Compaction-Aware Zone Allocation for LSM based Key-Value Store on ZNS SSDs

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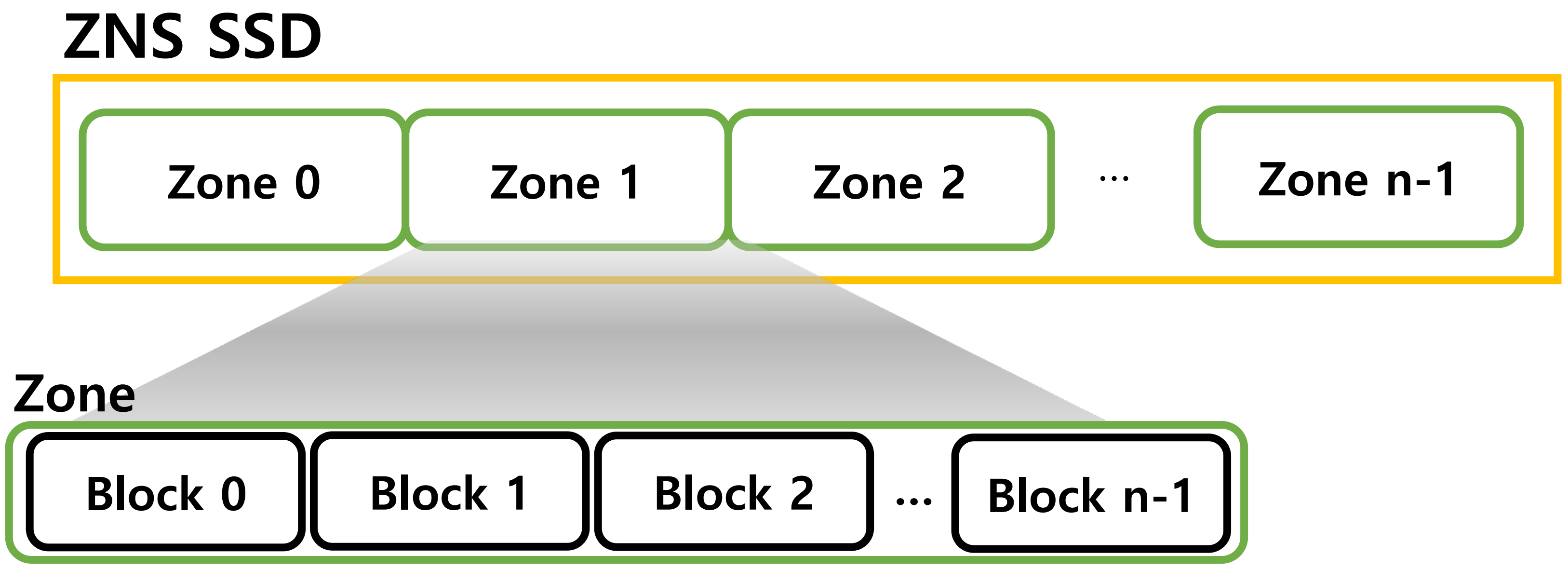
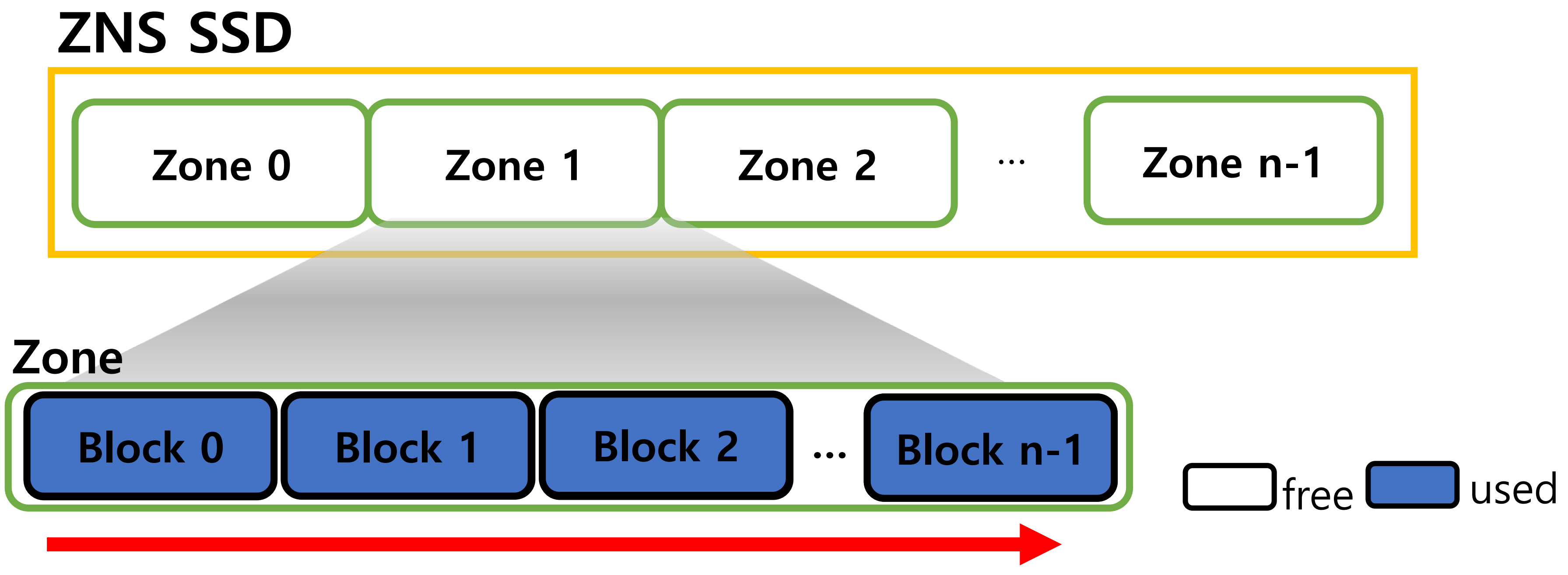
The 14th ACM Workshop on Hot Topics in Storage and File Systems
(HotStorage'22, June 27-28)

Zoned Namespace SSD(ZNS SSD)



- ❑ Group multiple logical blocks into a **zone**
- ❑ Zone is an erase unit of ZNS SSD.

Zoned Namespace SSD(ZNS SSD)



❑ Zone allows only sequential writes.

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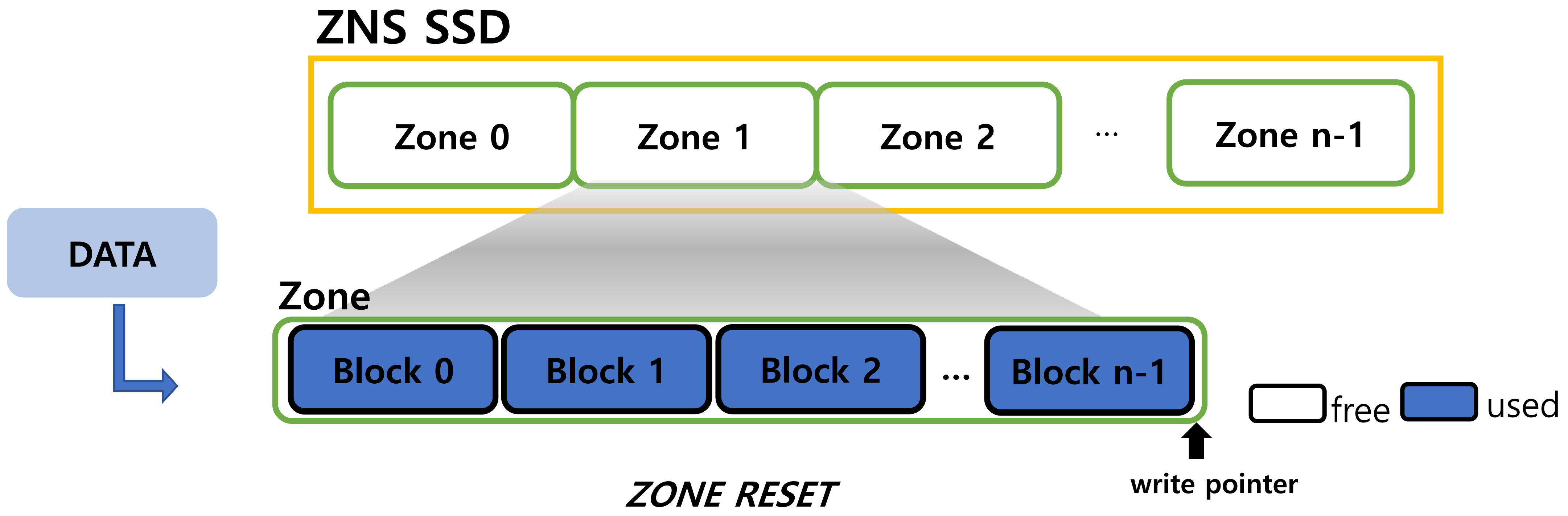

❑ Zone allows only sequential writes.

❑ Zone disallows overwrite on same logical blocks.

