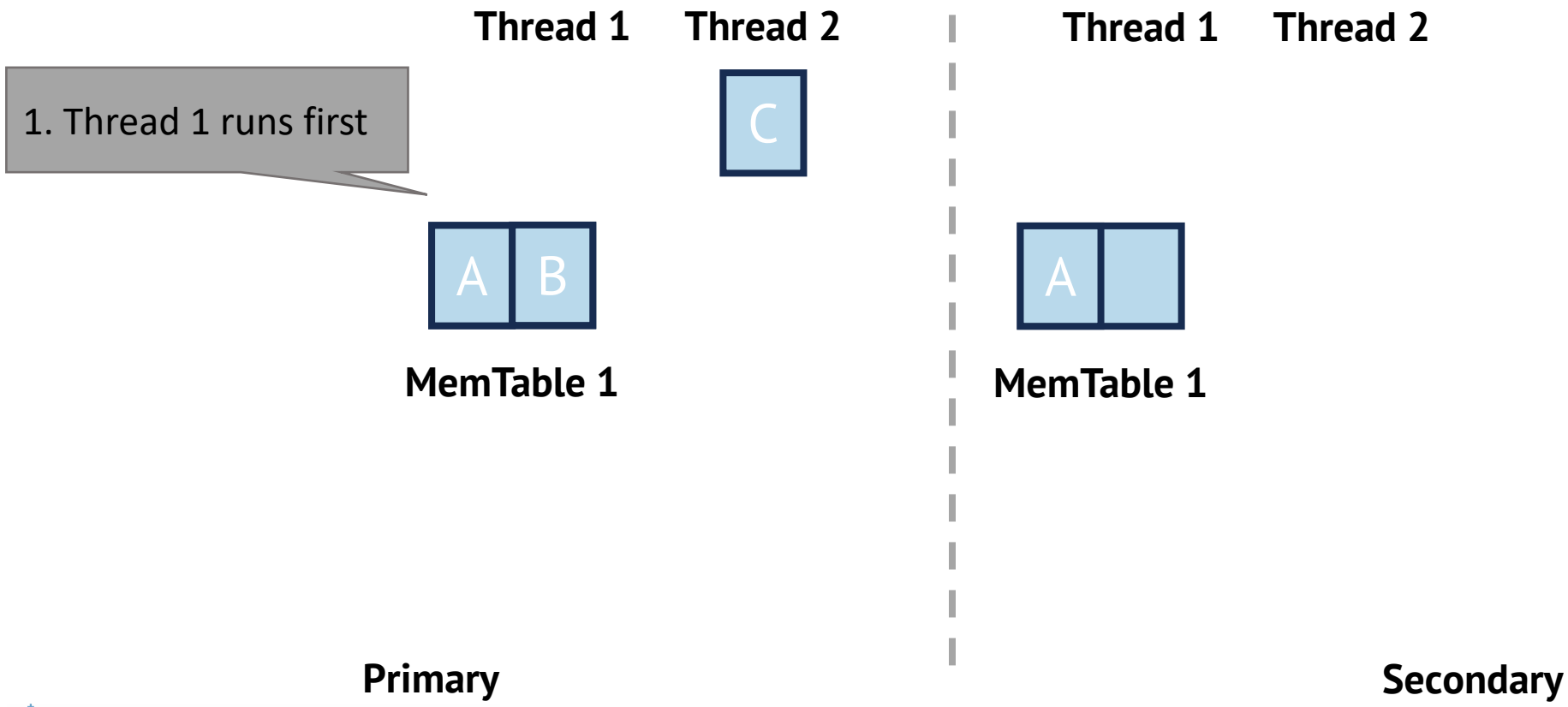

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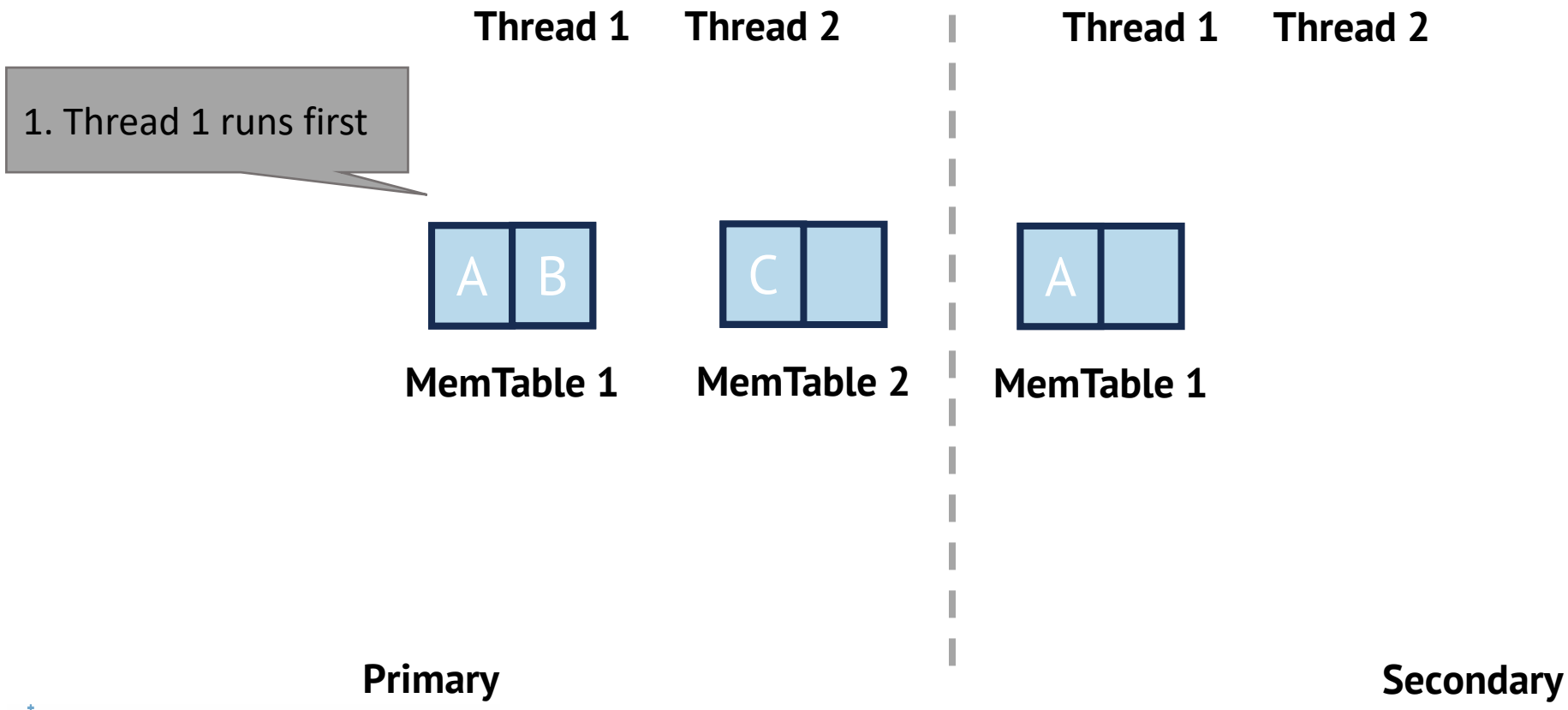

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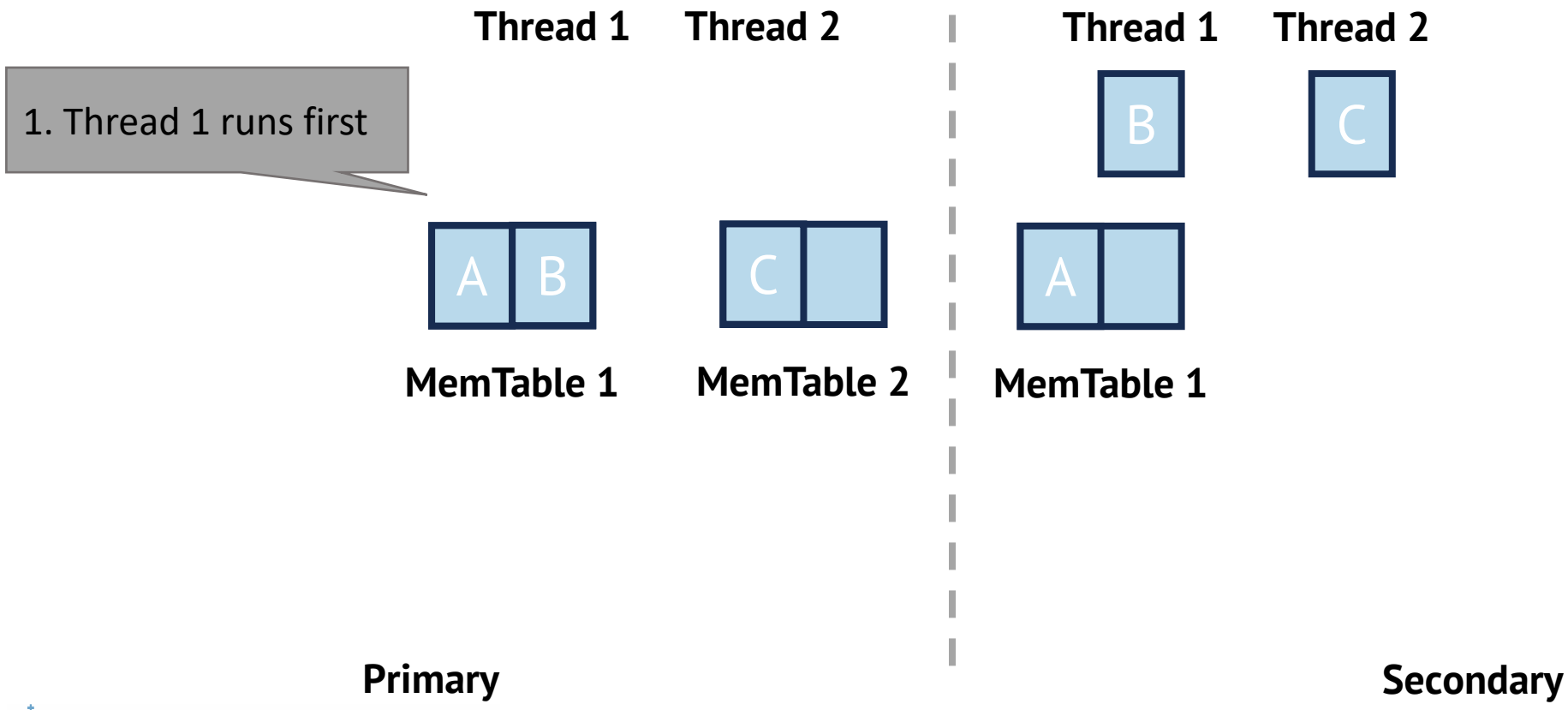

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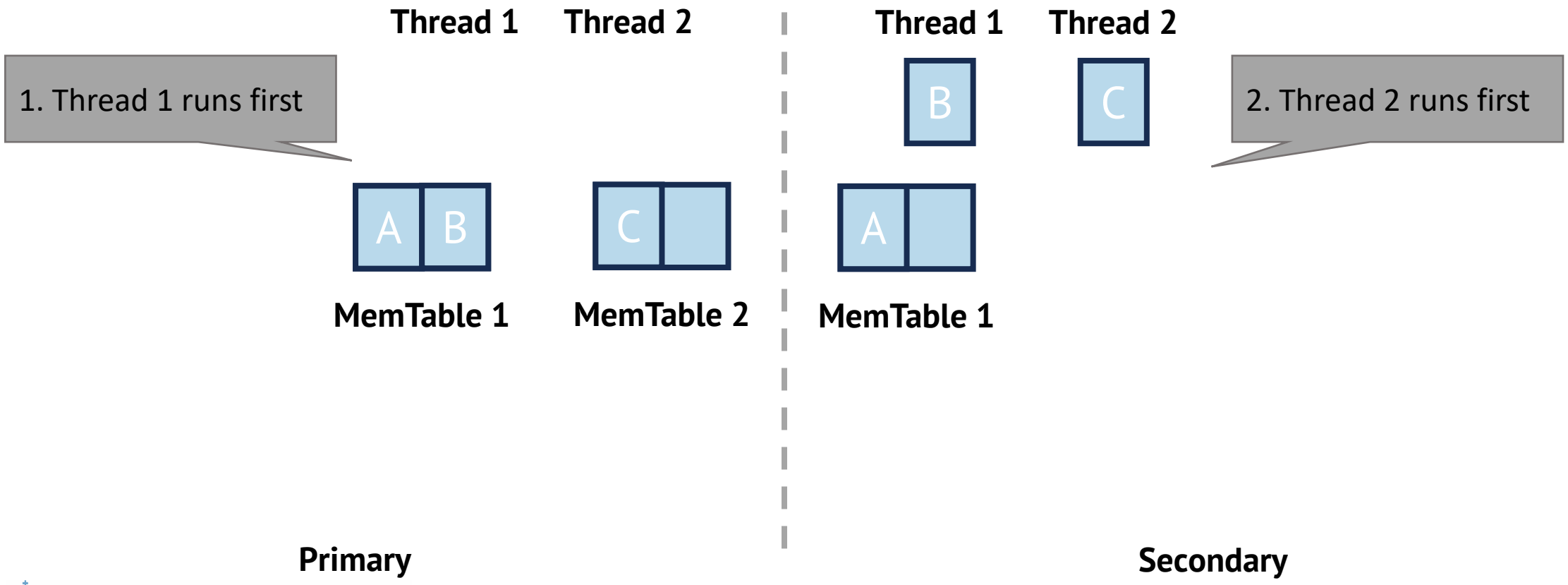

