Iterator Interface Extended LSM-tree-based KVSSD for Range Queries

Seungjin Lee[1], Chang-Gyu Lee[1], Donghyun Min[1], Inhyuk Park[2], Woosuk Chung[2], Anand Sivasubramaniam[3], Youngjae Kim[1]

[1] Sogang University, [2] SK hynix, [3] The Pennsylvania State University

Key-Value SSD

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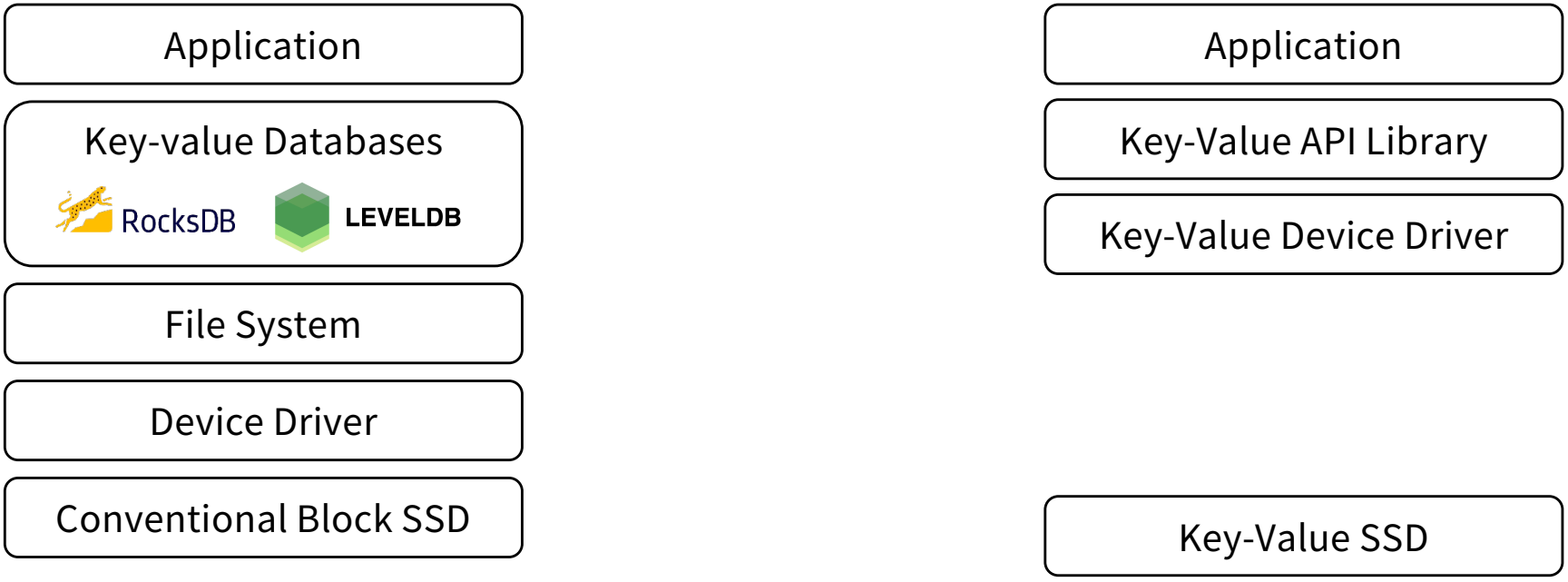

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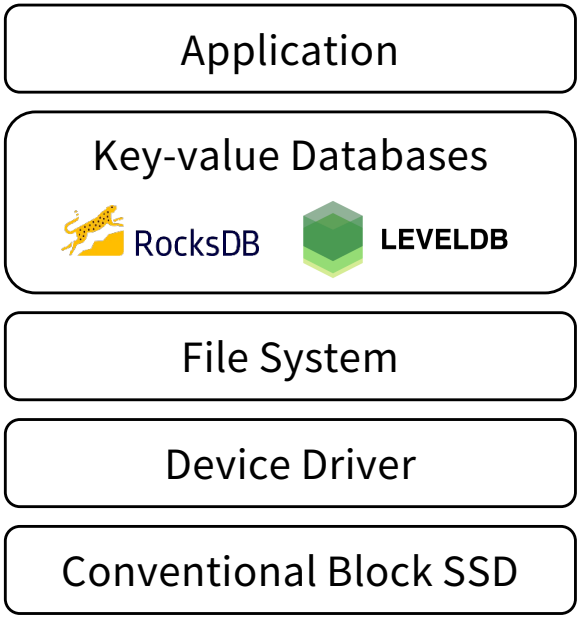

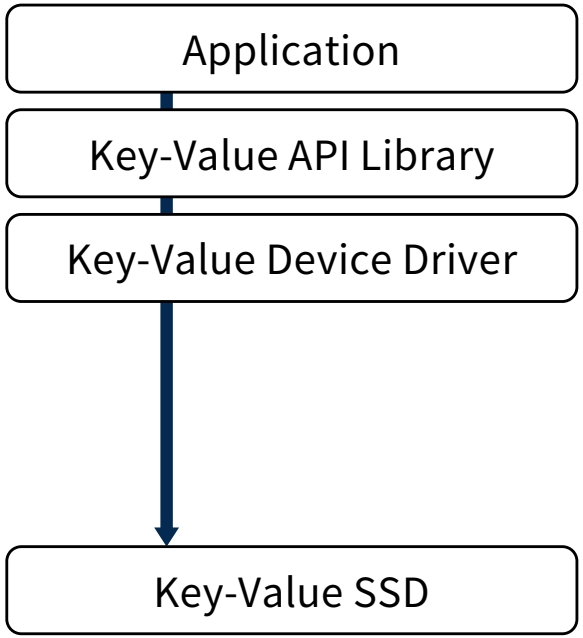

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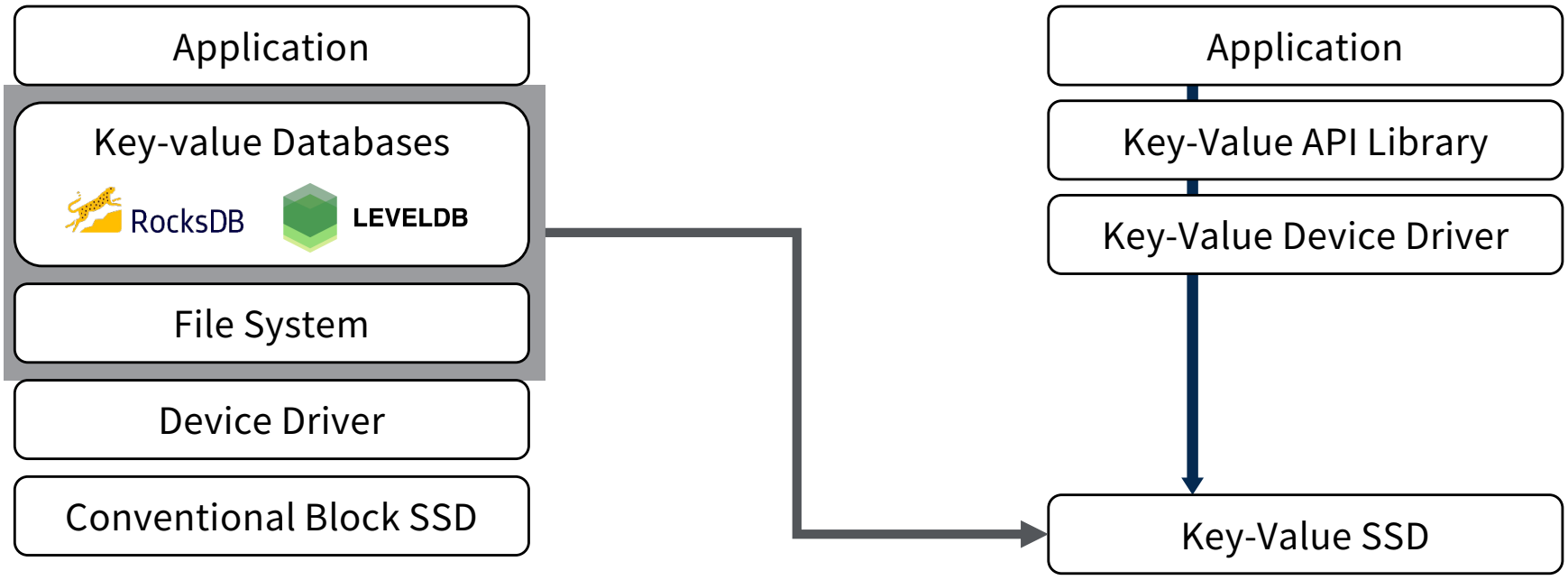

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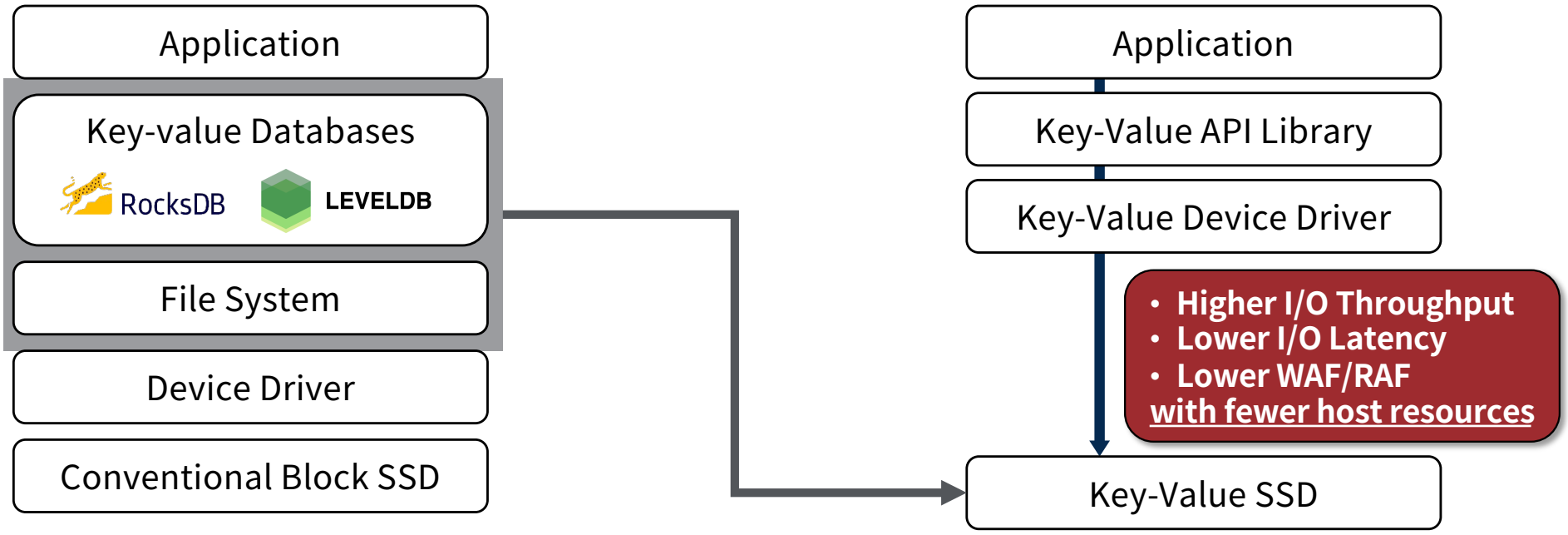

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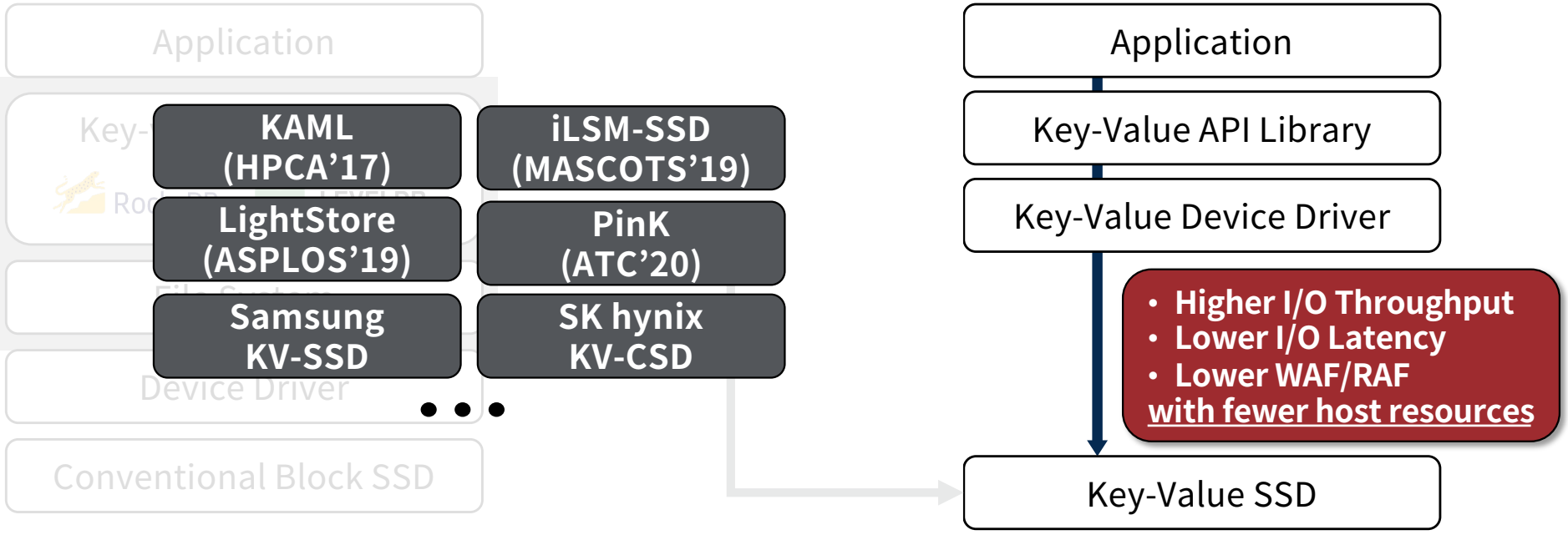

Range Query for KVSSD

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  - Index Pinning[1], Index Compression[2], H/W Accelerator for Compaction[1]
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- **Existing KVSSDs mostly focus on point queries (Put, Get)**
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- **What about range query?**
  - With ordered data structure, it is often considered simple to implement
  - In previous studies, the design detail of range queries is not covered
  - We claim that there are more things to consider for range query

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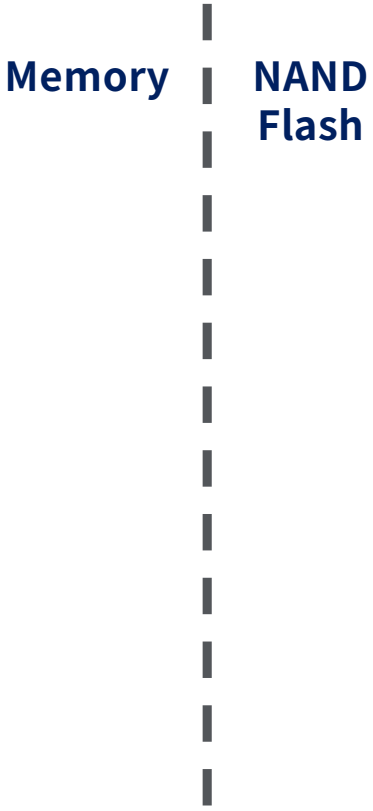

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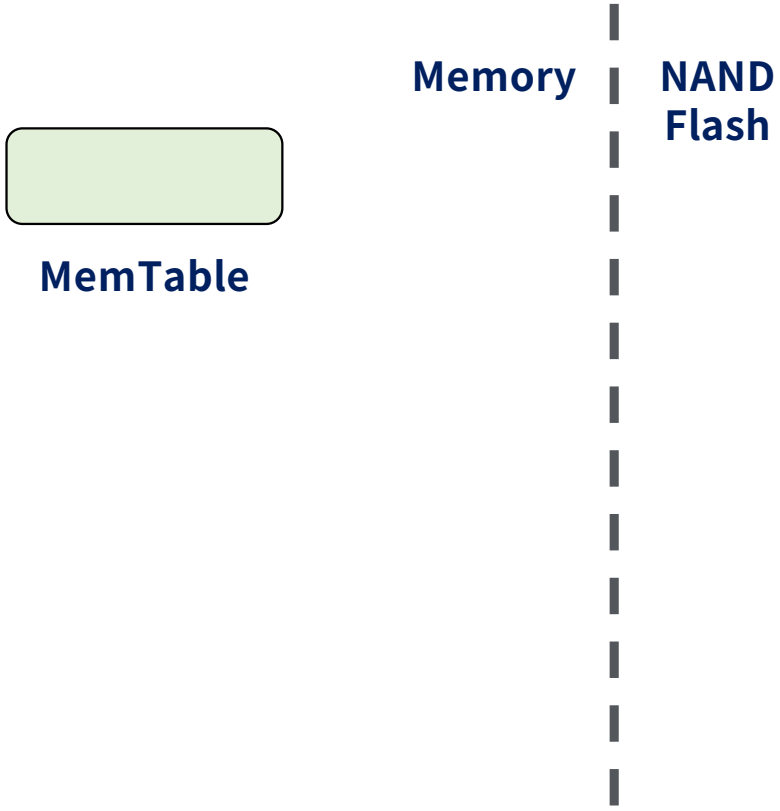

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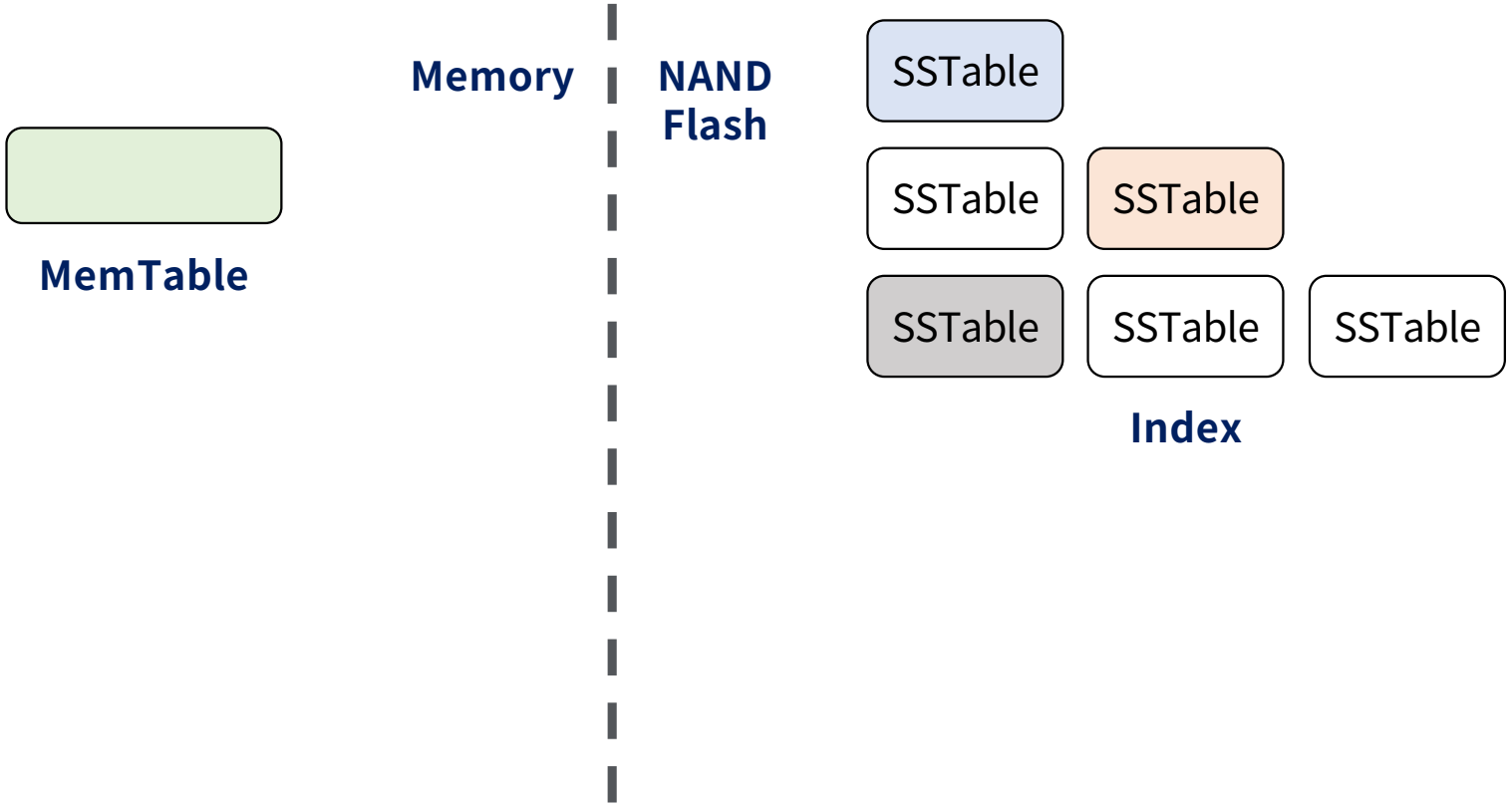

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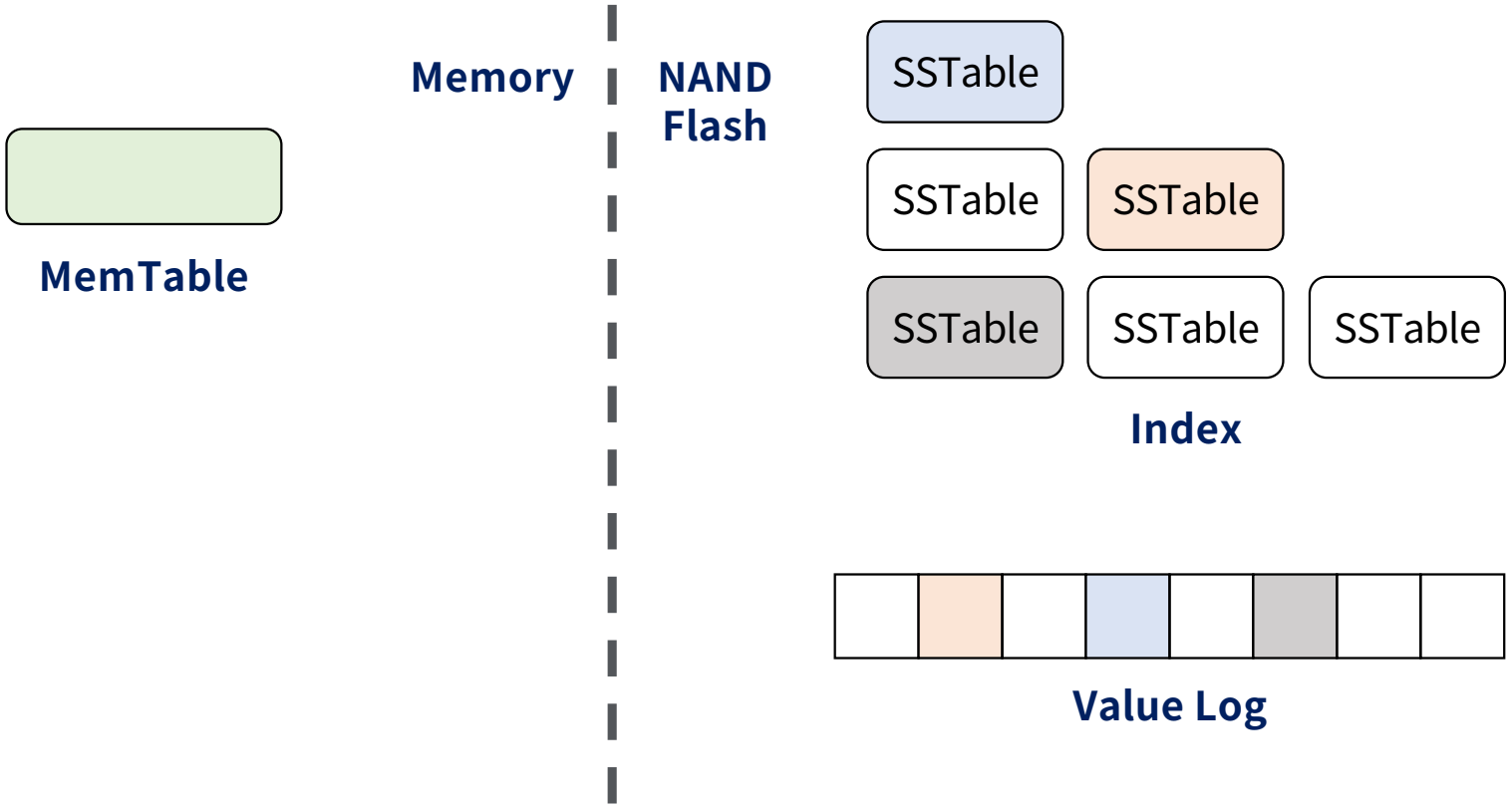