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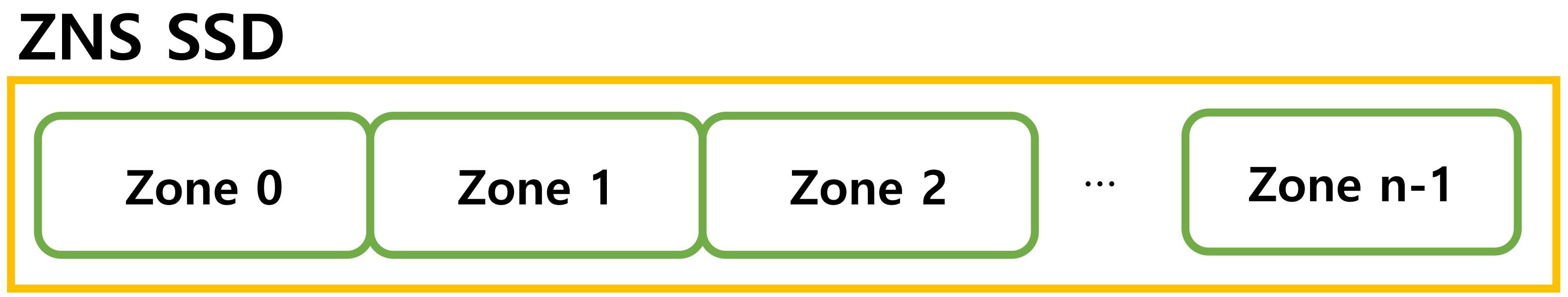


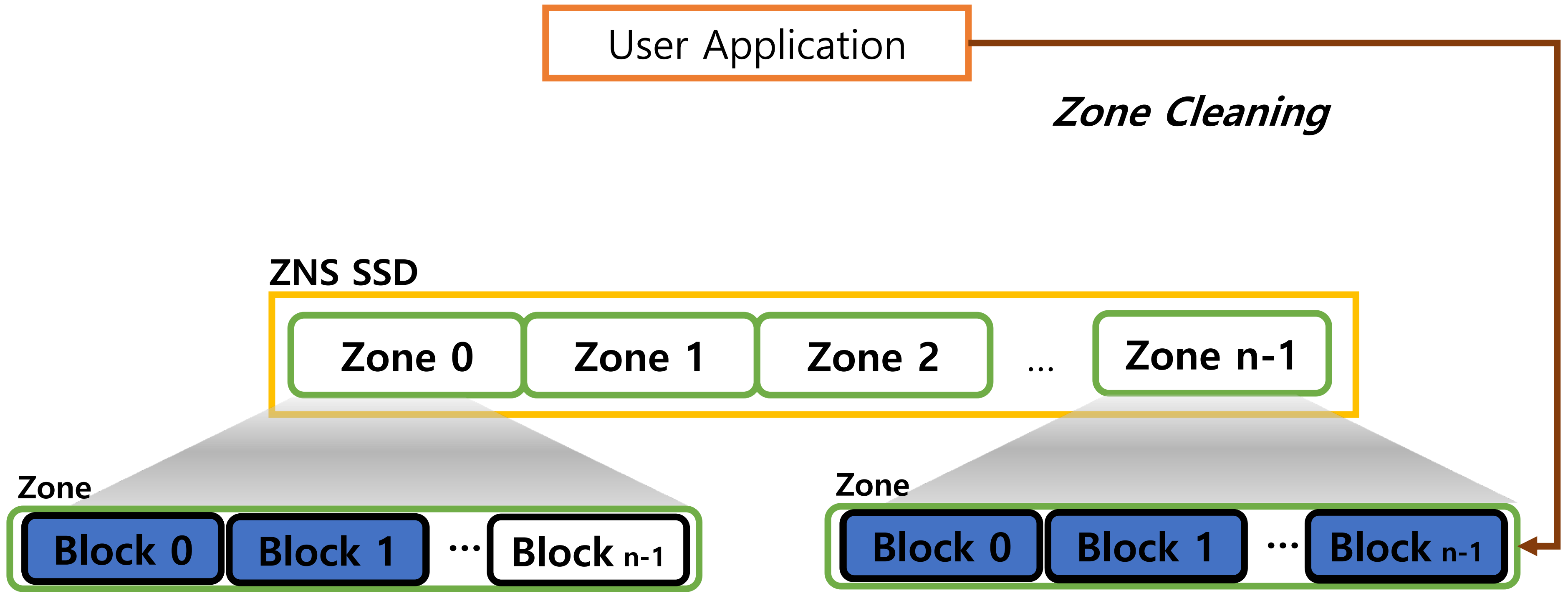
No More Garbage Collection in FTL

- ❑ Zone allows only sequential writes.
- ❑ Zone disallows overwrite on same logical blocks.

Zoned Namespace SSD(ZNS SSD)

User applications take over responsibility for

- **Free space reclamation (zone cleaning)**
- **Data placement (zone allocation)**



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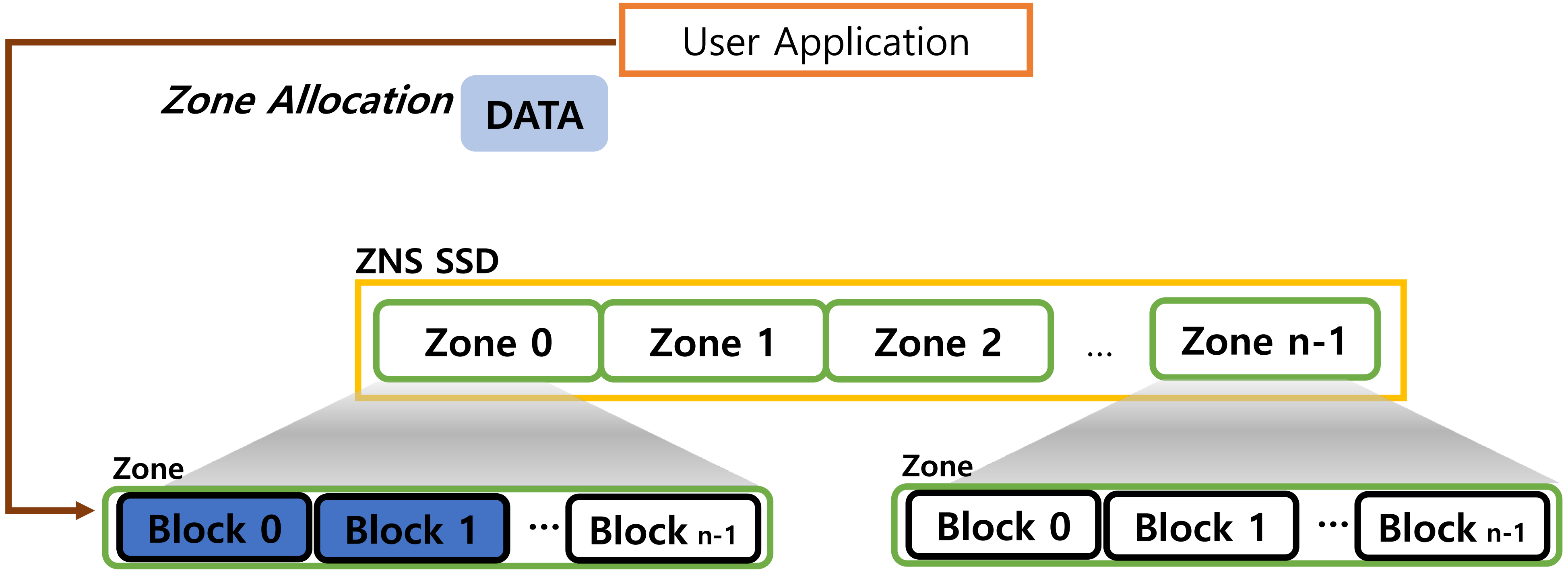


LSM-based Key-Value Store (LSM-KV)

LSM-KV is suitable for ZNS SSD.

- ❑ Log-structured merge-tree(LSM-tree)
  - ❑Sequential I/O pattern
  - ❑Out-of-place update

- ❑ Application

RocksDB LEVELDB

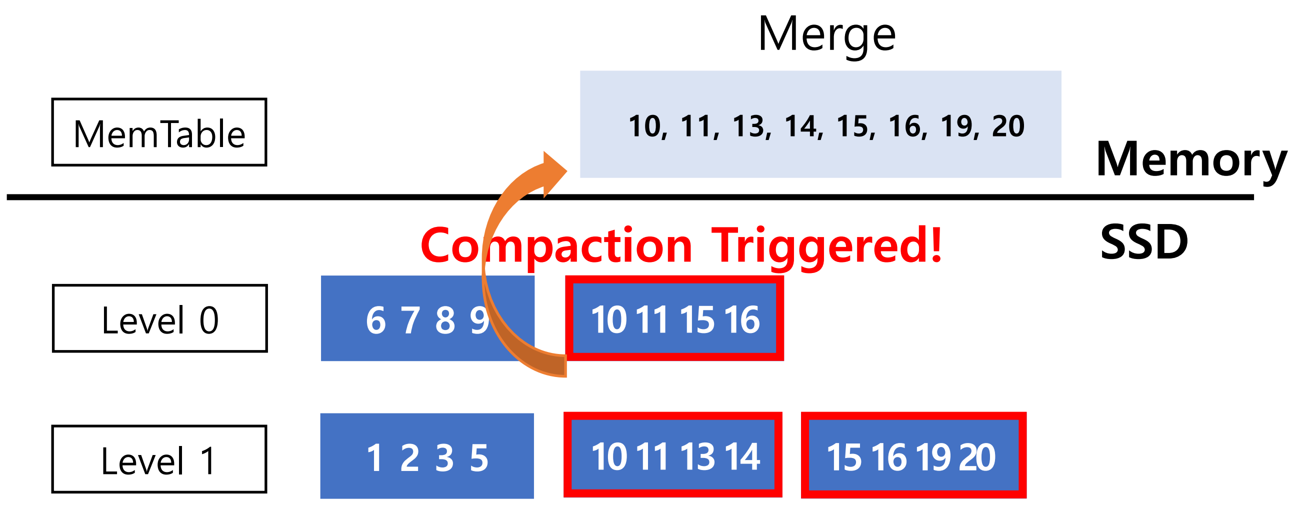
mongoDB® cassandra

LSM-based Key-Value Store (LSM-KV)

Data Update in LSM-tree

Compaction

LSM-tree updates data file(SSTable) via compaction.



