Exploring Data Deduplication in LSM-Tree Based Key-Value Stores

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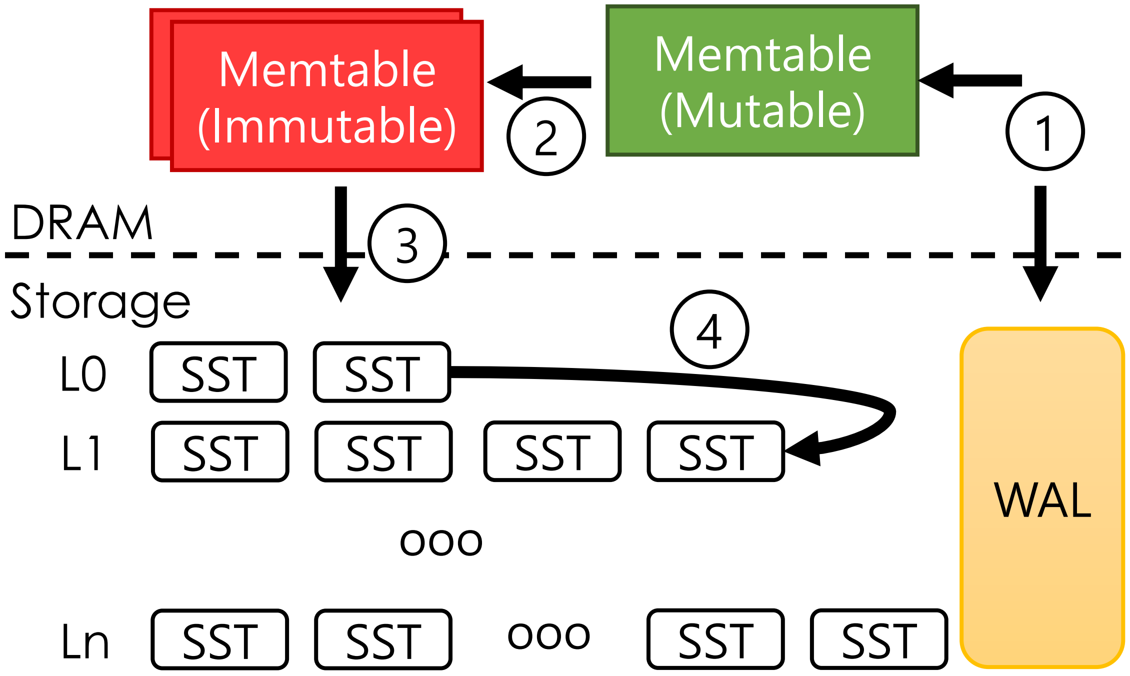
LSM Tree-based KV-stores Architecture



LSM-based KV-stores architecture

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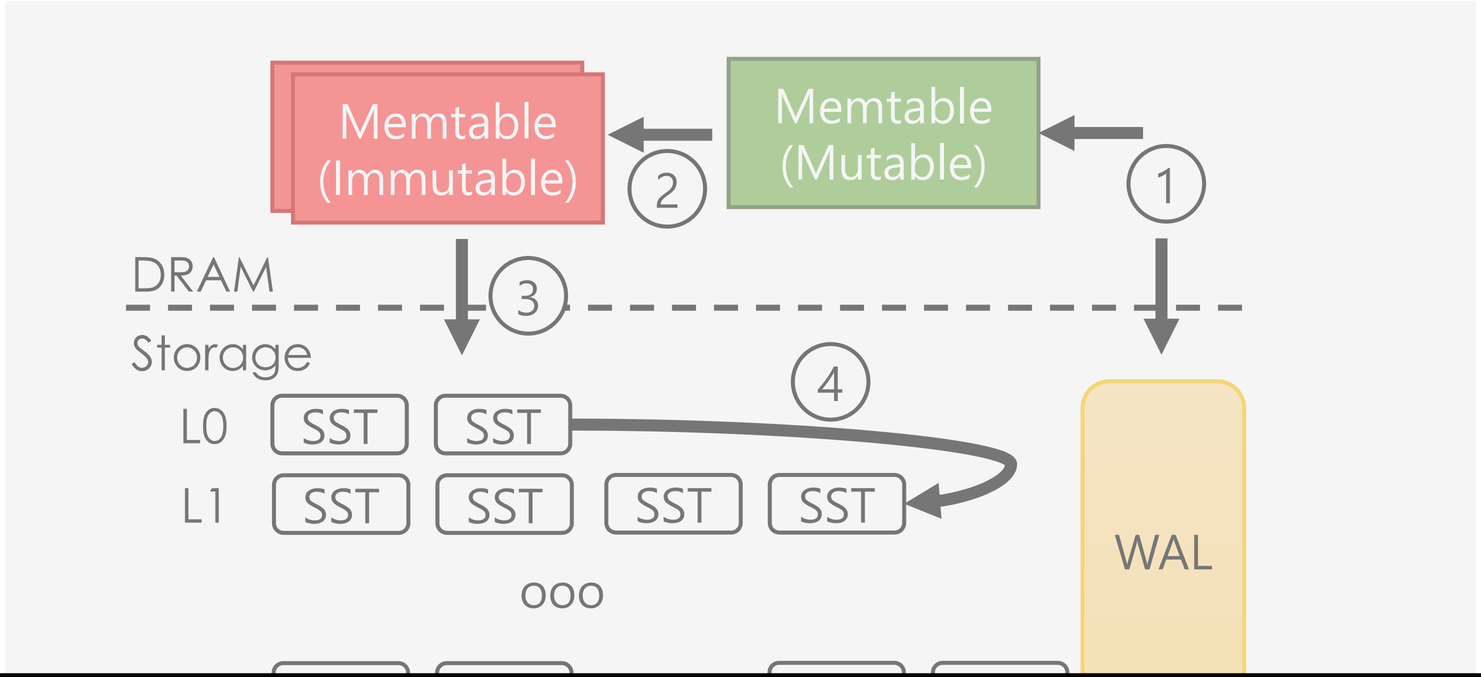


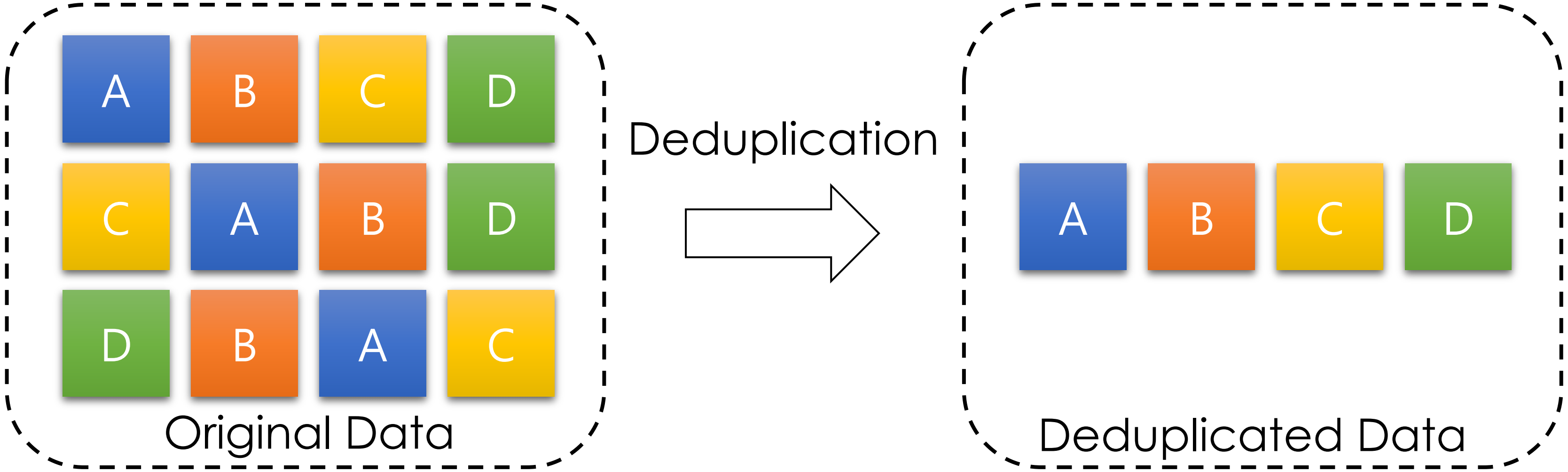
Limitations of LSM tree

- ❑ High write amplification (WA)
- ❑ High space amplification (SA)

Deduplication can be adopted to minimize the WA and SA

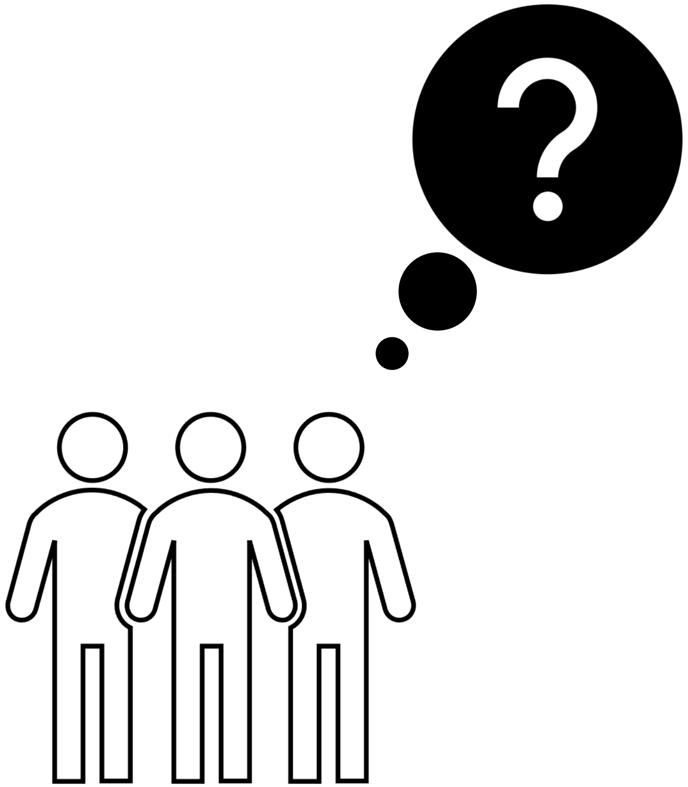
Deduplication in LSM

- Novel way to minimize WA and SA
  - SSTable can be a complete duplicate
  - A partition of SSTable can be duplicate
- Incorporating value-based deduplication
  - Can help reduce the actual size of KV-store



Basic Questions for Deduplication in LSM

- How to manage deduplication overhead?
  - Performance and storage overhead
- What deduplication technique?
  - Inline deduplication or offline deduplication?
- Where to apply deduplication?
  - Memtable or Immutable Memtables or SSTables?