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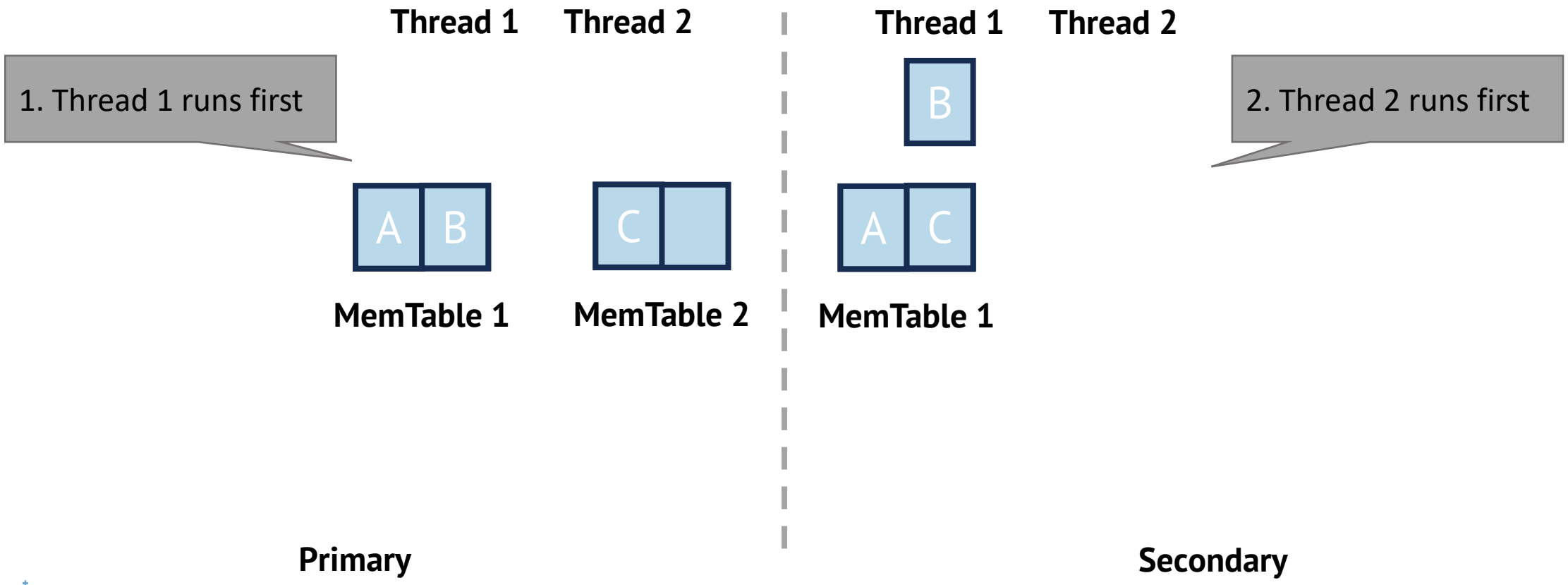

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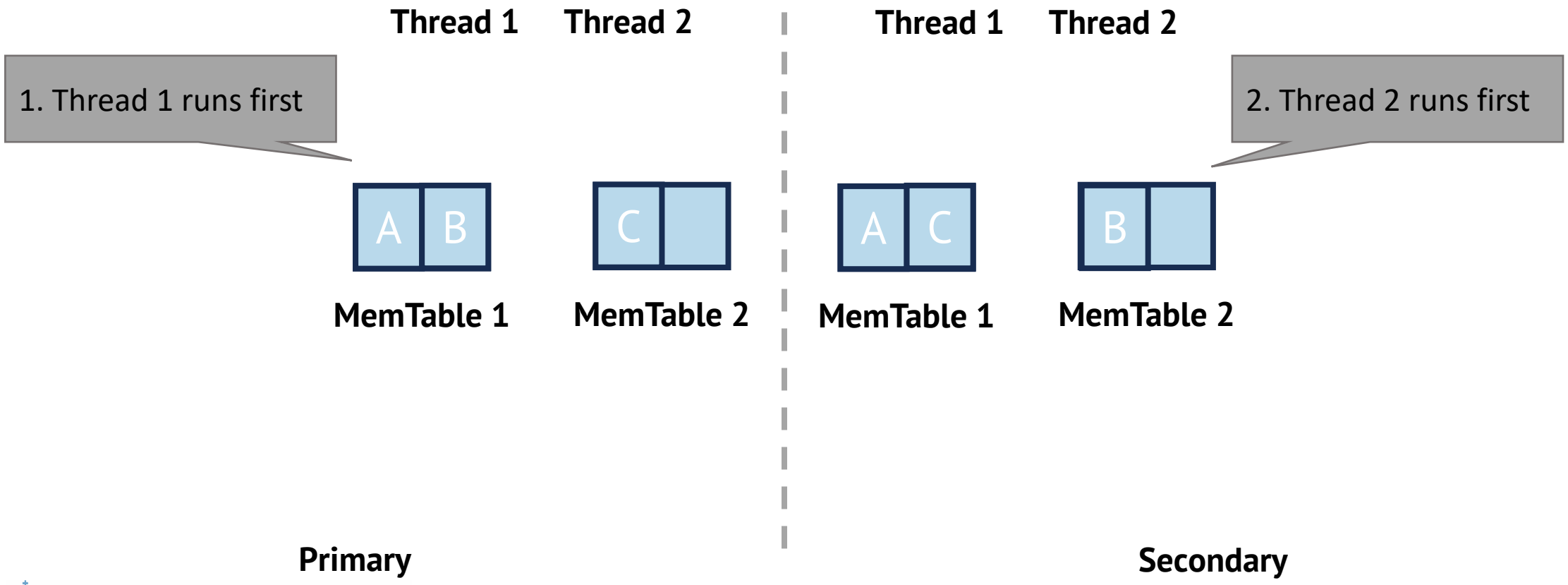

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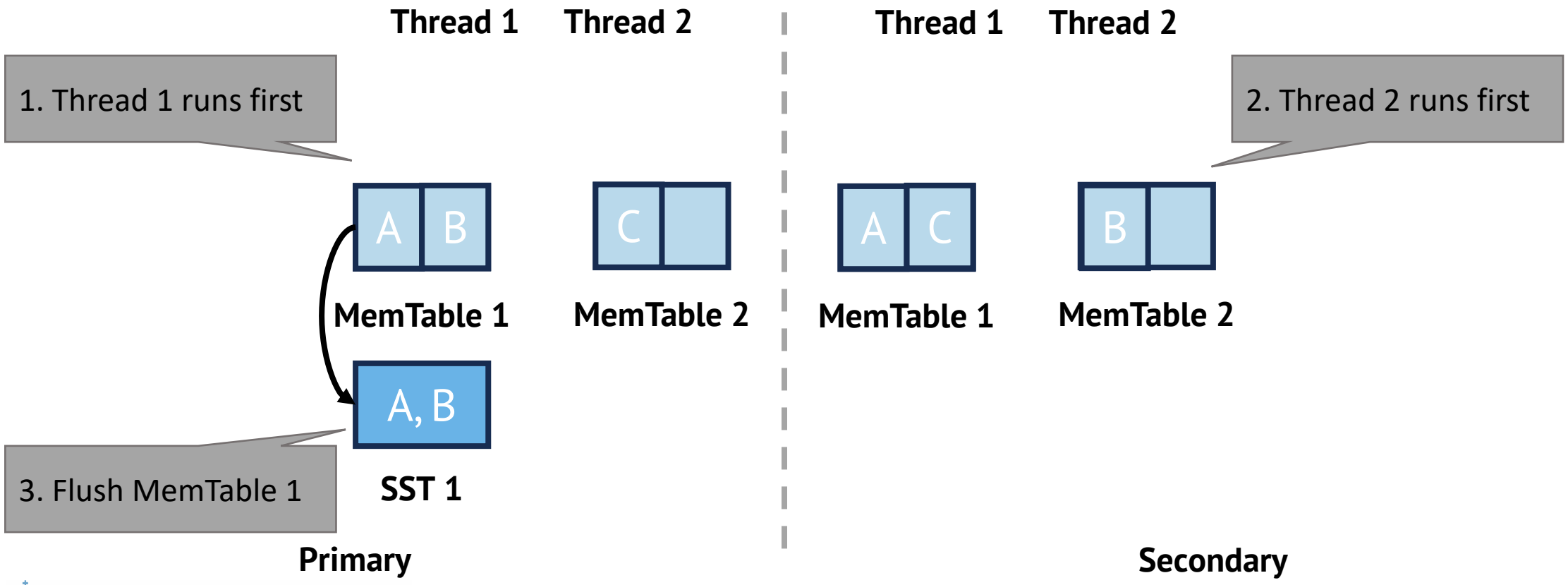

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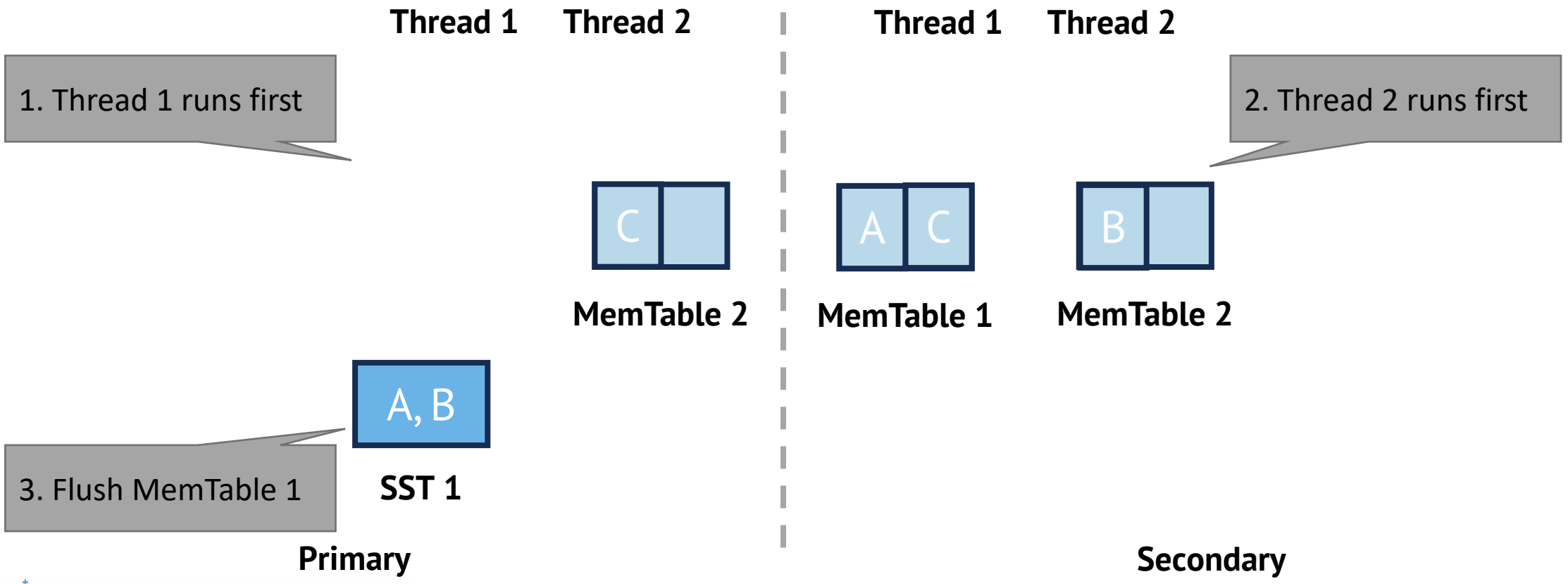

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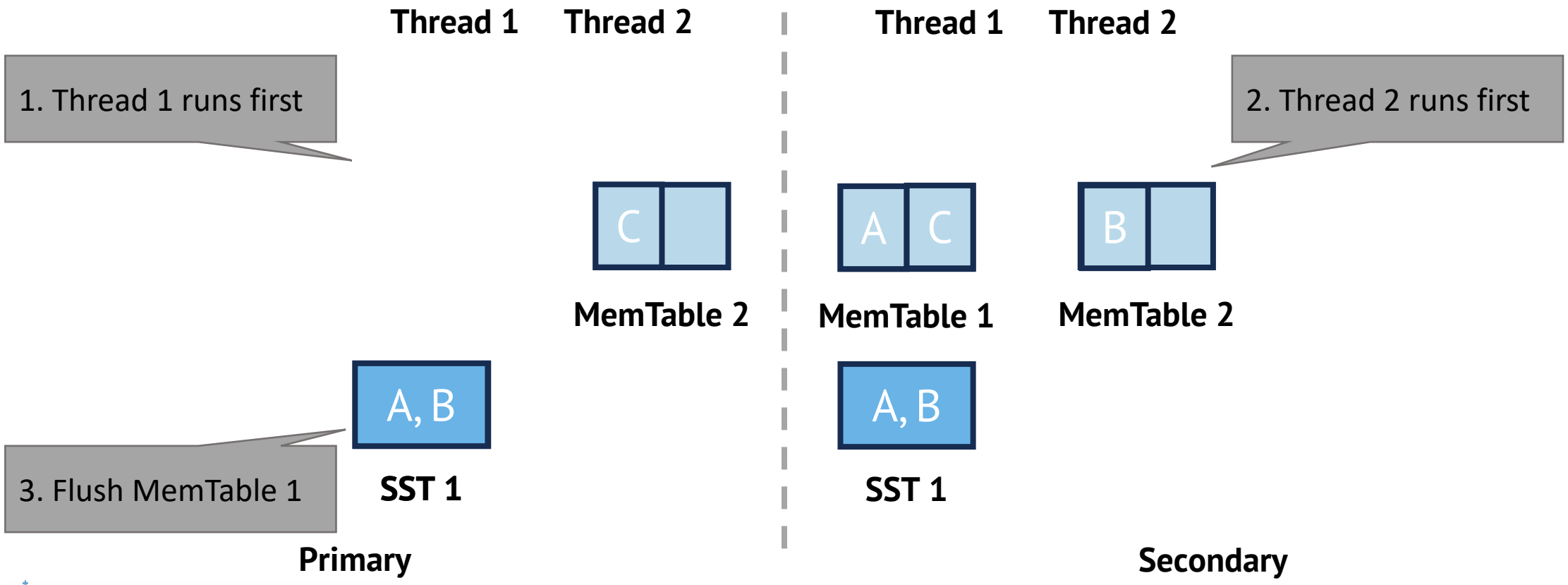