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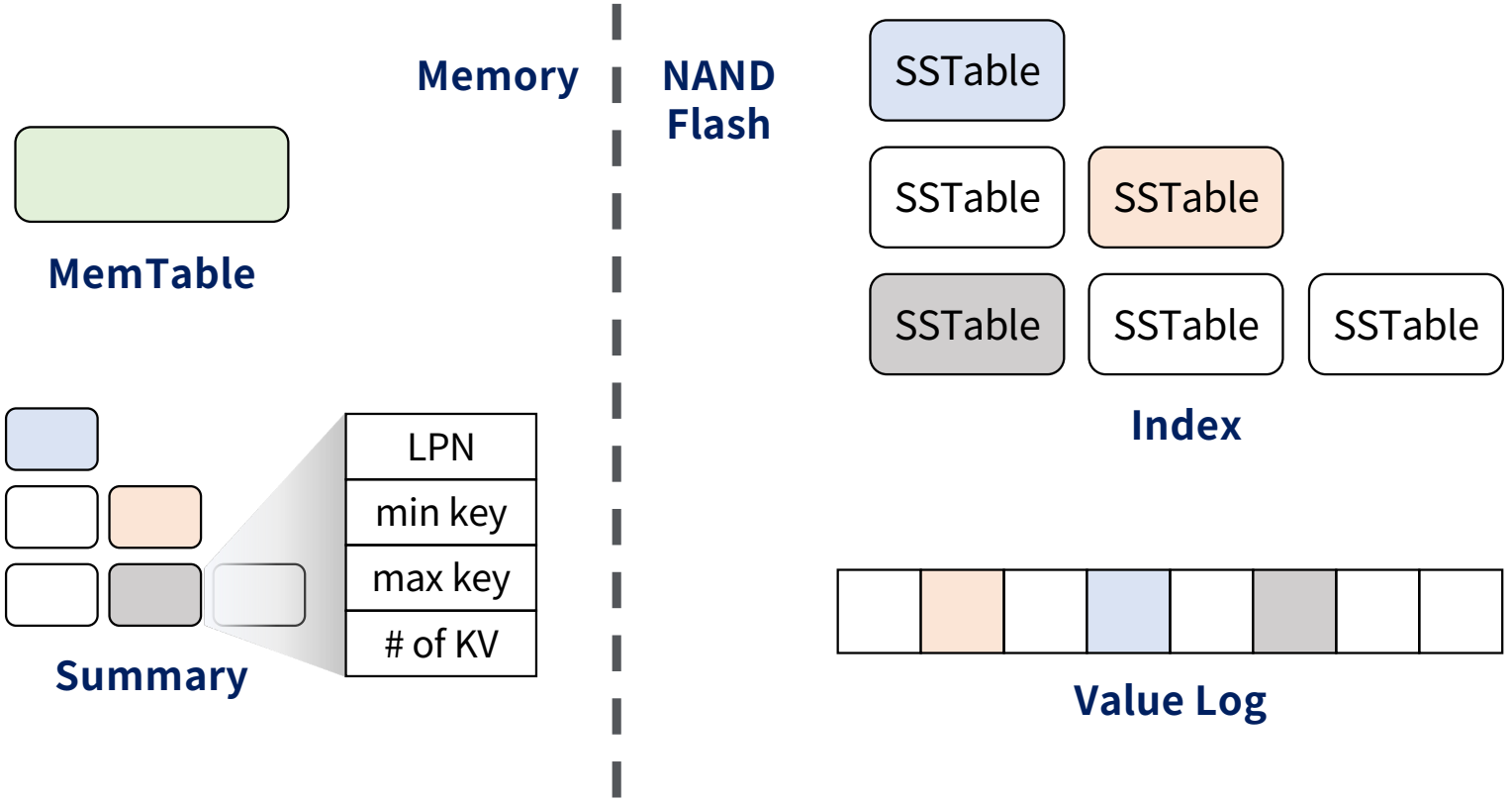

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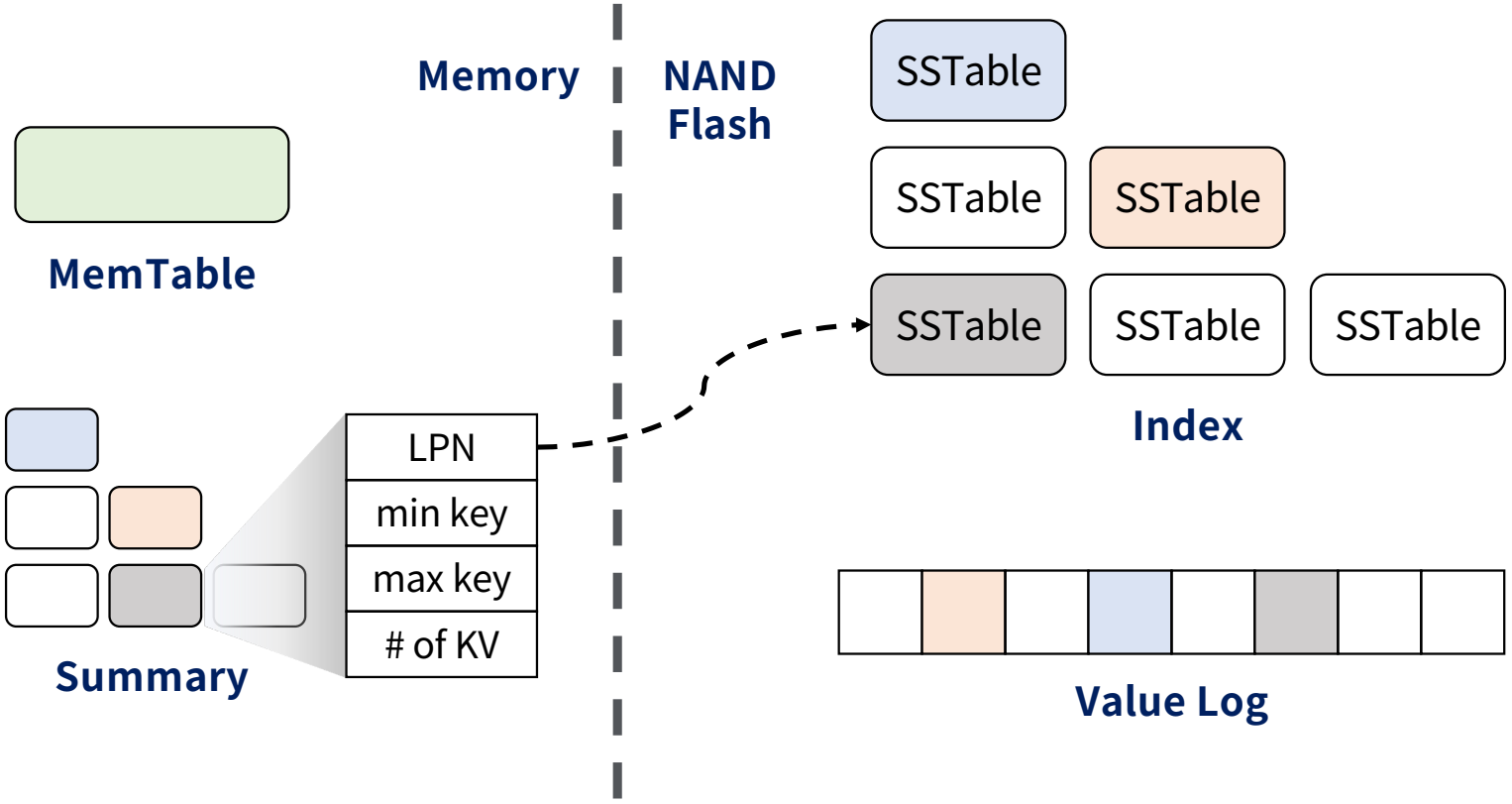

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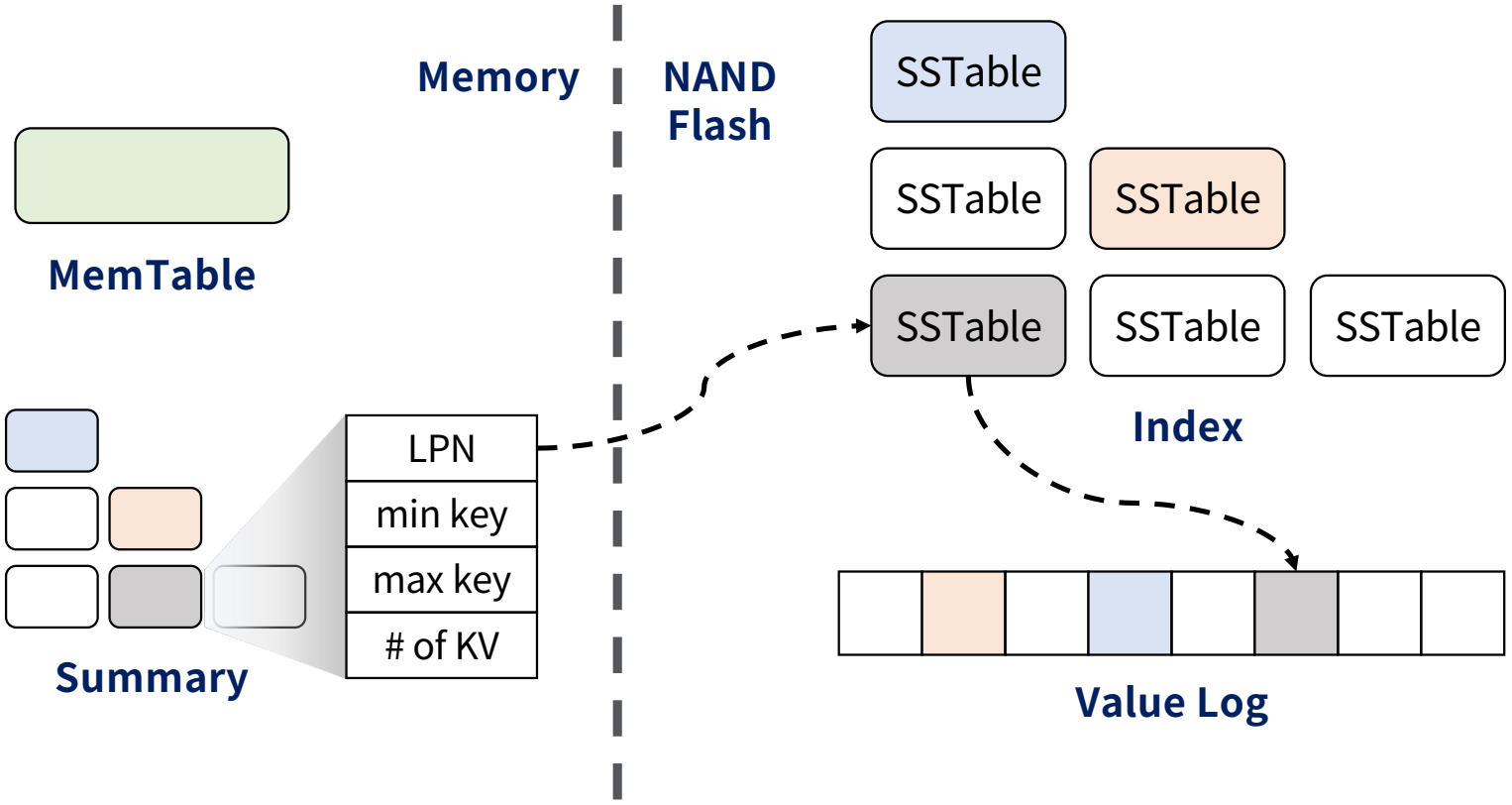

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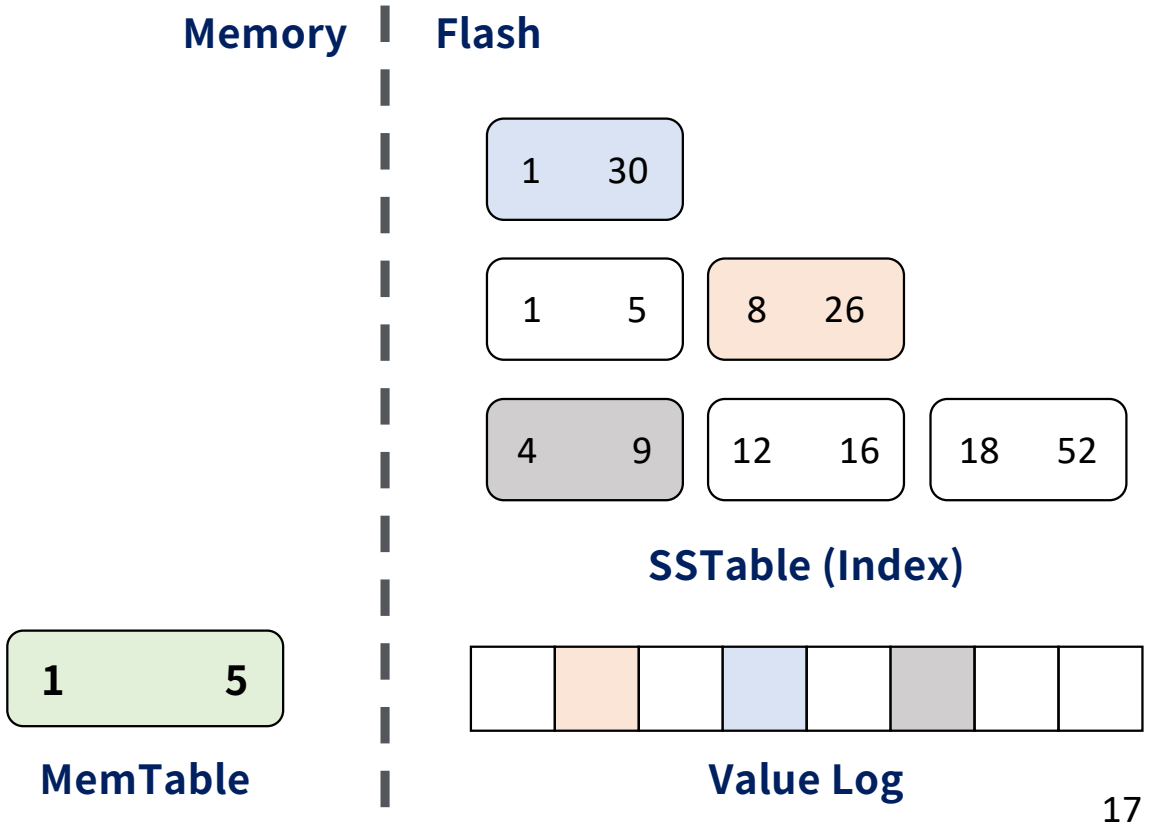

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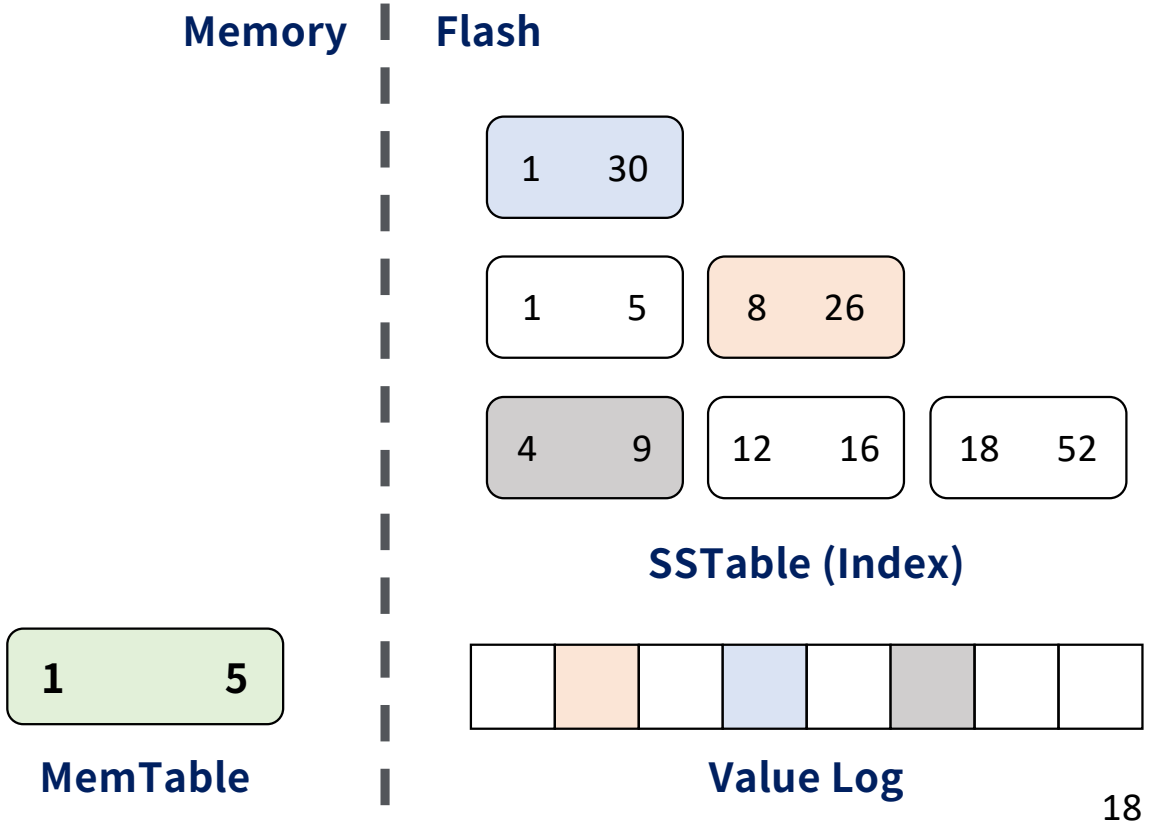
- **Range Queries are often served as Iterator Interface**
  - Seek() and Next()



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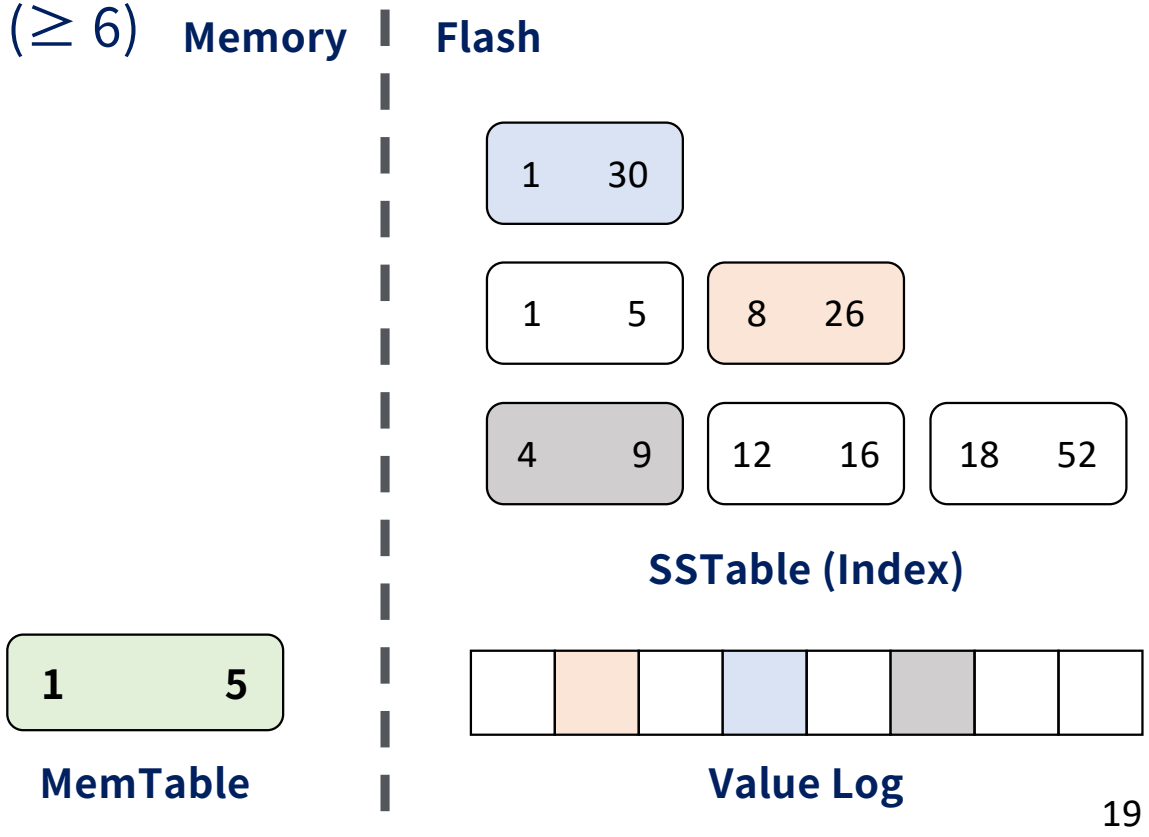

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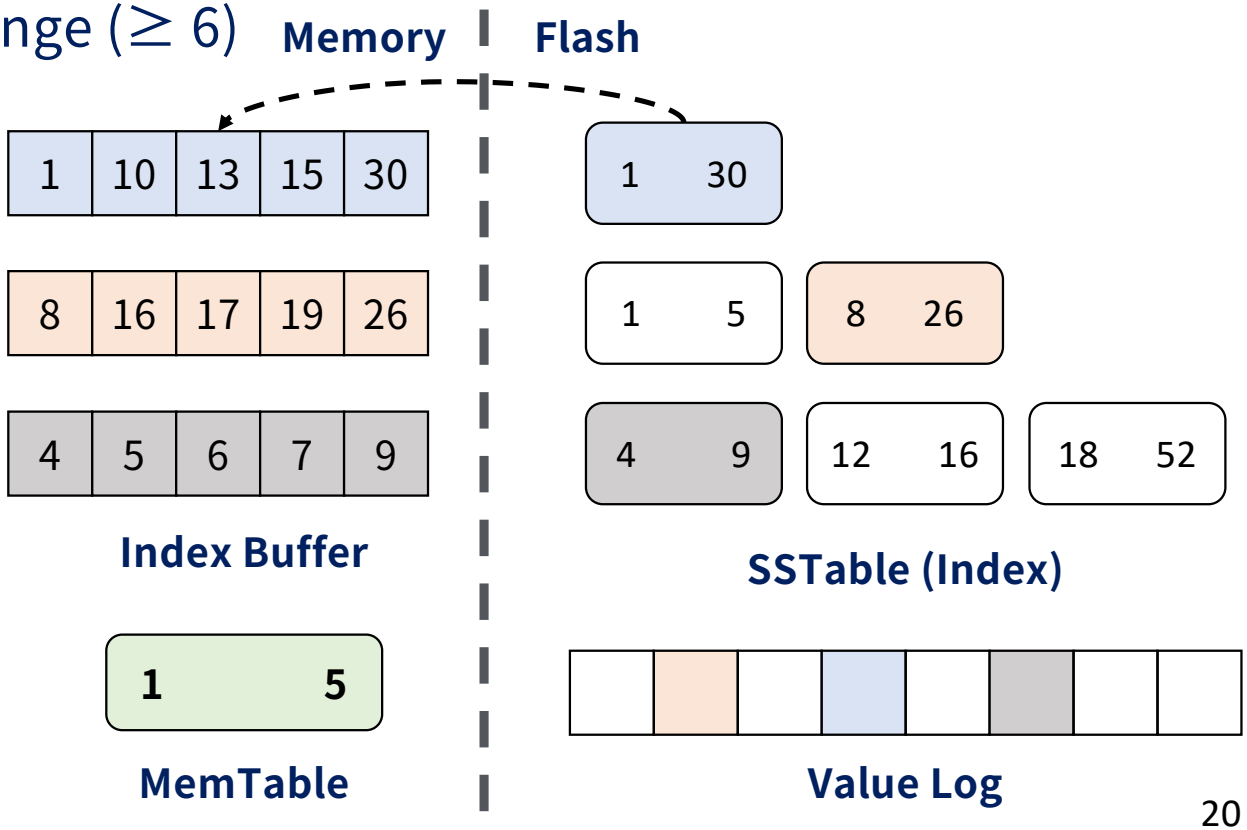