Inline Deduplication at MemTable (MemDedup)

Deduplication at Memtable-level (MemDedup)

- Inline deduplication
  - Intercepts PUT request and performs deduplication before storing to Memtable
  - With inline dedup, less data is written to the Memtable
    - Leads to less data at all levels of LSM
  - Maintains deduplication metadata in Chunk Information Table

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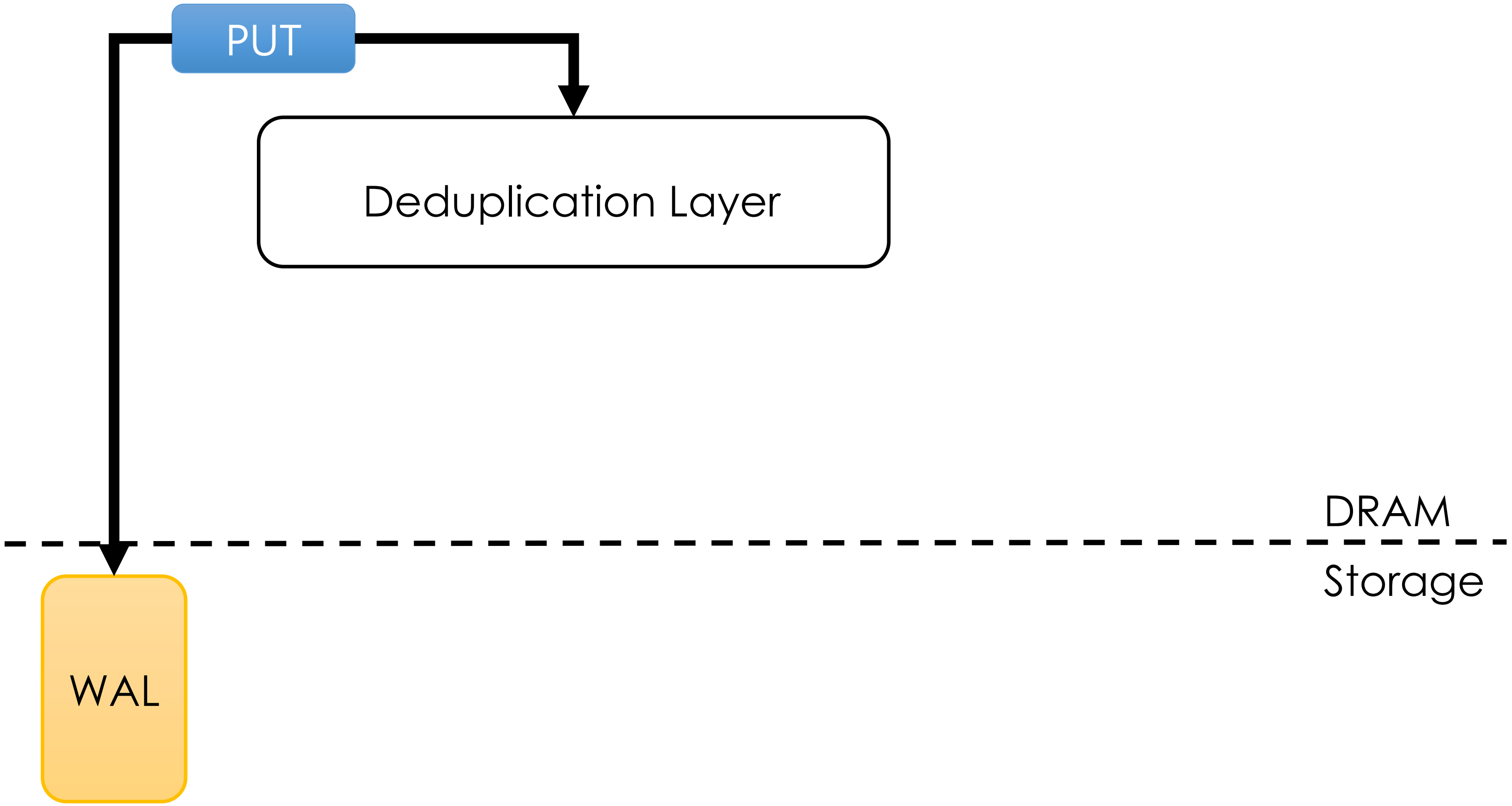
Fingerprint of value FP(V)	List of parent keys (PK[])	Reference count (RC)	Value location (Offset)
FP(12)	K1	1	0xf8
FP(34)	K2, K3	2	0xff

Chunk Information Table

Deduplication at Memtable-level (MemDedup)



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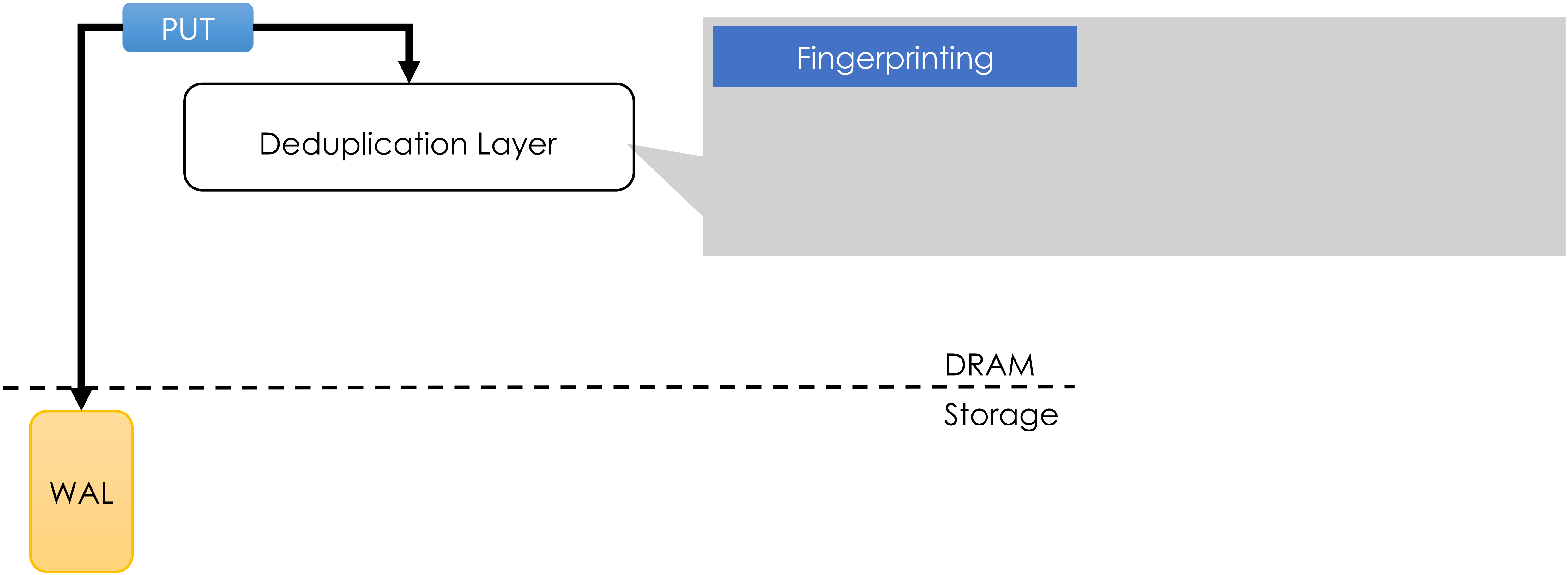

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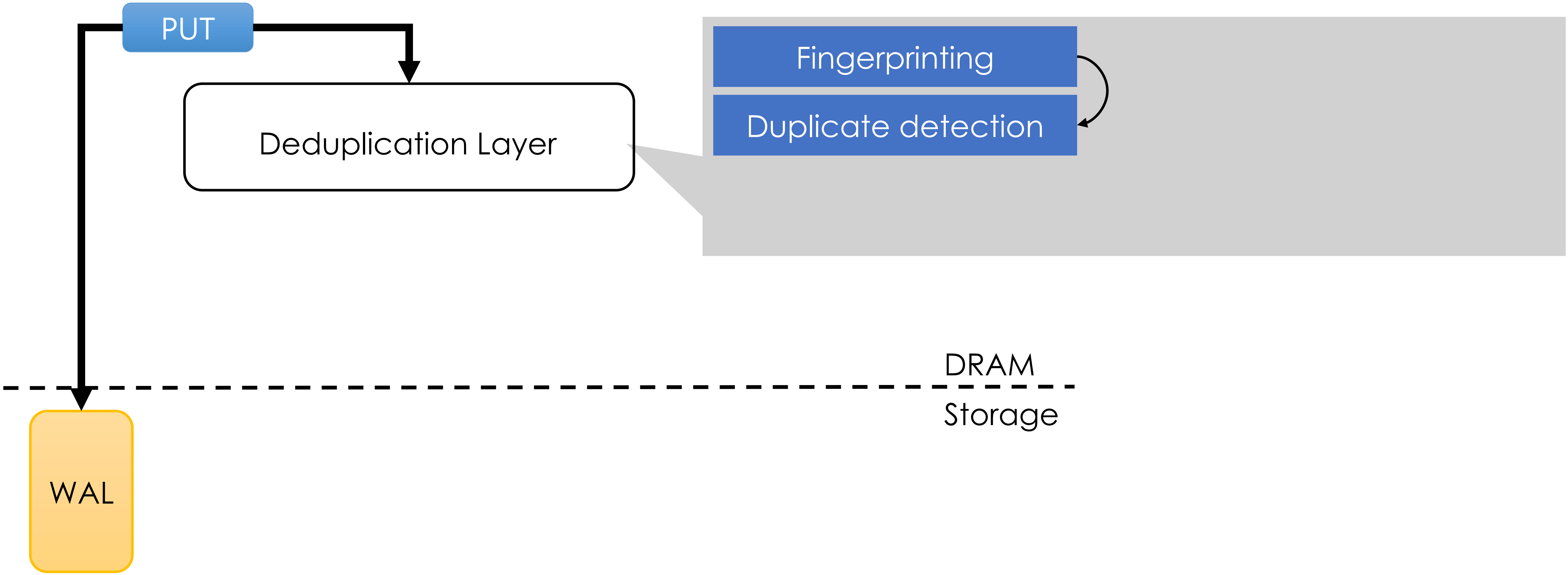