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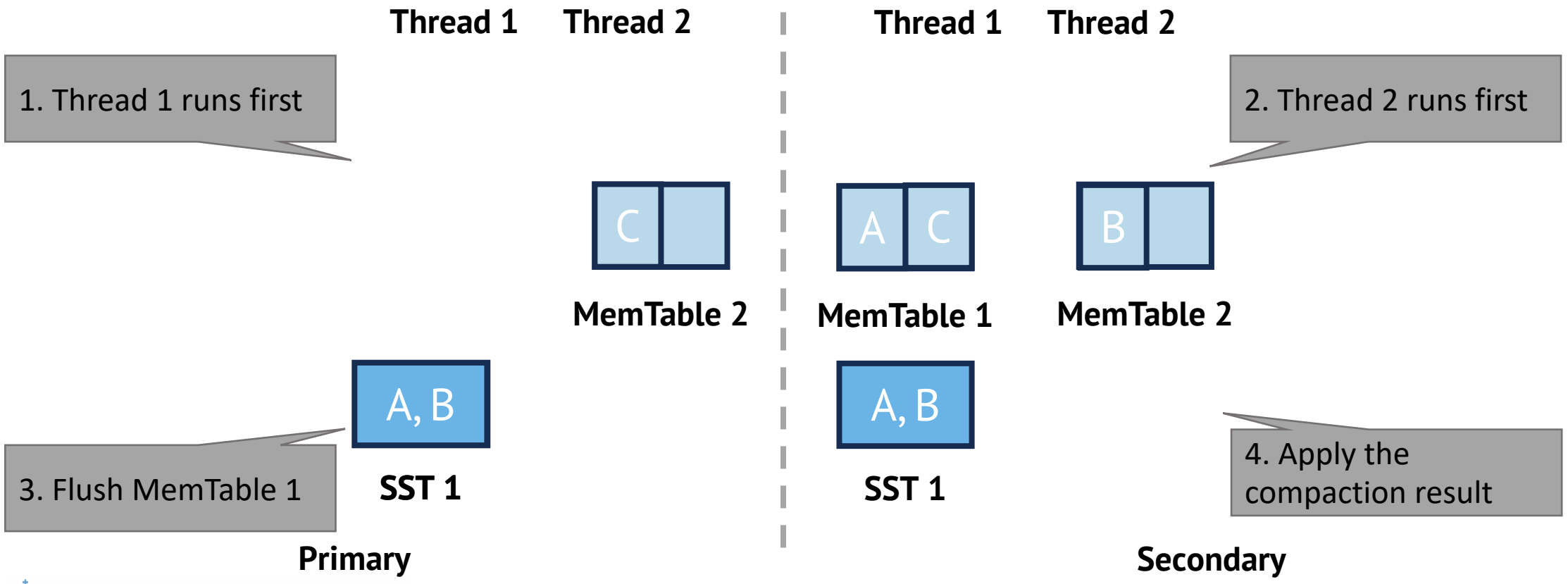

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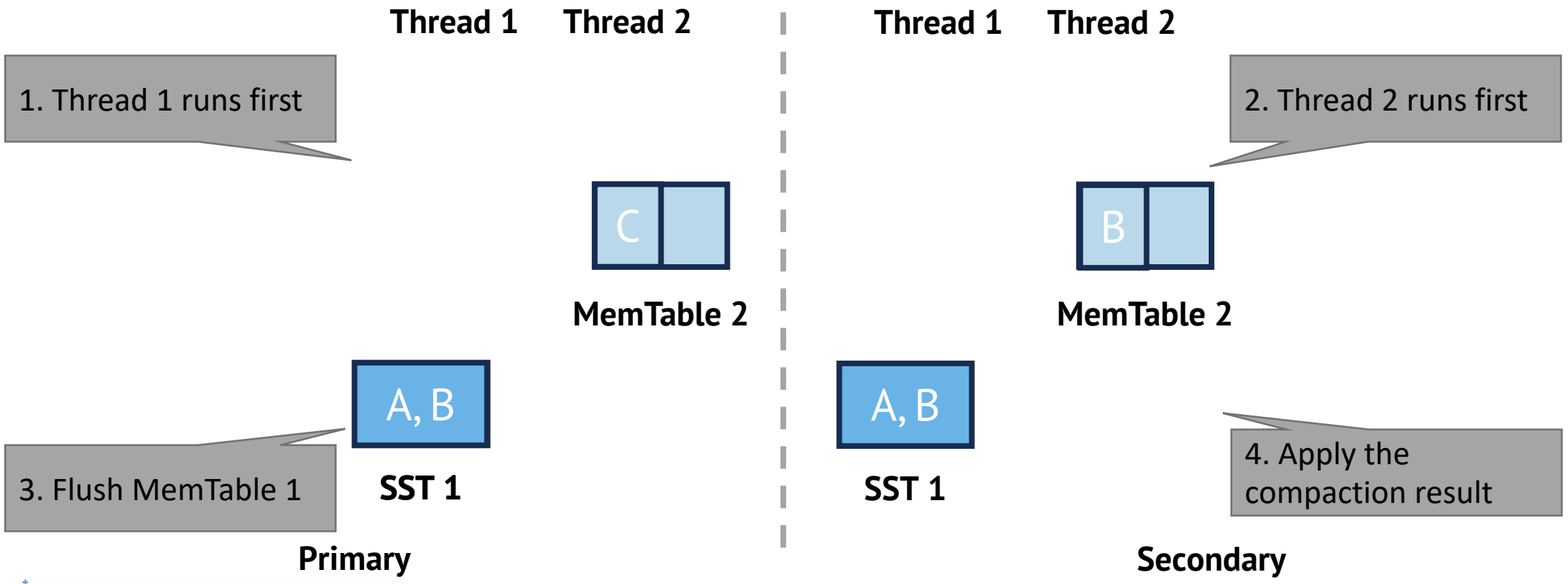

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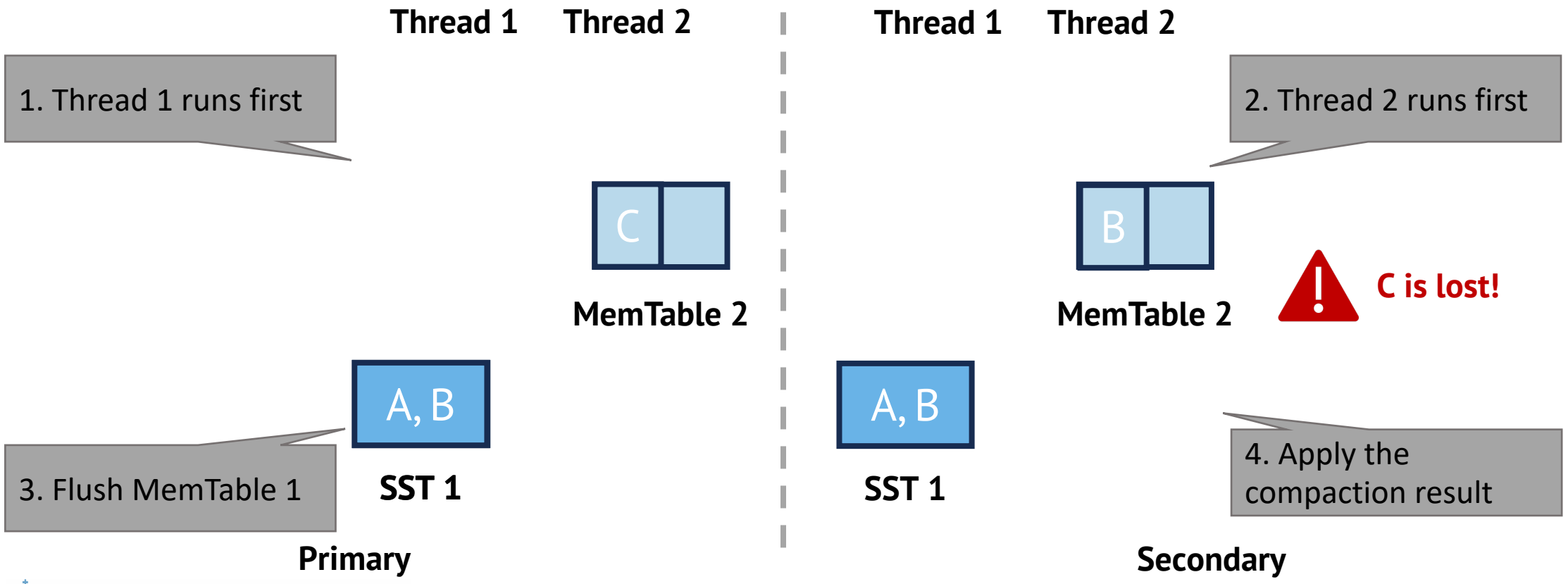

Partial order of write requests in RubbleDB

Goal: MemTables with a same ID should store the same data

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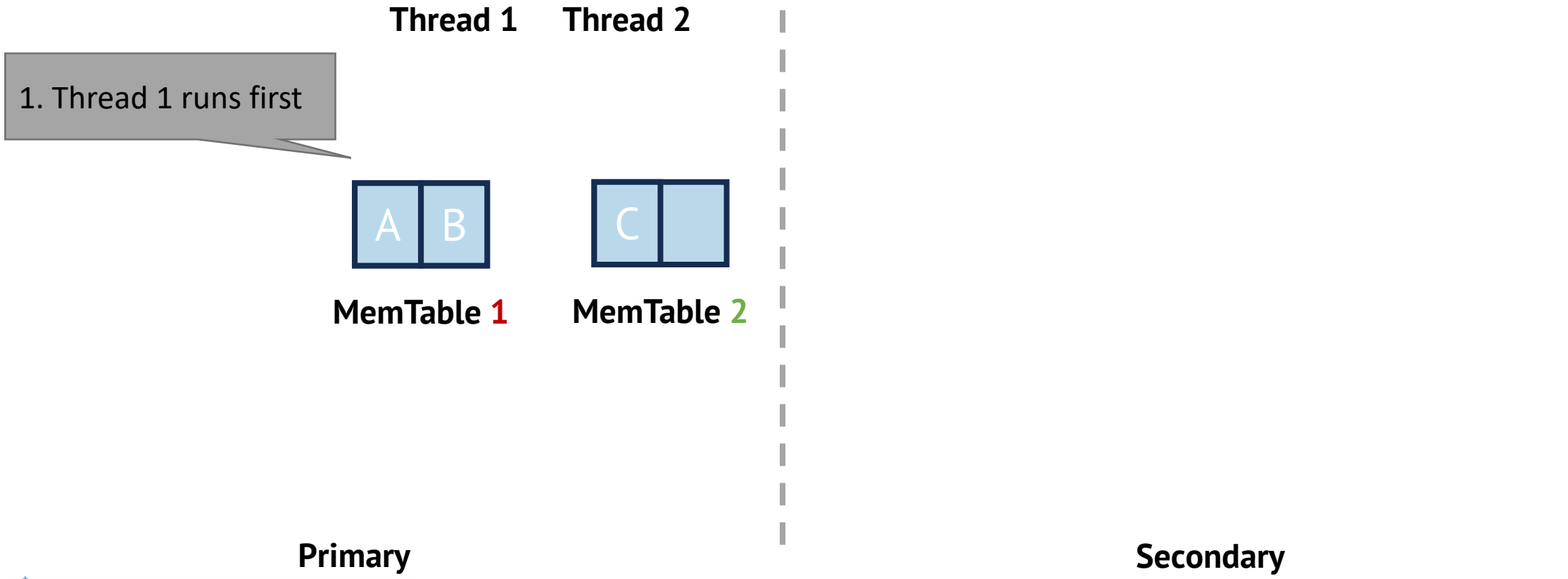