🟦 : SSTable

In this Example :
- SSTable size limit : 4 keys
- Level 0 limit : 2 SSTs
- Level 1 limit : 4 SSTs

LSM-based Key-Value Store (LSM-KV)

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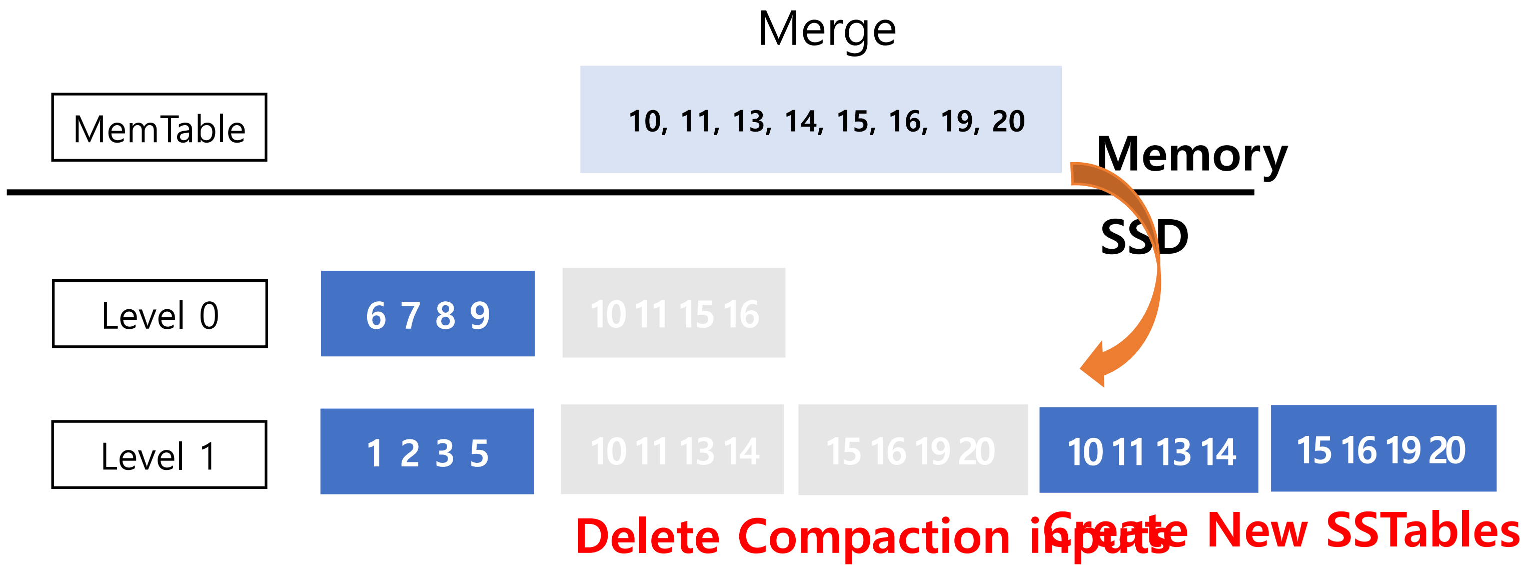

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ZenFS[1] [ATC'21]

❑ User-level file system for LSM-KV

❑ Backend module for RocksDB

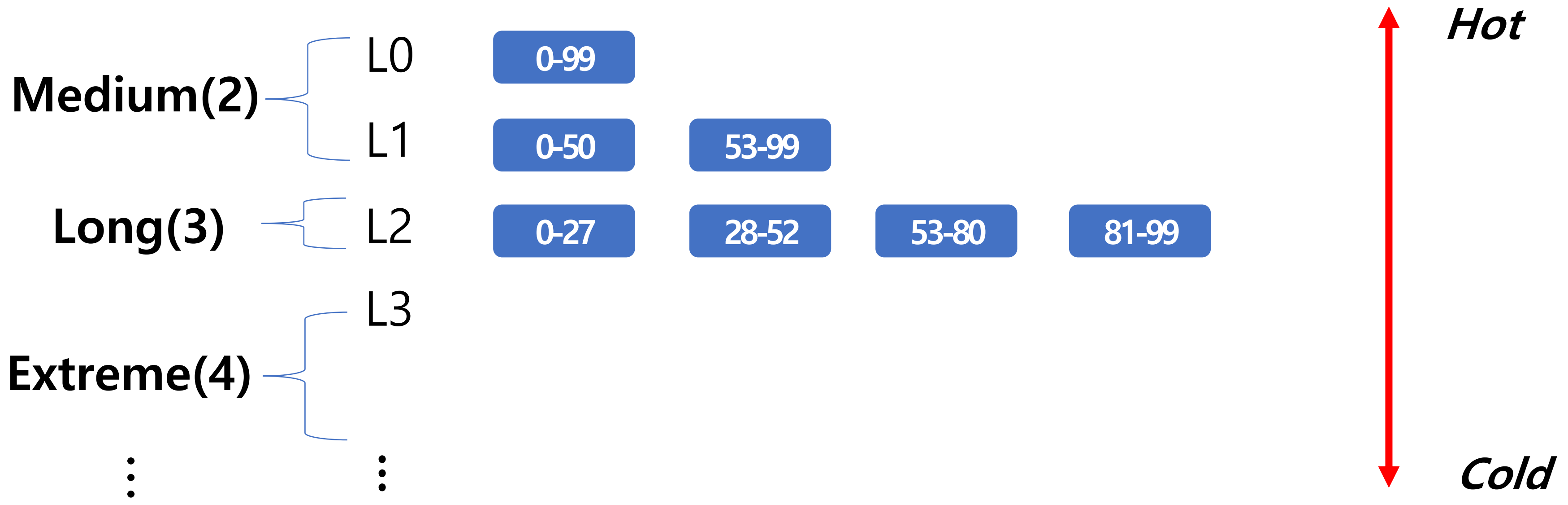
❑ Responsible for

- Zone Allocation of data in LSM-KV
- Zone Cleaning for free space reclamation

1) Bjørling, Matias, et al. *ZNS: Avoiding the Block Interface Tax for Flash-based SSDs, ATC'21*

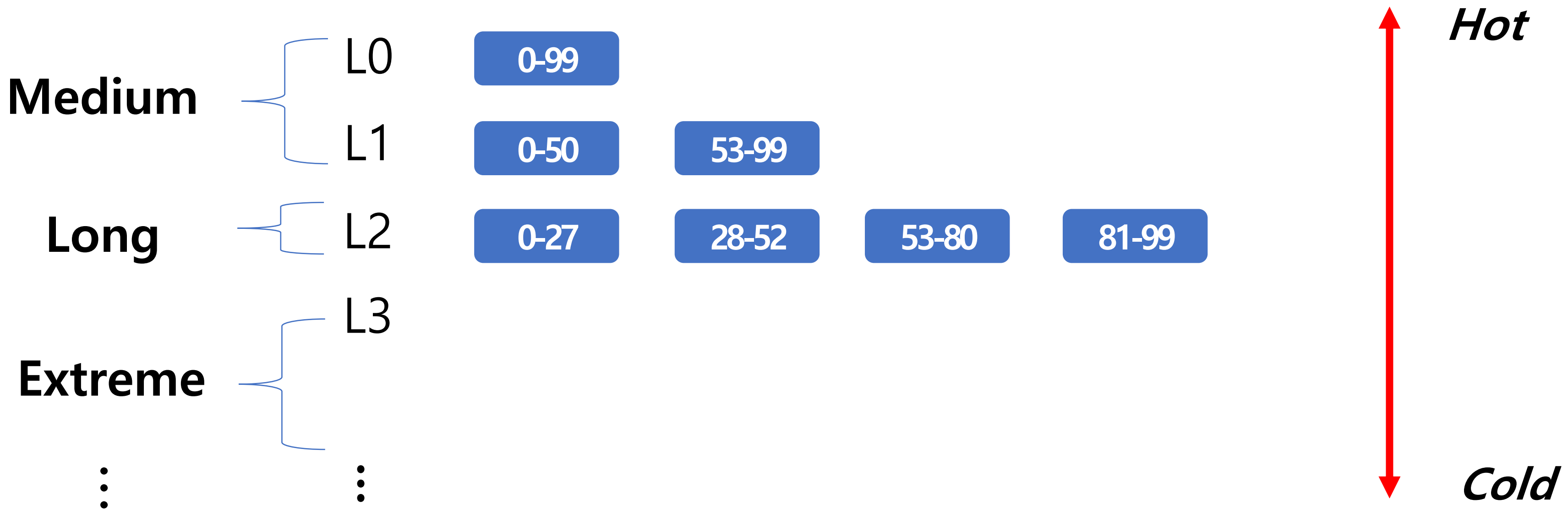
LifeTime based Zone Allocation in ZenFS

❑ **LifeTime :** Reflect data hotness according to level in LSM-tree



LifeTime based Zone Allocation in ZenFS

LifeTime - indicator of **when an SSTable is invalidated** in the device



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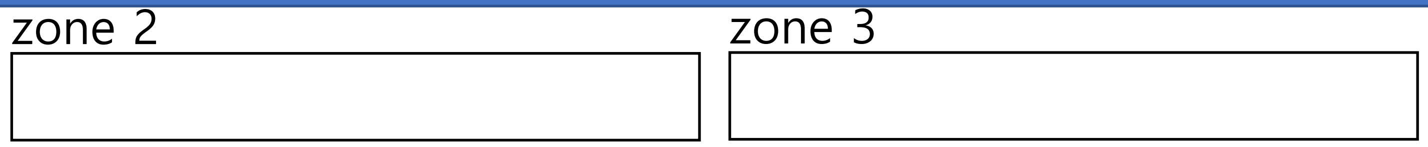
LifeTime based Zone Allocation in ZenFS

- **Zone Allocation using LifeTime**

  - ZenFS allocates SSTables with same LifeTime into the same zone.