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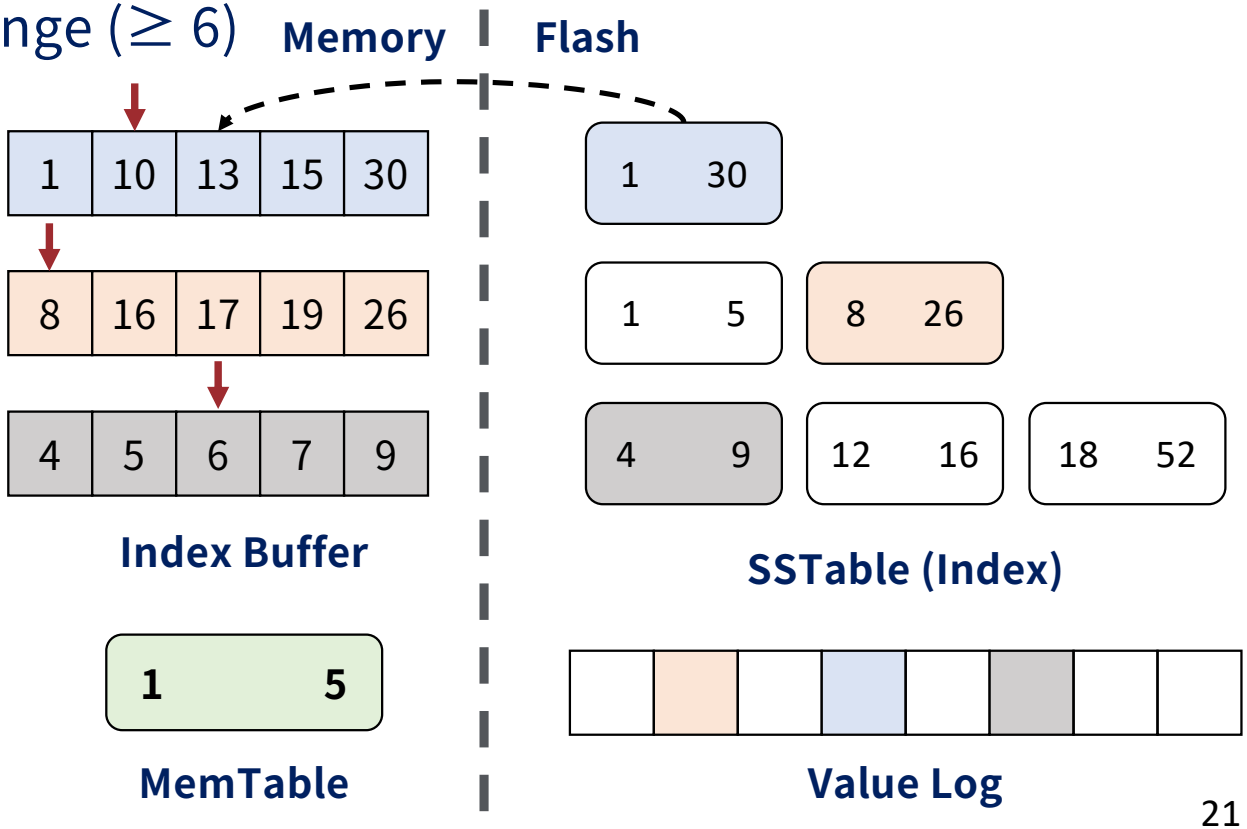

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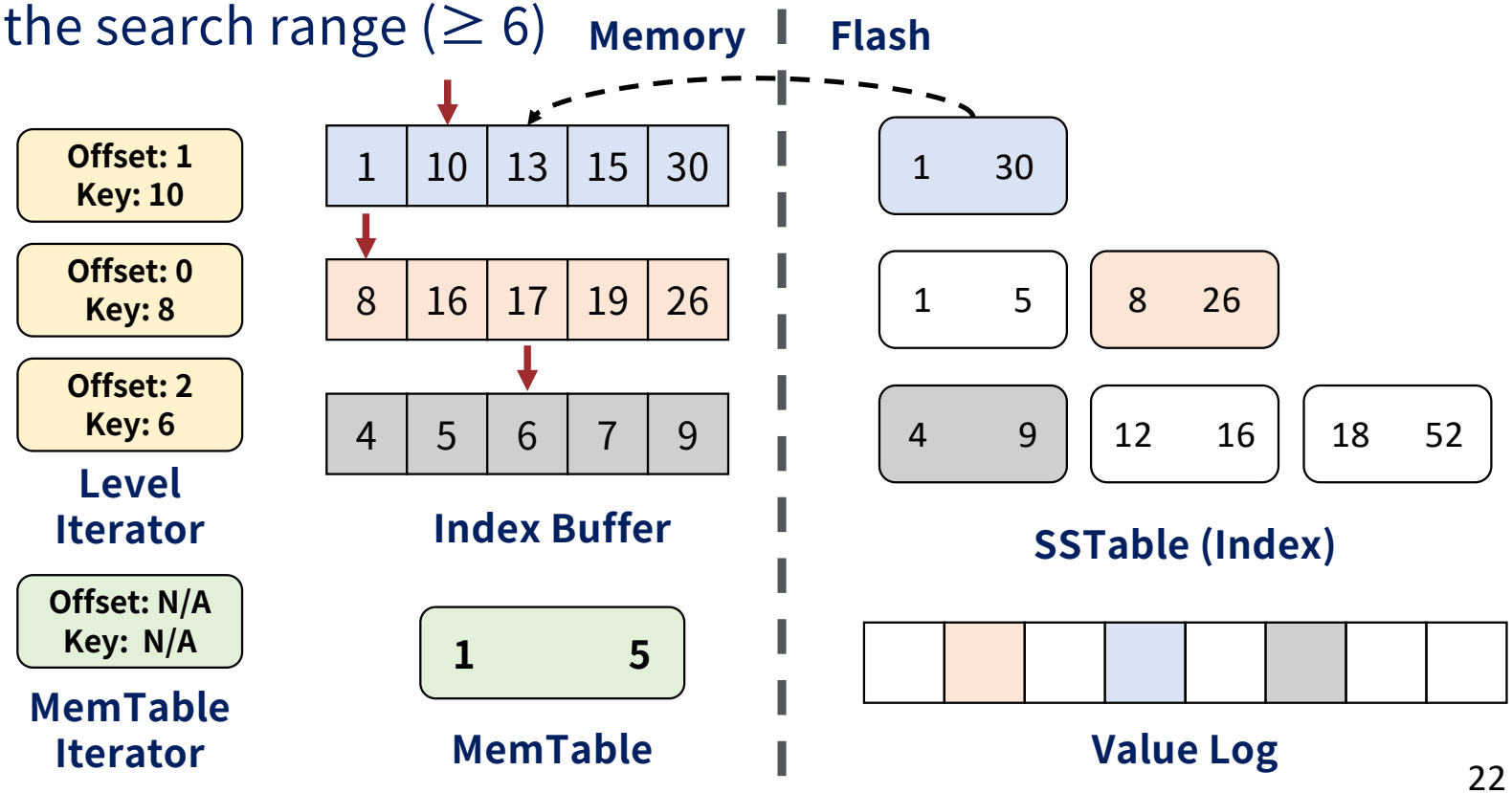

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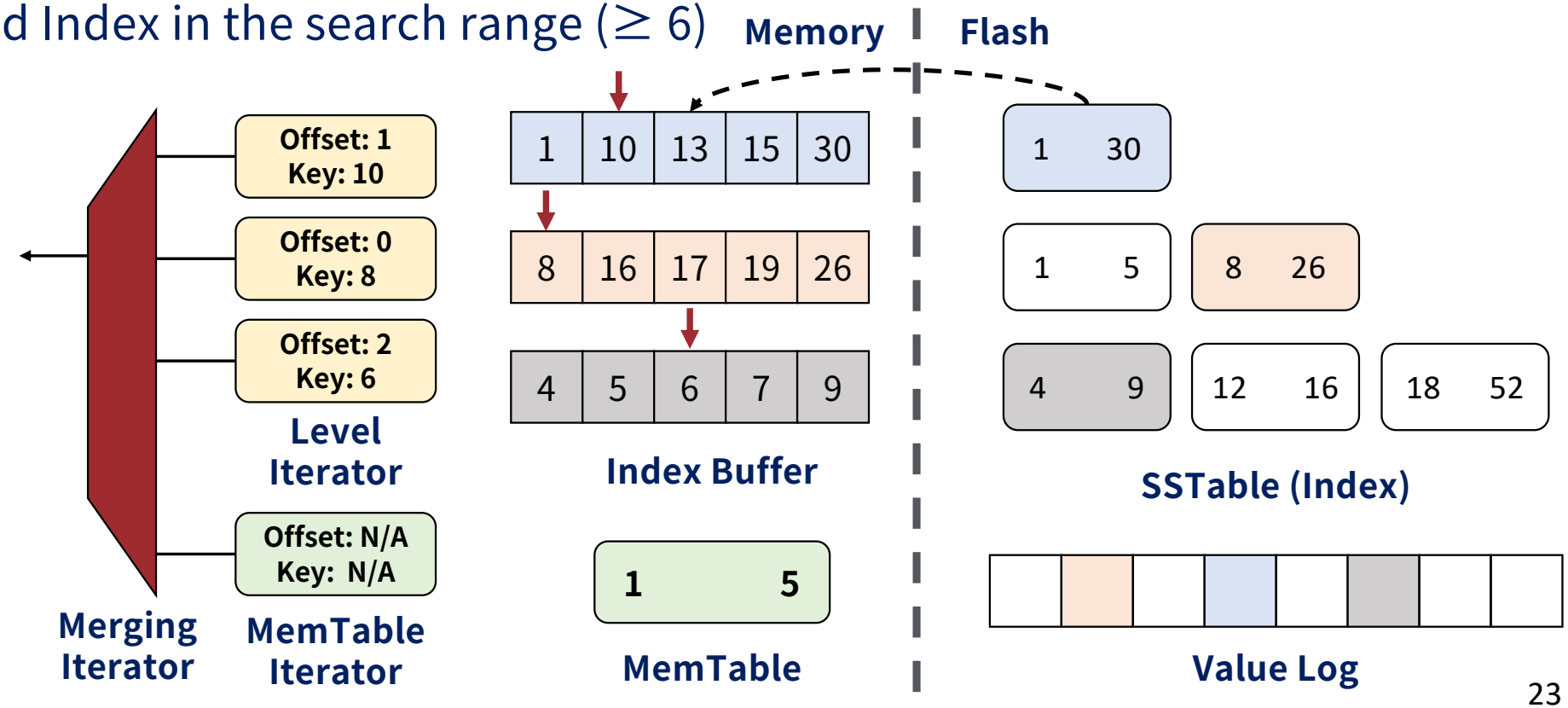

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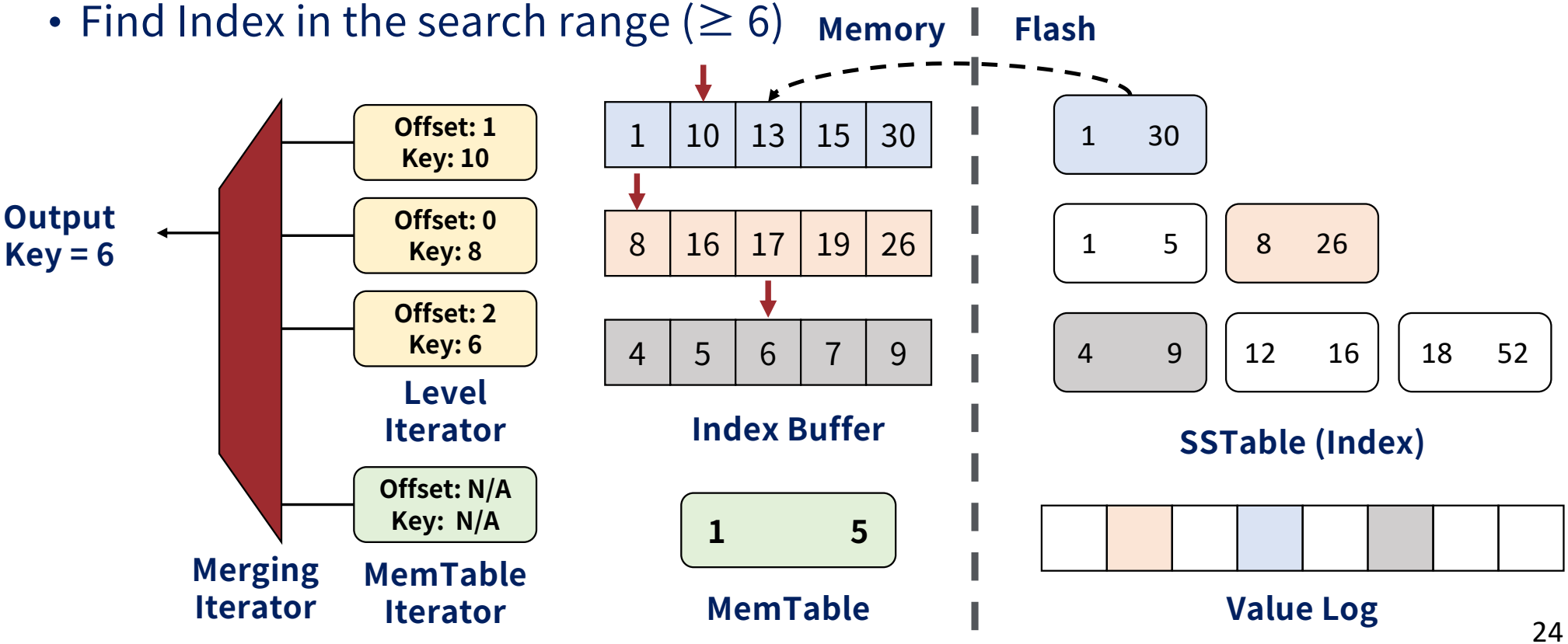

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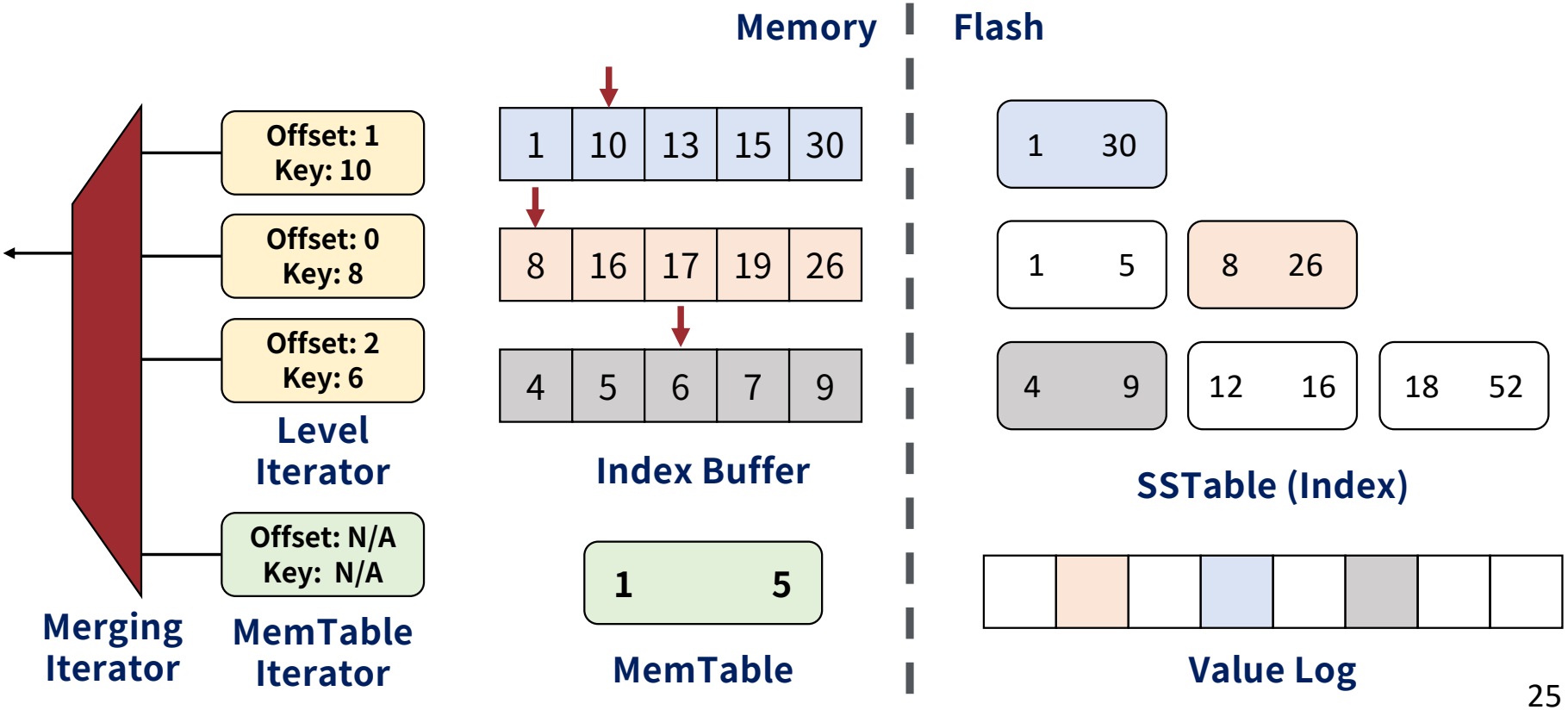

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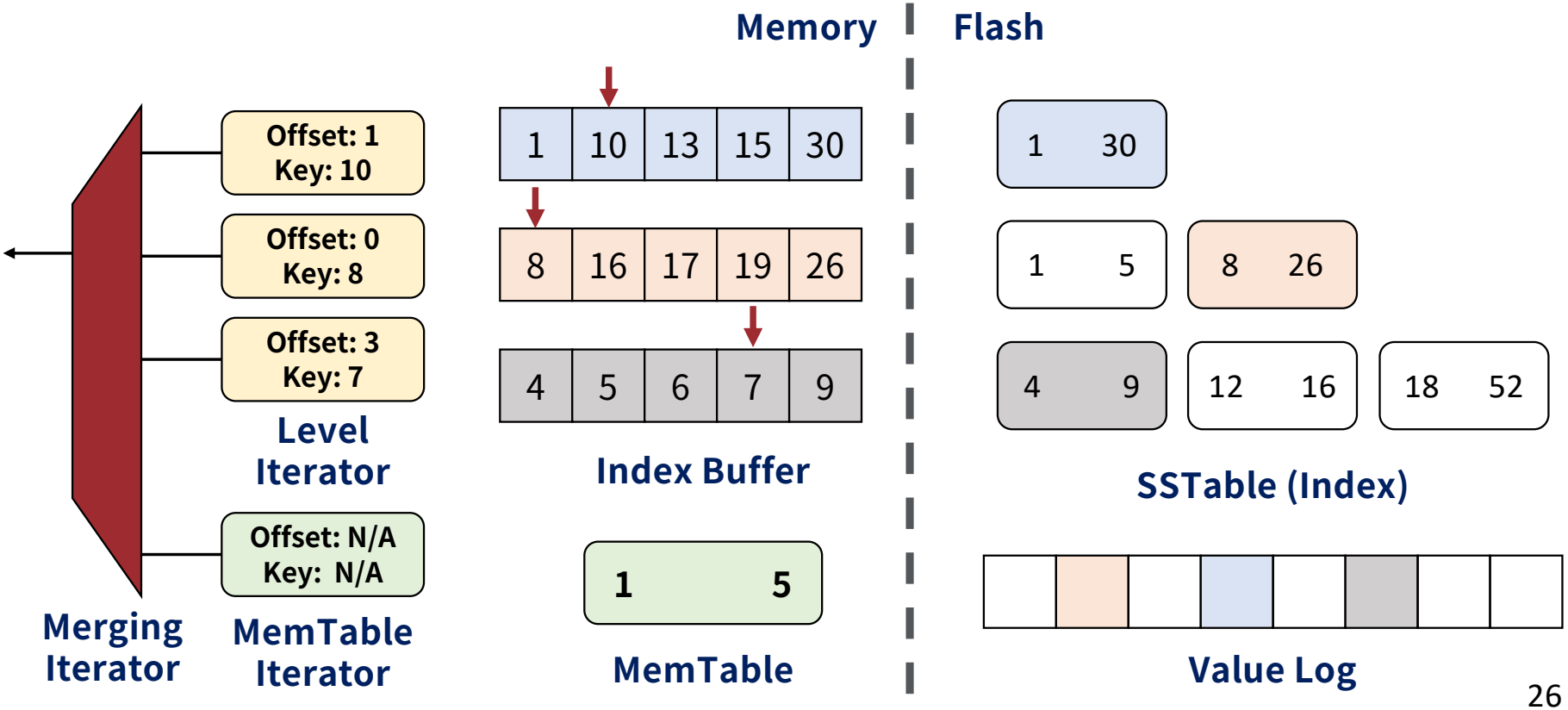

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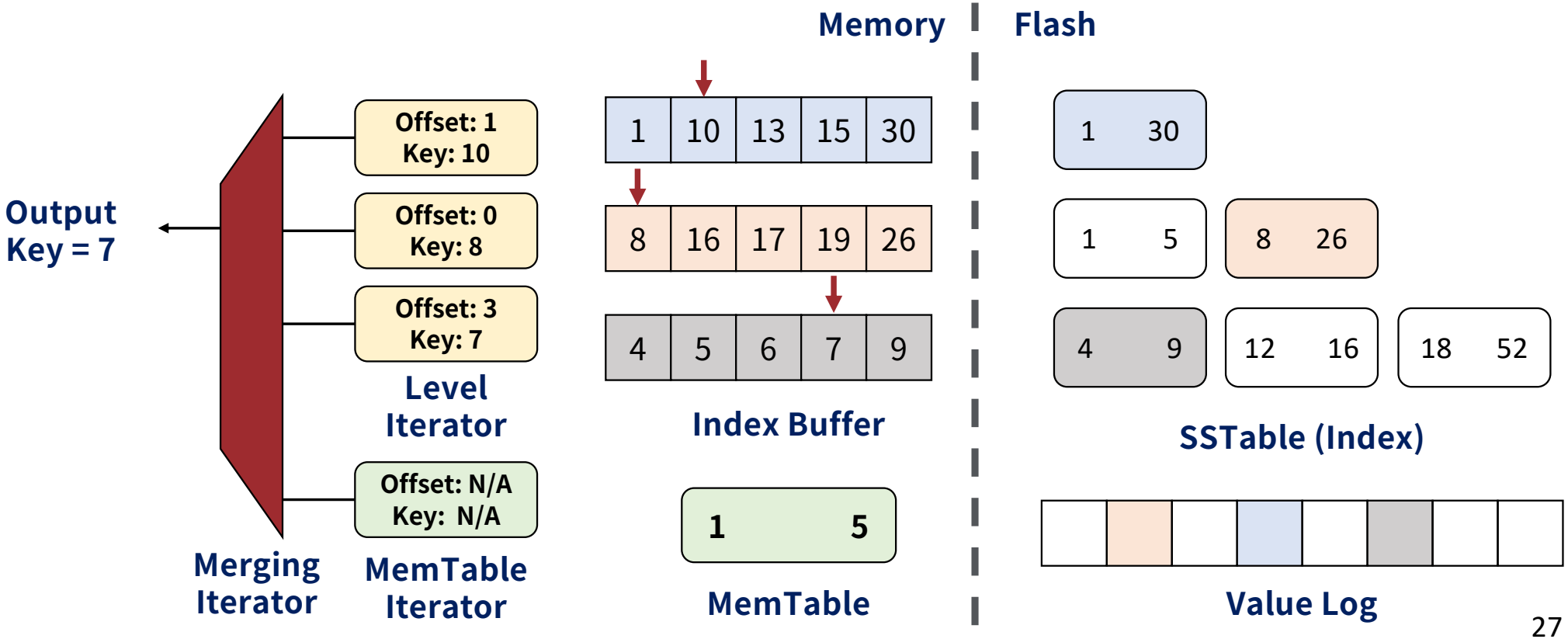