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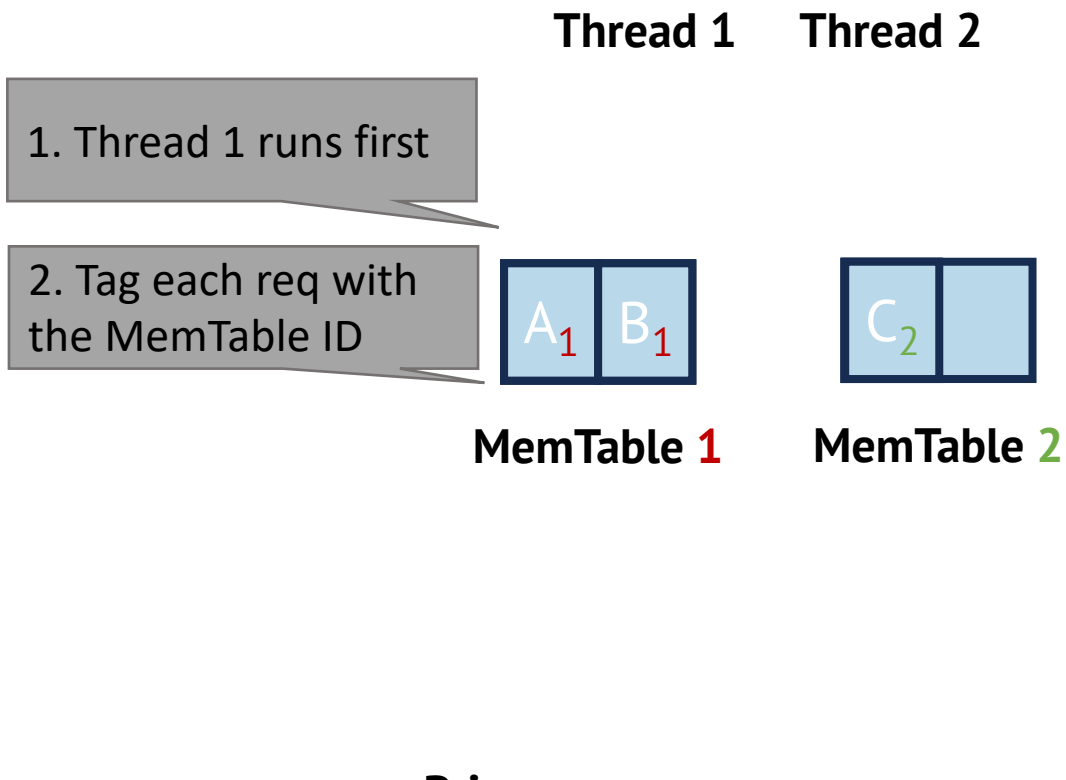

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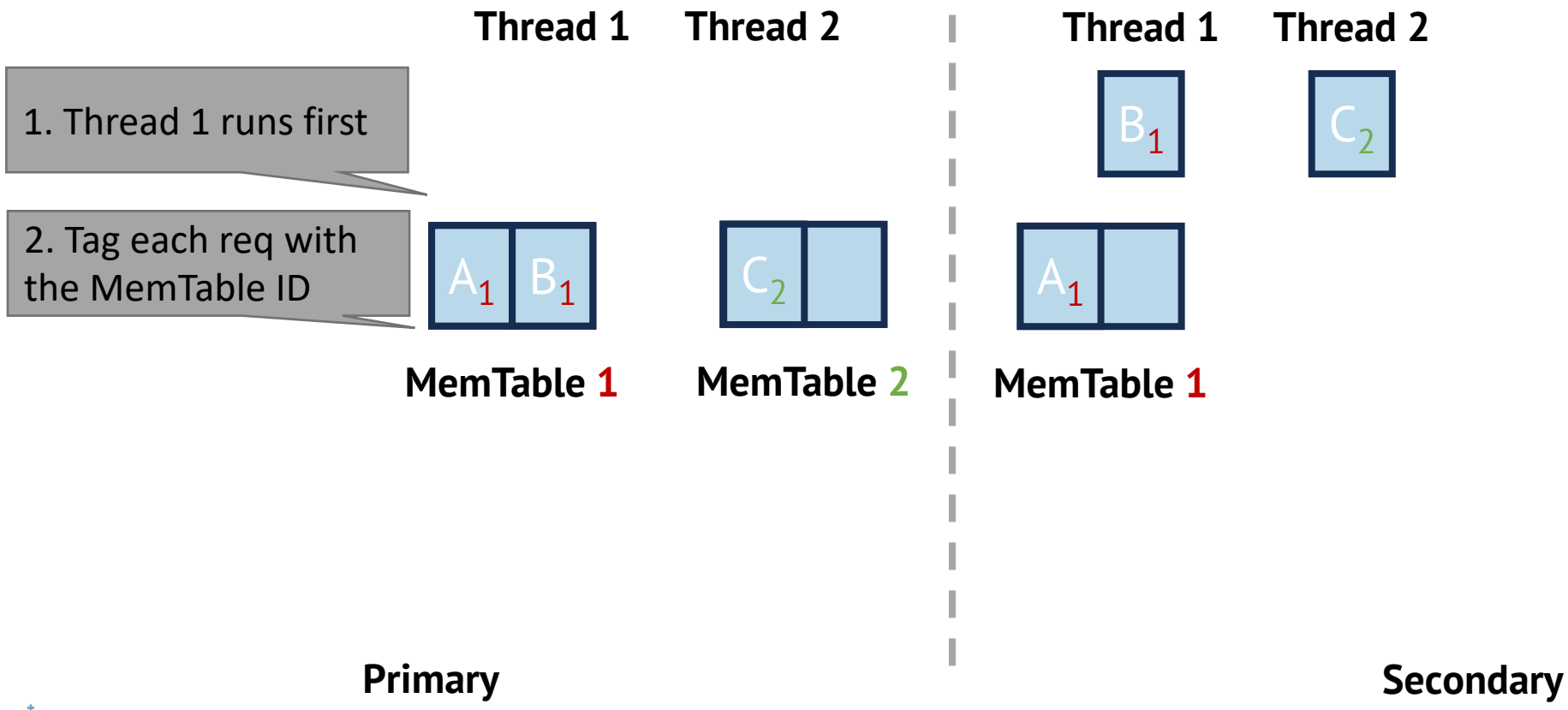

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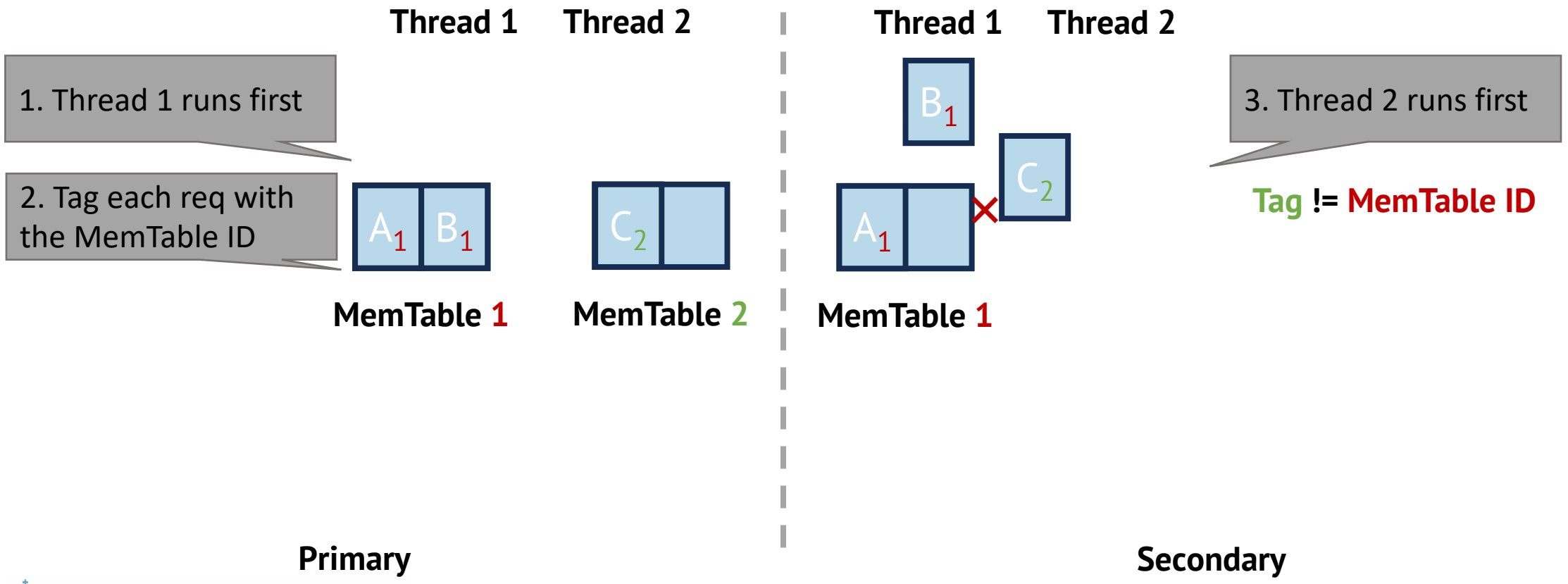

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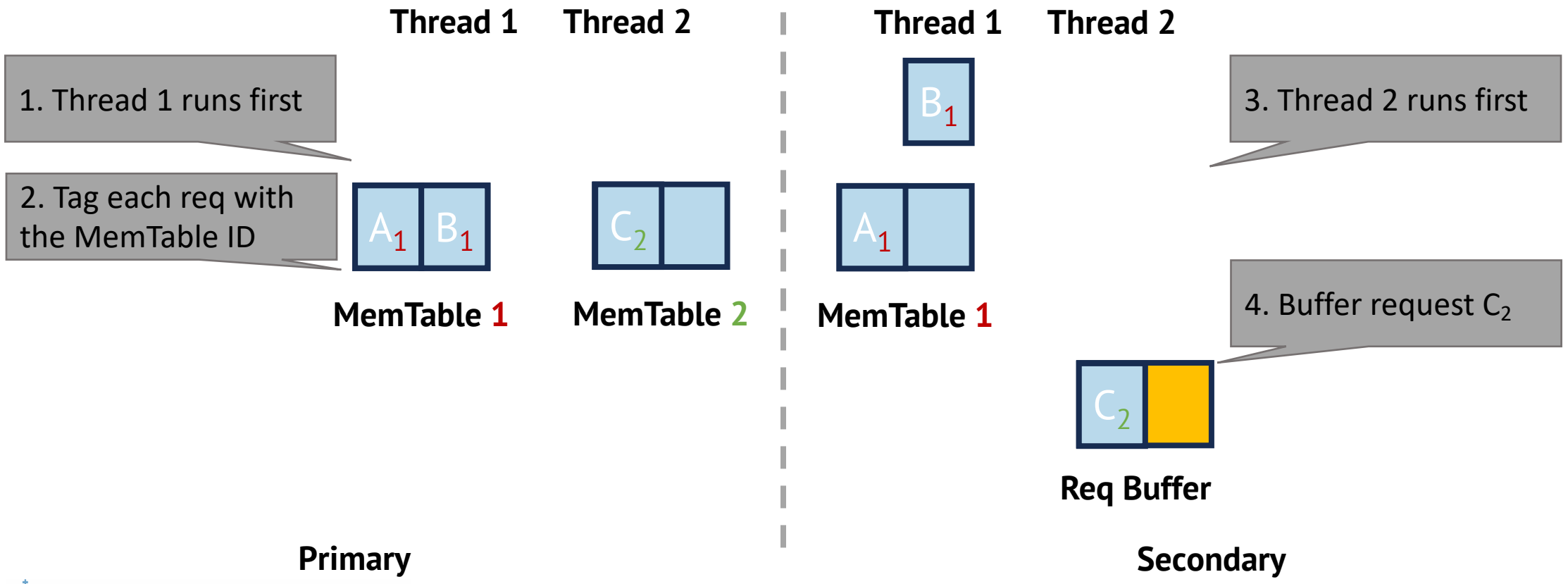

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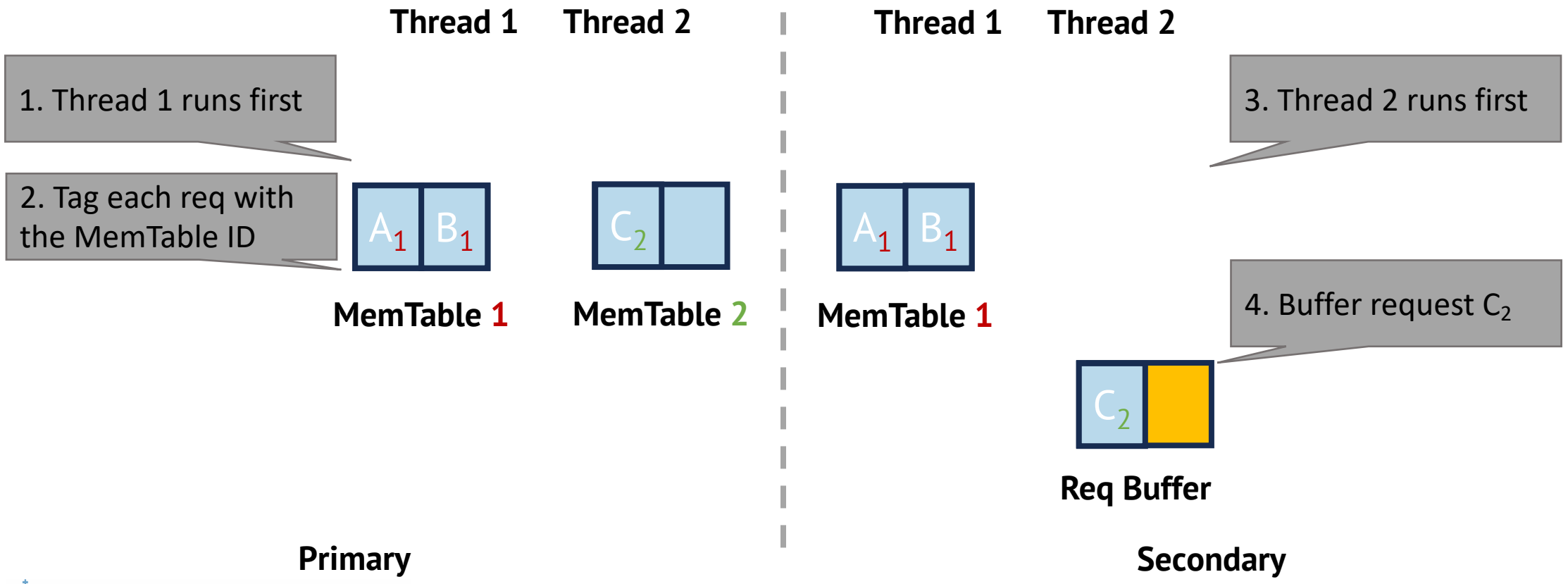