ZenFS fails to precisely predict which

<u>SSTables will be deleted together</u>

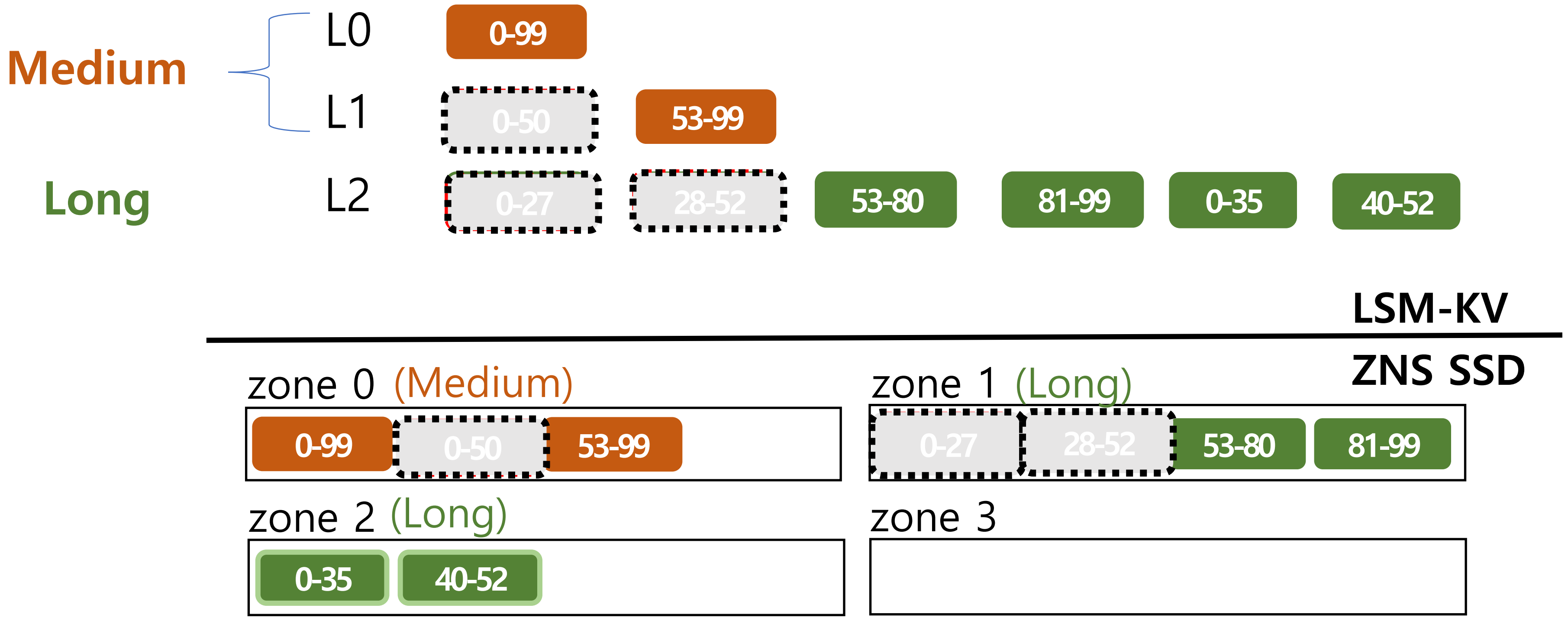


LifeTime based Zone Allocation in ZenFS

ZenFS fails to precisely predict which SSTables will be deleted together.

① Trigger Compaction in L1 ② Select Compaction inputs / Merge them

③ Create / Allocate new SSTables ④ Delete Compaction inputs



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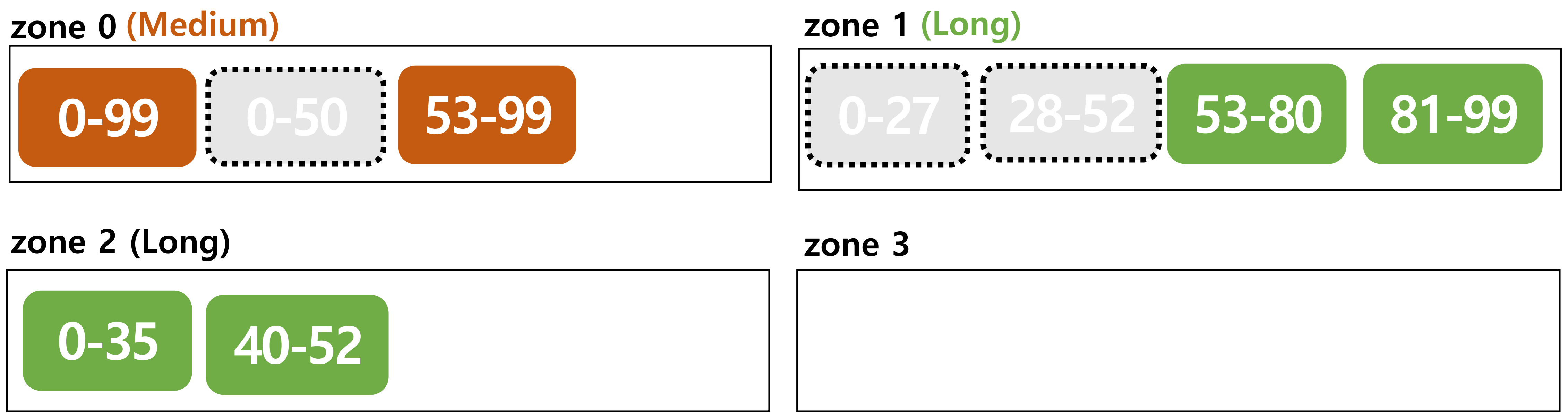

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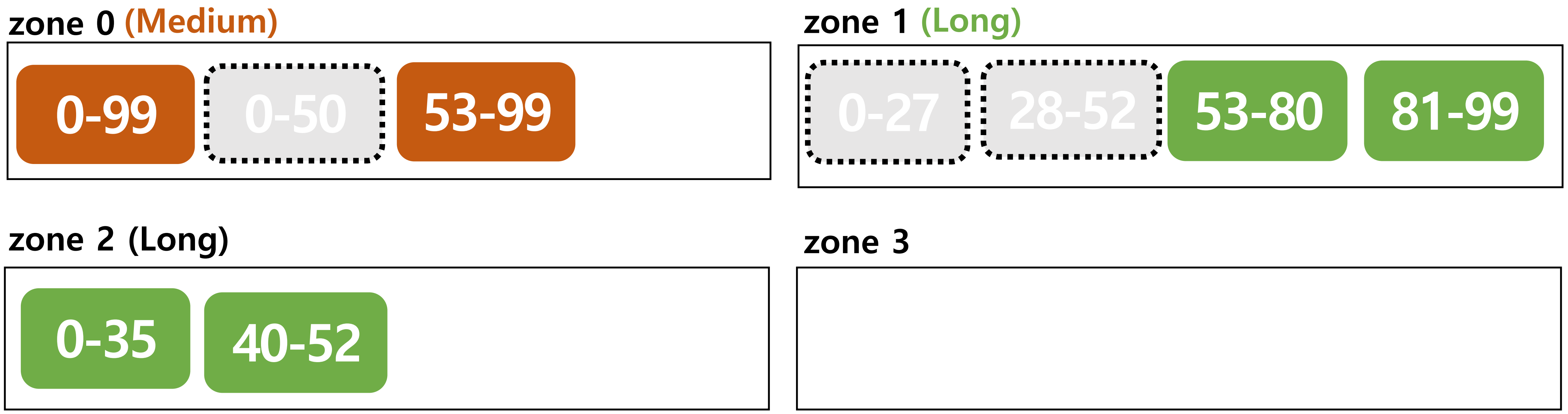

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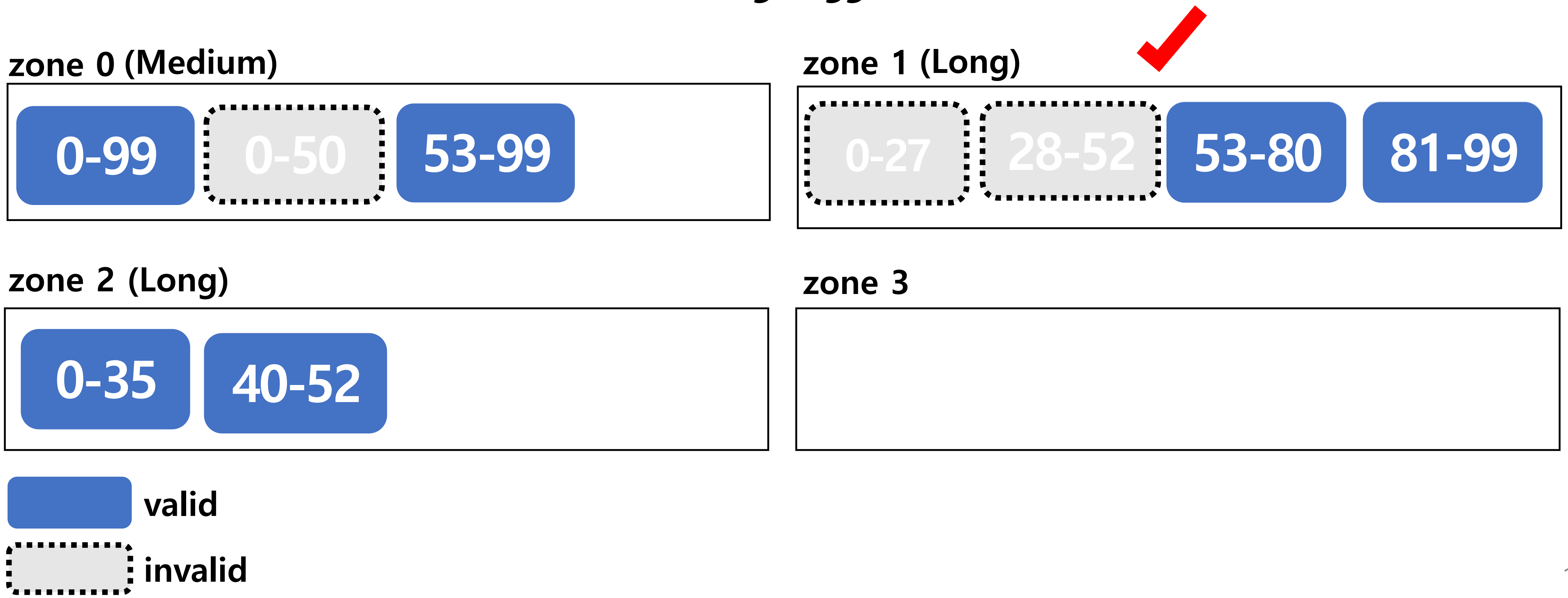
Overhead of ZenFS Allocation

Write Amplification

Prediction failure of deletion time leads to valid data copying during zone cleaning.