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- **Problem #3 – Poor Range Query Performance**
  - Every Seek, Next command entails Value Read from Value Log
  - This NAND Access (Value Read) incurs poor overall performance

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- **Versioning Problem**
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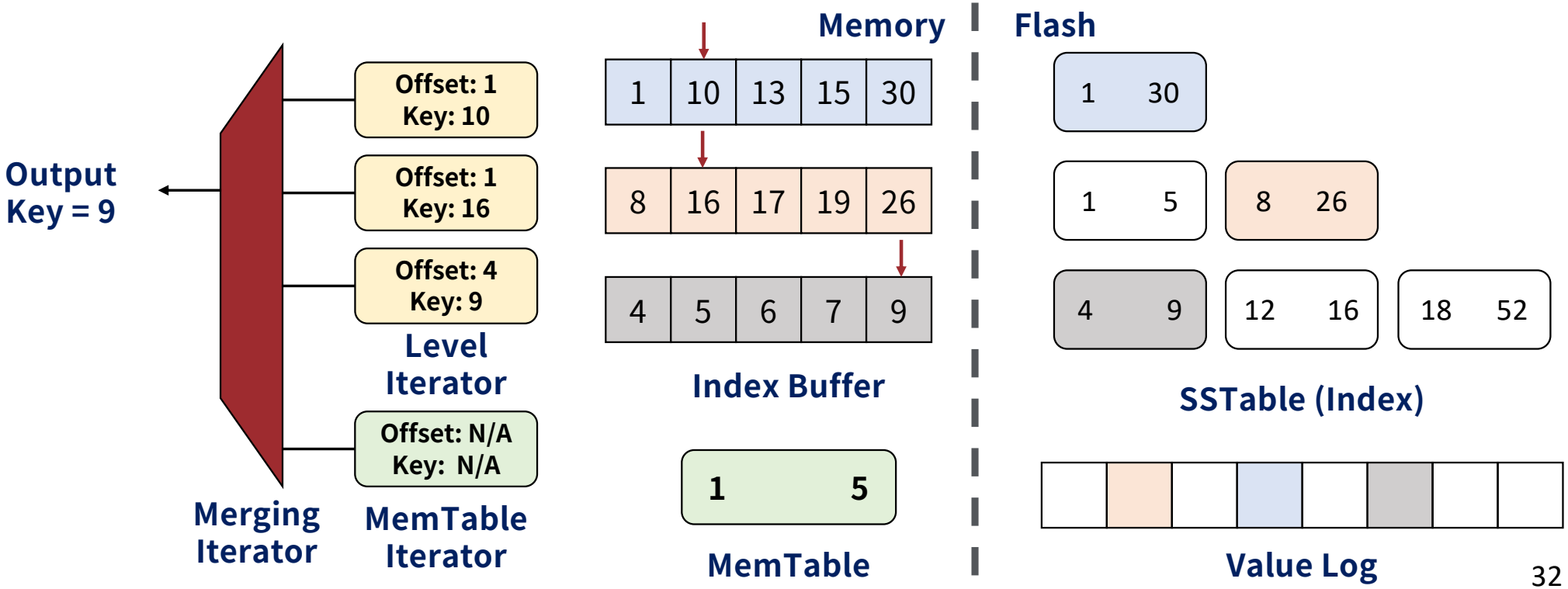

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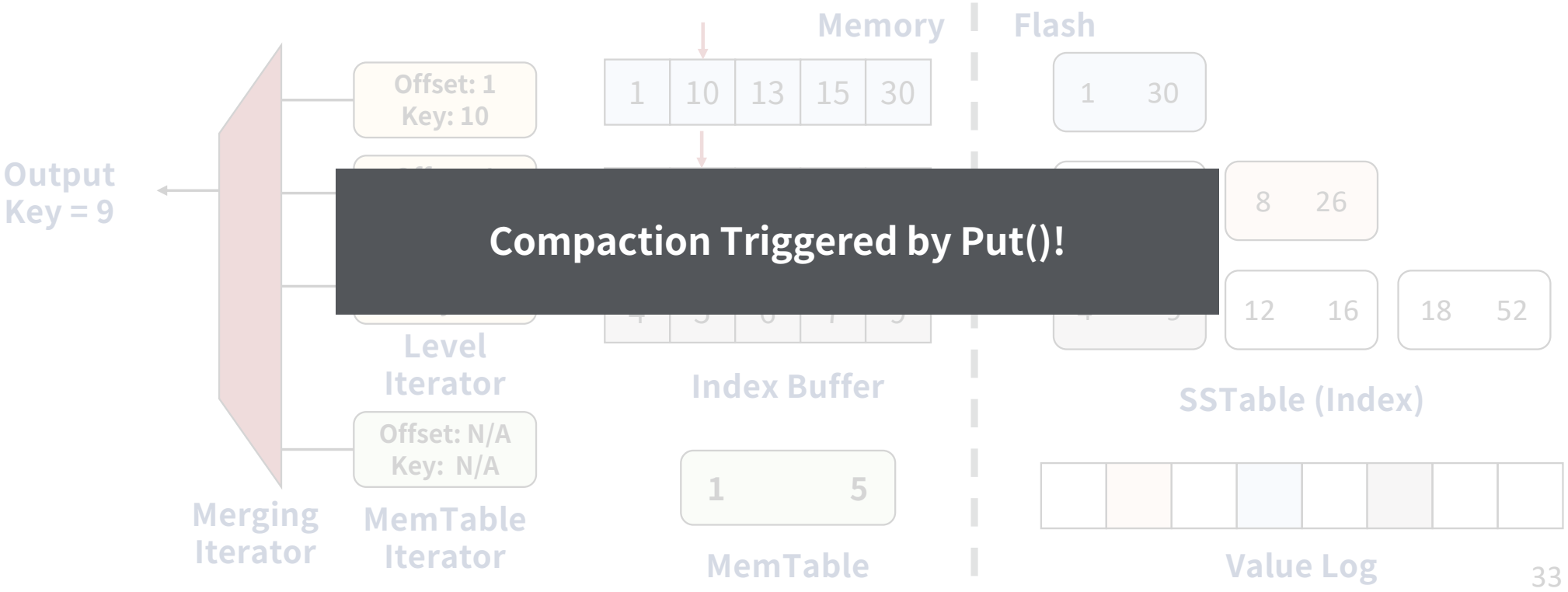

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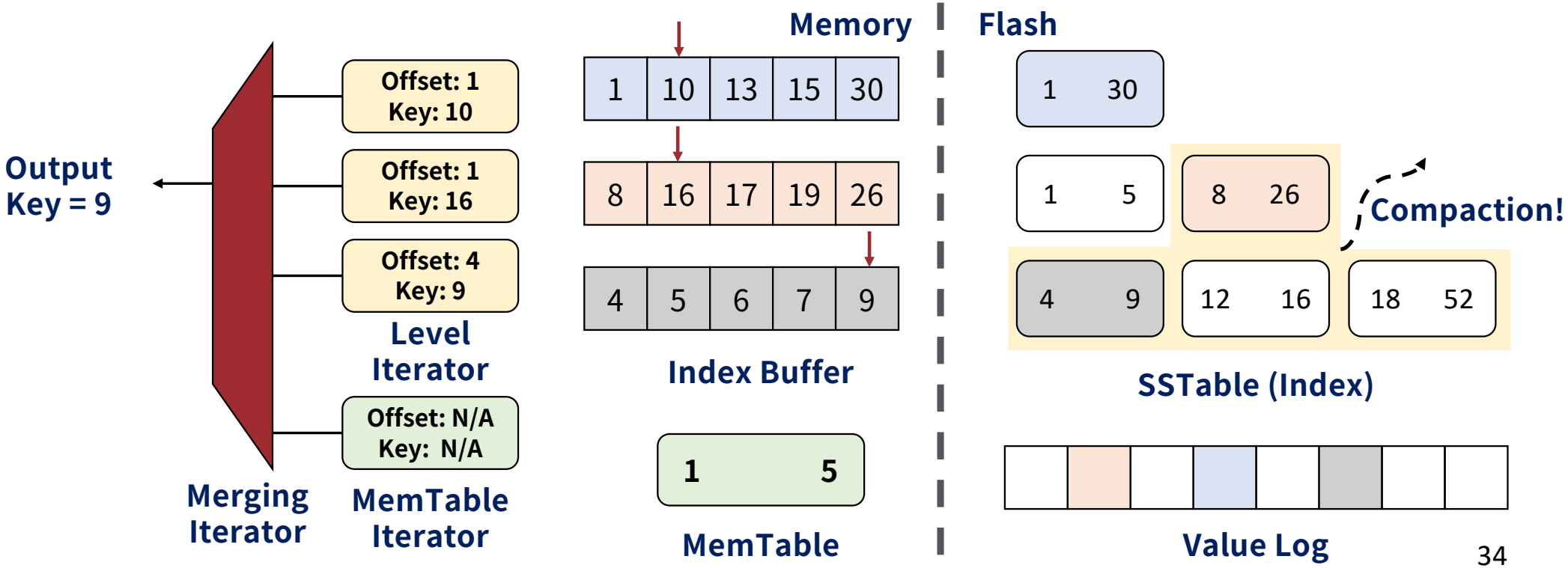

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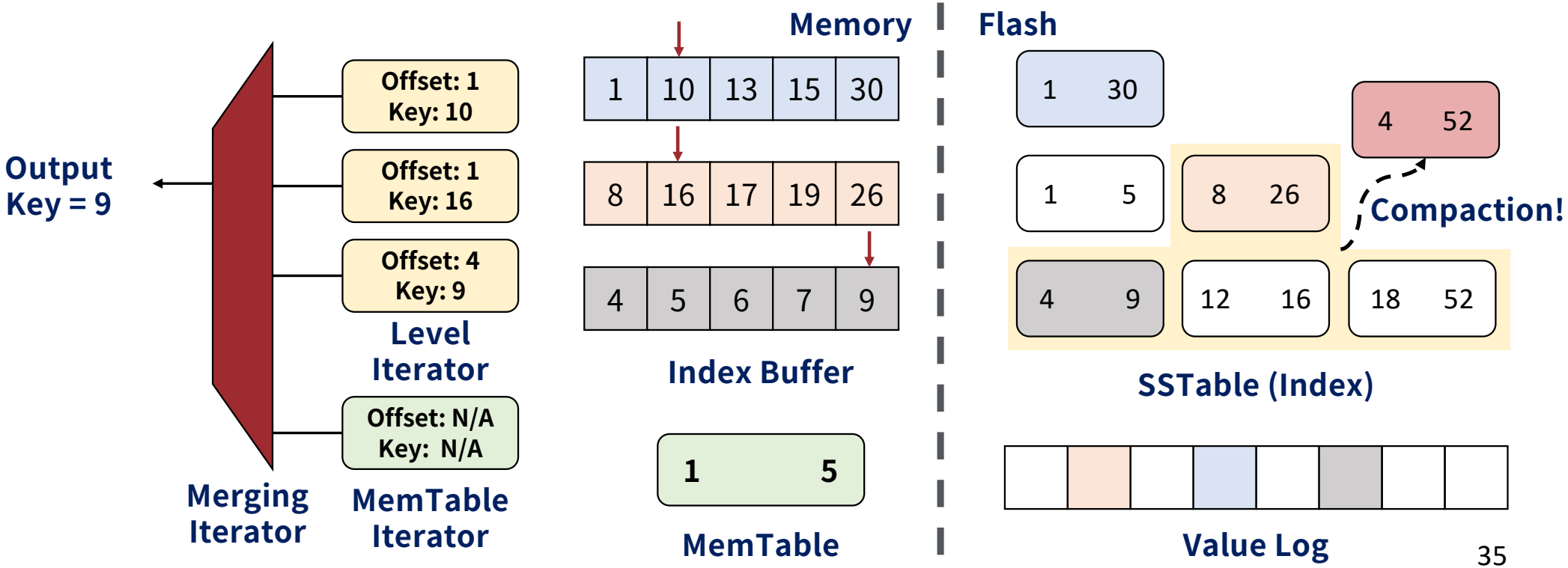

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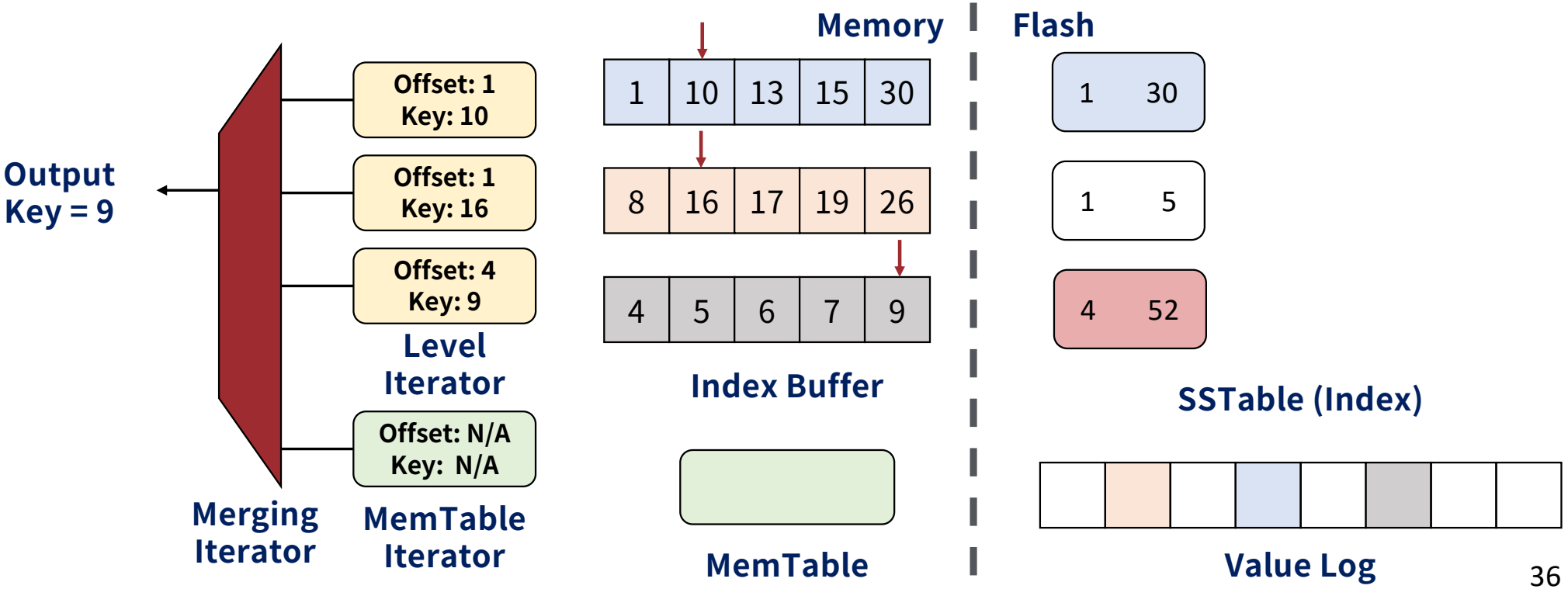

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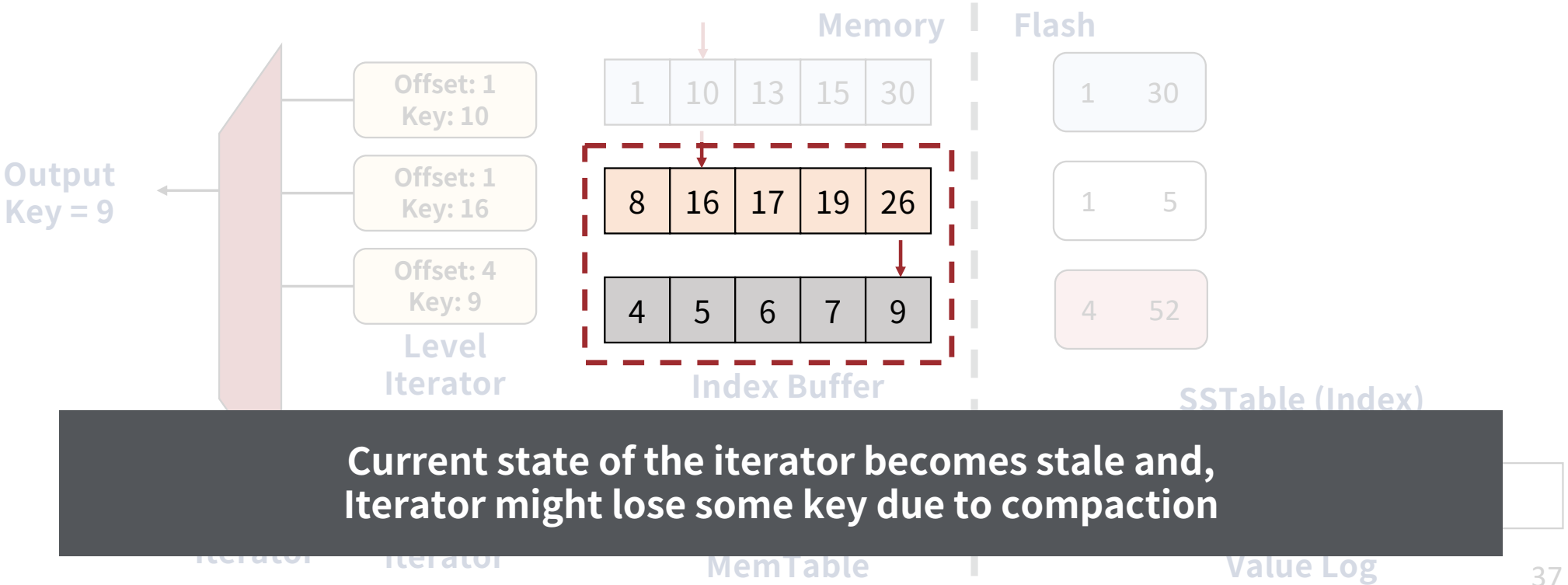

**Current state of the iterator becomes stale and,
Iterator might lose some key due to compaction**

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However, inside the device, memory-efficient versioning is needed!

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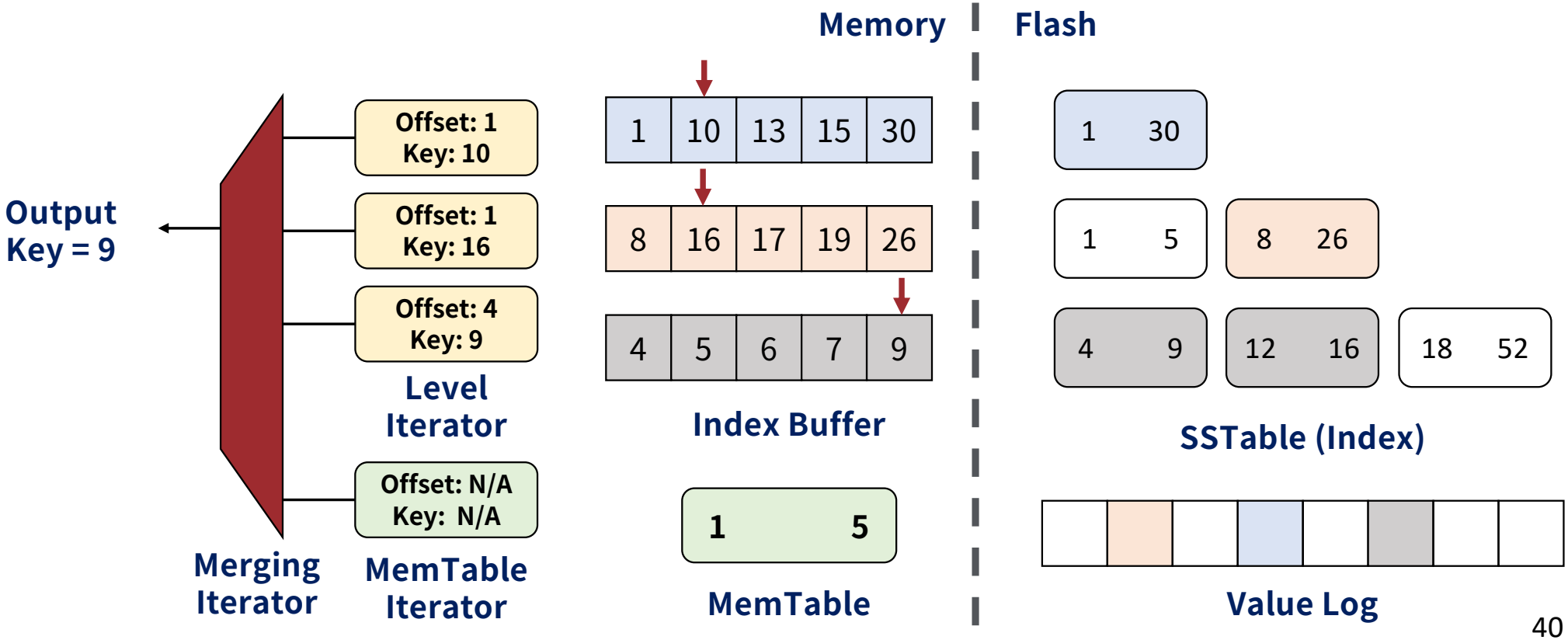
- **Synchronous NAND Flash Access for Index Read**



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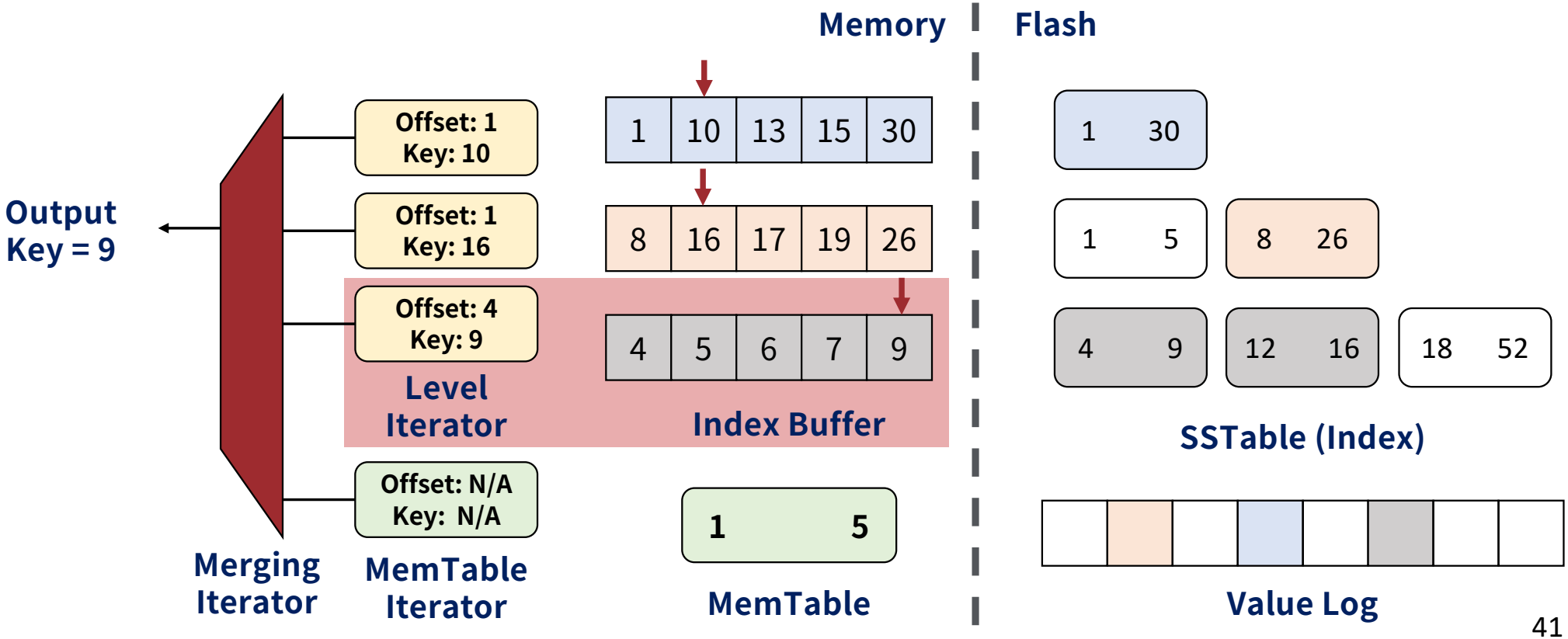