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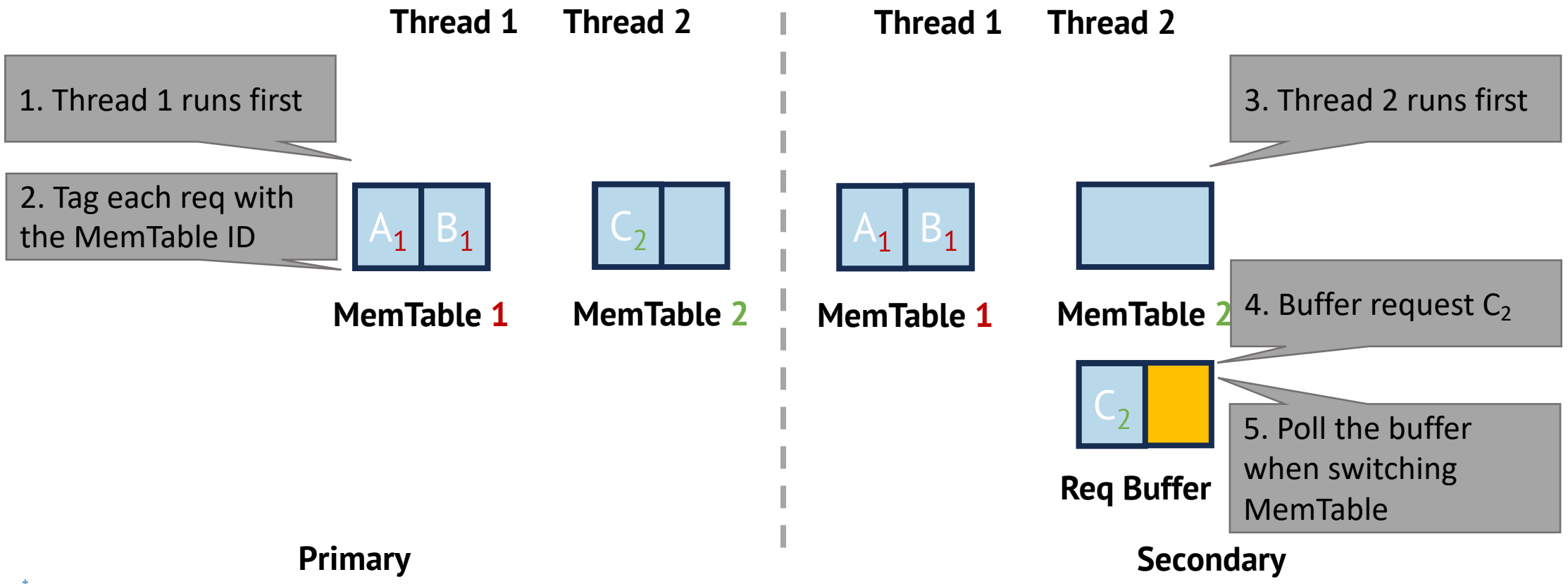

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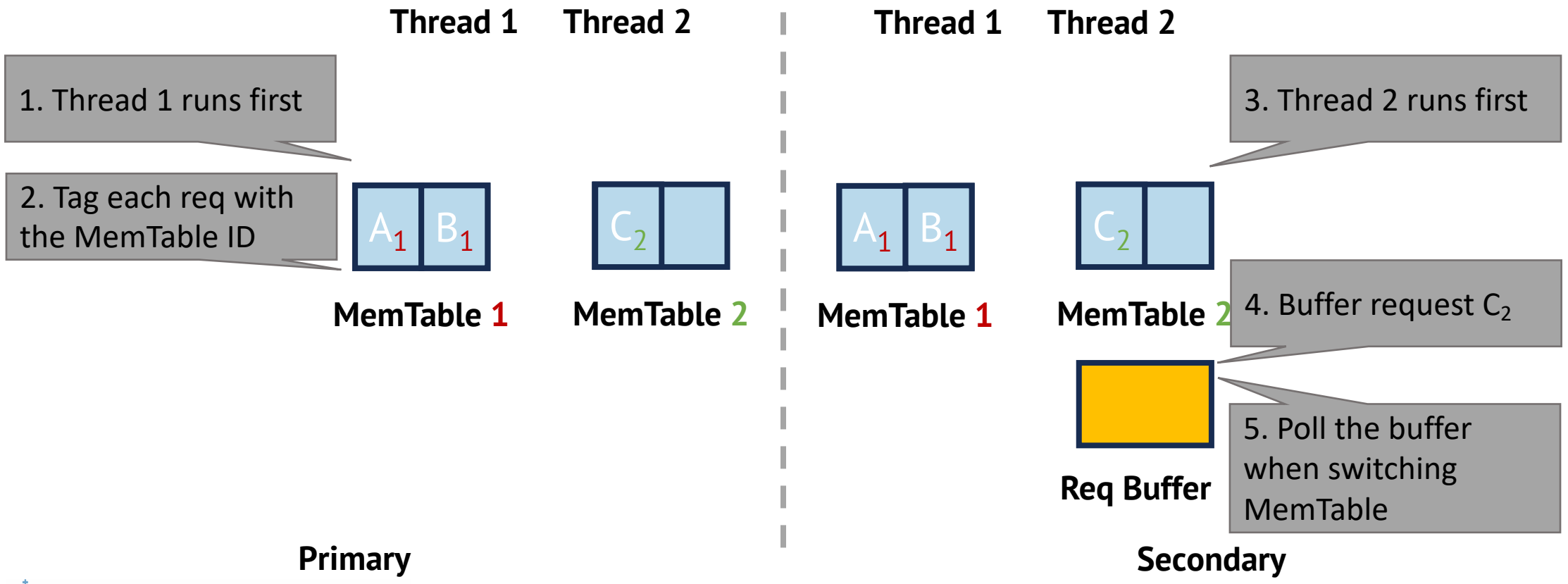

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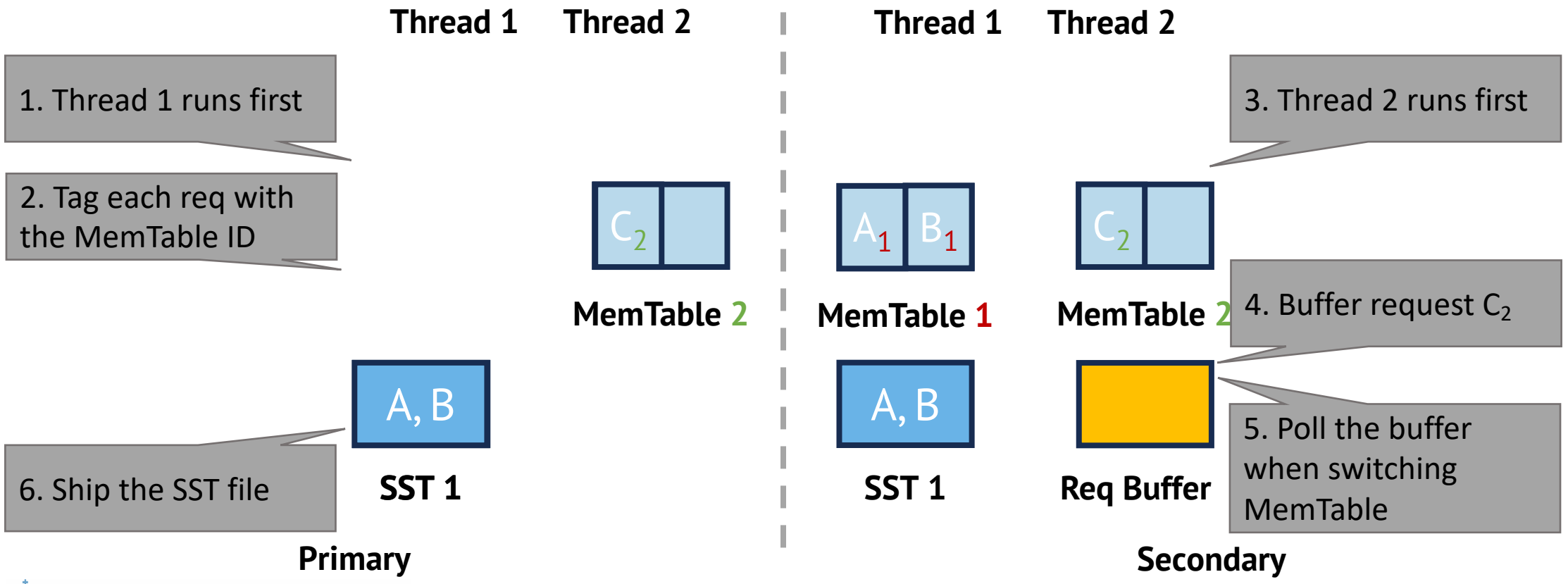

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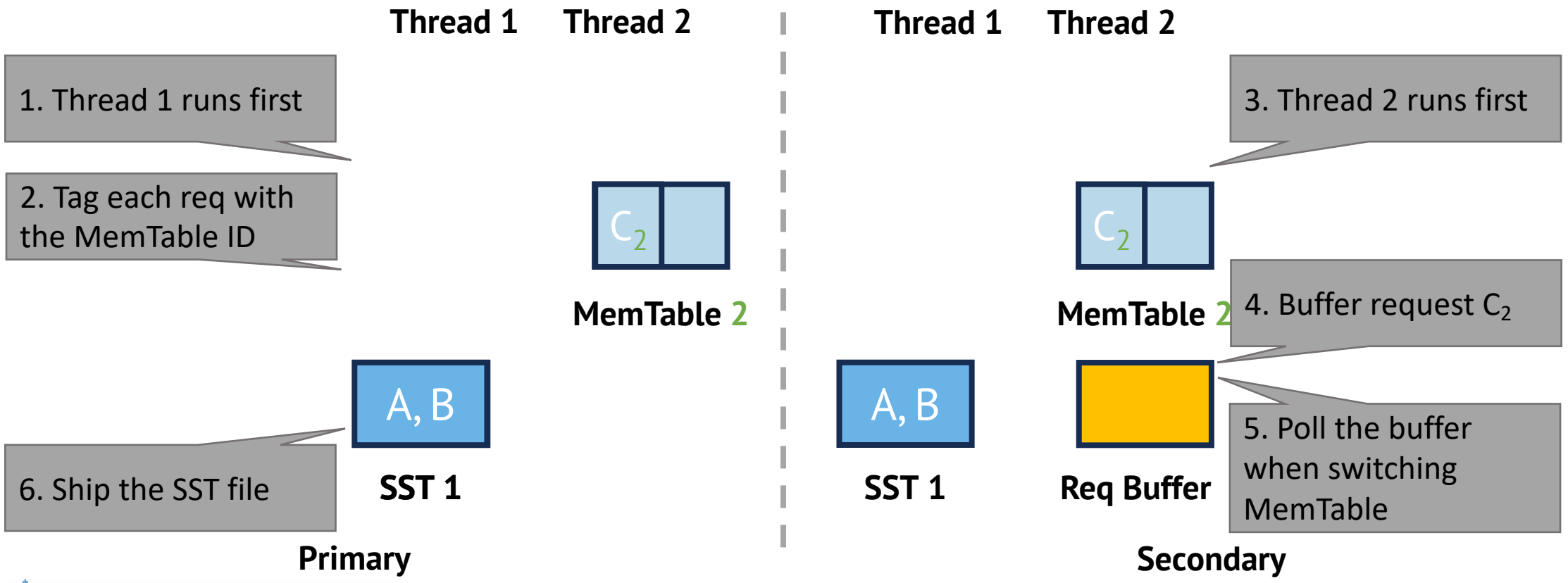


Evaluation

- How much can RubbleDB improve the end-to-end performance?
- What is the trade-off behind the improvement?
- How do different storage types affect RubbleDB?
- How fast can RubbleDB recover from failures?