Zone Cleaning Trigger



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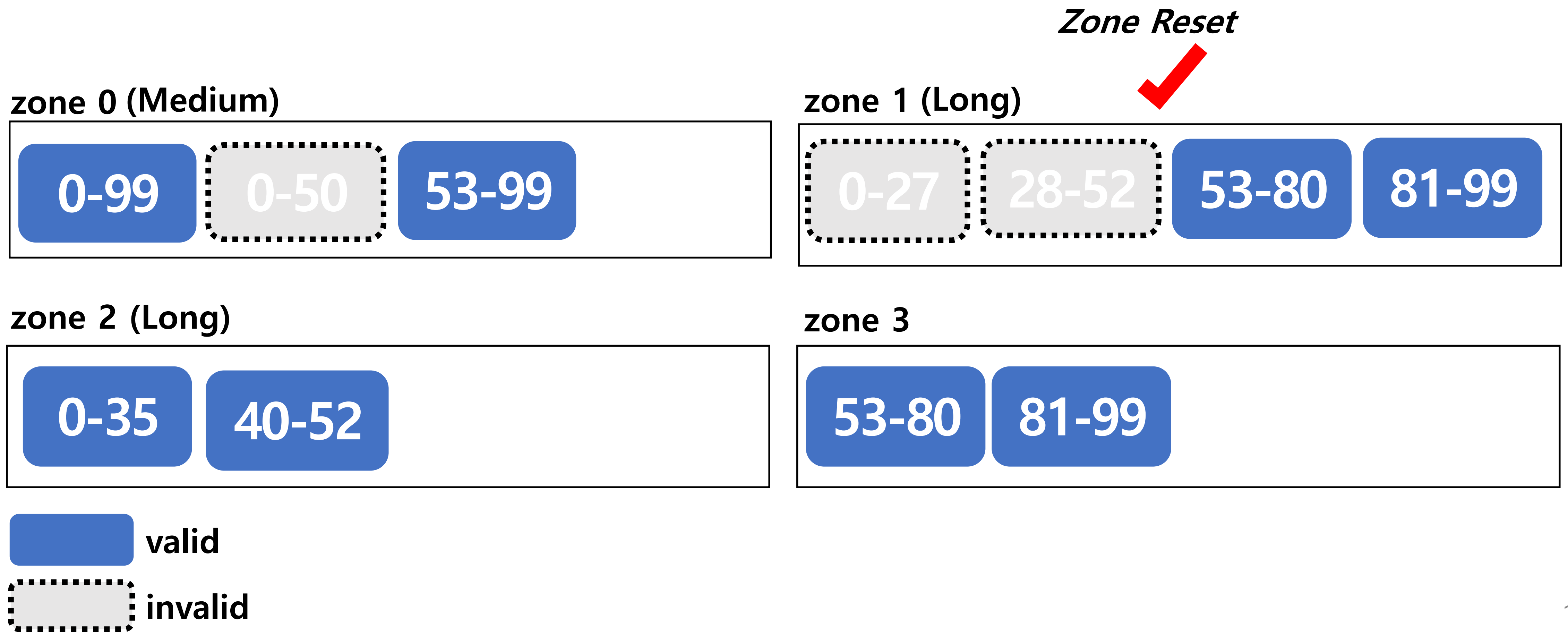


Compaction-Aware Zone Allocation (CAZA)

Main Idea

- ❑ We observed that SSTables to be compacted together are invalidated at the same time.
- ❑ We allocate SSTables to be compacted together into the same zone.

Challenge : How can we predict which SSTables will be compacted together ?

Compaction-Aware Zone Allocation (CAZA)

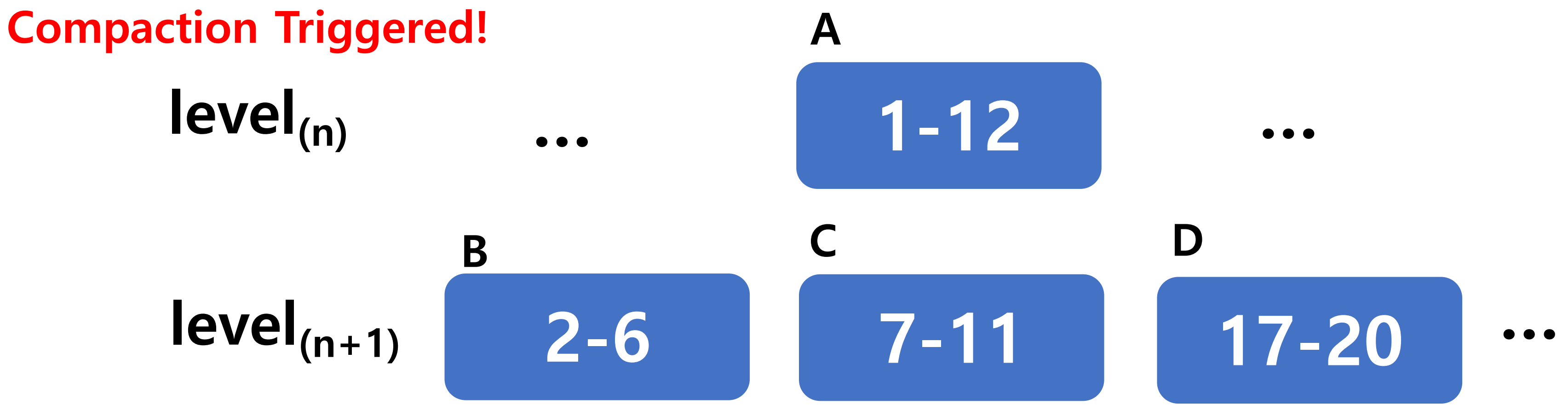
Conditions for SSTables to be compacted together

Condition 1: SSTables that are located in adjacent levels

Condition 2 : SSTables that have overlapping key ranges

Compaction-Aware Zone Allocation (CAZA)

Compaction Input Picking in LSM-tree



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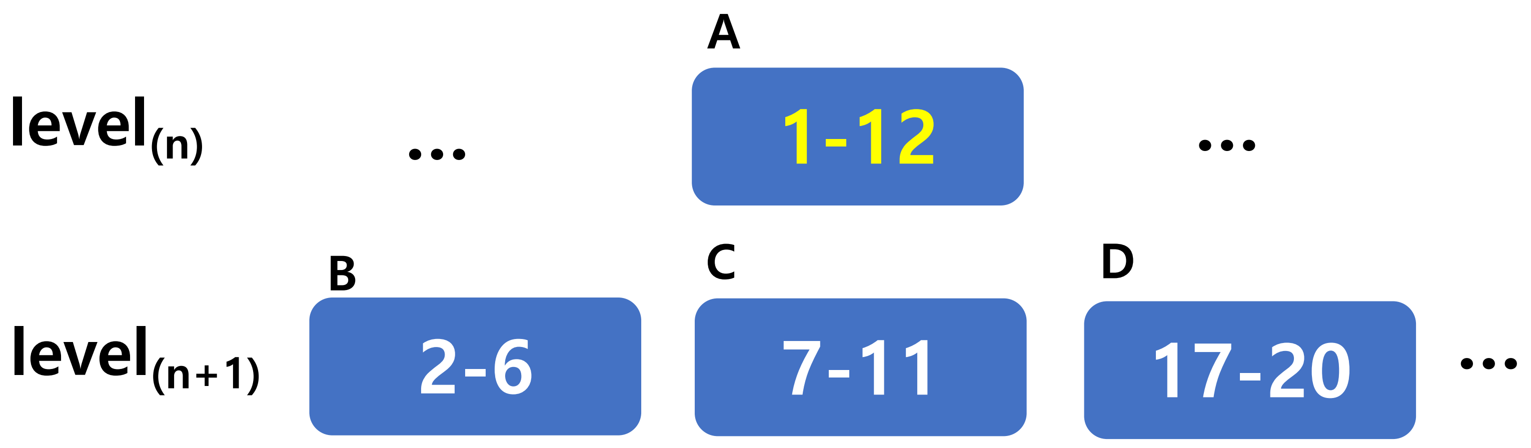

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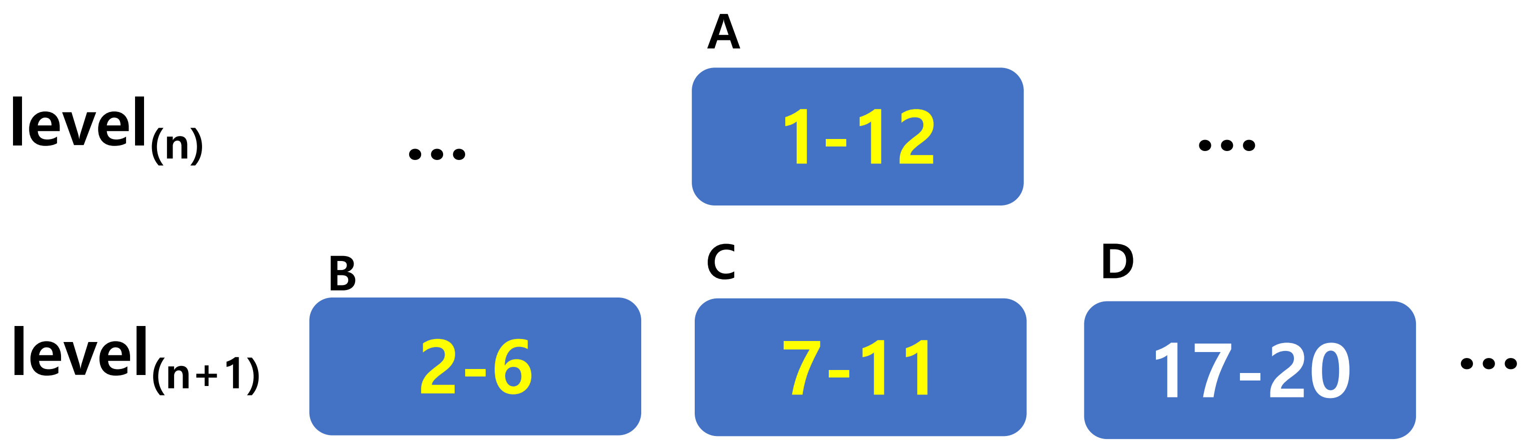