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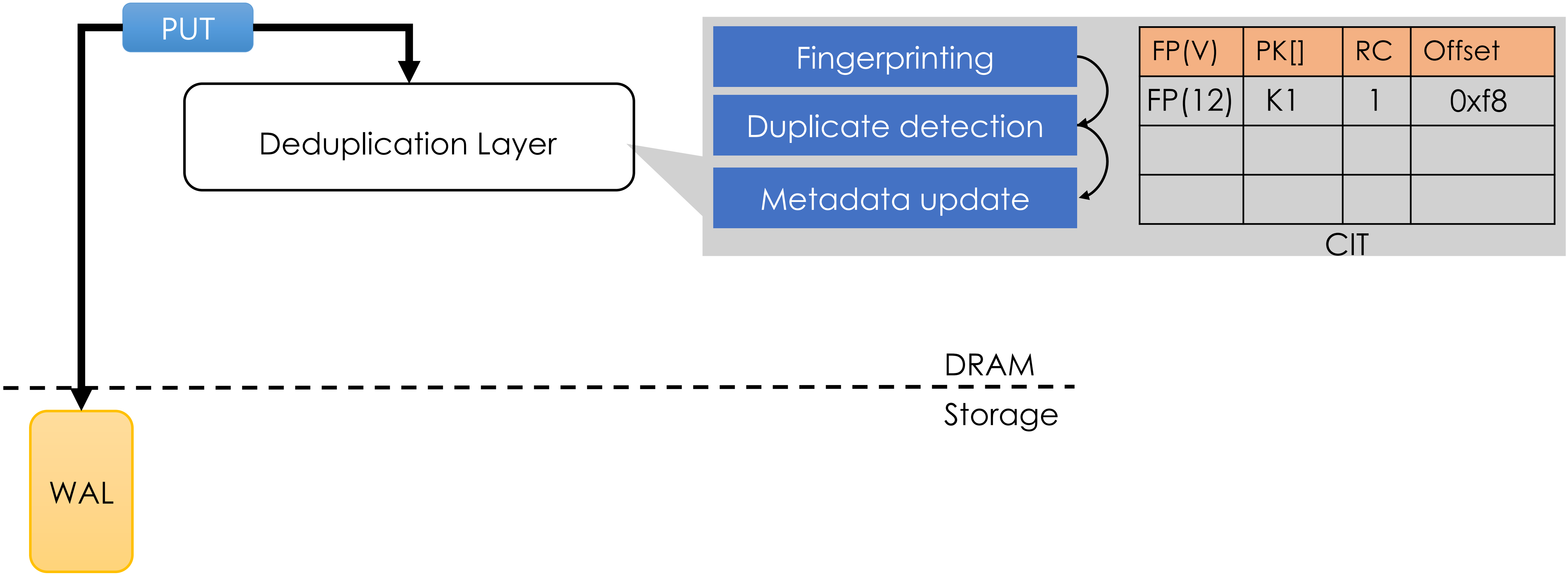

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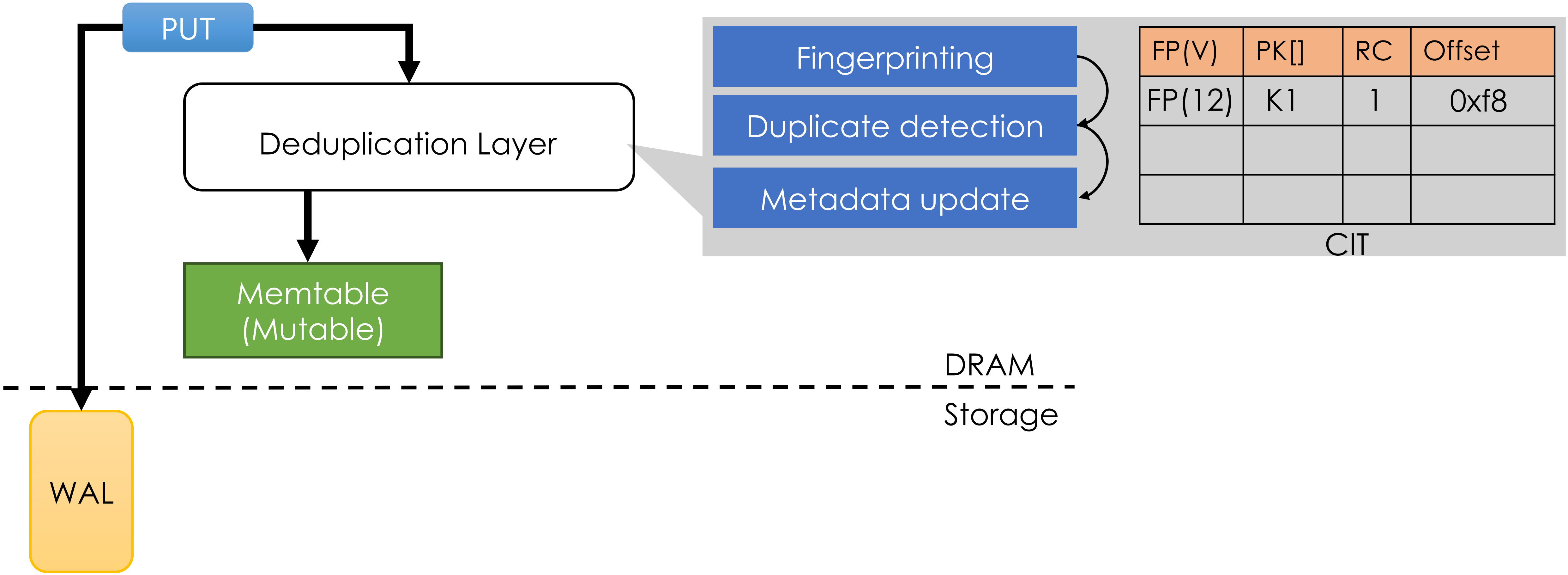

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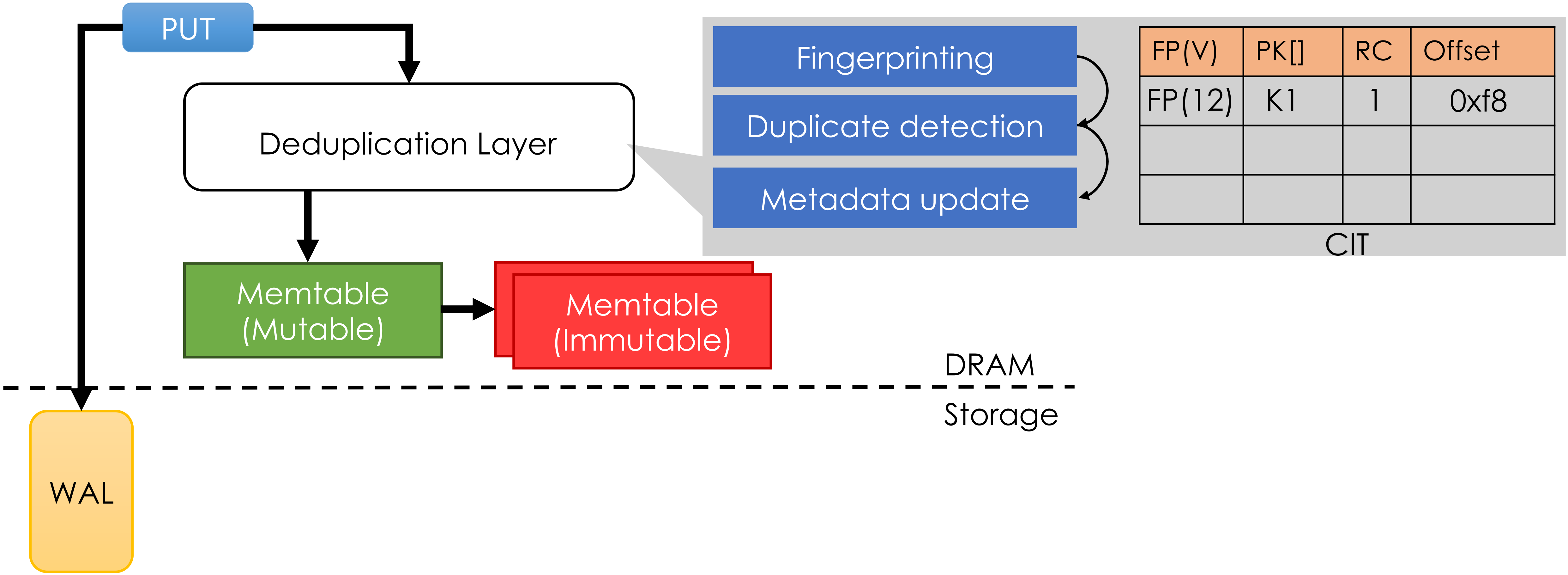

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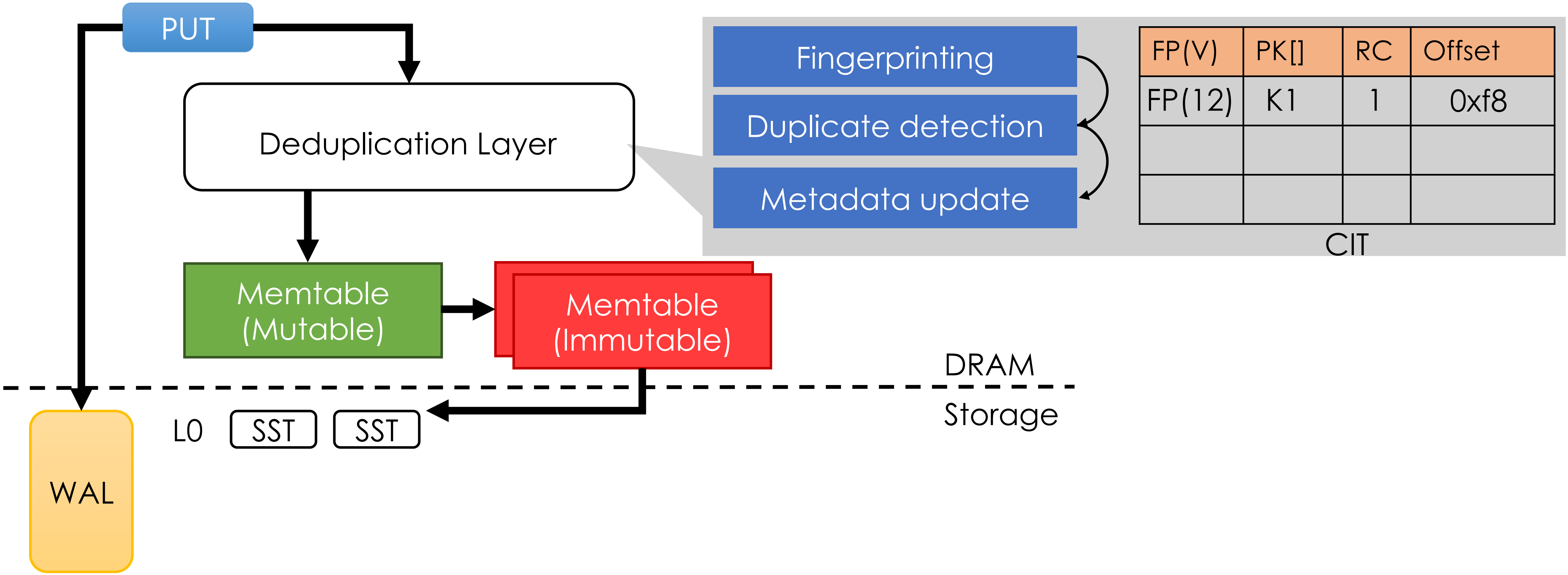