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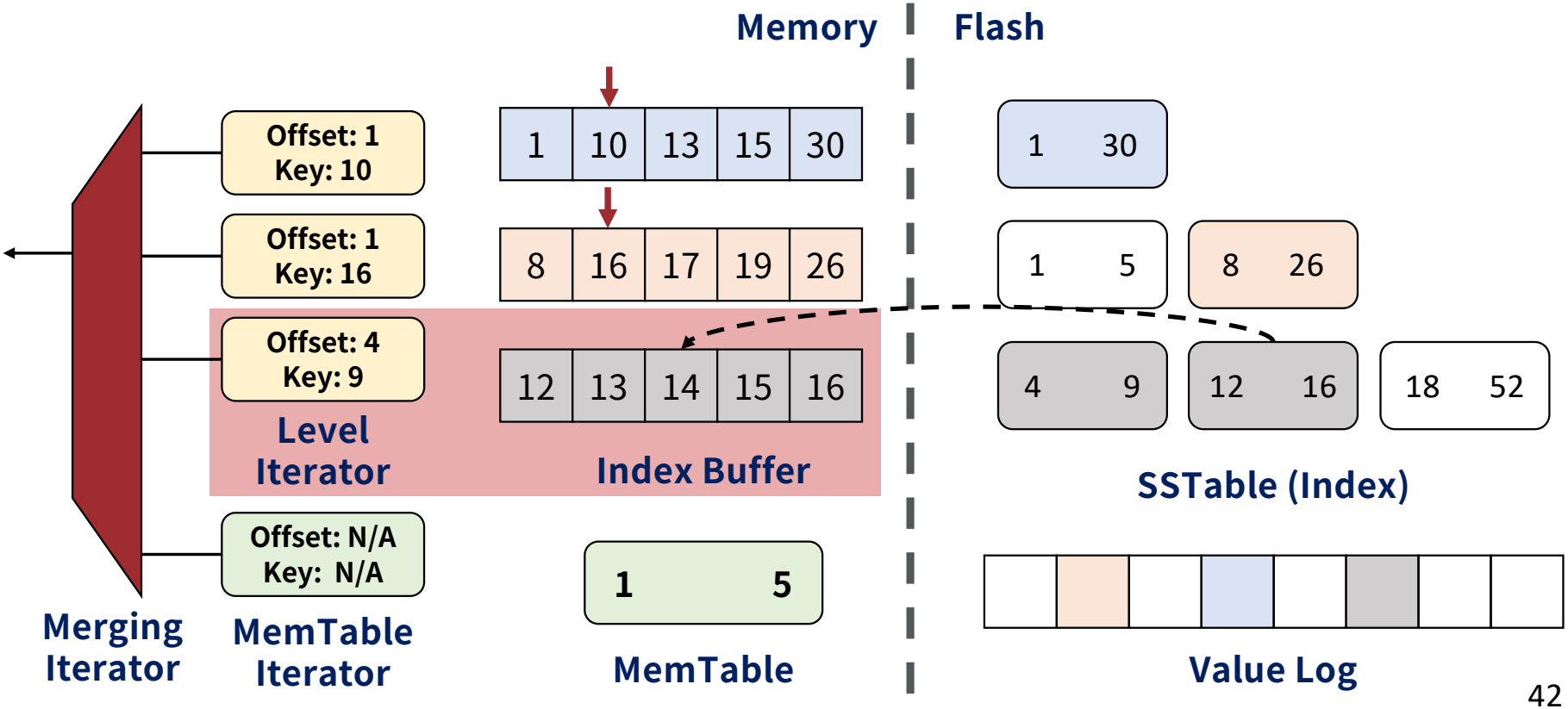

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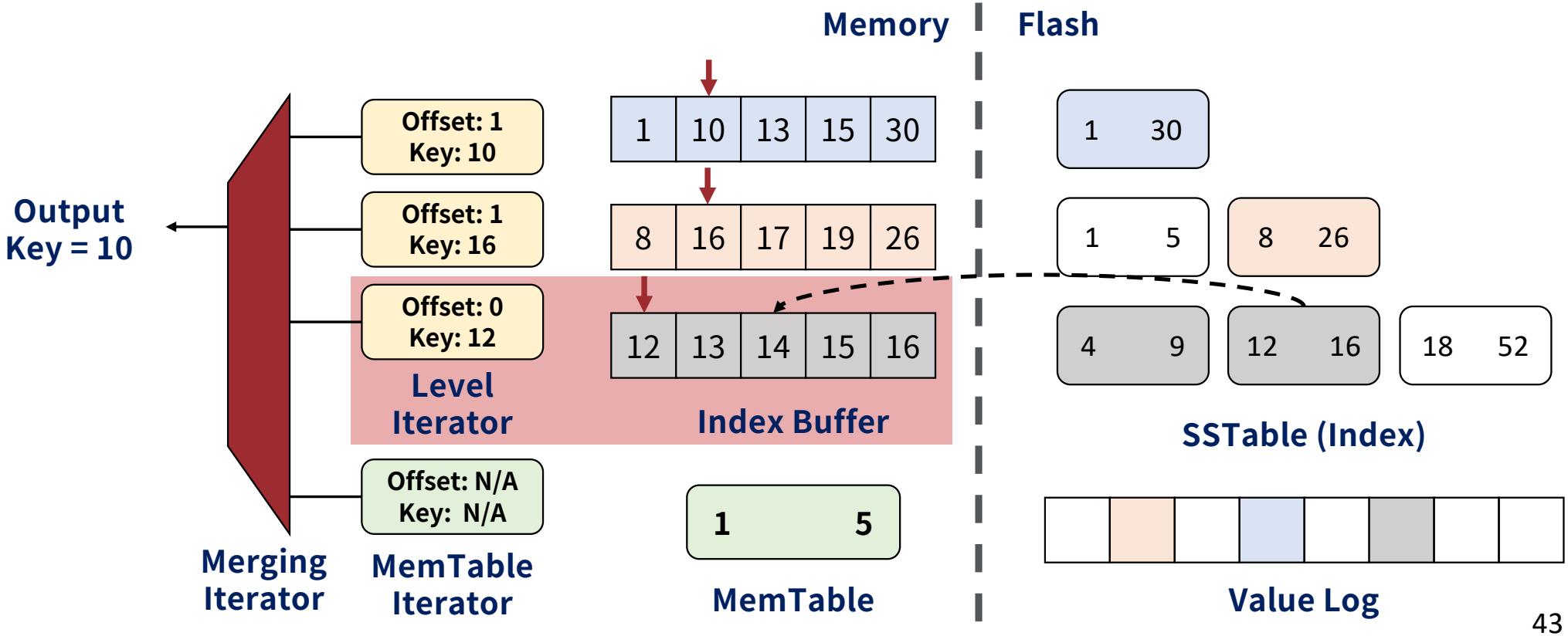


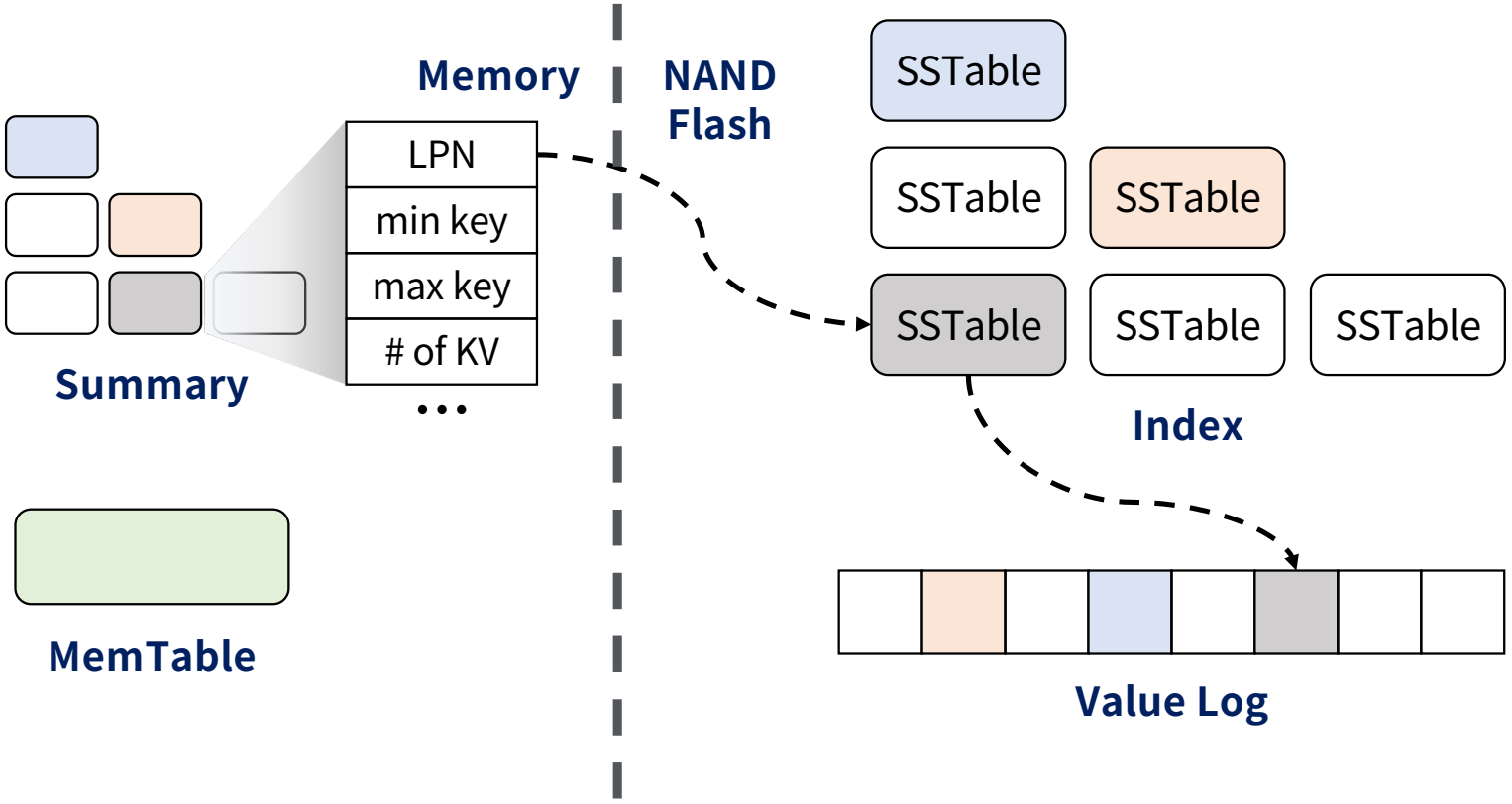
Problem #3 – Synchronous Value Read

- **Design Challenge #3 – NAND Flash Access for Value Read**
  - **Every Seek() and Next() command** requires NAND Flash Access for Value
  - Considering that NAND Flash access is much slower than the other steps, synchronous NAND Flash access for Value may woefully aggravate the overall performance

Design of IterKVSSD

Memory Efficient Versioning Data Structure

- How to support Versioning inside the device?



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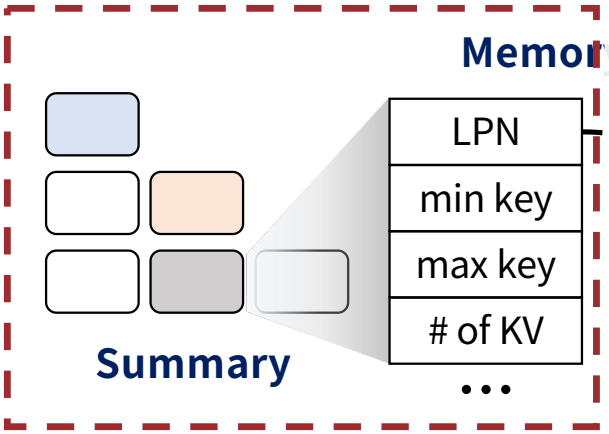

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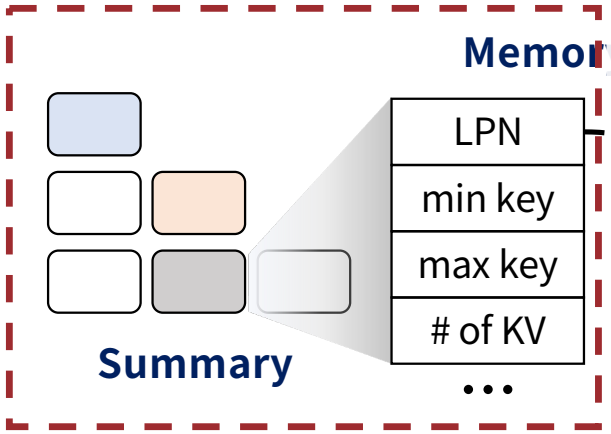

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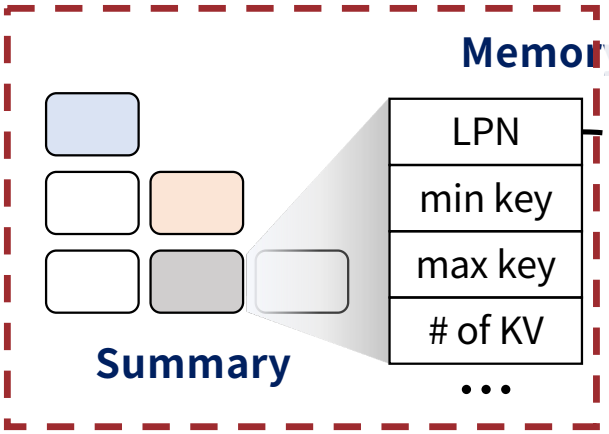

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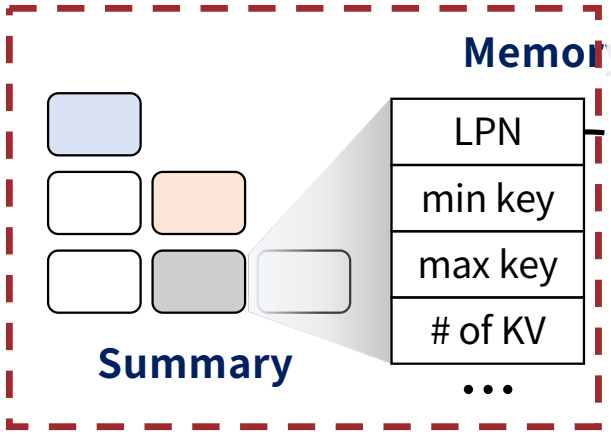

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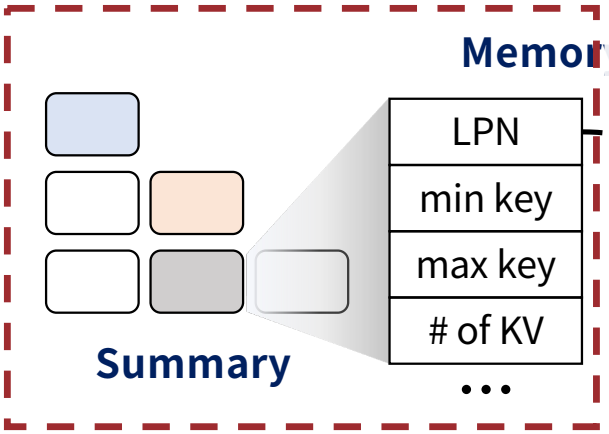

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Keeping Summary for every Iterator is too expensive!

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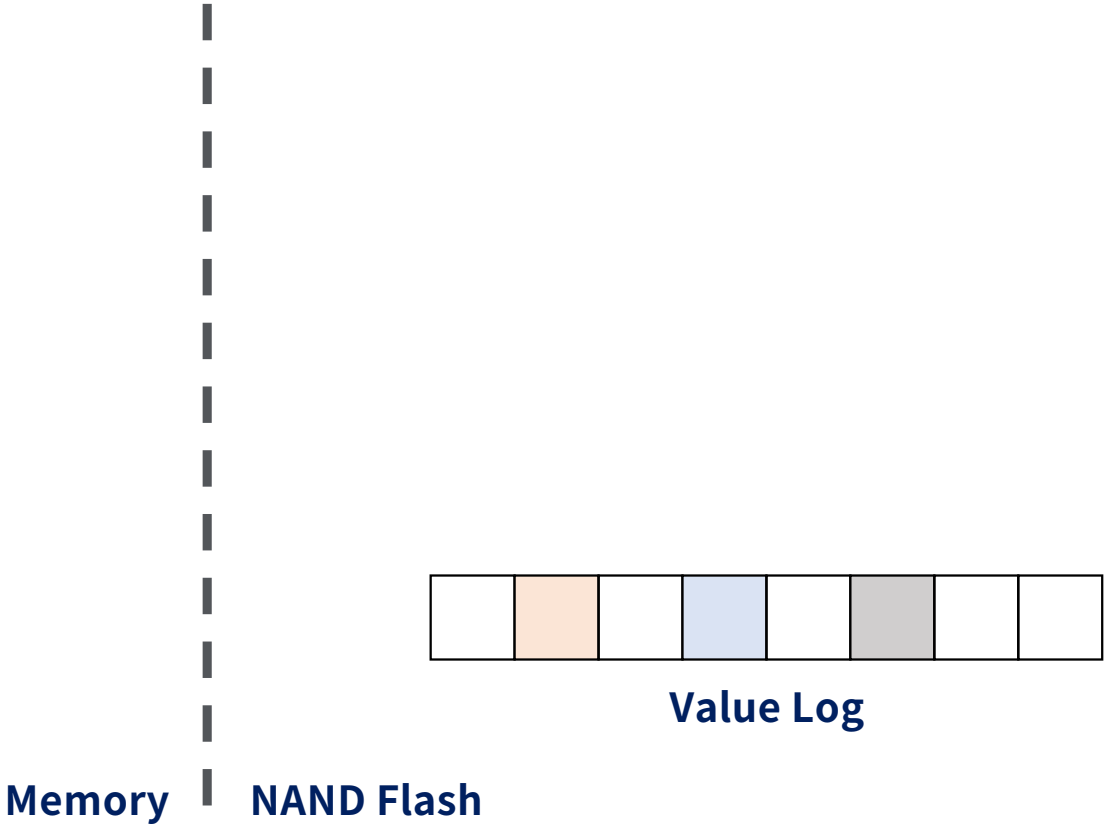

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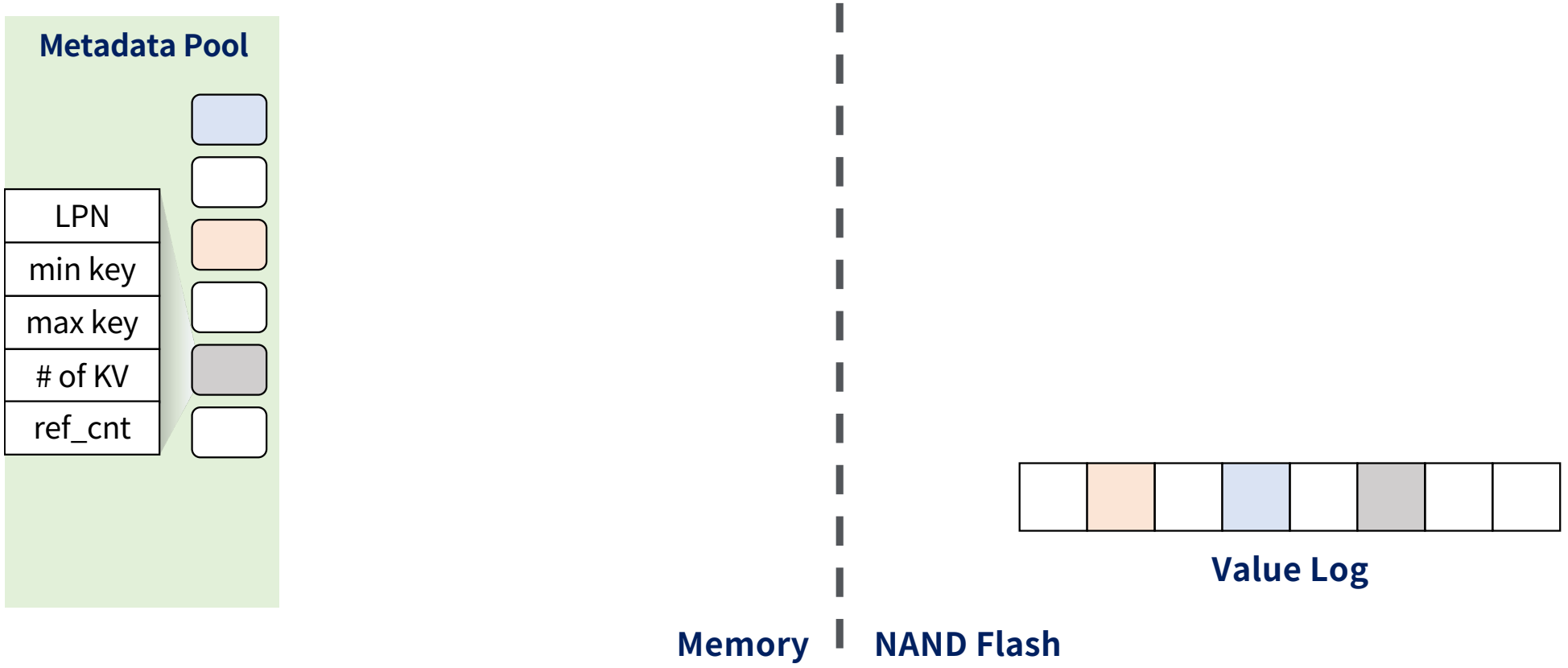