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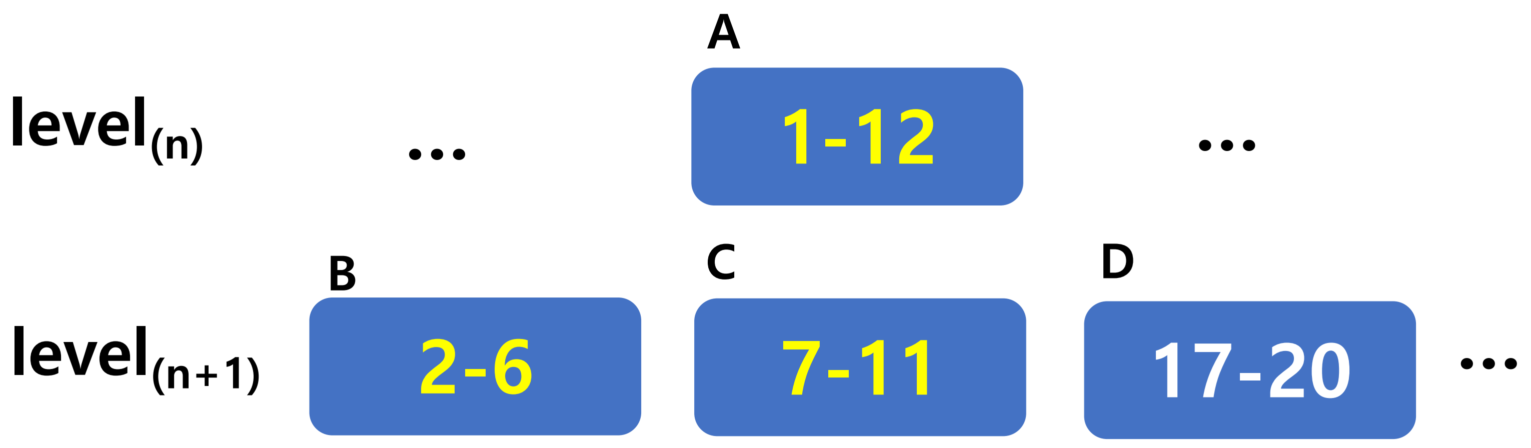

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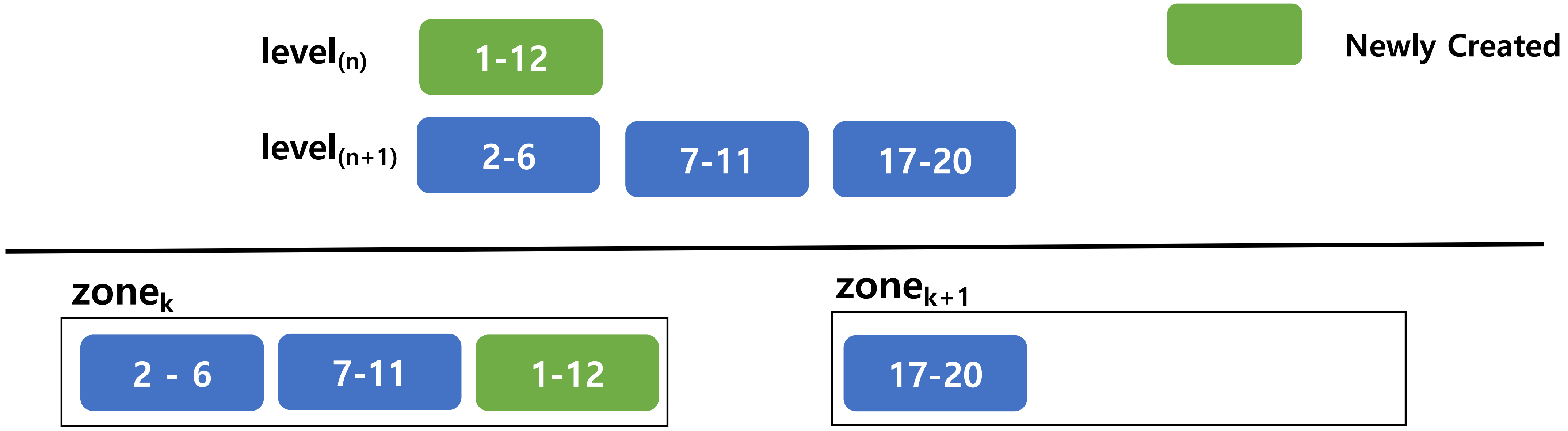

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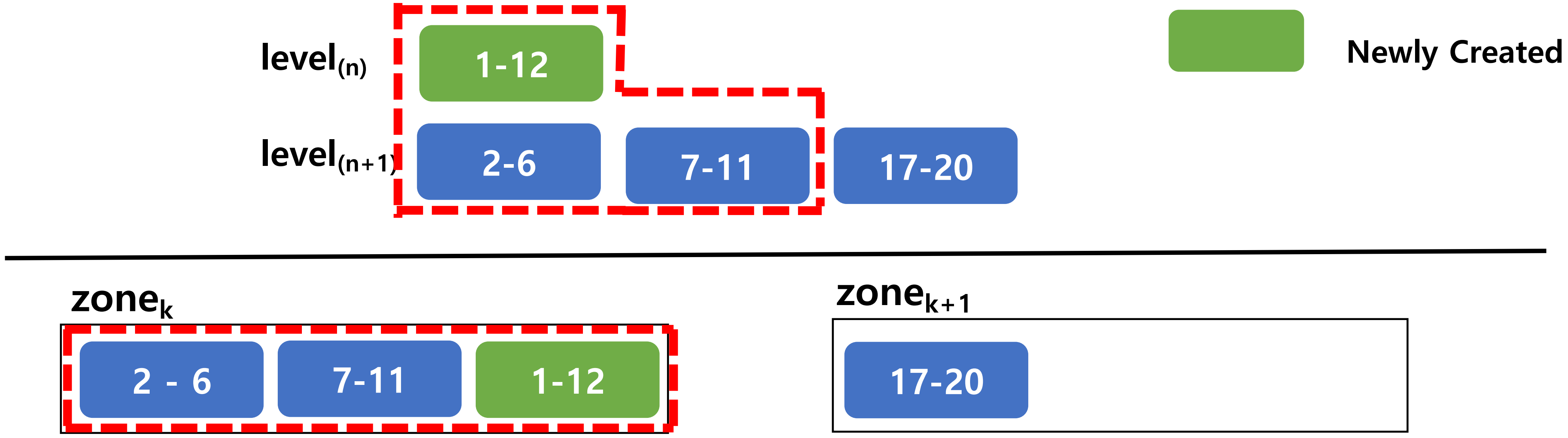