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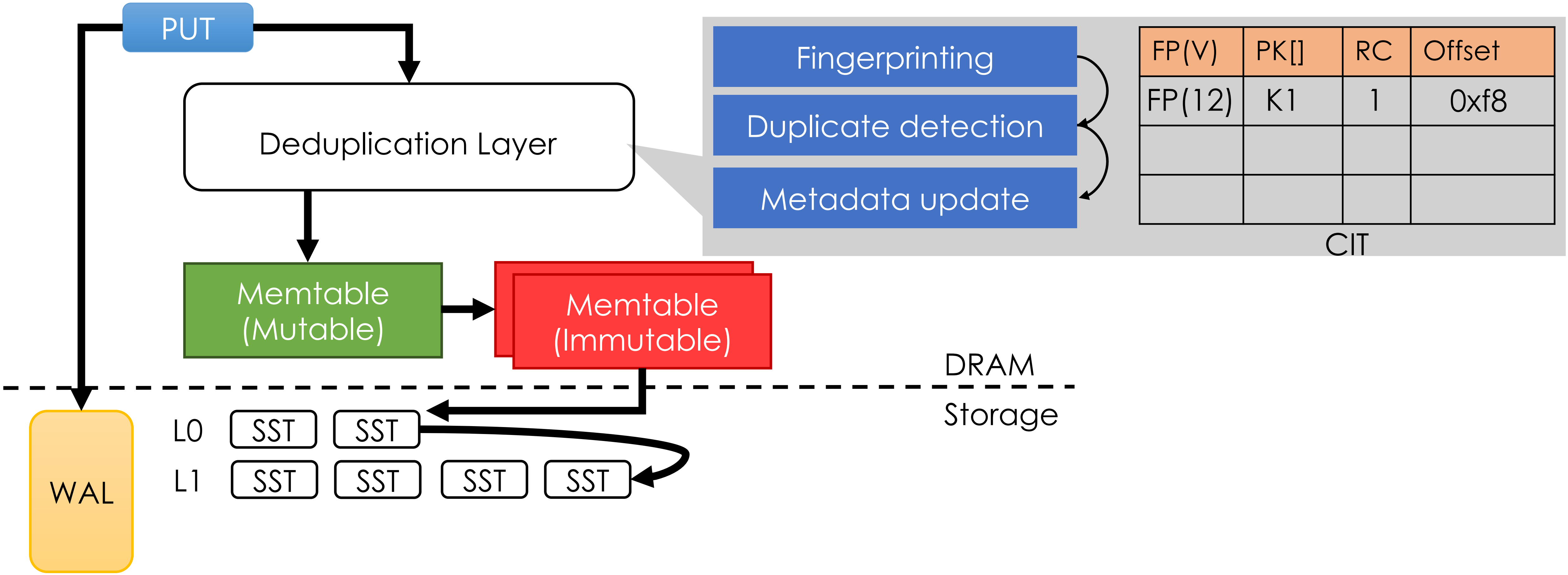
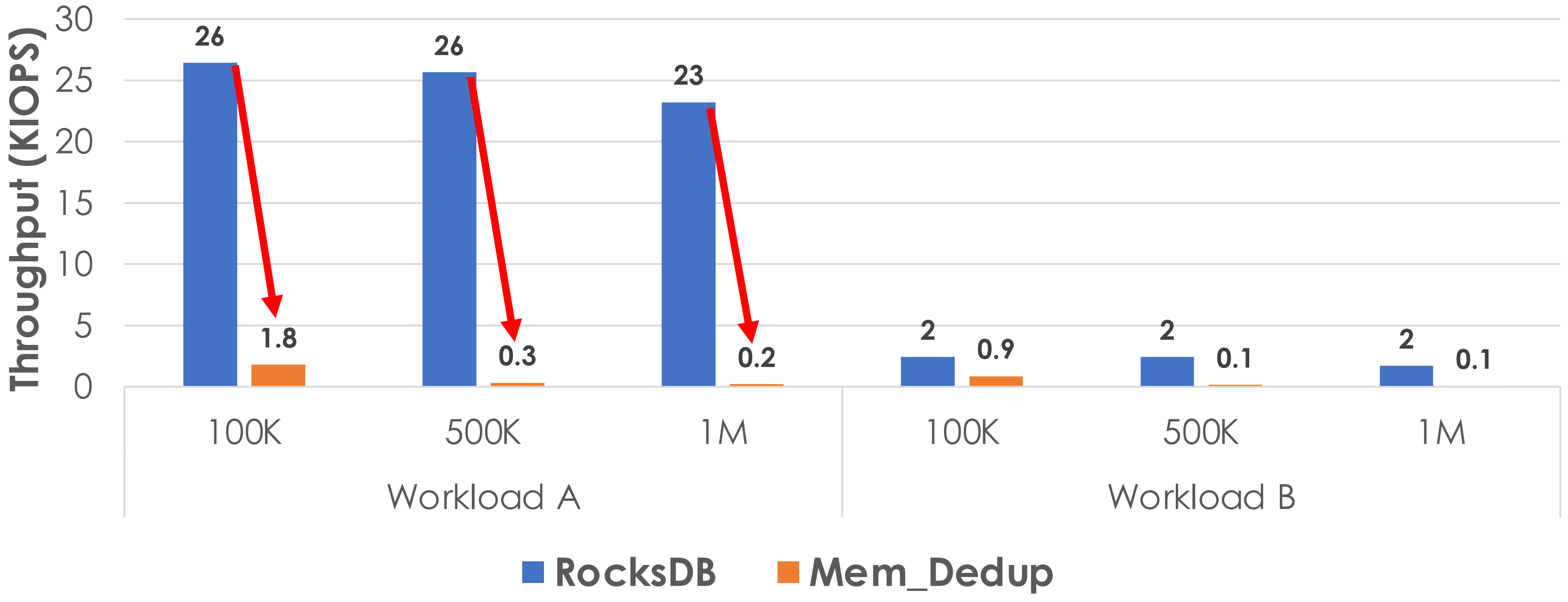


Deduplication at Memtable-level (MemDedup)

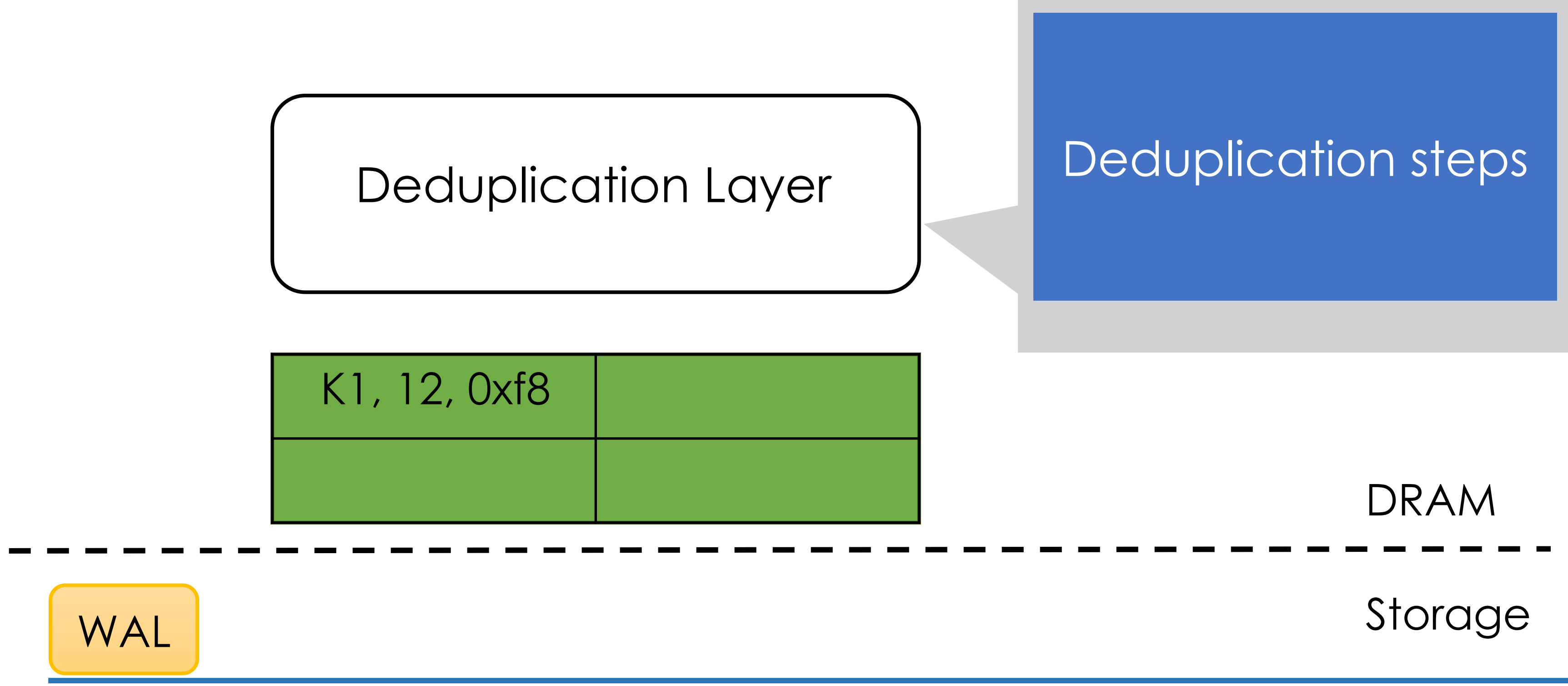
- Limitations
  1. High performance overhead
     - Dedup steps – fingerprinting
     - Frequent dedup metadata update/traversal



YCSB Benchmark | Workload A: 100% Write | Workload B: 50% write & 50% read

Deduplication at Memtable-level (MemDedup)

- Limitations
  1. High performance overhead
  2. Inconsistency issue
     - In-place update operations at Memtable