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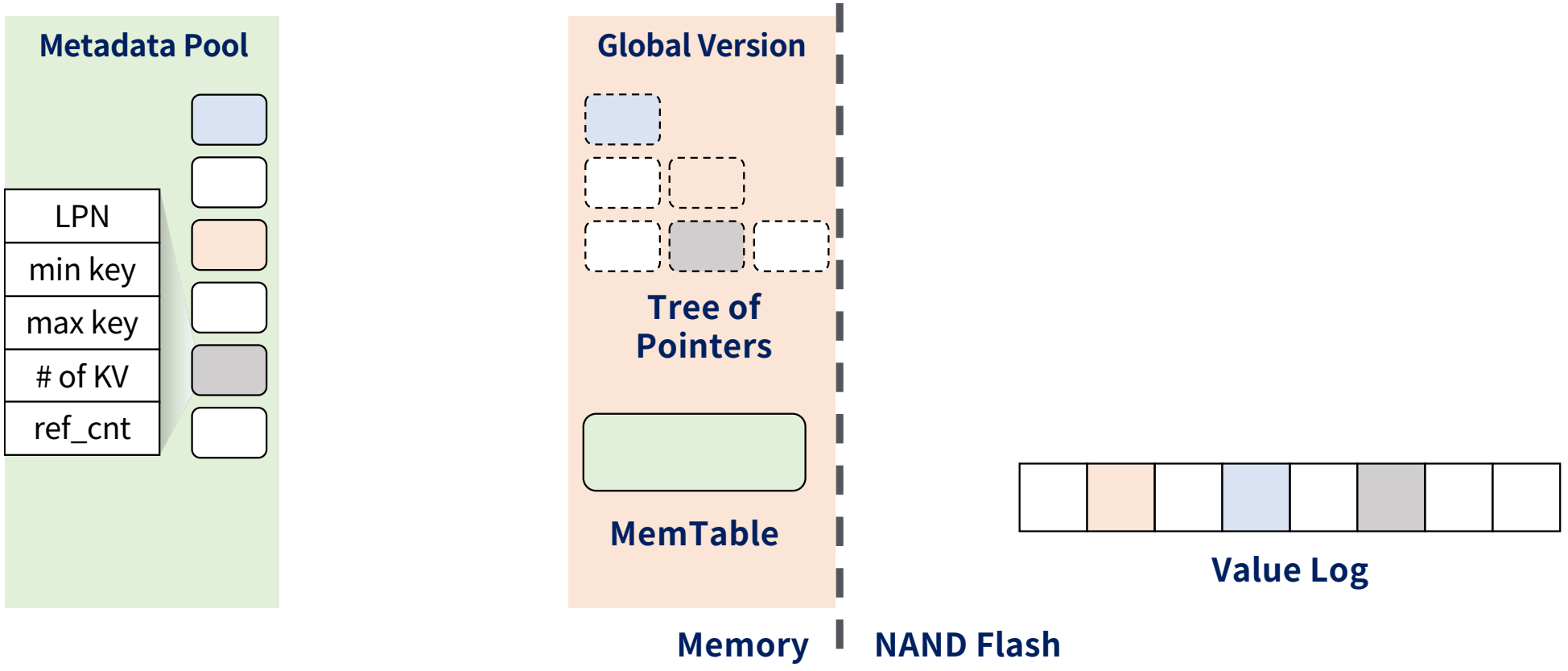

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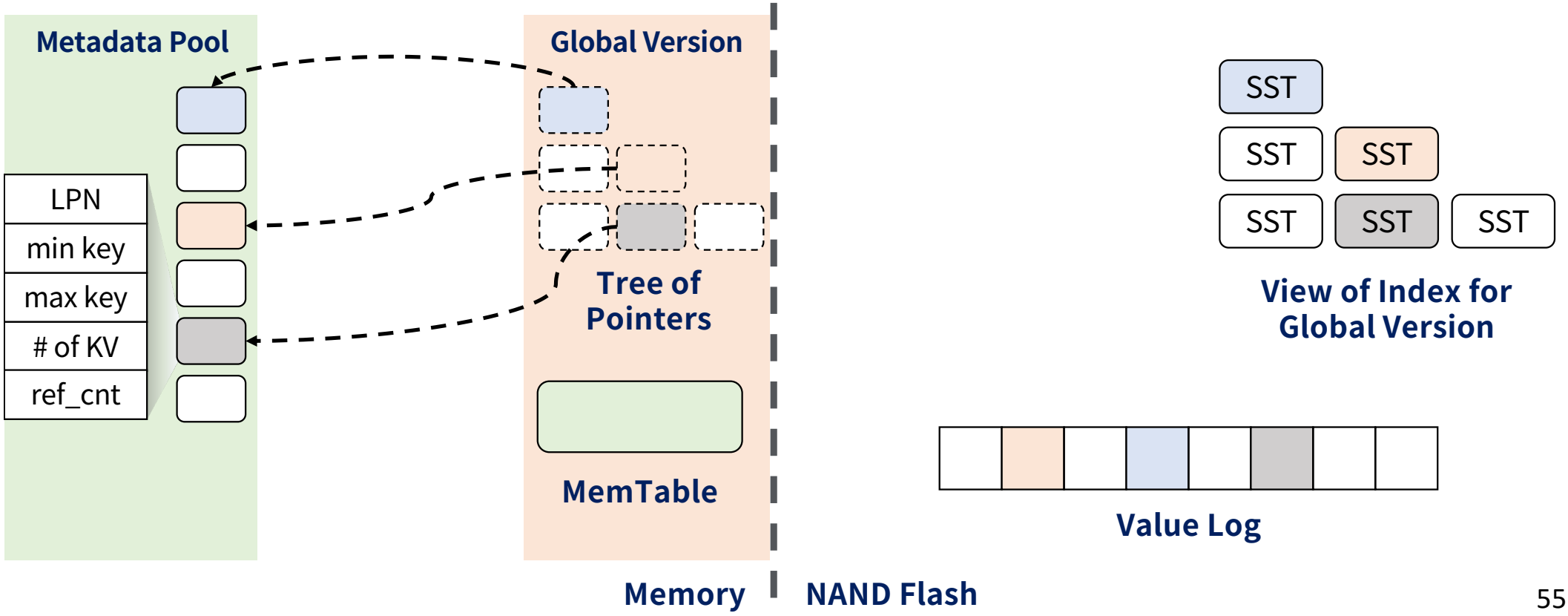

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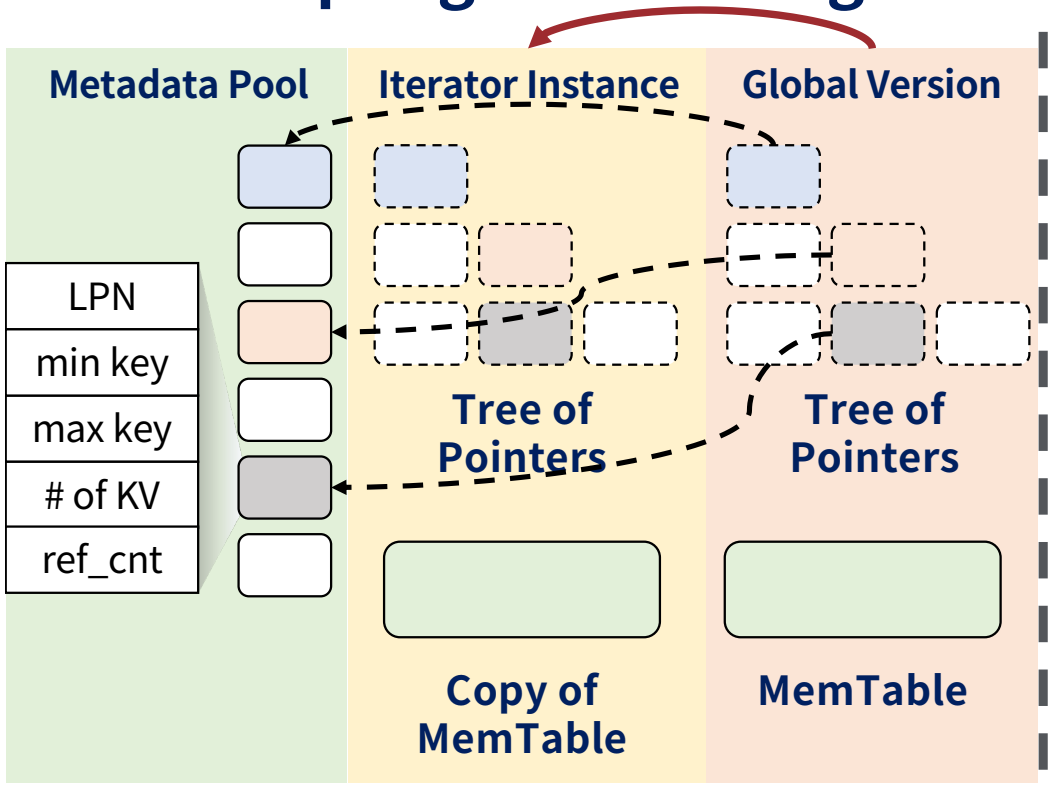

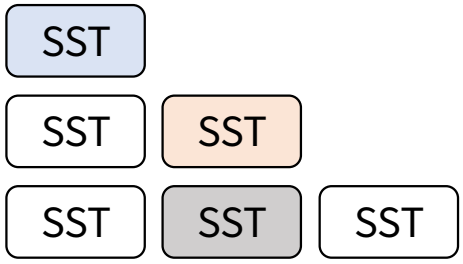

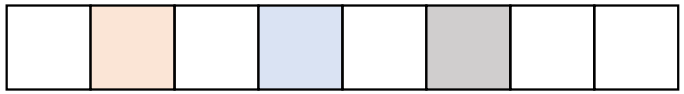

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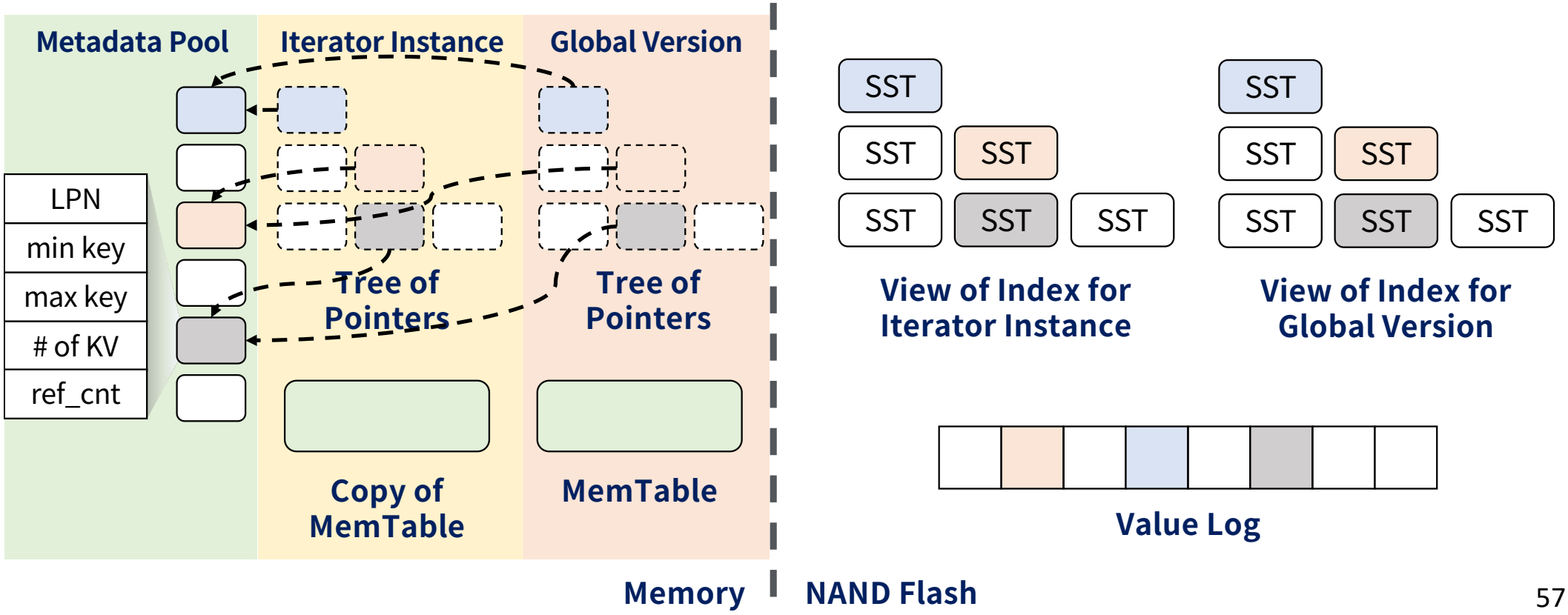

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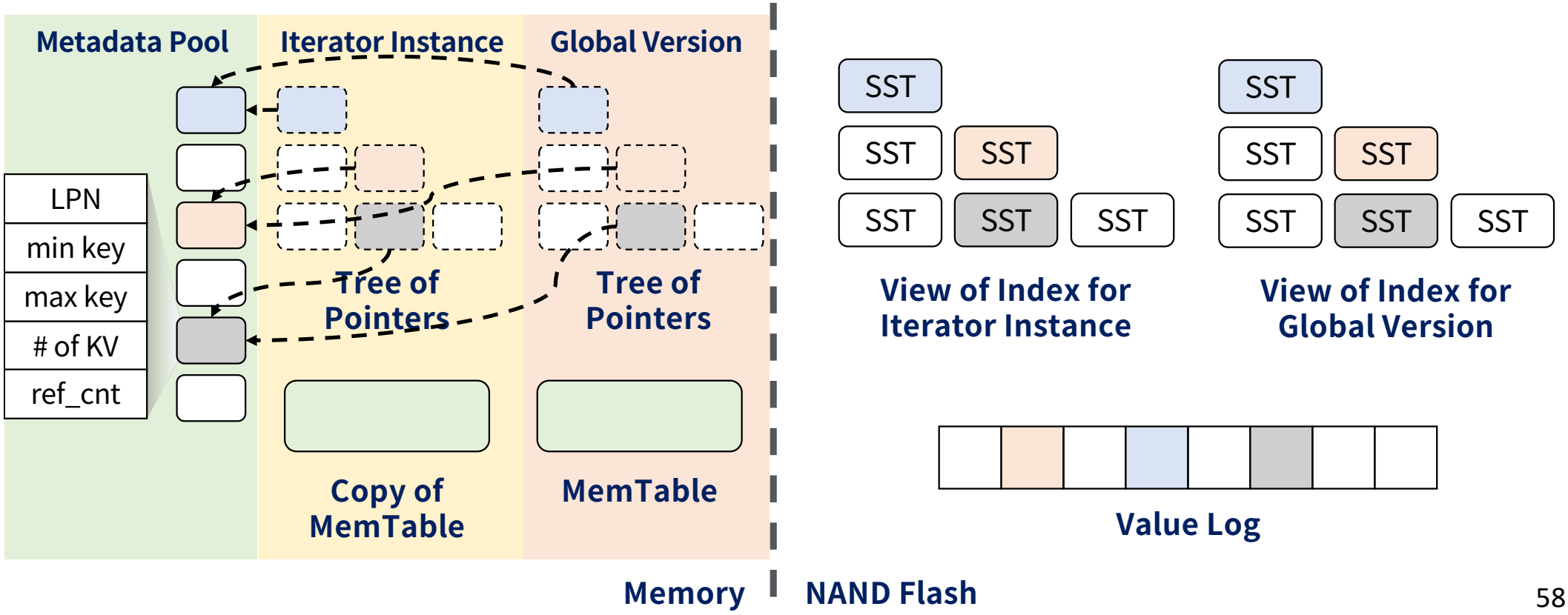

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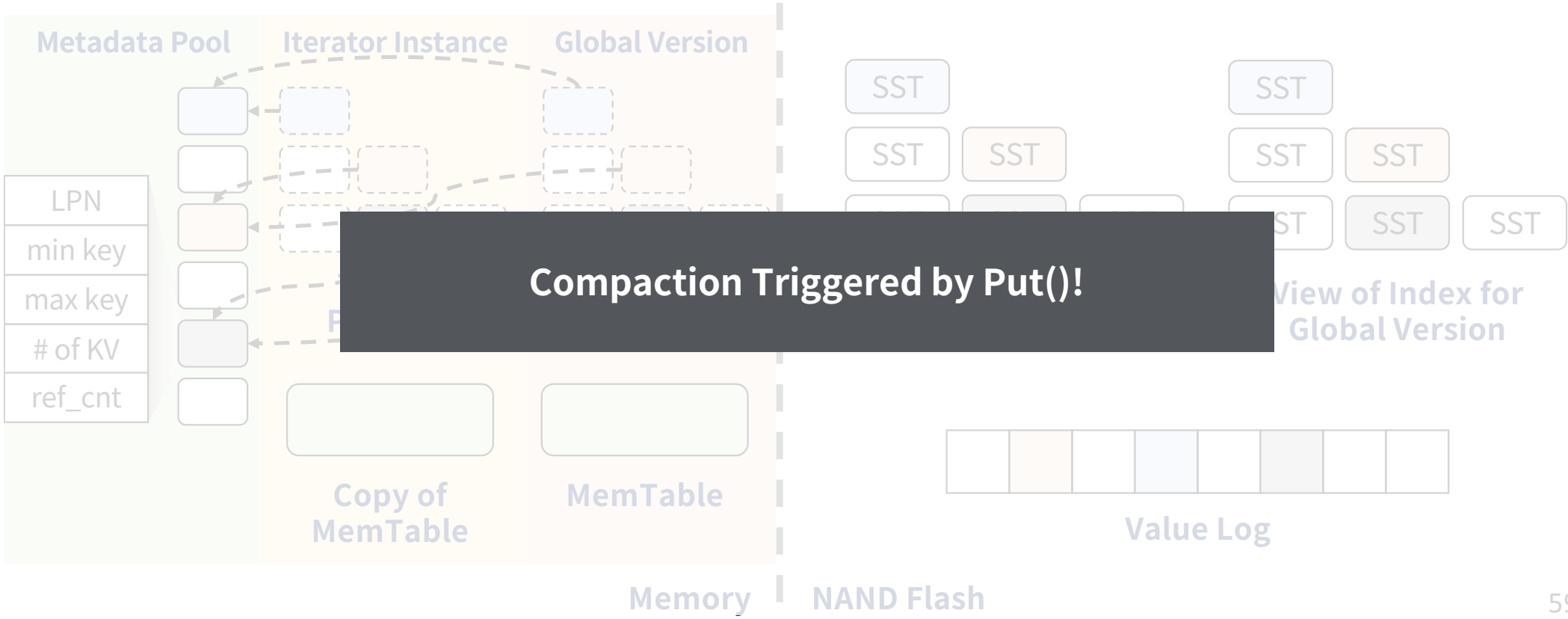

Compaction Triggered by Put()!

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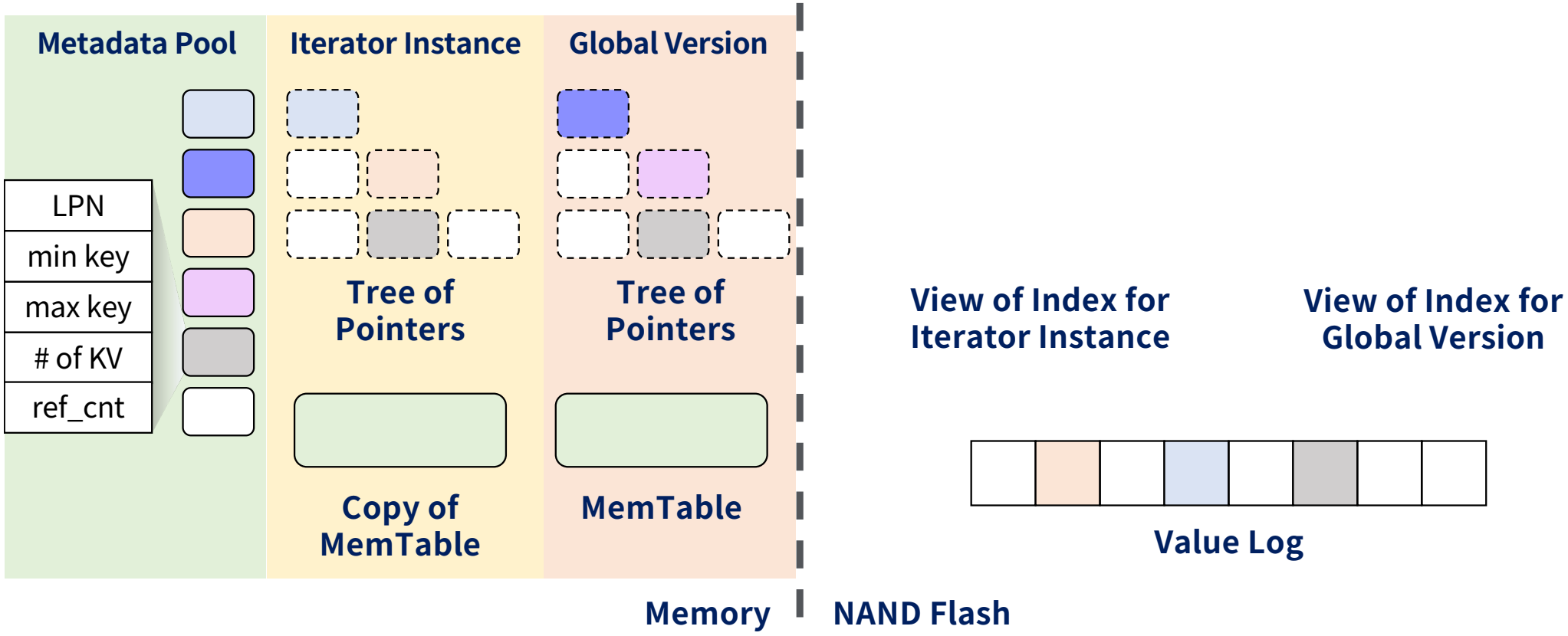

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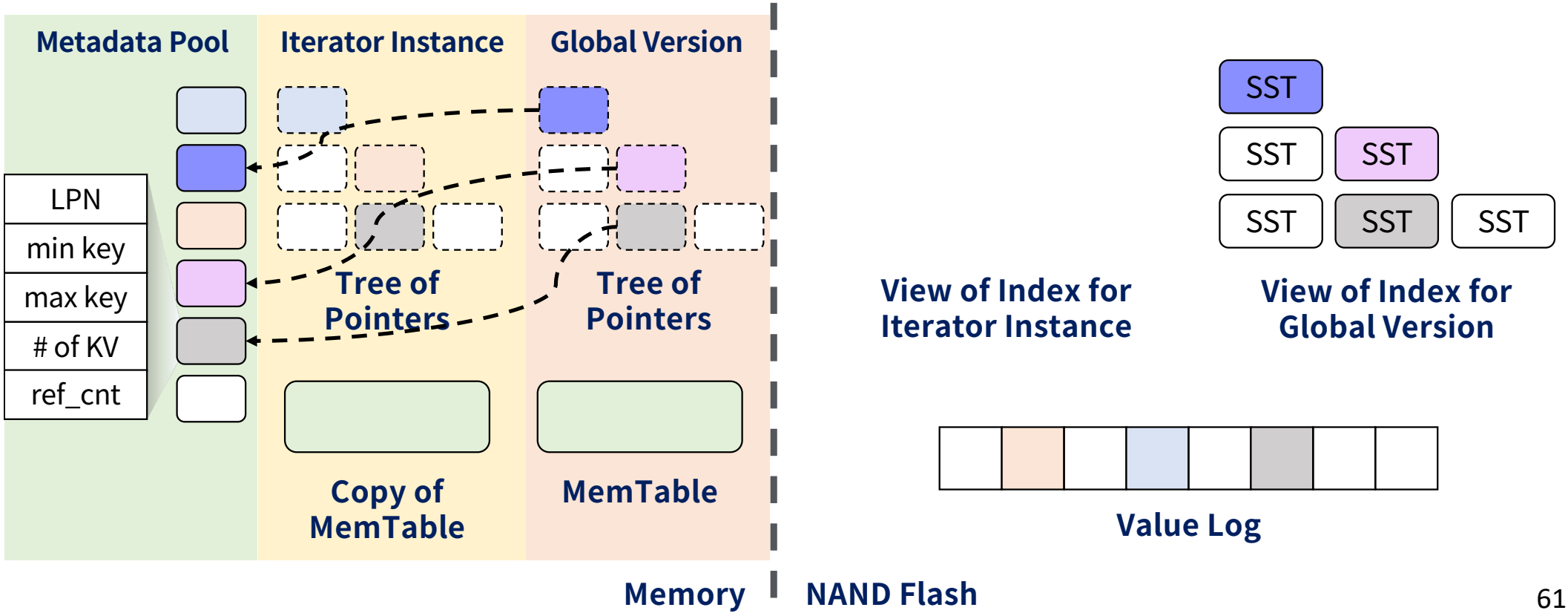