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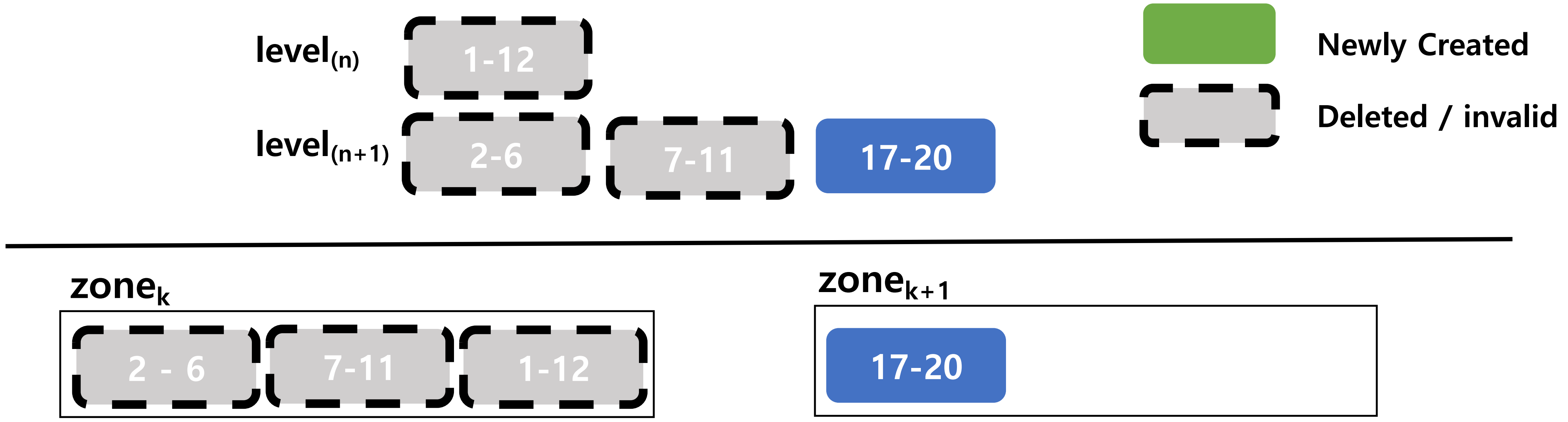
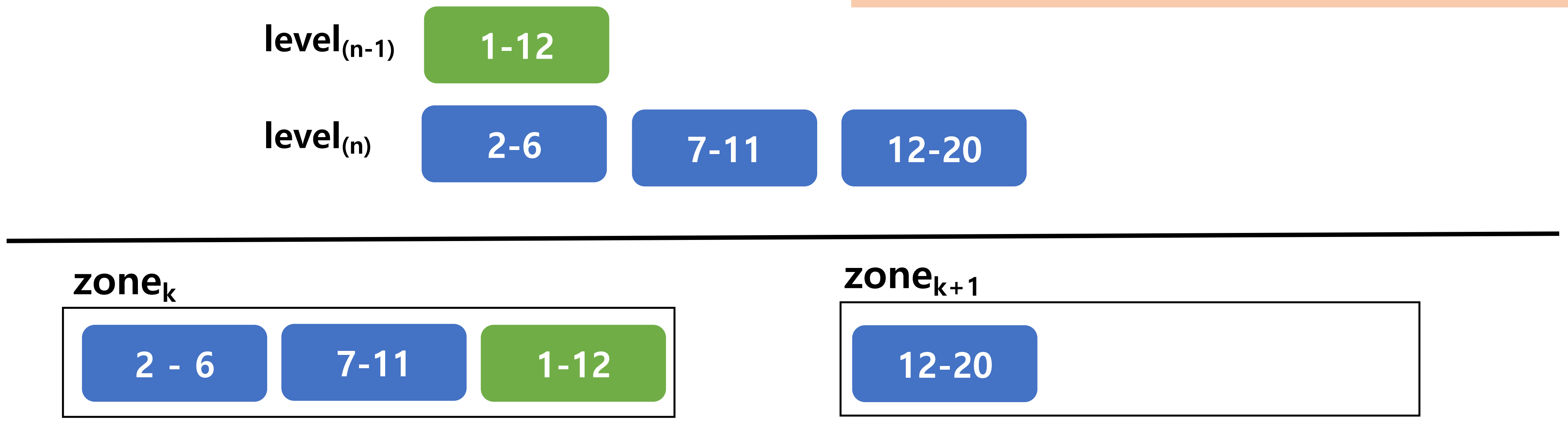


Compaction-Aware Zone Allocation (CAZA)

❑ Compaction-Aware Zone Allocation Rules

Case 1) SSTables with overlapping key ranges spread in several zones.

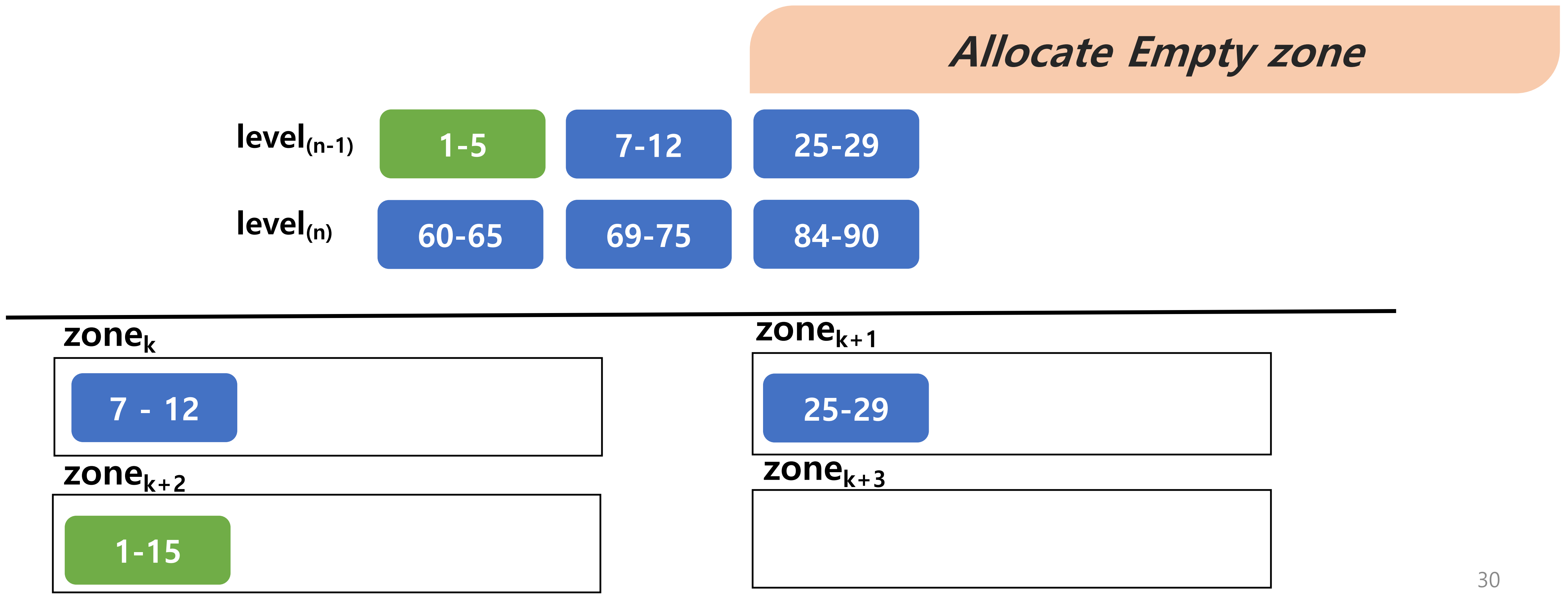
Allocate the zone with more SSTables



Compaction-Aware Zone Allocation (CAZA)

❑ Compaction-Aware Zone Allocation Rules

Case 2) No matching SSTables that meet the compaction condition



Compaction-Aware Zone Allocation (CAZA)

❑ Compaction-Aware Zone Allocation Rules

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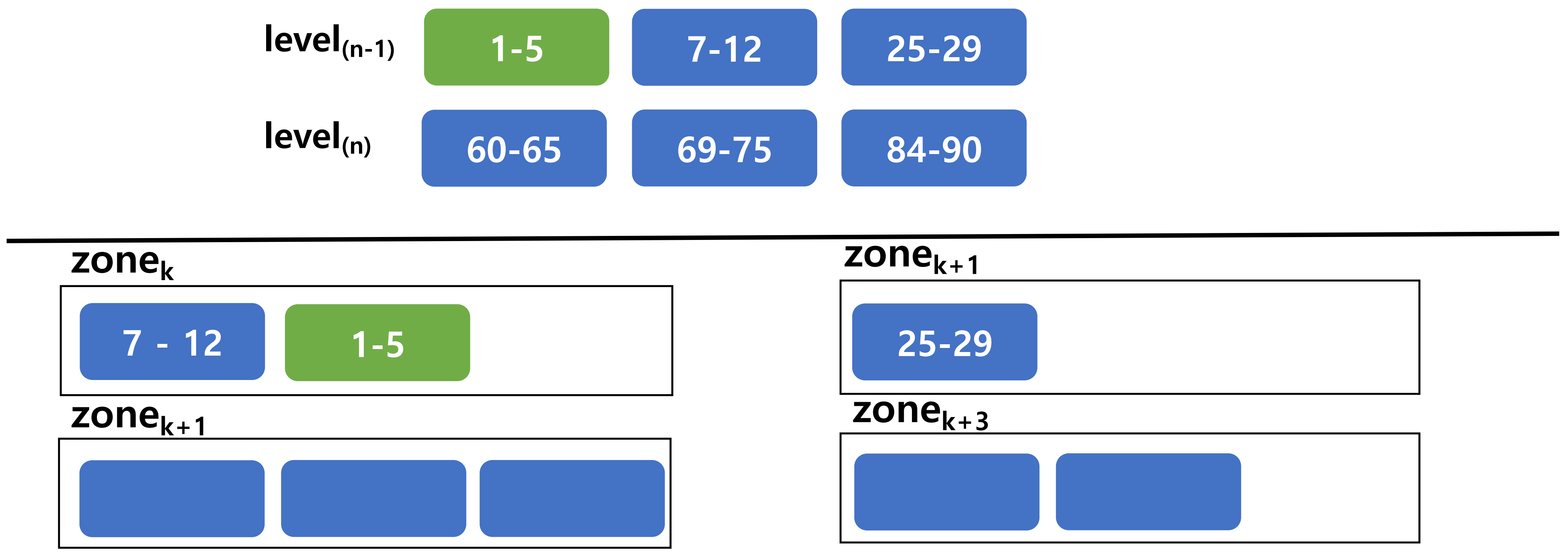
Allocate Zone with SSTables in (1) Same level (2) Closest key range



Compaction-Aware Zone Allocation (CAZA)