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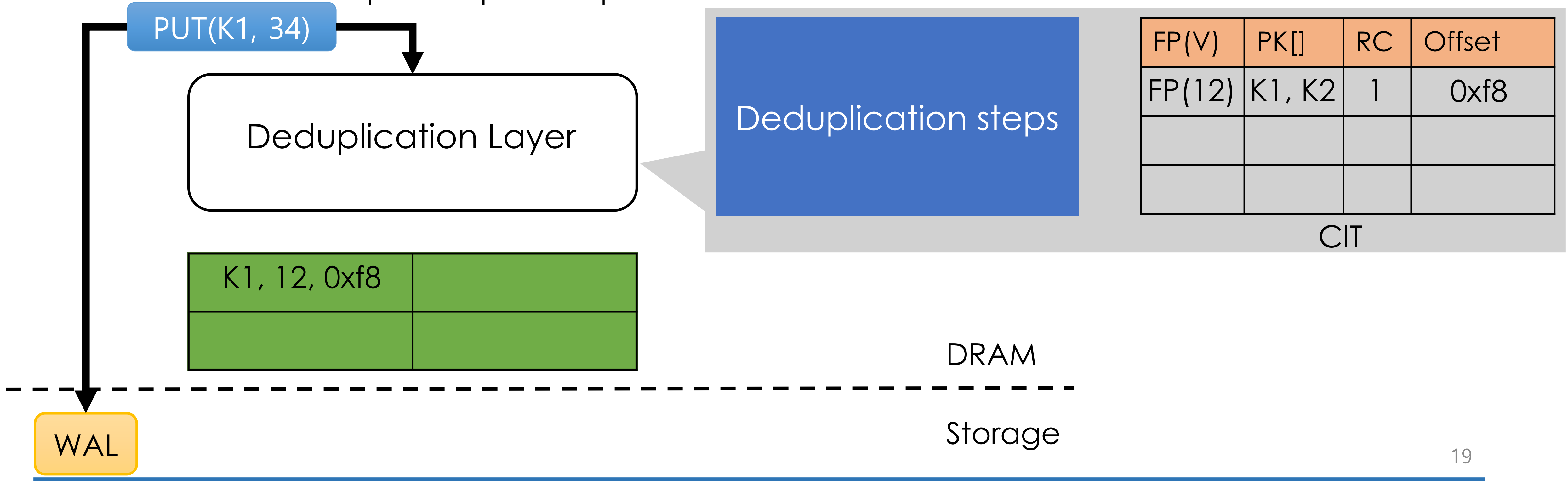

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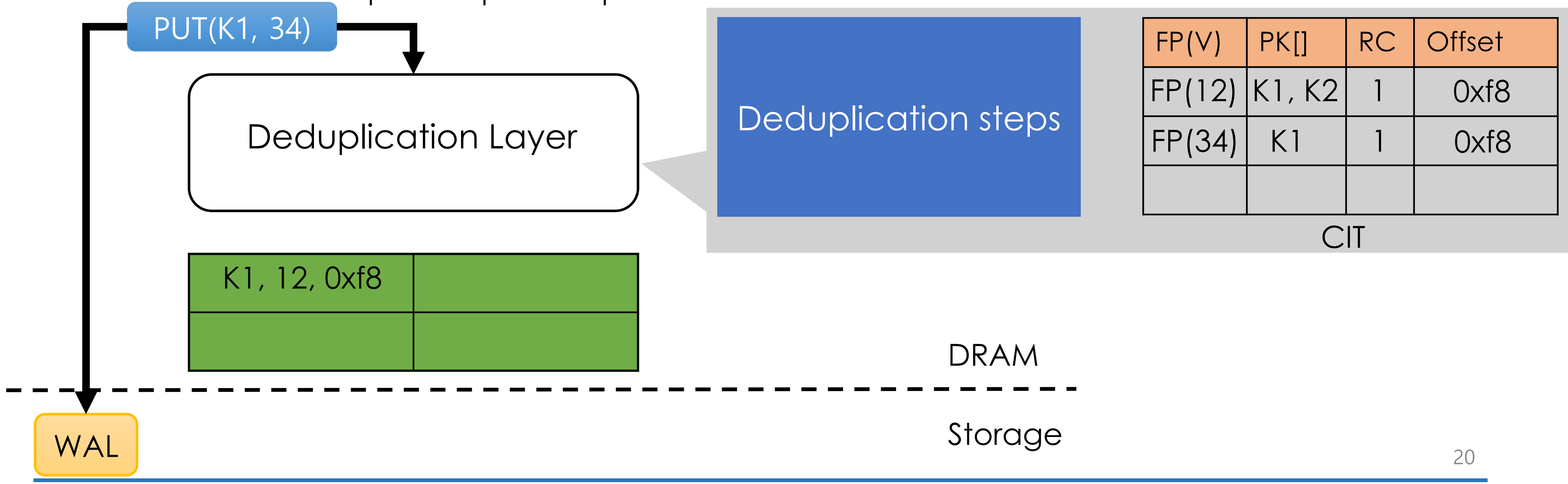

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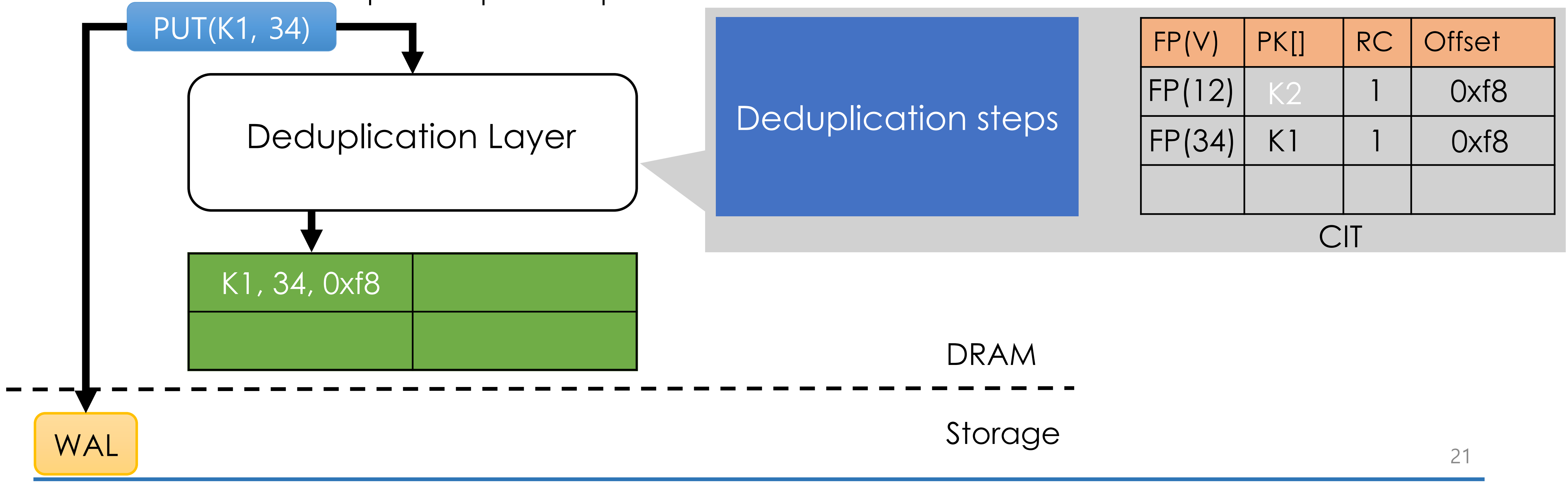

FP(V)	PK[]	RC	Offset
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FP(34)	K1	1	0xf8

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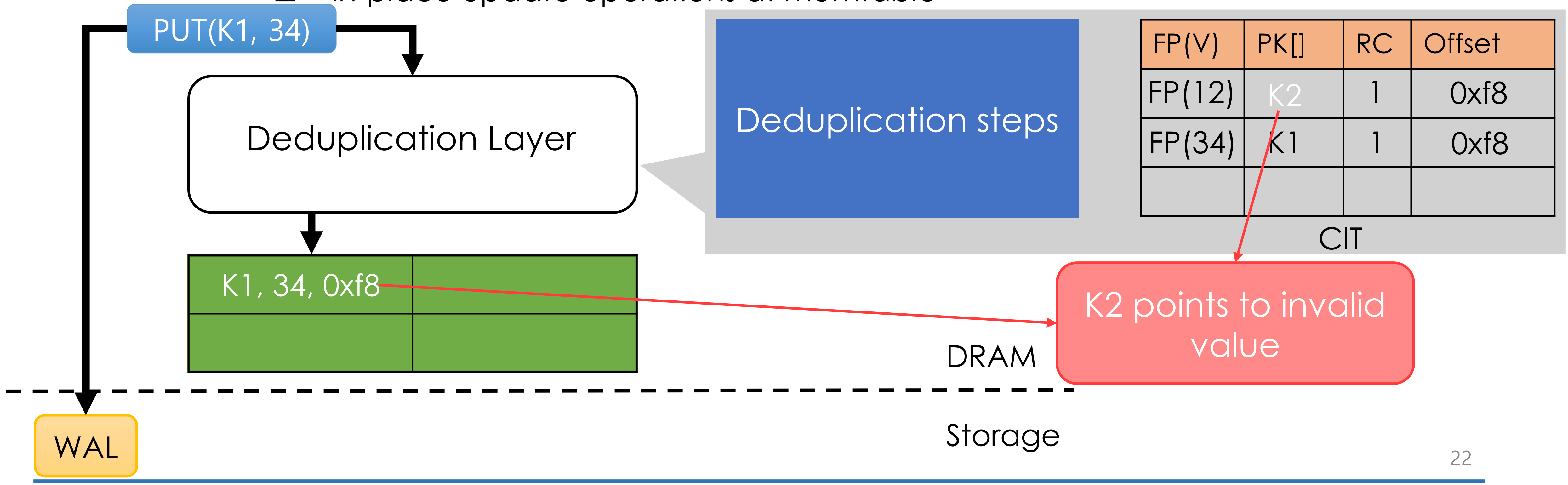
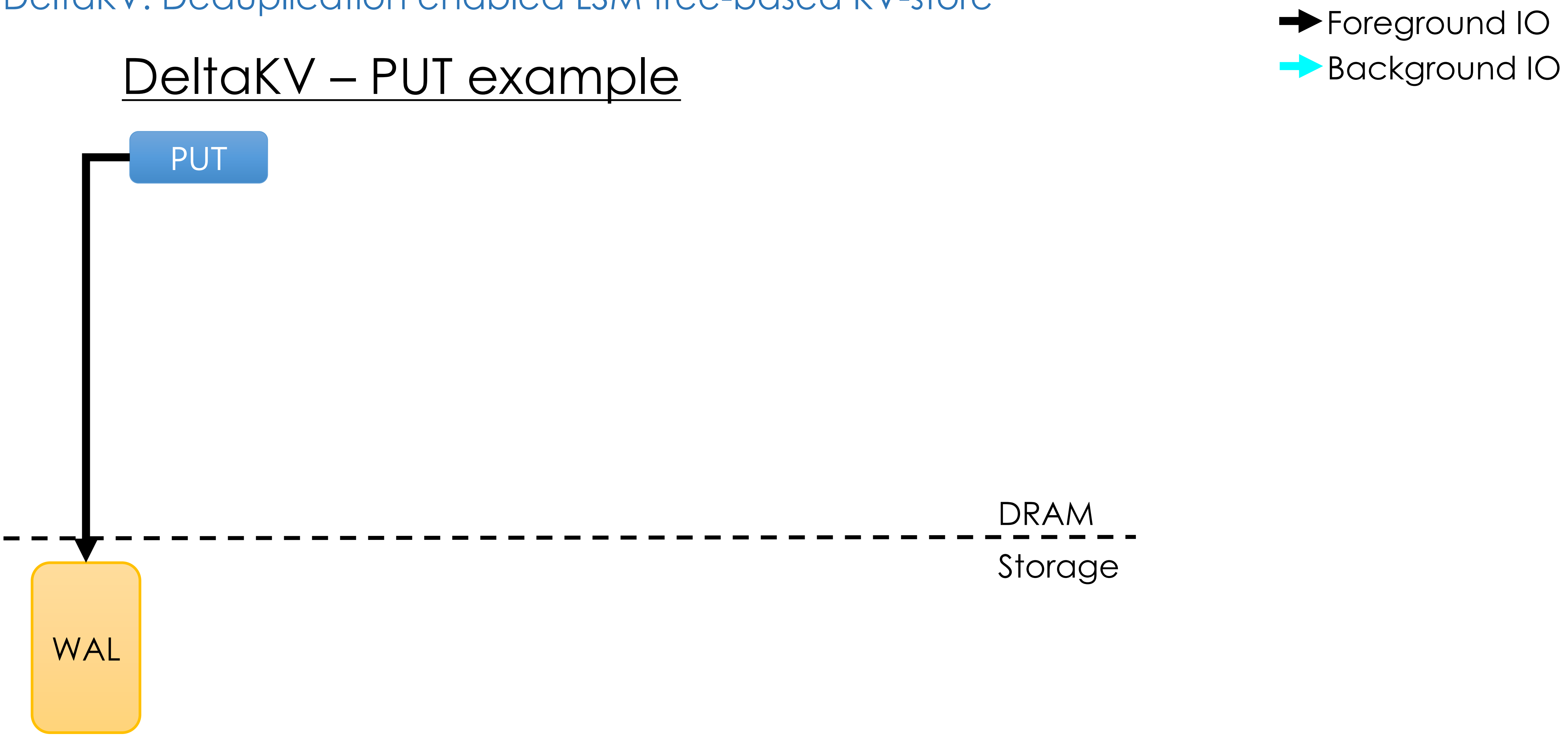