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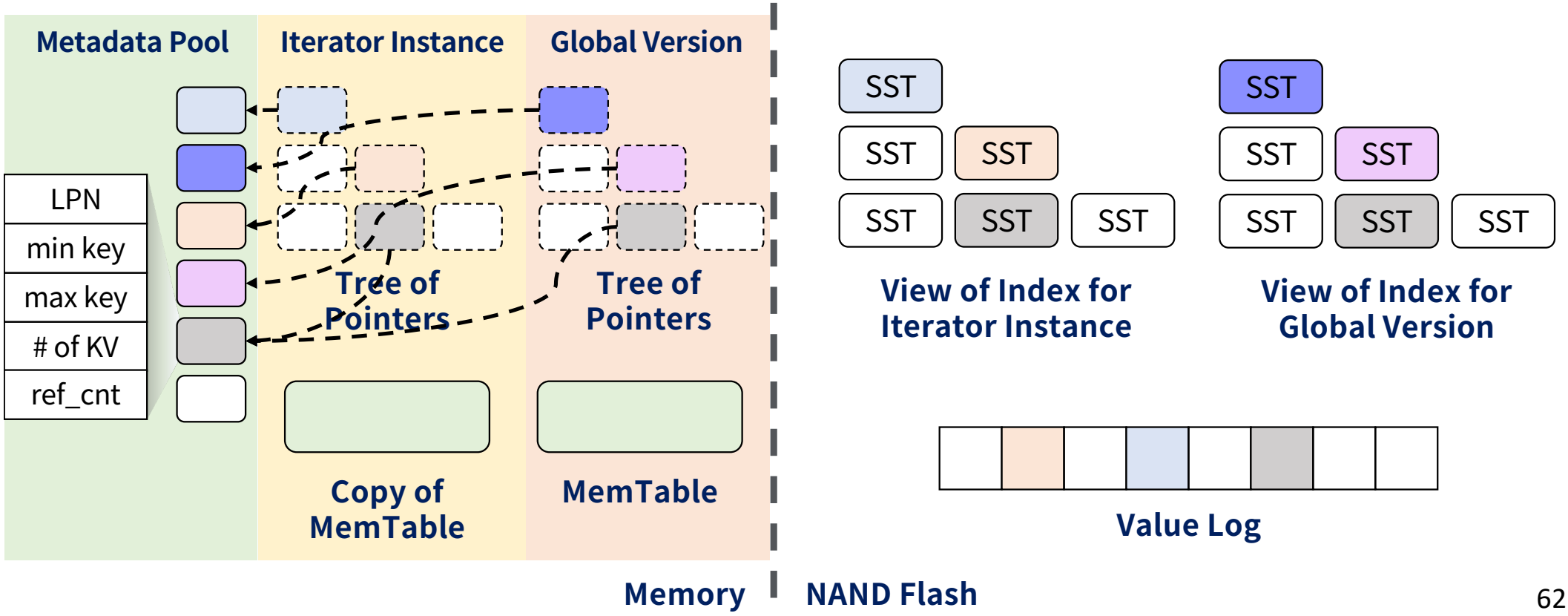

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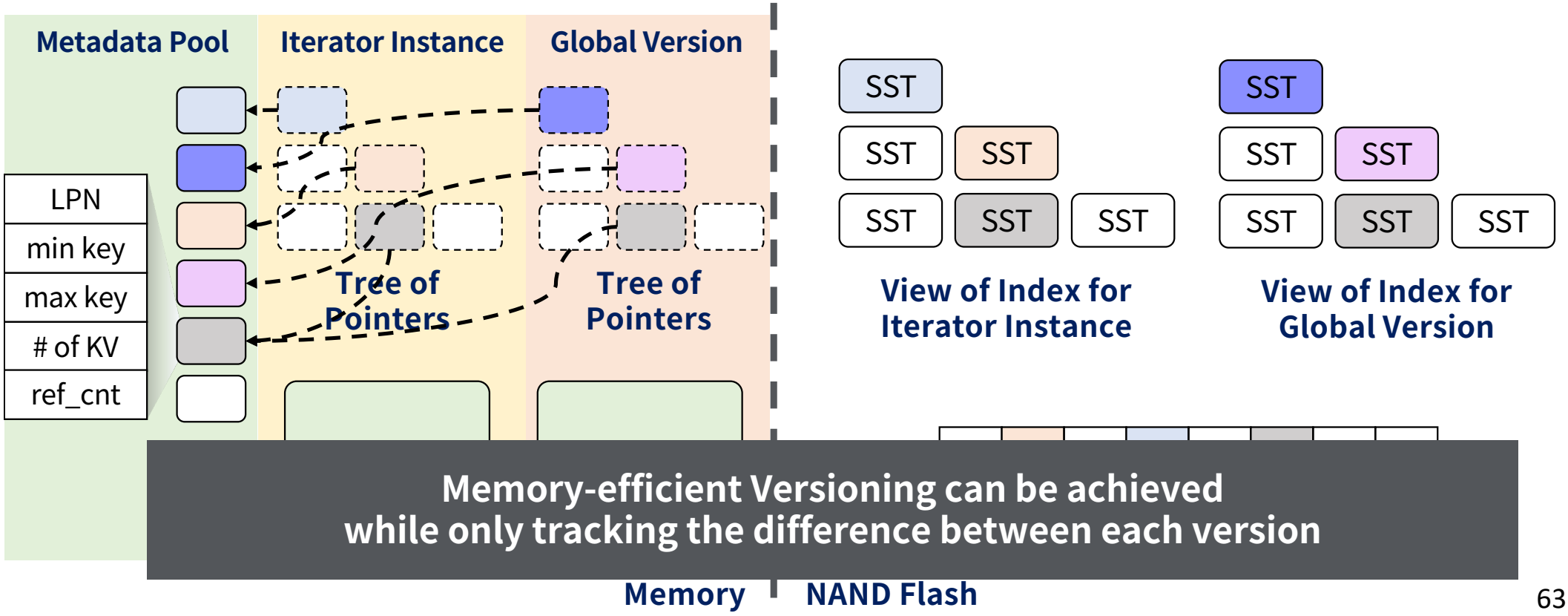

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   - KVSSD can overlap NAND Flash access with processing storage protocol and the other steps in parallel

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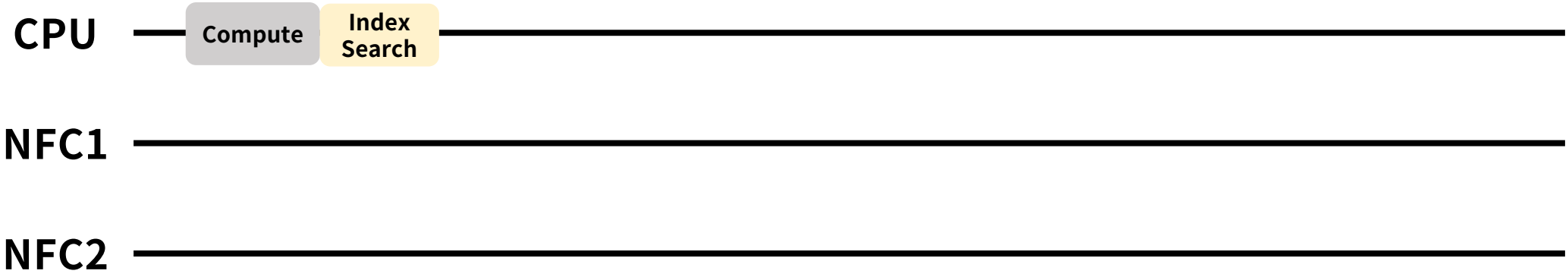

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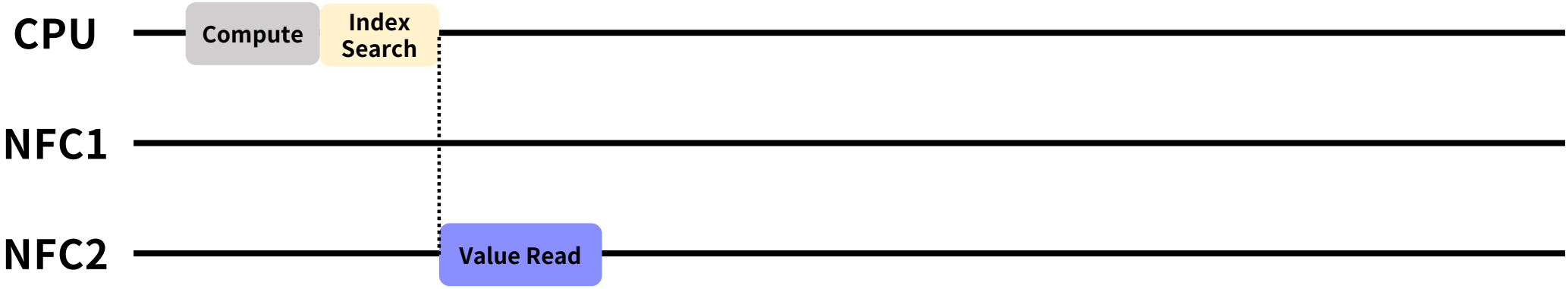

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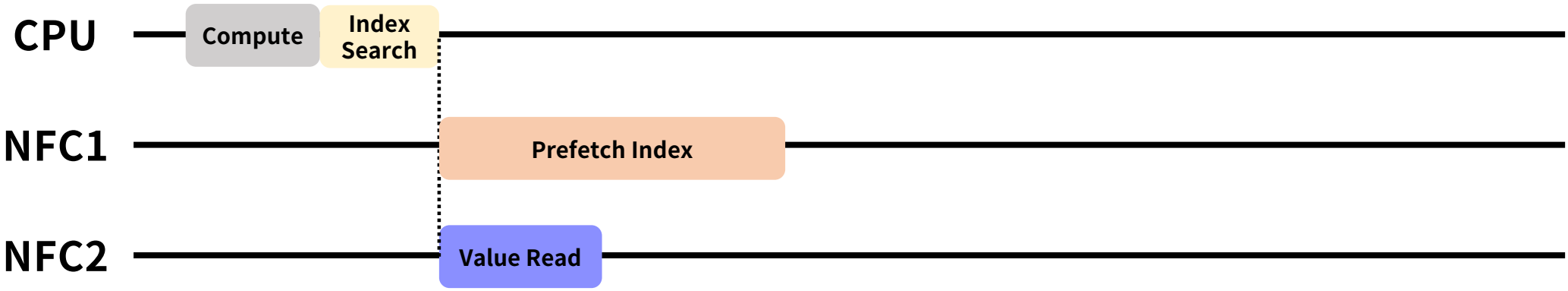

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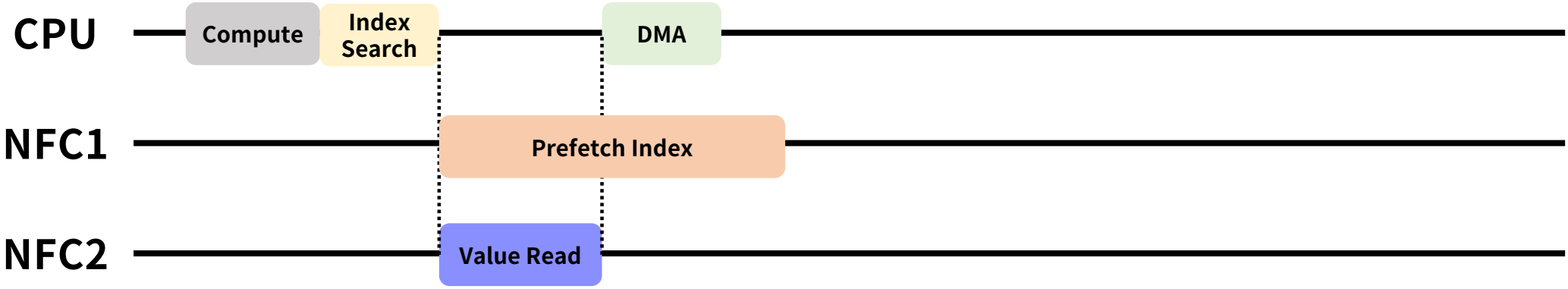

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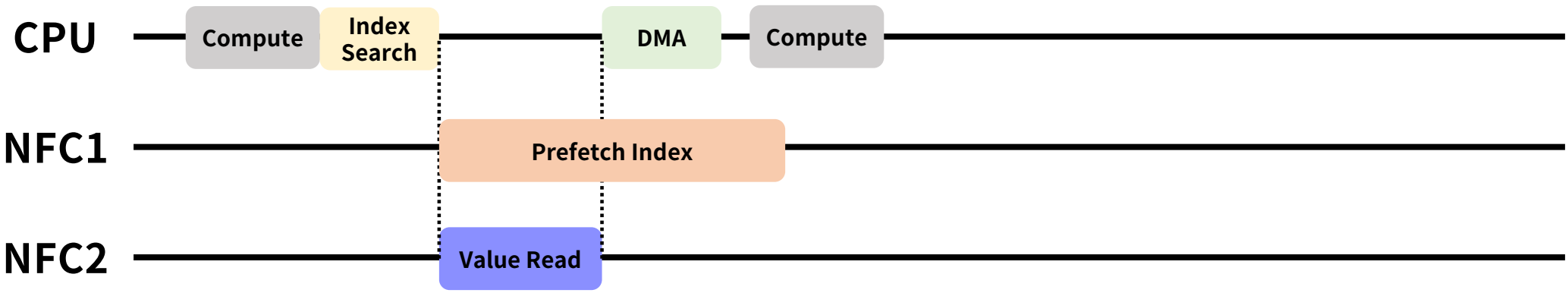

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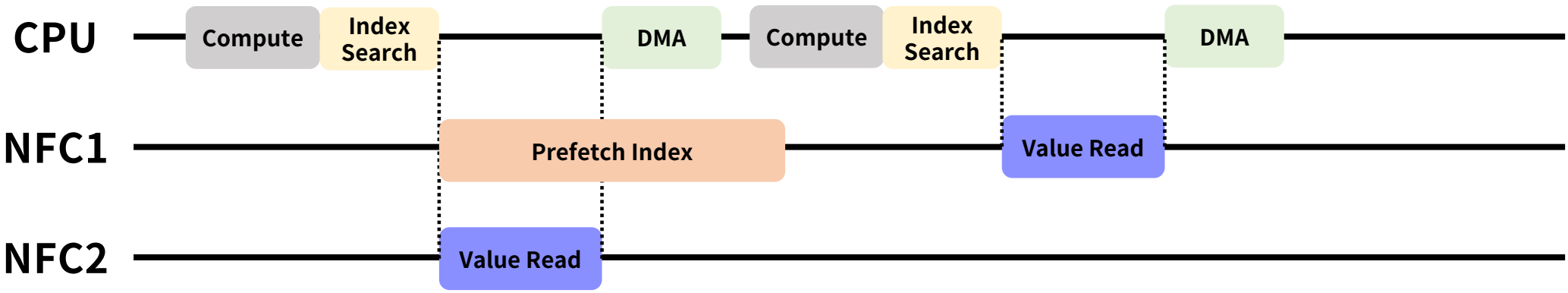

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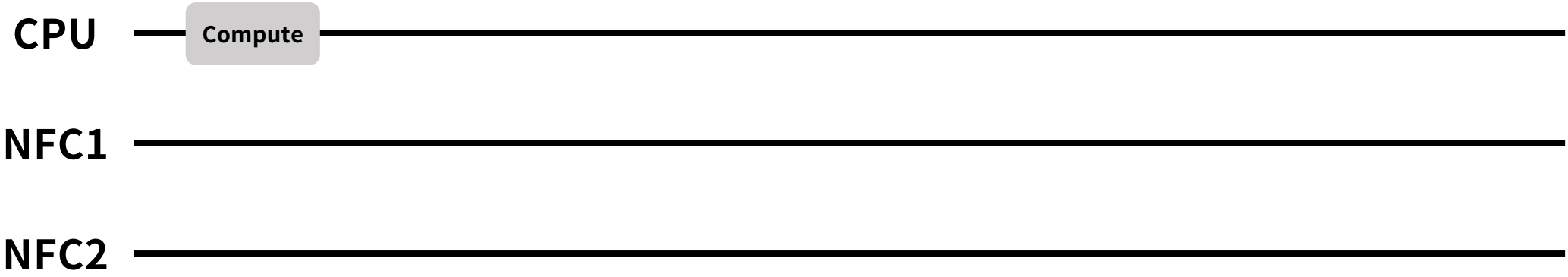

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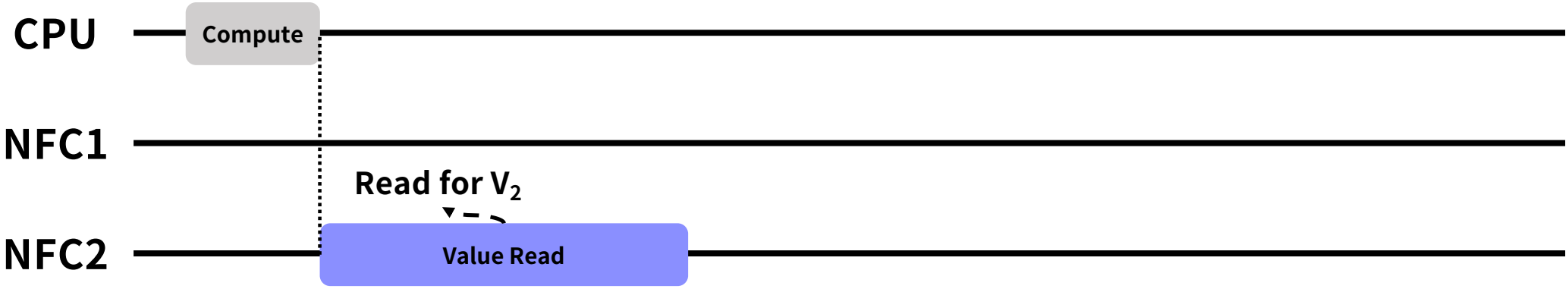

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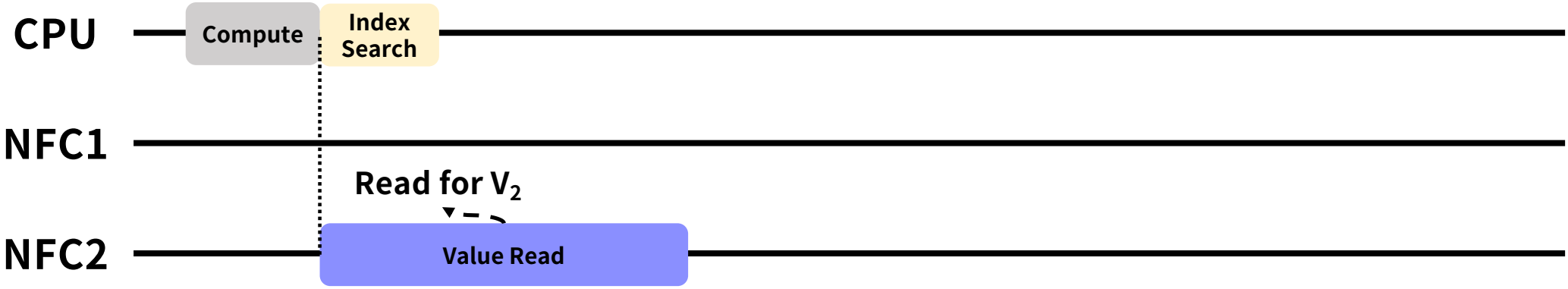

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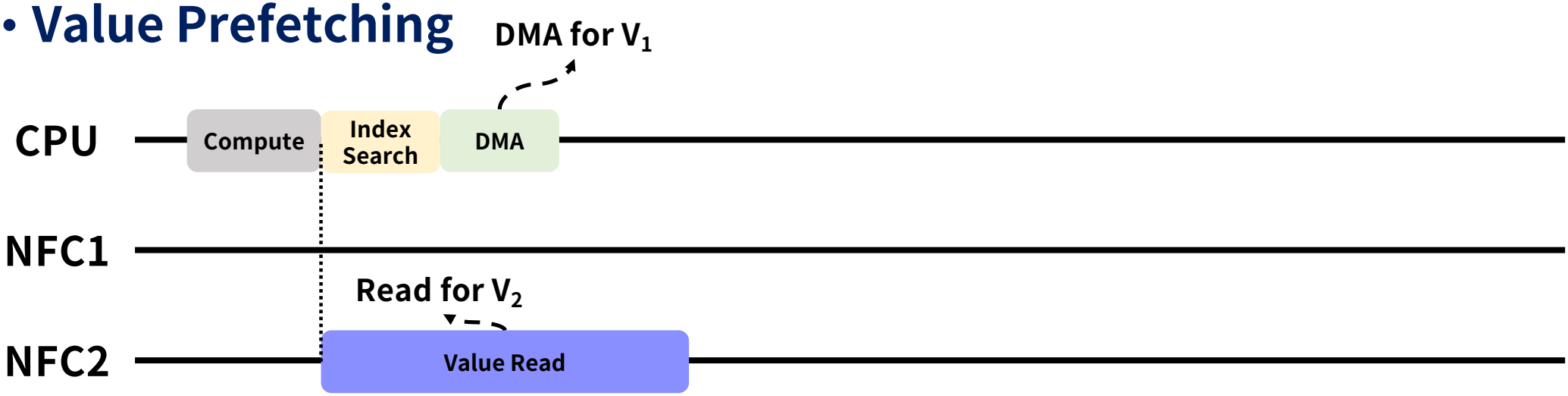

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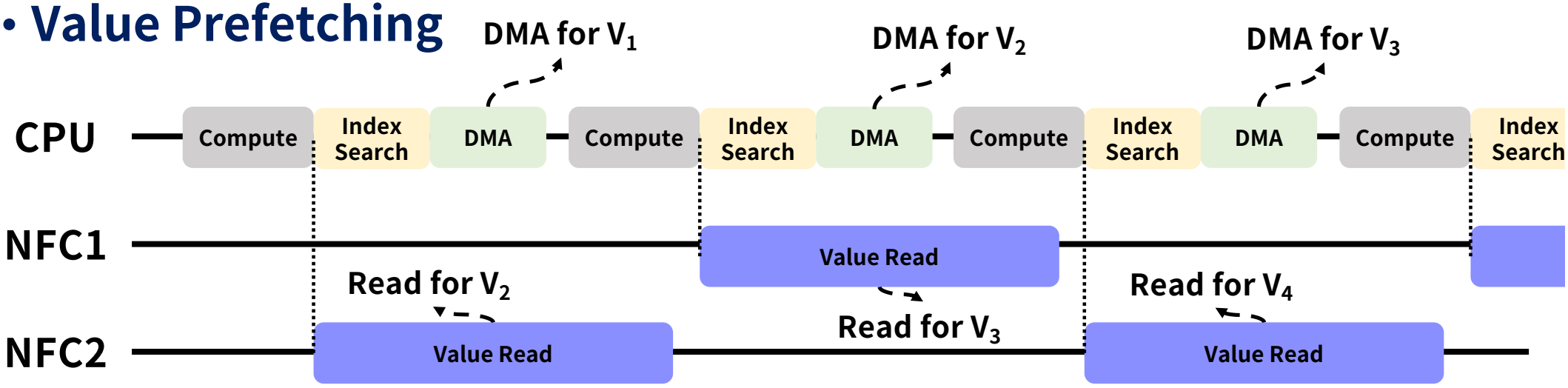

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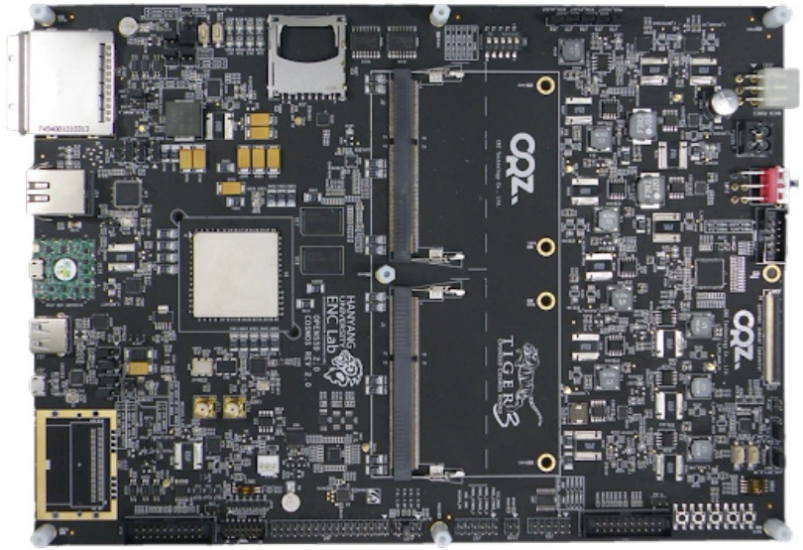
  - Prototyped on OpenSSD Cosmos+
  - Extended NVMe Protocol for Iterator Command