} In the paper

Evaluation setup

Testbed: CloudLab r6525

- CPU: Two 32-core AMD 7543 at 2.8GHz
- Disk: One 1.6TB NVMe SSD
- NIC: Dual-port Mellanox ConnectX-6 100Gb

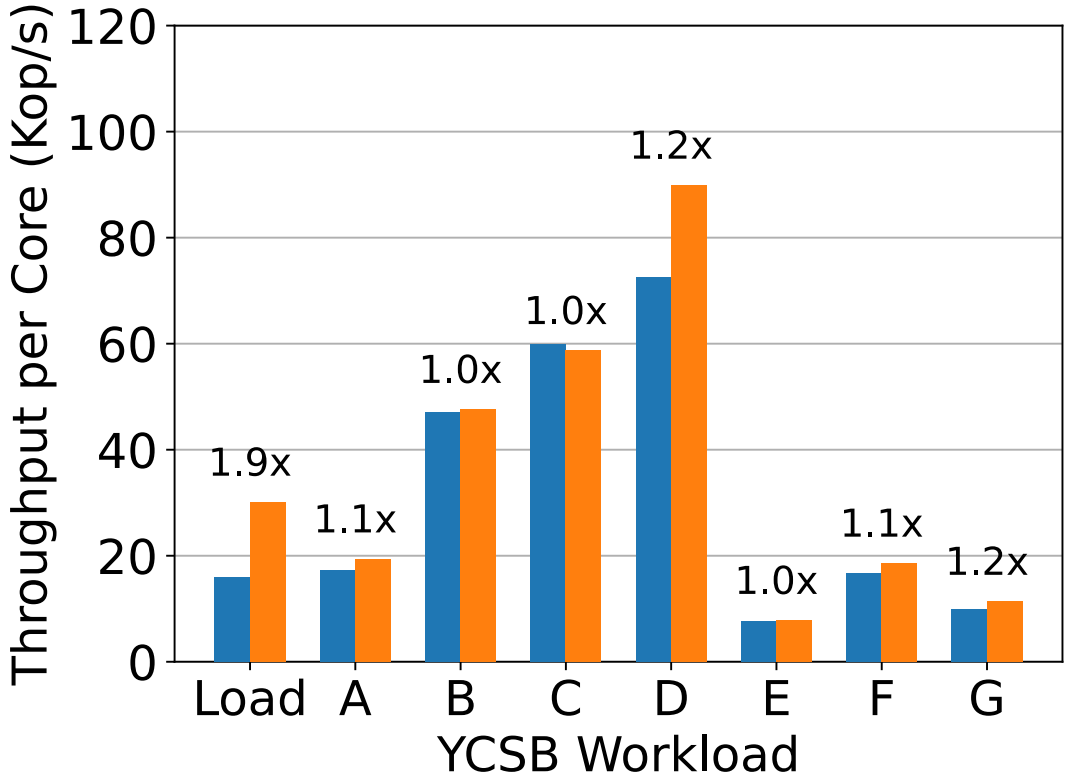
Benchmark:

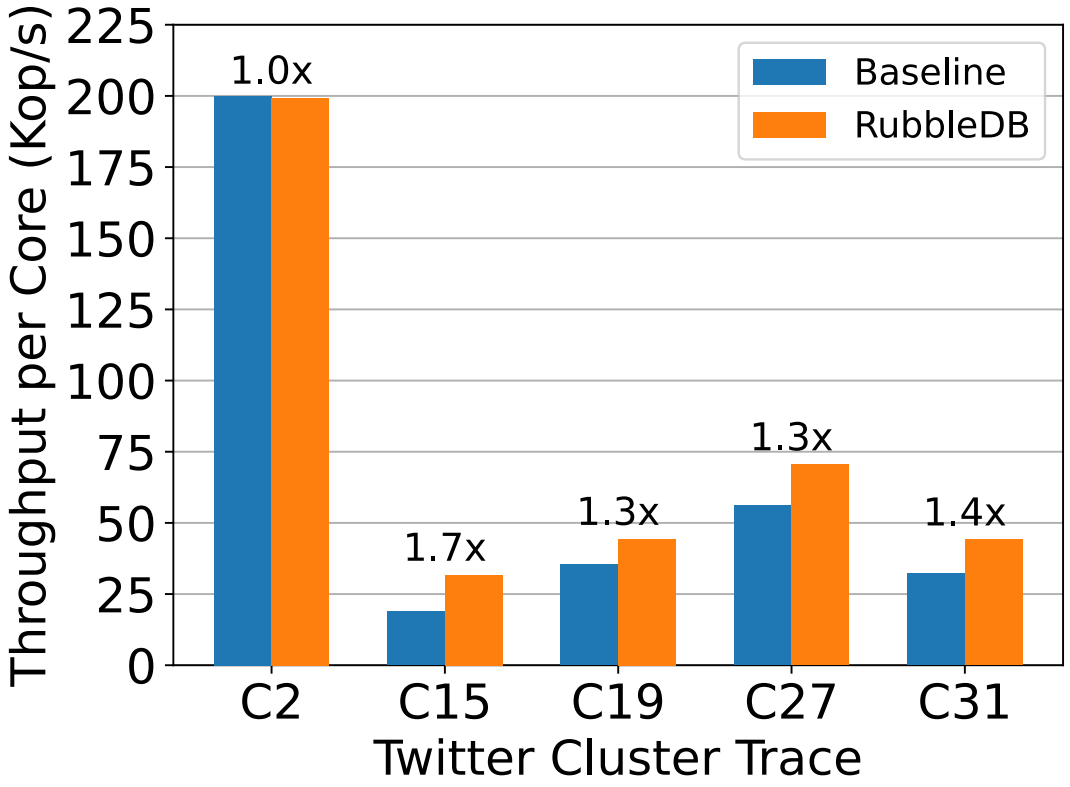
- YCSB load and A-G workloads
- Five Twitter cluster traces

Baseline:

- Replicated RocksDB with compactions in secondaries

Throughput under different workloads





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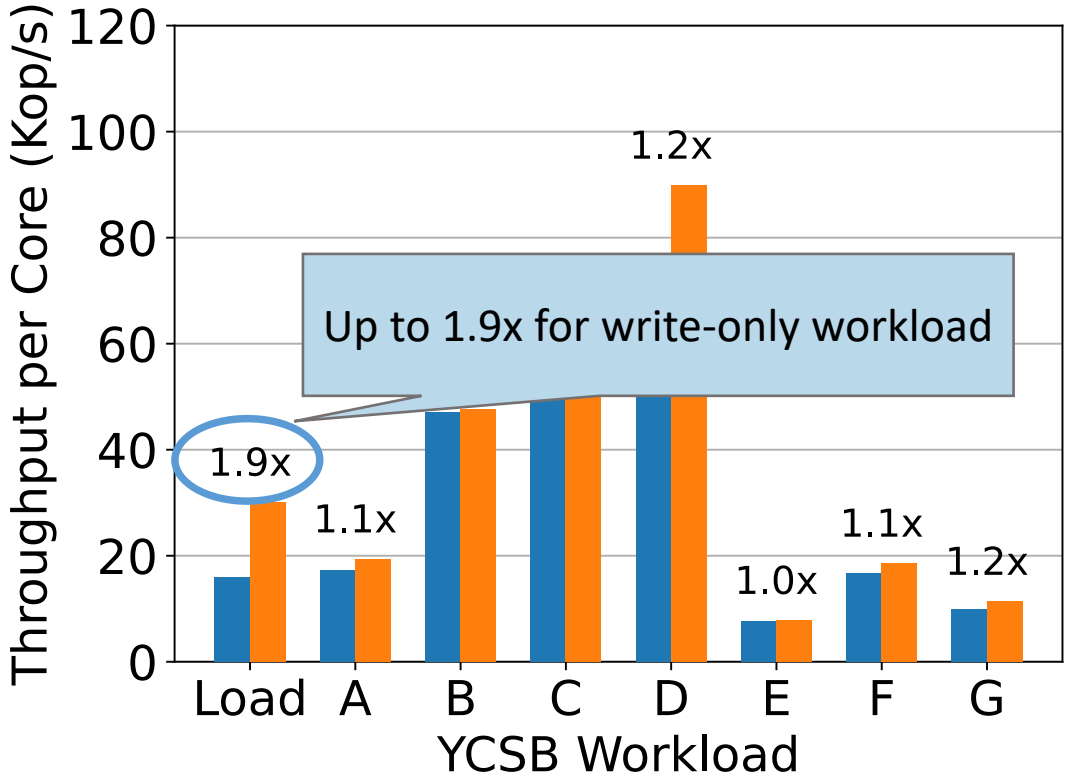

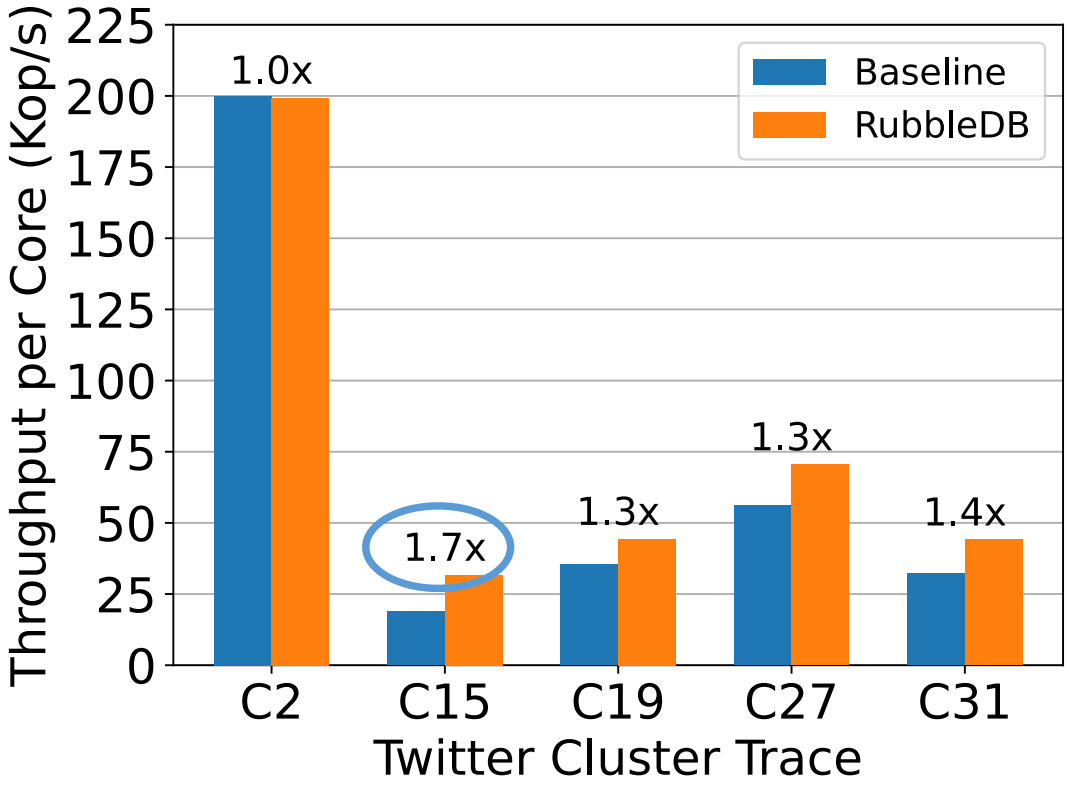

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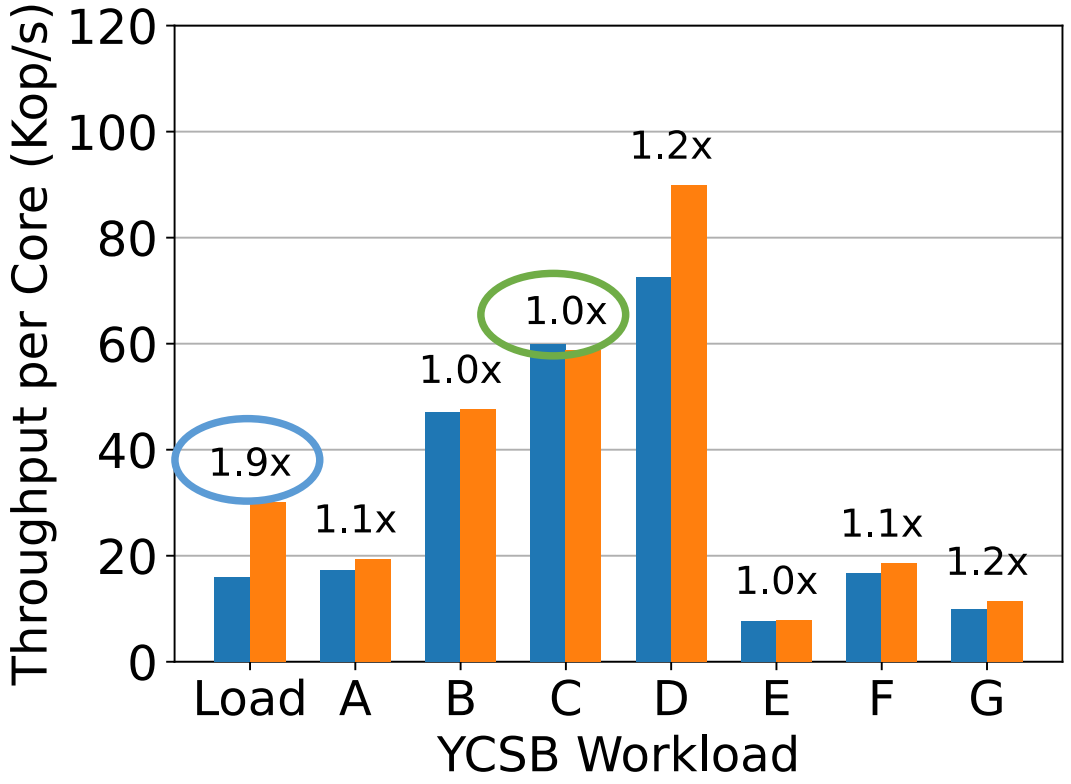