Deduplication enabled LSM Tree-based Key-Value Store (DeltaKV)

DeltaKV

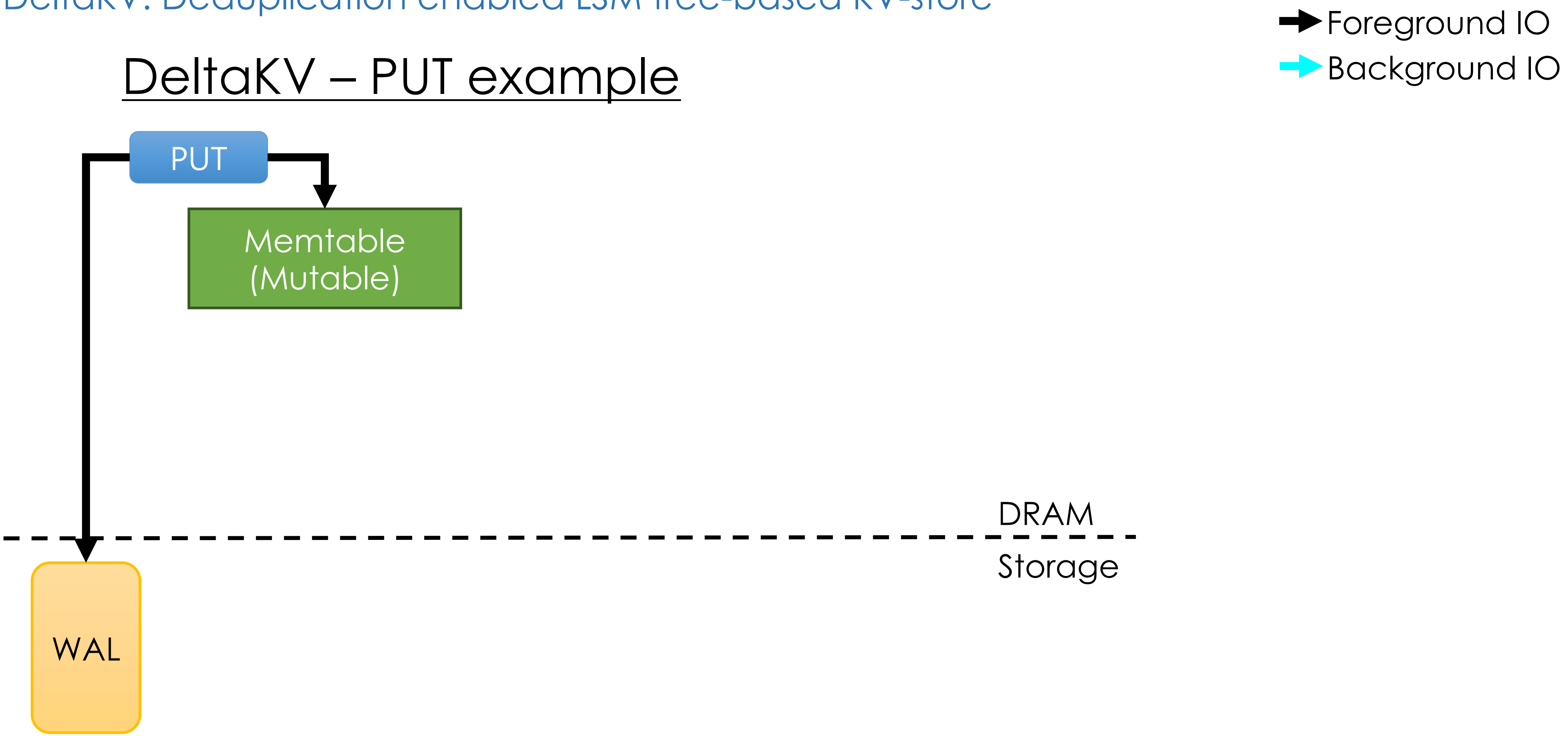
- Offline deduplication (dedup)
  - Delays dedup to FLUSH operation
    - When Immutable Memtables are written to SSTables
- Background threads perform dedup
  - No interference with foreground IOs → less performance effect
- Mitigate inconsistency issue
  - Dedup performed on immutable data
  - No direct manipulation by foreground IOs
- Further Optimization
  - Divides dedup metadata in two data structures
    - Value Information Table (VIT) – for write/update operations
    - B+-Tree – for read operations

DeltaKV – PUT example



B+-Tree node contains: Keys and their corresponding offsets.

DeltaKV – PUT example



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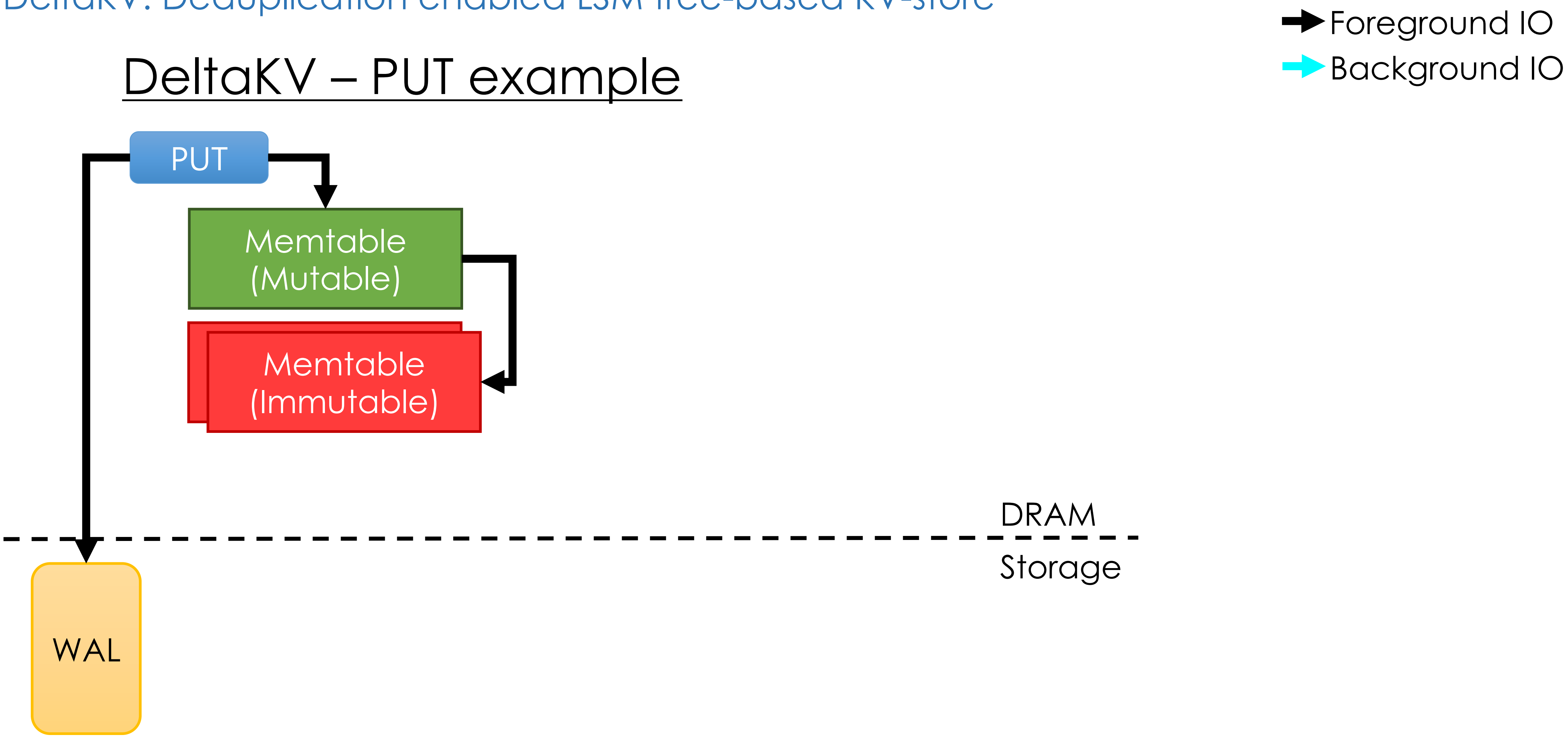