- Compaction-Aware Zone Allocation Rules

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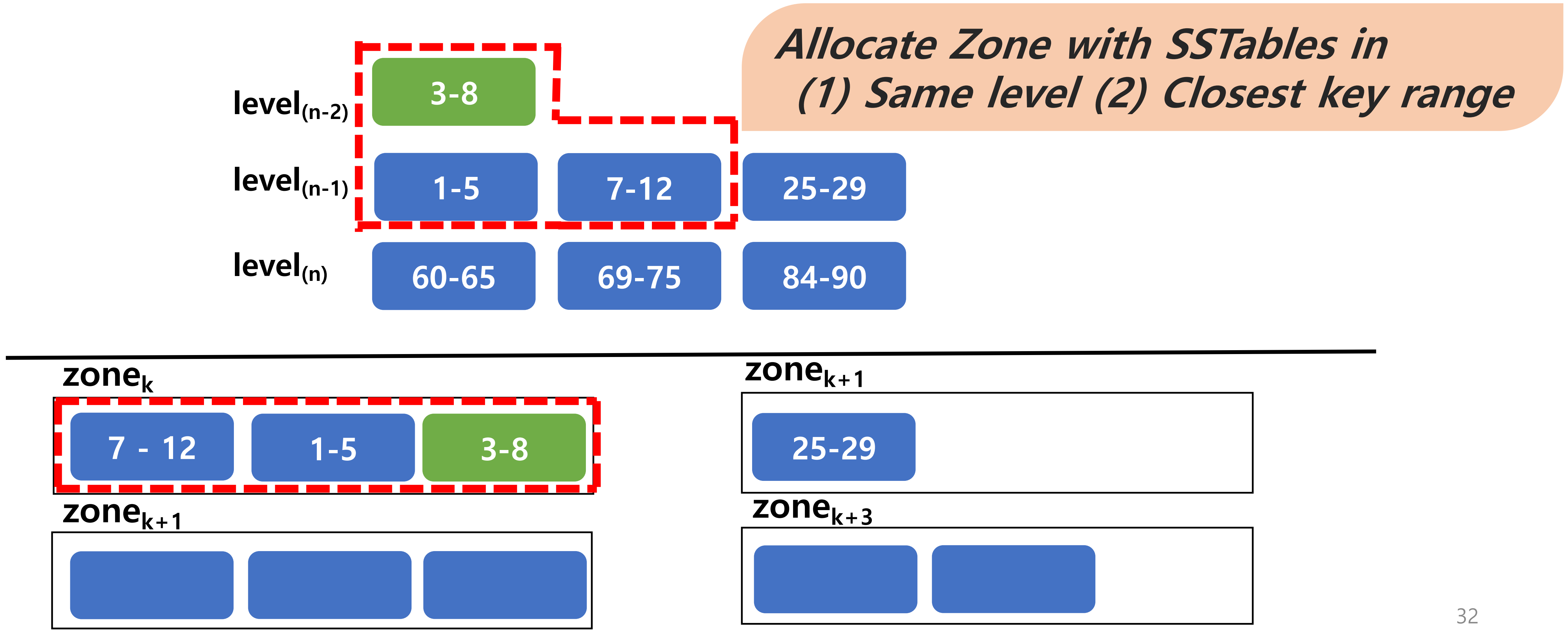

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Compaction-Aware Zone Allocation (CAZA)

❑ Compaction-Aware Zone Allocation Rules

No matching case..

➔ Follow Zone Allocation in ZenFS

Evaluation

❑ Comparison

- **LIZA** : LifeTime-based Zone Allocation in ZenFS
- **CAZA** : Compaction-Aware Zone Allocation

Testbed Specifications	
ZNS SSD	100GB Capacity DRAM Emulation 1GB-sized zone (total 100 zones)
CPU	Intel Xeon E5-2640
LSM-KV	RocksDB v6.13
OS	Linux Kernel 5.10.13

❑ Workload

- RocksDB micro-benchmark
  (*overwrite after fillseq*)
- 40GB KVs, 16B key & 128B Value

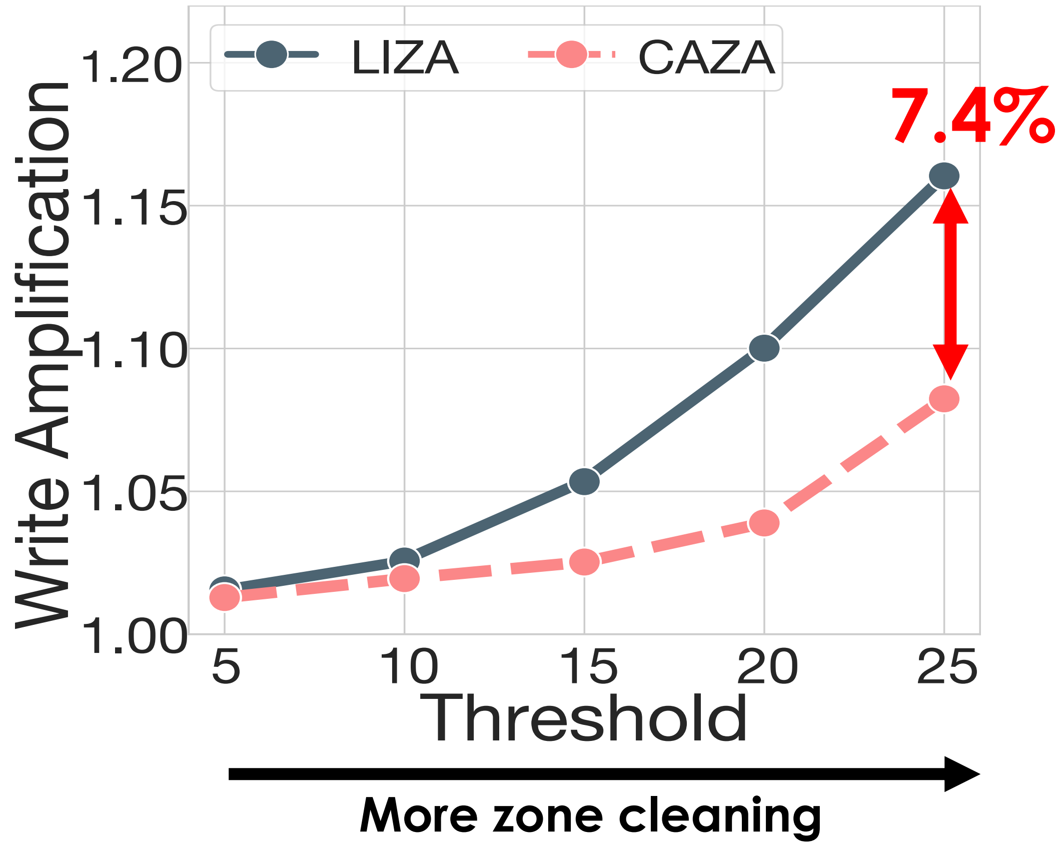
❑ Zone Cleaning

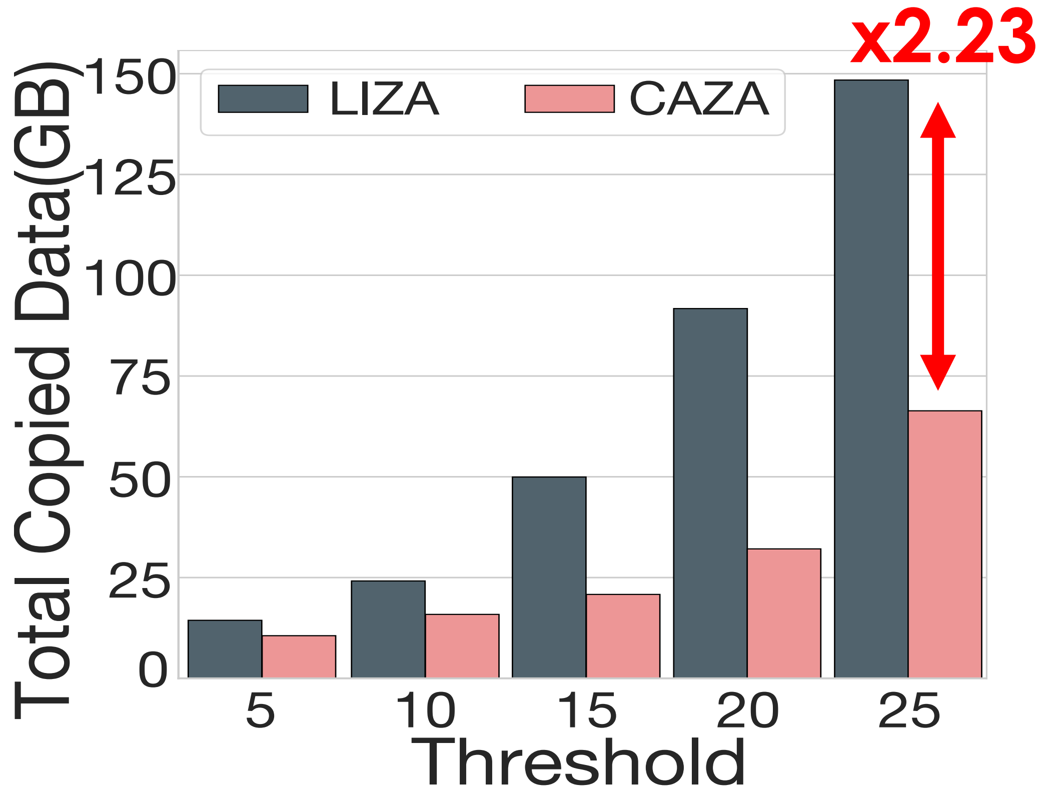
- **Greedy Zone Cleaning** : Select zones with most invalid data for reset
- Varying threshold(5%, 10%, 15%, 20%, 25%) where zone cleaning must reclaim for free space

Evaluation

Write Amplification(WA)

$$WA = \frac{Written\ by\ LSM{-}KV + \ Copied\ by\ Zone\ cleaing}{Written\ by\ LSM{-}KV}$$





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Conclusion

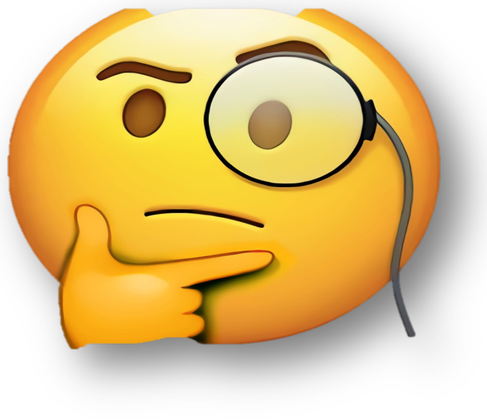
❑ Compaction-Aware Zone Allocation(CAZA)

- We proposed novel data placement algorithm for LSM-KV on ZNS SSDs.
- CAZA precisely estimates lifetime of SSTables.
- CAZA offers 7.4% lower write amplification and 2x lower data copying during zone cleaning than LIZA.

Q&A

Thank you!

Any Questions?



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