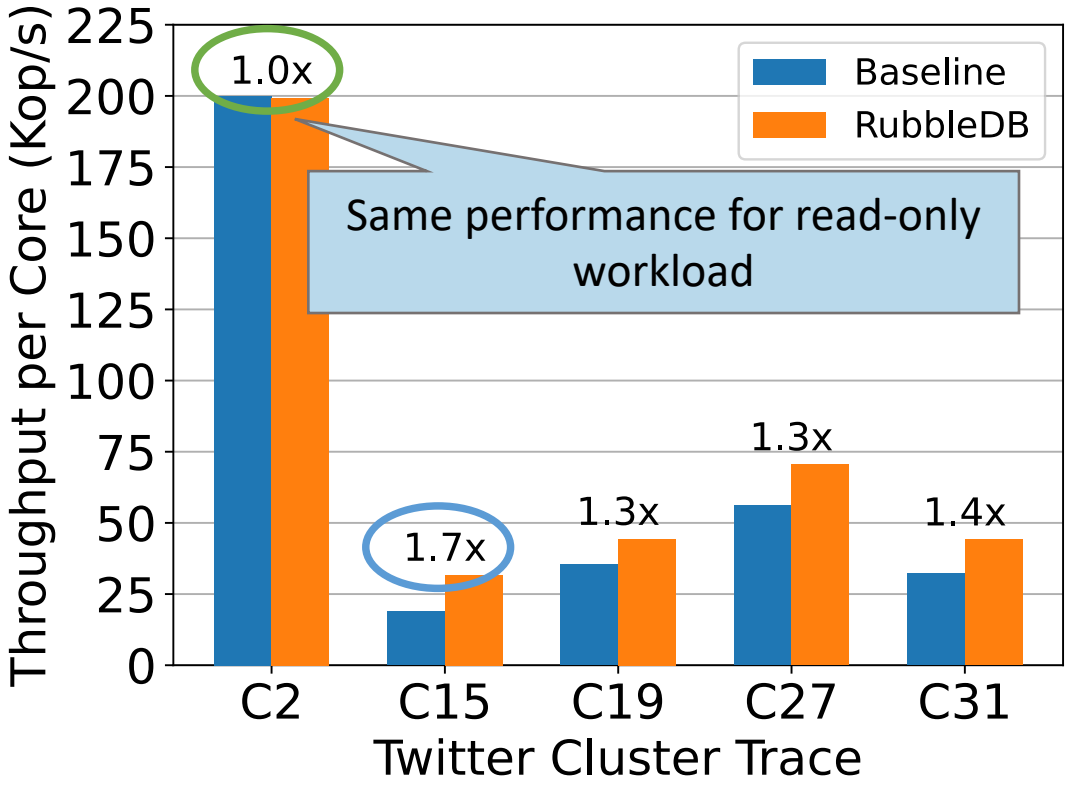

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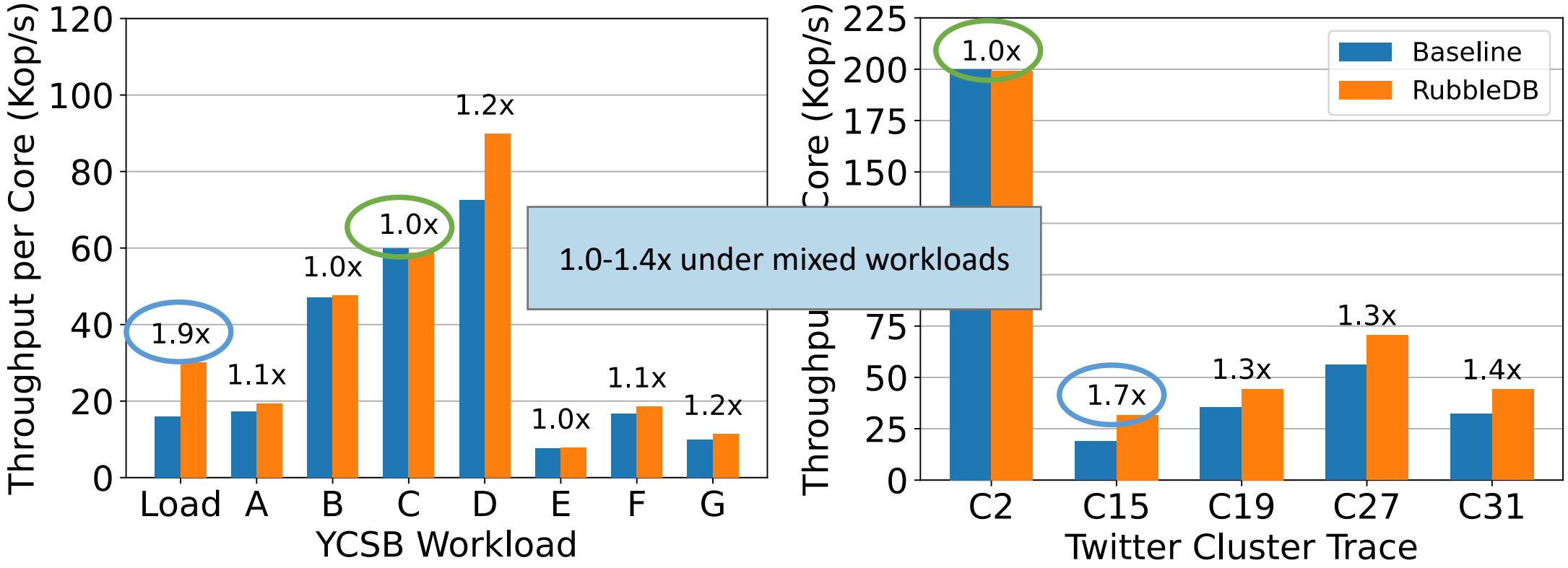
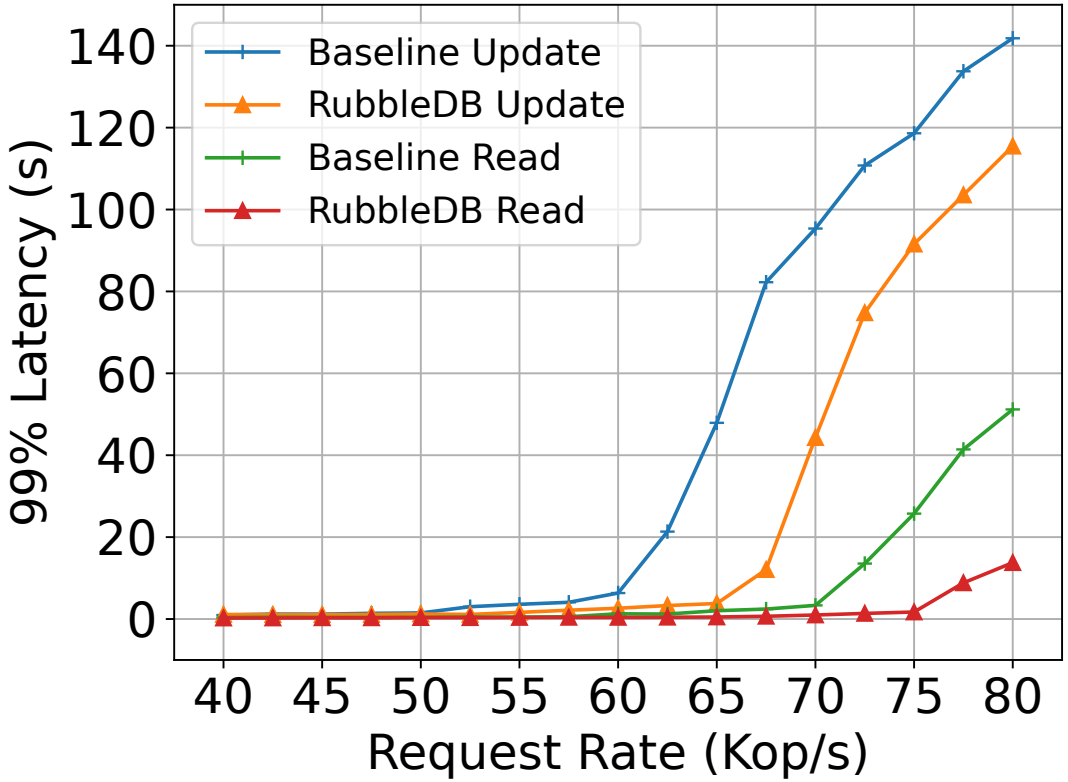


Tail latency comparison



Fewer compactions lead to fewer write stalls in RubbleDB

YCSB Workload A (50% read and 50% update), 30GB DB size, and three-way replication

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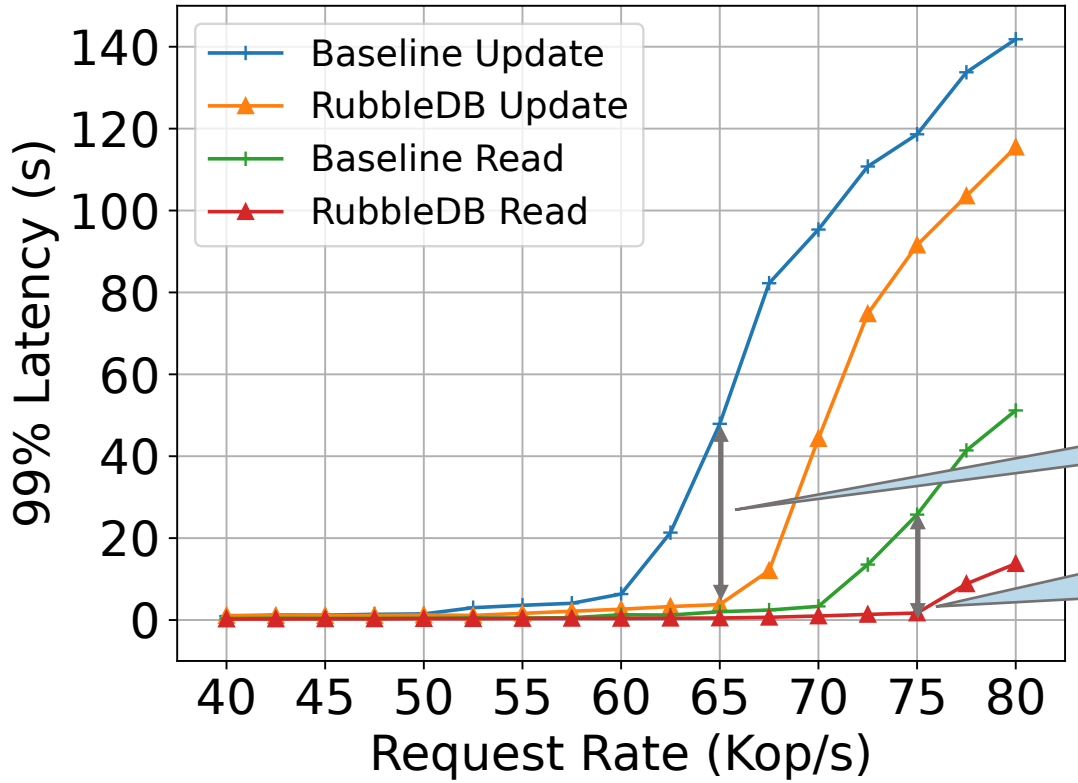

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Up to 93.4% lower read tail latency

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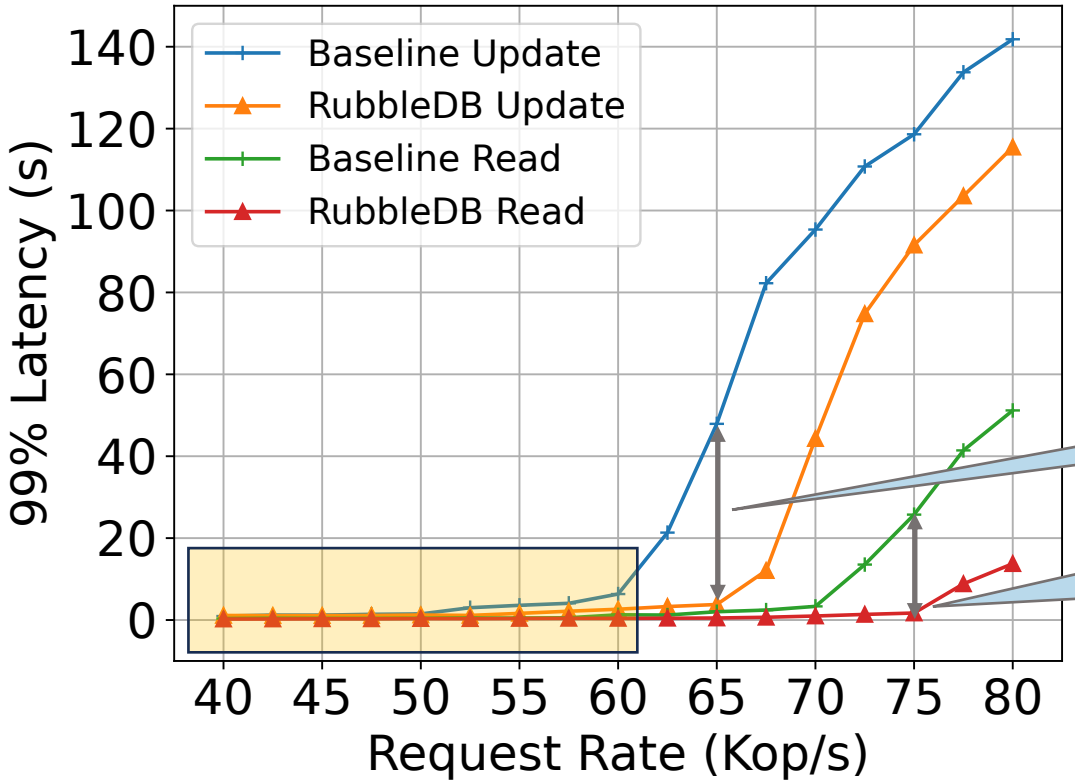