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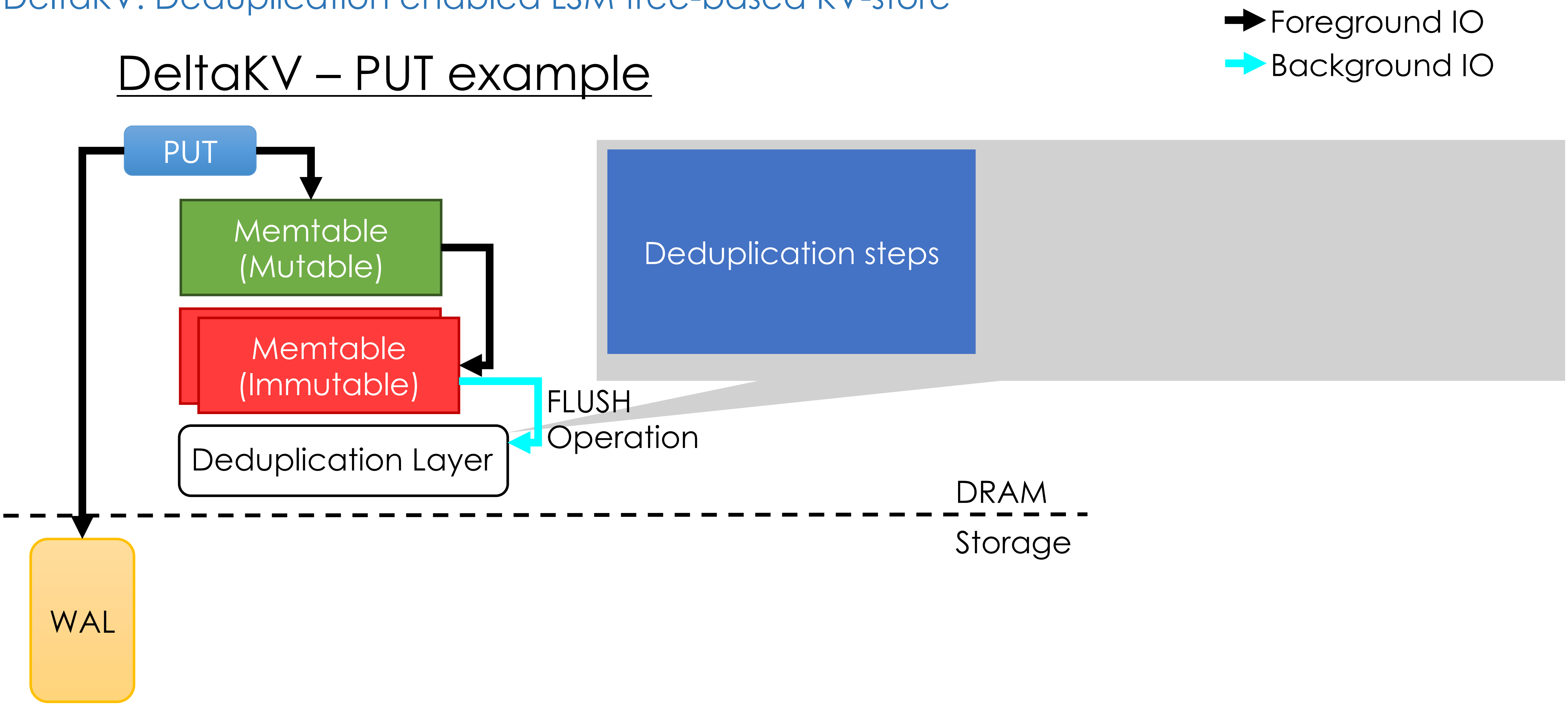
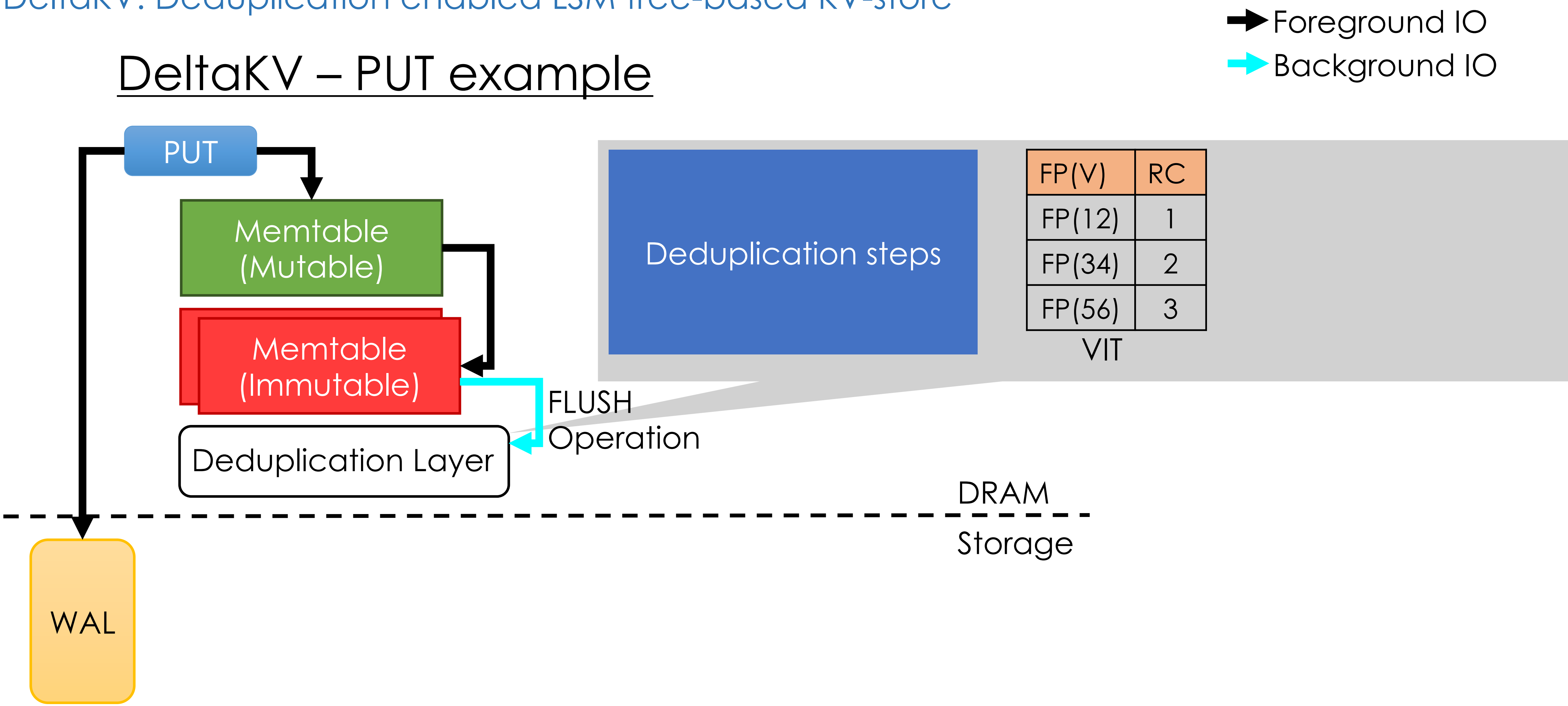


MKK B+-Tree node contains: Keys and their corresponding offsets.

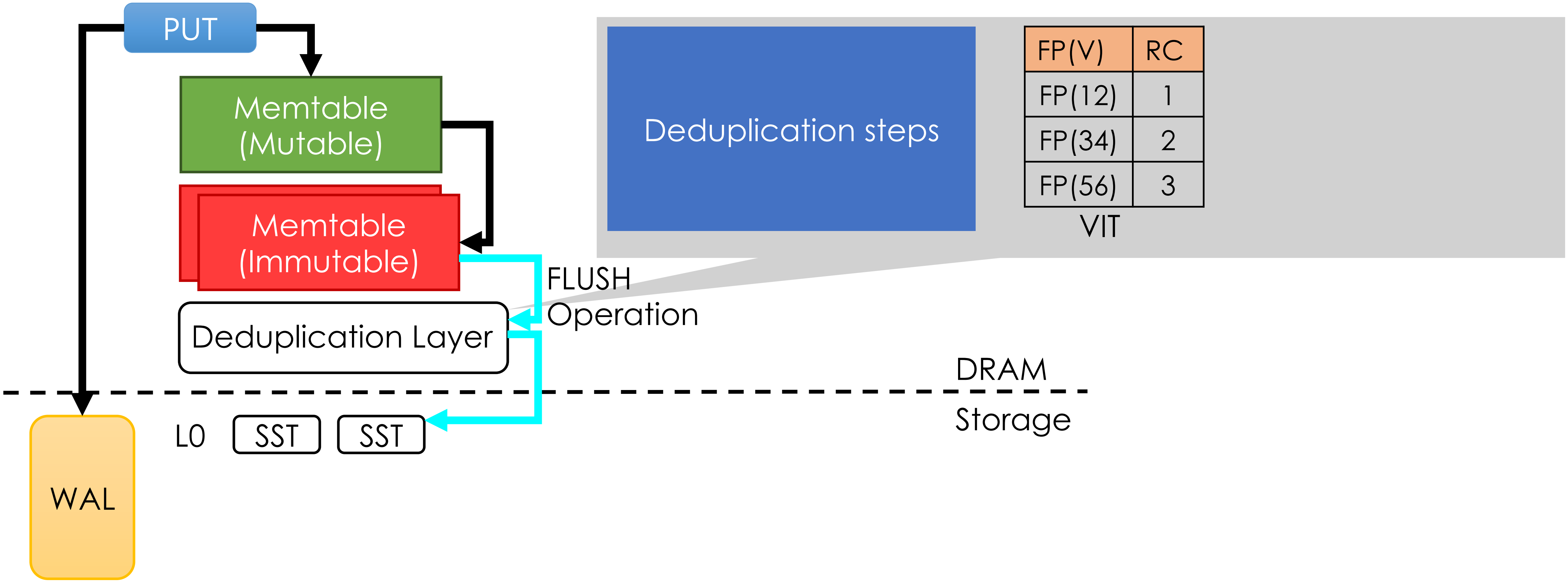
DeltaKV – PUT example



B+-Tree node contains: Keys and their corresponding offsets.