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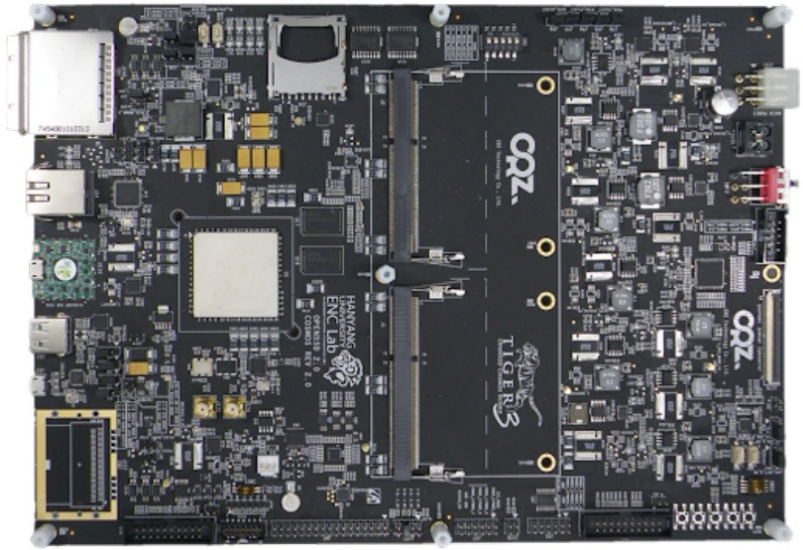
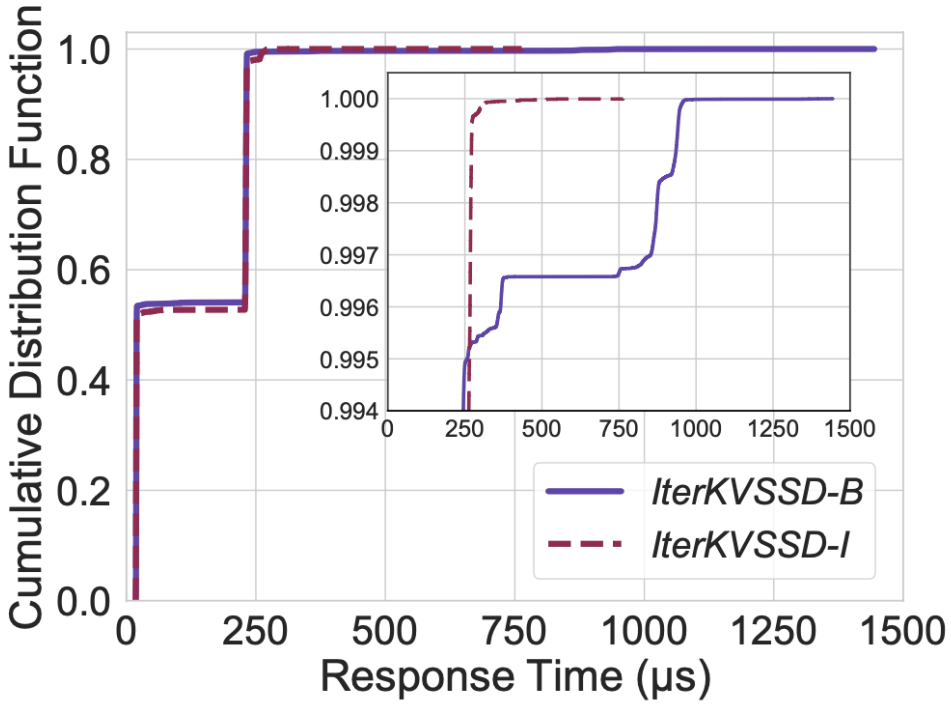


- **Experiment**
  - Evaluated with RocksDB ***db_bench*** benchmark
  - Populated with 3M Key-Value pairs with 4B Key
  - Evaluated with ***SeekRandom*** workload
  - Evaluated by varying scan length*, value size, and prefetch degree for value prefetch

scan length = the number of KV pairs retrieved during a range query

Evaluation – Index Prefetch

- **Effect of Index Prefetching**



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- **IterKVSSD-I**: w/ Index Prefetch + w/o Value Prefetch

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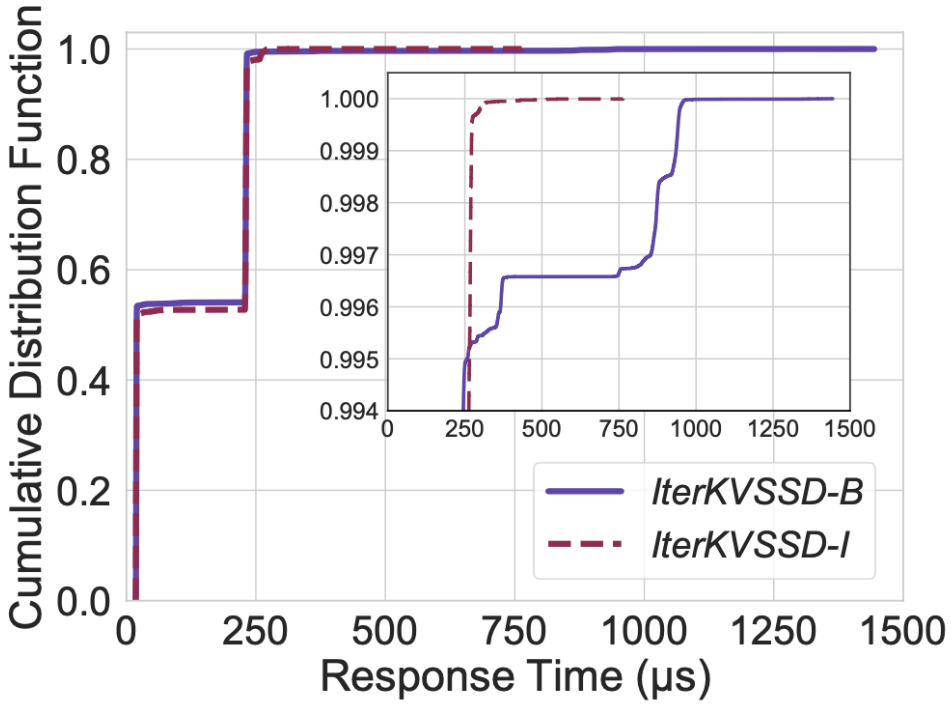

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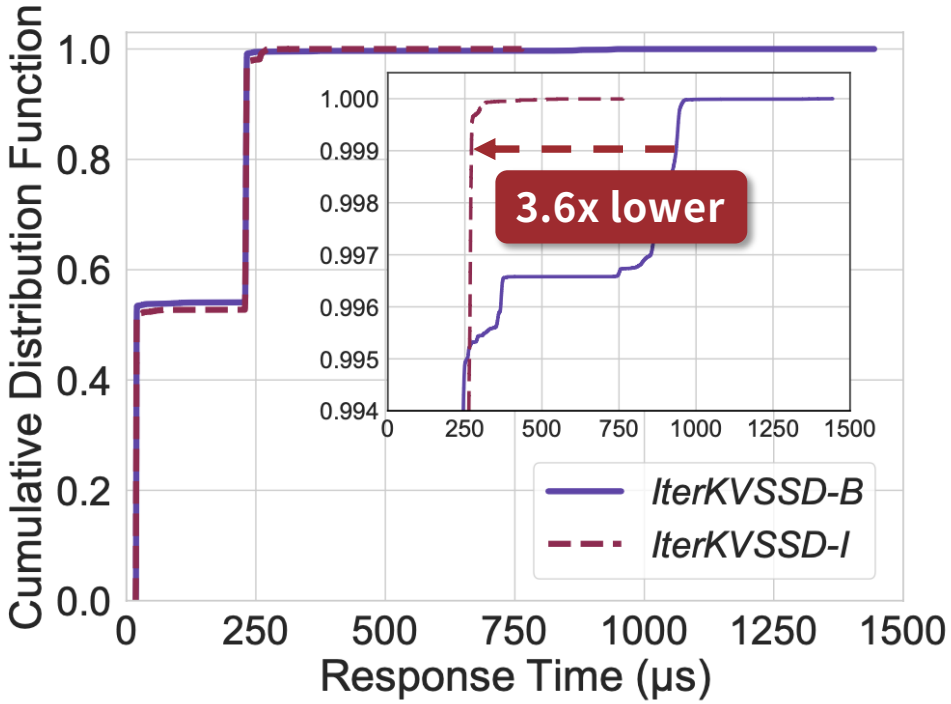

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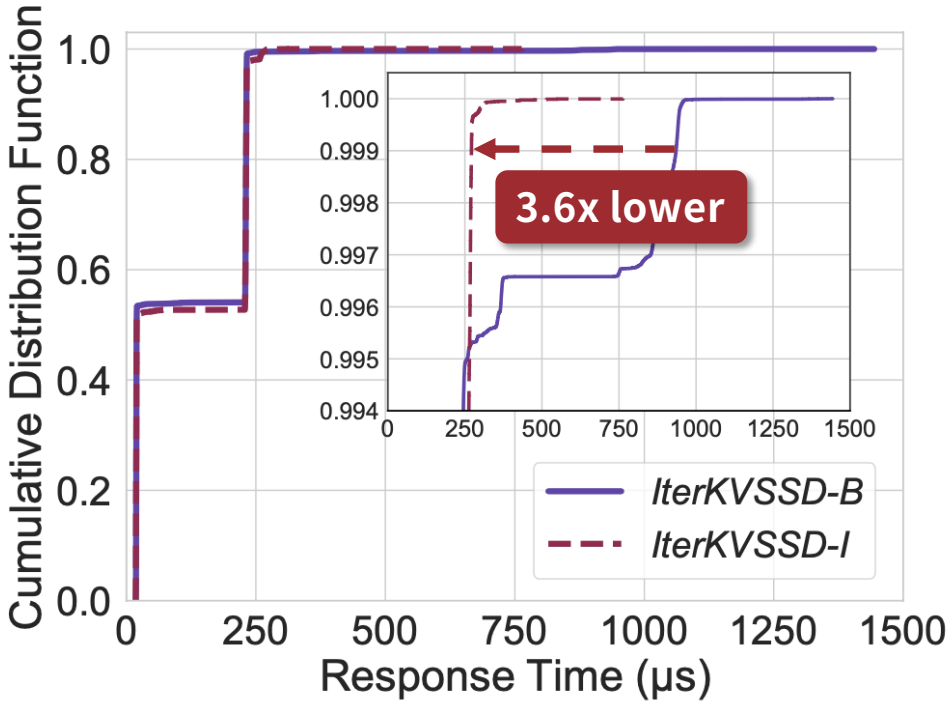

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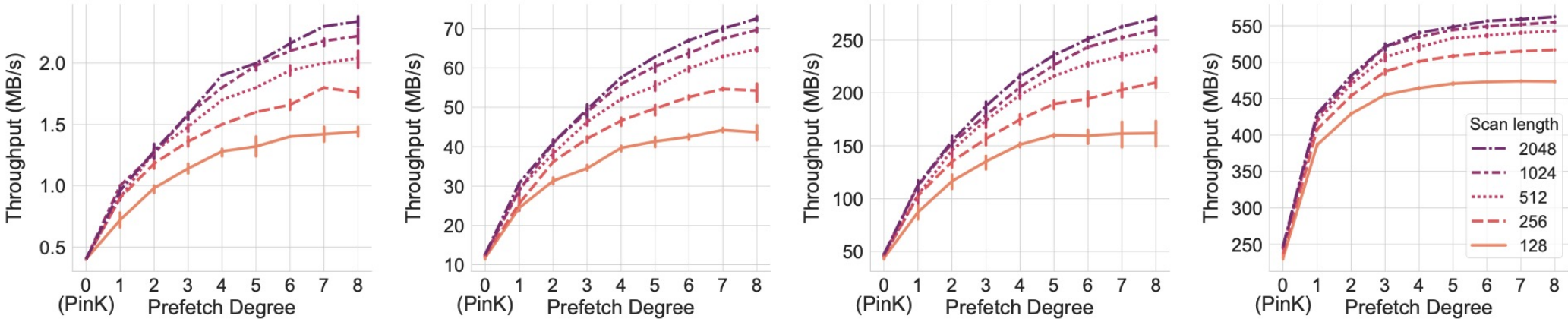
- Scan Length = 200,000 which is enough to trigger Synchronous Index Read
- Show about 3.6x better P99.9 tail latency
- Channel conflict prevents it from being removed completely

Evaluation – Value Prefetch

- **Effect of Value Prefetching**
  - Evaluated with ***SeekRandom*** workload
  - Prefetch Degree: 0 – 8
  - Value Size : 128B, 4KB, 16KB, 128KB
  - Scan Length: 128, 256, 512, 1024, 2048

Evaluation – Value Prefetch

- **Effect of Prefetching Degree**



(a) 128 B (b) 4 KB (c) 16 KB (d) 128 KB

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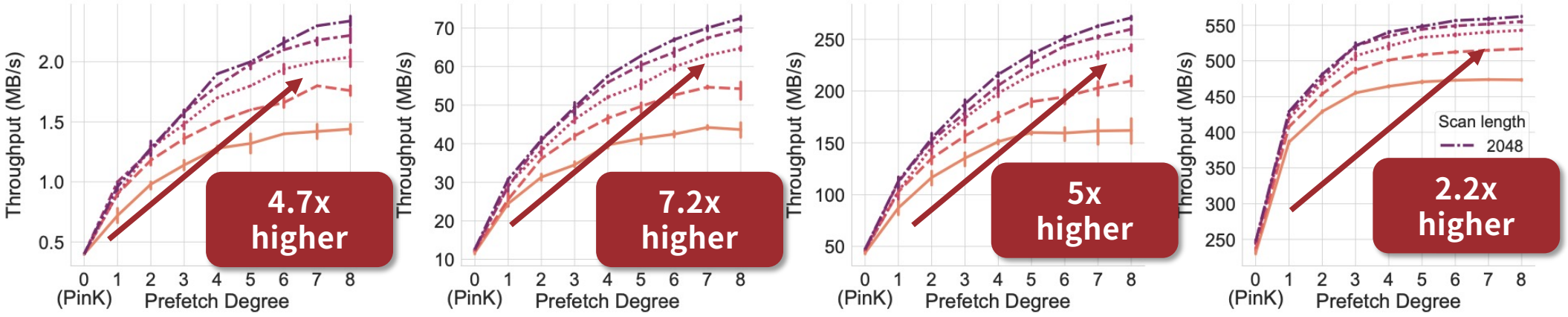
- **Effect of Prefetching Degree**
  - With higher prefetch degree, better I/O performance because small prefetch degree is not enough to hide NAND Flash access latency completely



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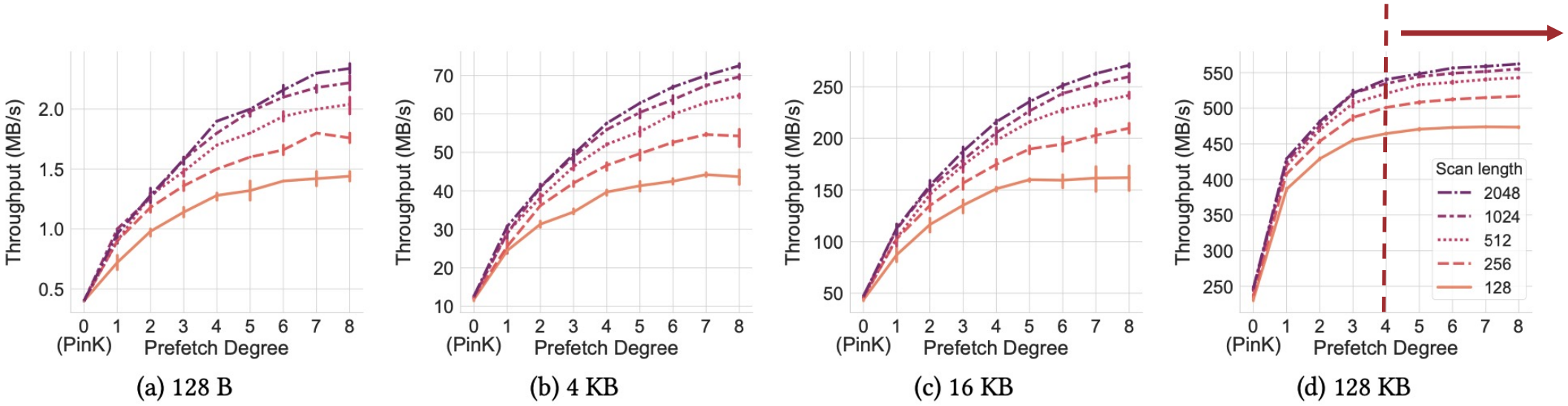

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- **Effect of Prefetching Degree**
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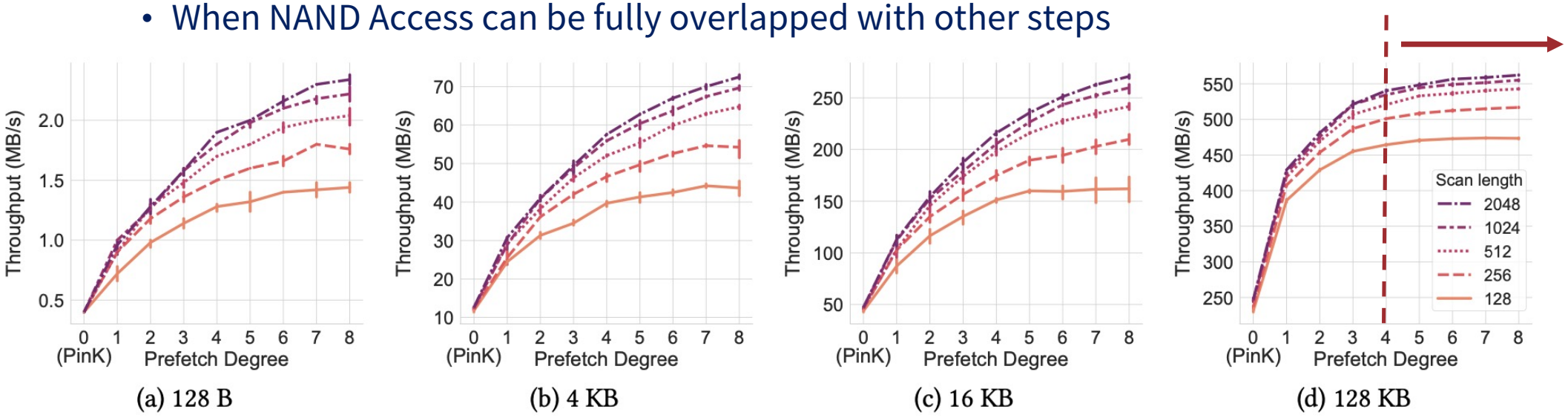
  - However, prefetch degree over some degree will not improve performance
    - When internal bandwidth is saturated
    - When NAND Access can be fully overlapped with other steps



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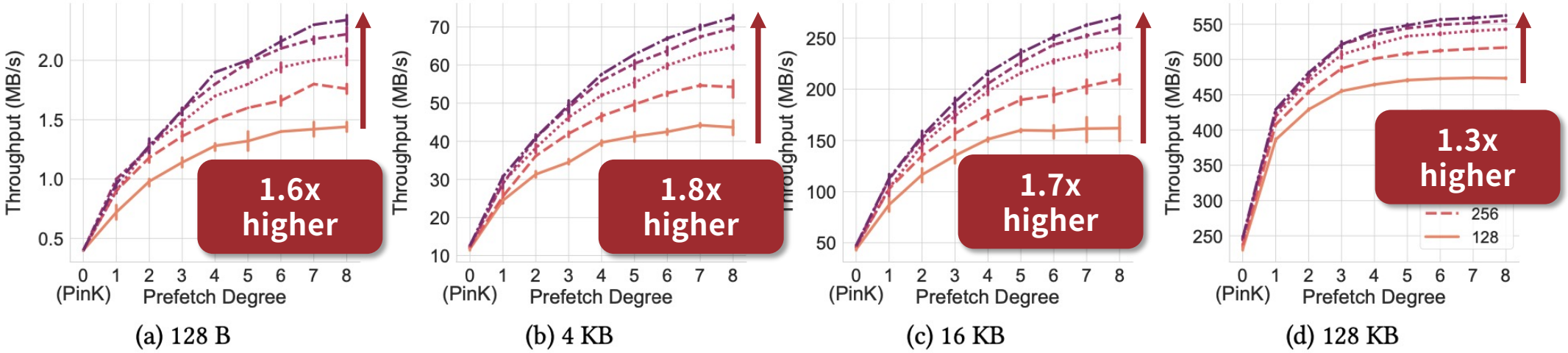
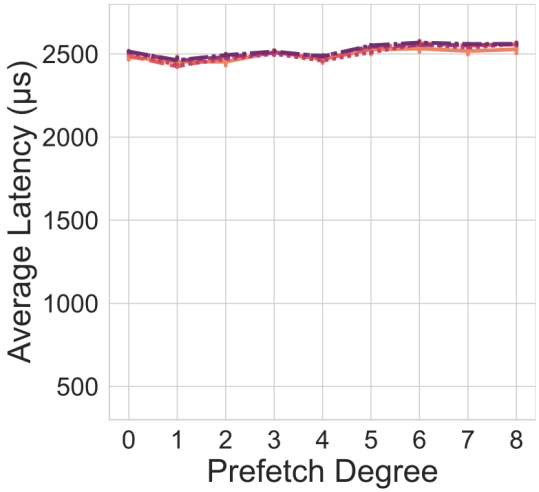
Evaluation – Value Prefetch

- **Effect of Scan Length in Range Query**
  - With higher scan length, better I/O throughput

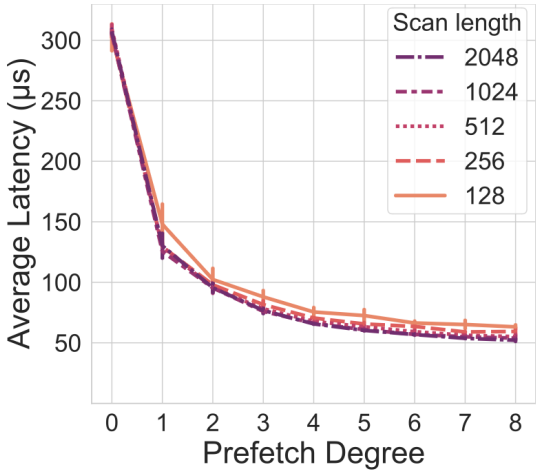


Evaluation – Value Prefetch

- **Effect of Value Prefetching**
  - 1 **Seek** + *N* **Next** (*N*: Scan Length)
  - **Seek** shows much higher latency than **Next**
  - Therefore, the higher scan length shows the better overall I/O performance



(a) Seek()



(b) Next()

Conclusion

- **Iterator Interface Extended LSM-tree-based KVSSD**
  - Explore three problems of current iterator interface
    1. Versioning Problem
    2. Synchronous Index Read Problem
    3. Synchronous Value Read Problem
- **IterKVSSD**
  - Propose solutions for the above problem by exploit the characteristics of KVSSD
  - Memory-efficient Versioning through decoupling and pooling metadata
  - Index/Value Prefetch to mitigate NAND Flash Access Penalty
  - Shows **2x** lower P99.9 tail latency, up to **7.2x** better I/O throughput

Thank you for listening! Q&A

Iterator Interface Extended LSM-tree-based KVSSD for Range Queries

Seungjin Lee[1], Chang-Gyu Lee[1], Donghyun Min[1], Inhyuk Park[2], Woosuk Chung[2], Anand Sivasubramaniam[3], Youngjae Kim[1]

[1] Sogang University, [2] SK hynix, [3] The Pennsylvania State University