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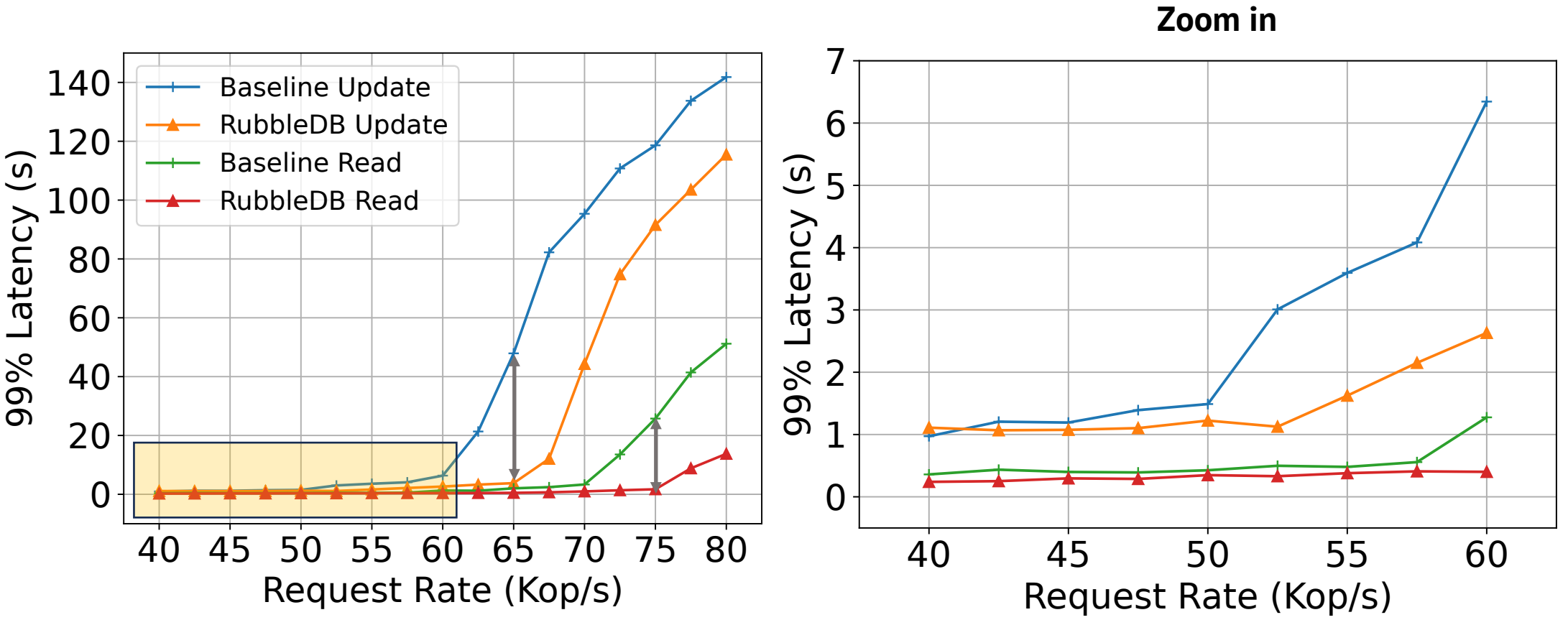

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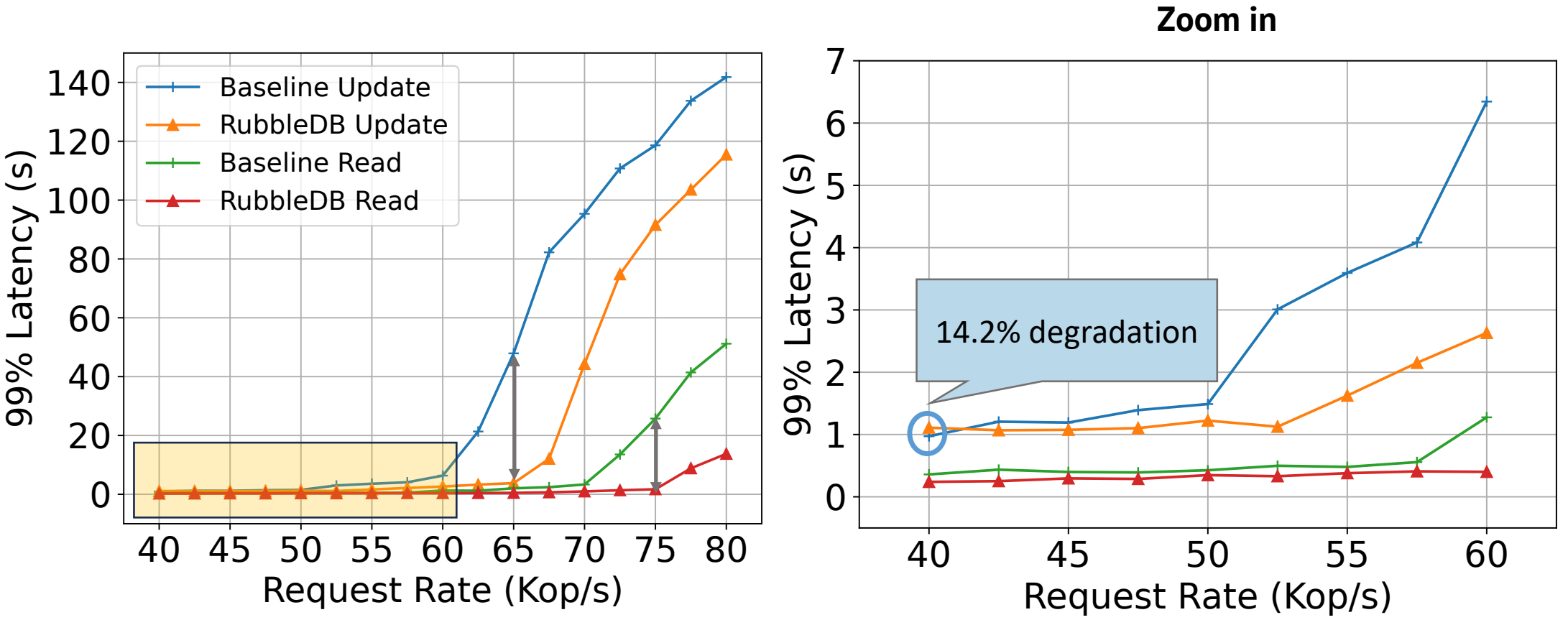

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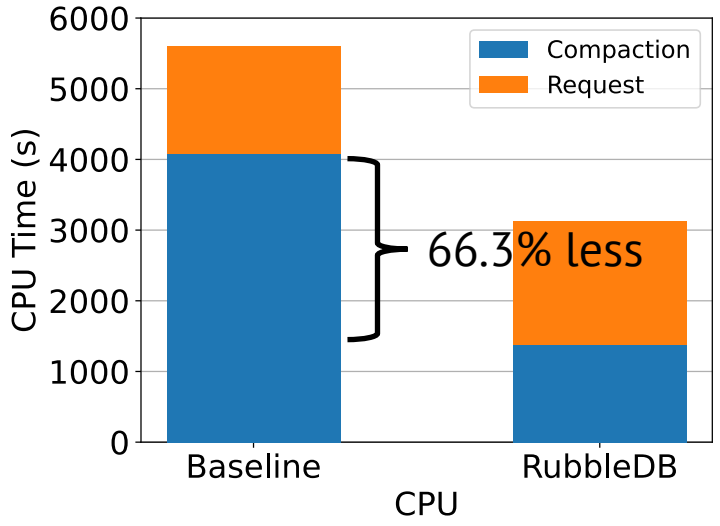

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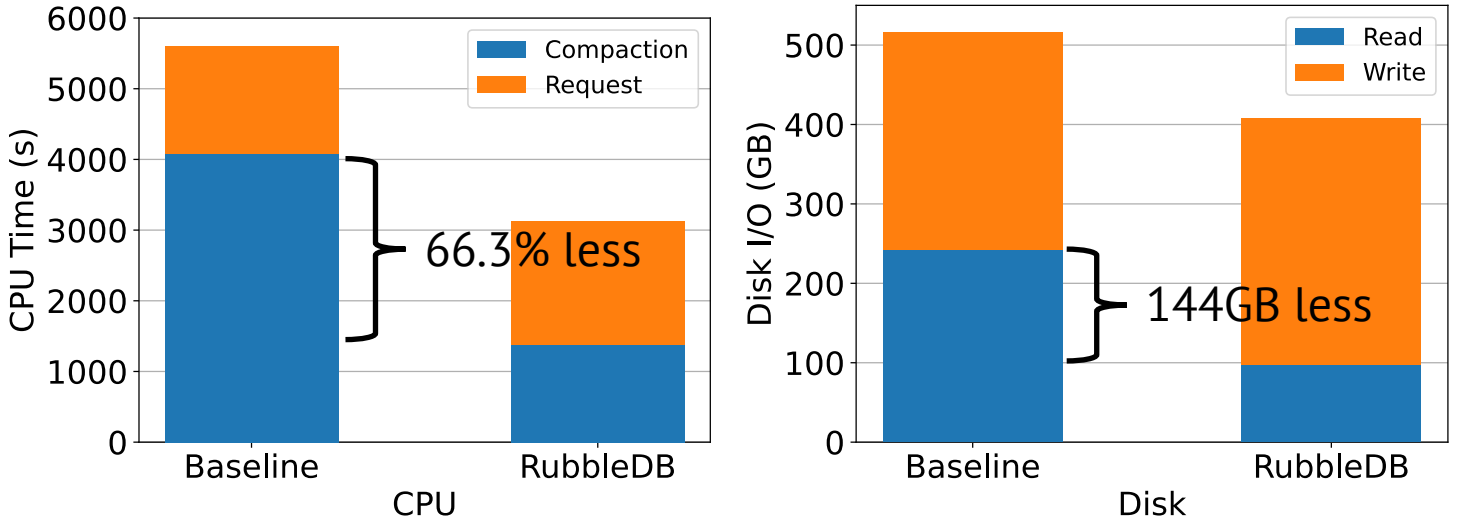

YCSB load, 30GB DB size, and three-way replication

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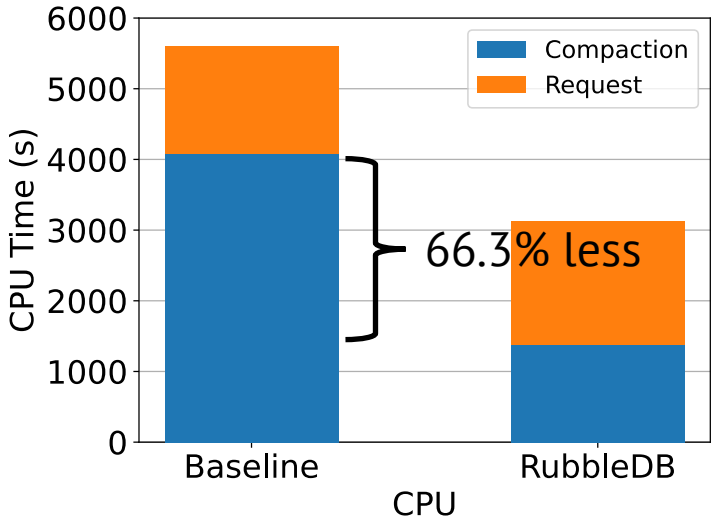

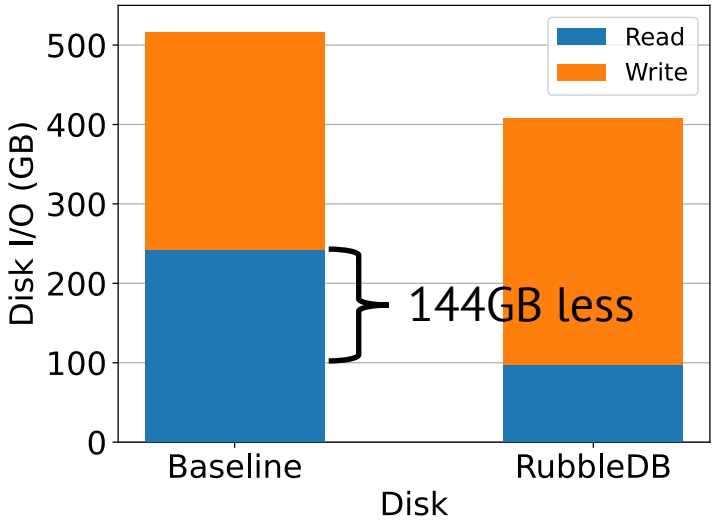

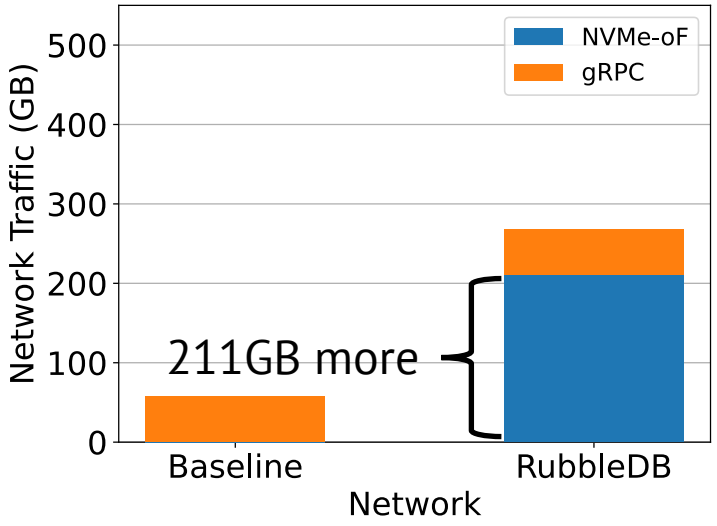

YCSB load, 30GB DB size, and three-way replication

Conclusions

- NVMe-oF is an attractive opportunity for replicated storage systems
- RubbleDB trades network for CPU and disk read I/O by shipping compactions results to secondaries
- Try RubbleDB at https://github.com/lei-houjyu/RubbleDB

Thank you!

haoyu.li@columbia.edu

Backup Slides

Cluster topology

- K replication groups spread on R servers
- Saving compactions in secondaries gives the primary more CPU