DeltaKV: Deduplication enabled LSM tree-based KV-store

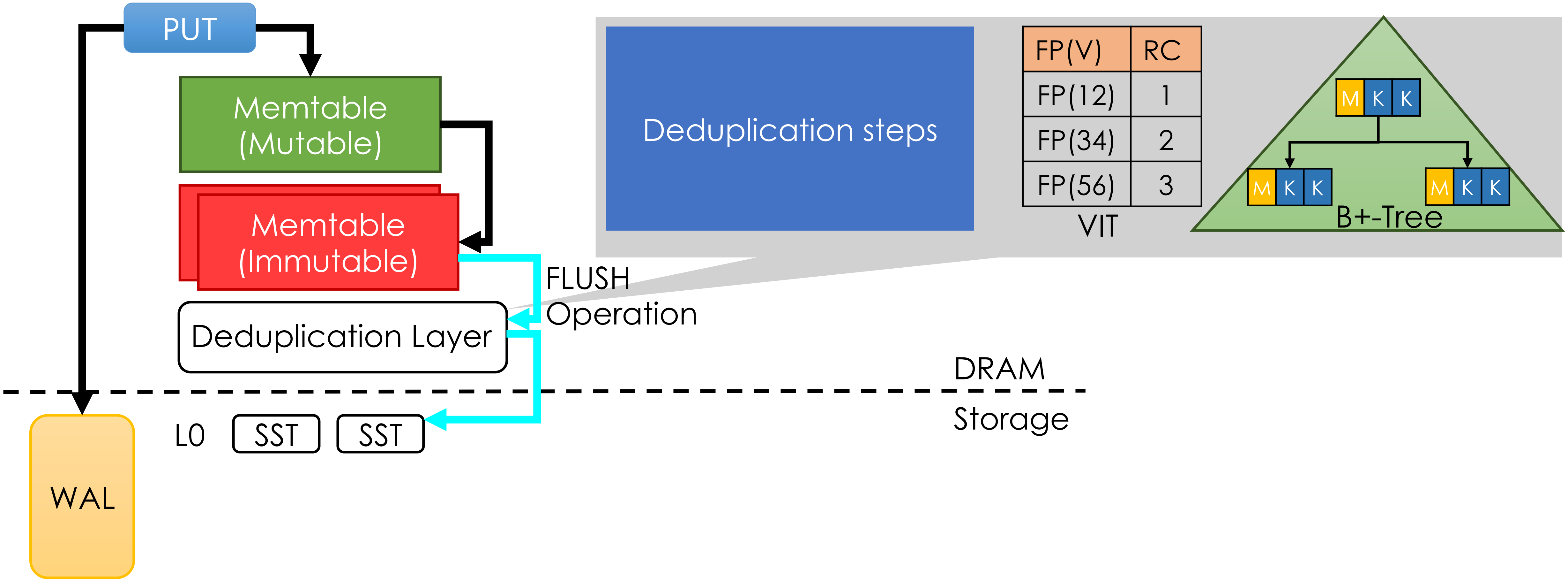
DeltaKV – PUT example



B+-Tree node contains: Keys and their corresponding offsets.

DeltaKV – PUT example

Foreground IO
Background IO



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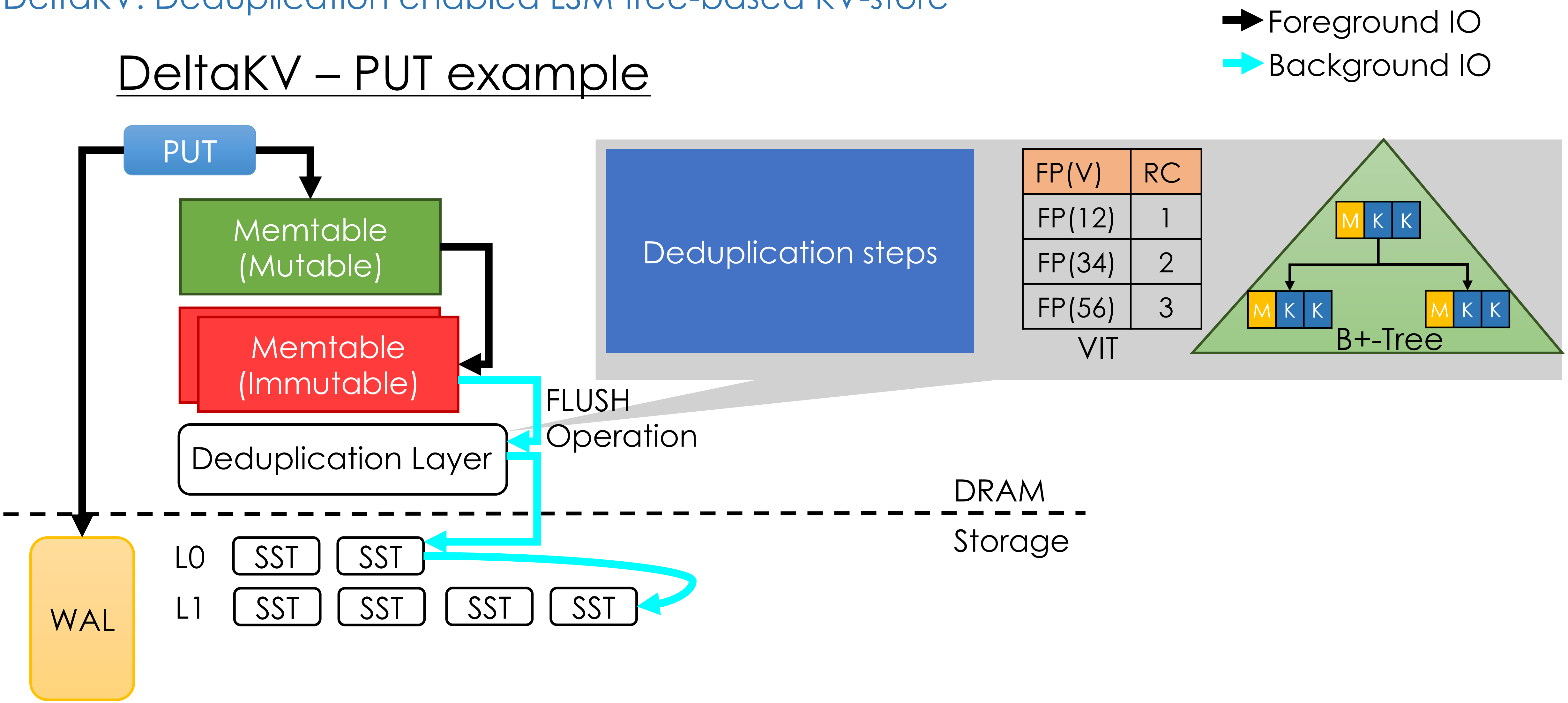
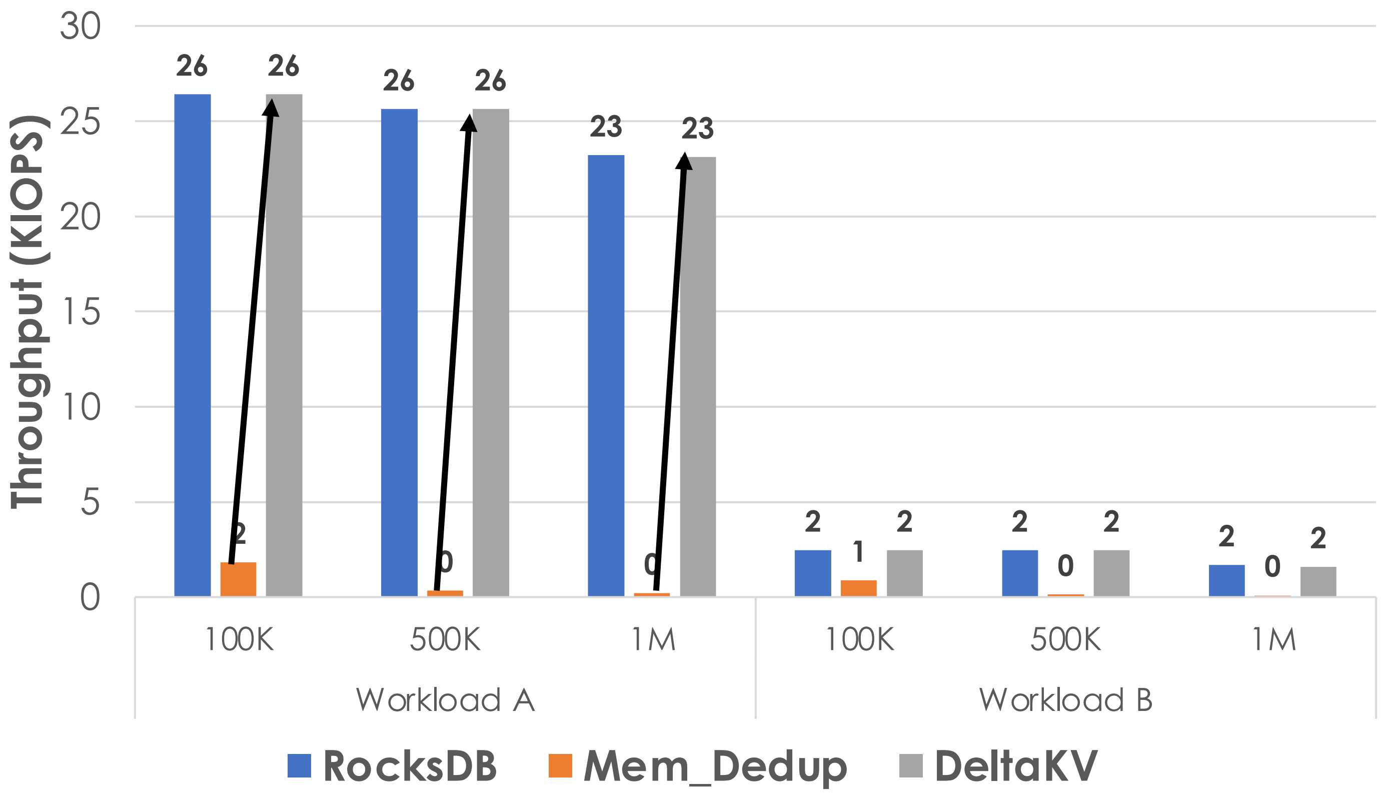


M K K B+-Tree node contains: Keys and their corresponding offsets.

DeltaKV vs MemDedup

- Preliminary evaluation
  - DeltaKV → VIT integration at FLUSH operation
  - Similar performance as baseline RocksDB



Concluding Remarks

- Explored data deduplication for LSM tree-based KV-stores
- MemDedup
  - Inline deduplication
  - Intercepts operations at the Memtable-level
  - Suffers from huge performance drop and inconsistency issue
- DeltaKV
  - Offline deduplication → FLUSH operation
  - Background thread performs dedup
  - Maintains the performance of LSM tree

Thank you

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