Lifetime-Leveling LSM-tree Compaction for ZNS SSD

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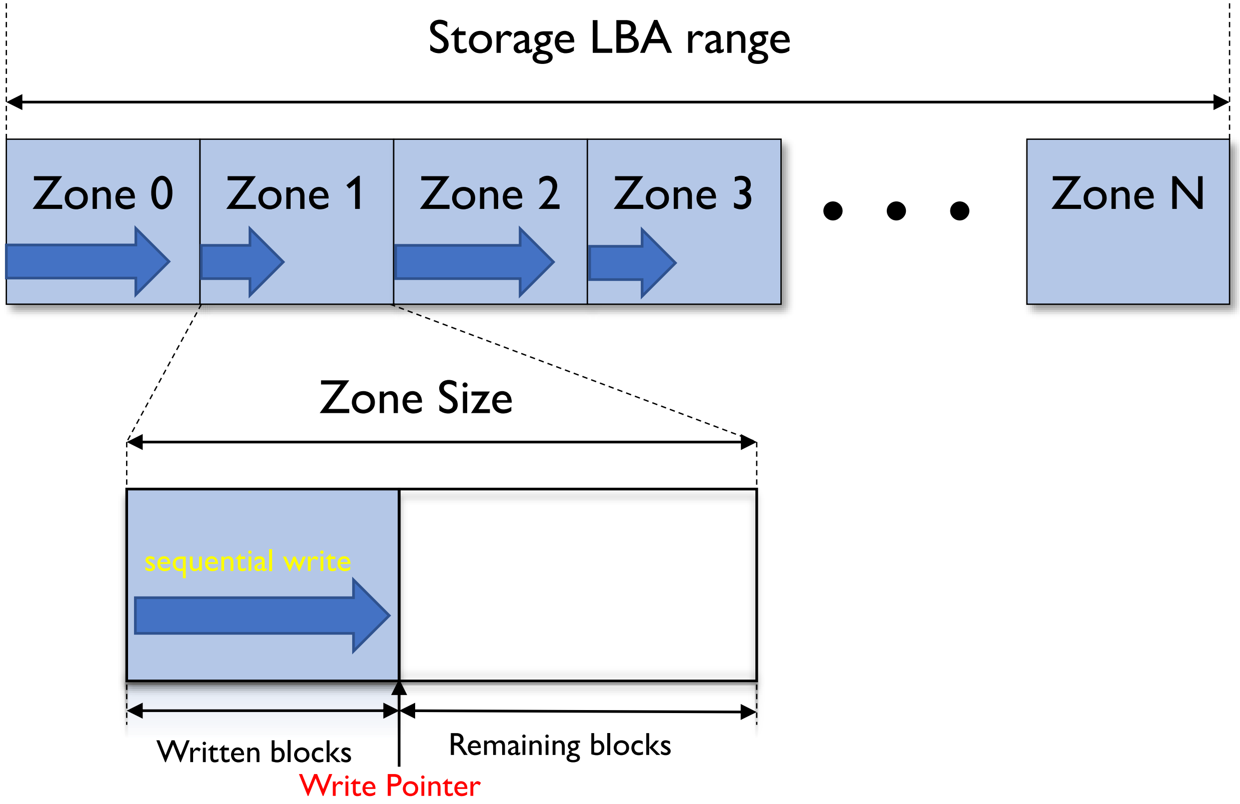
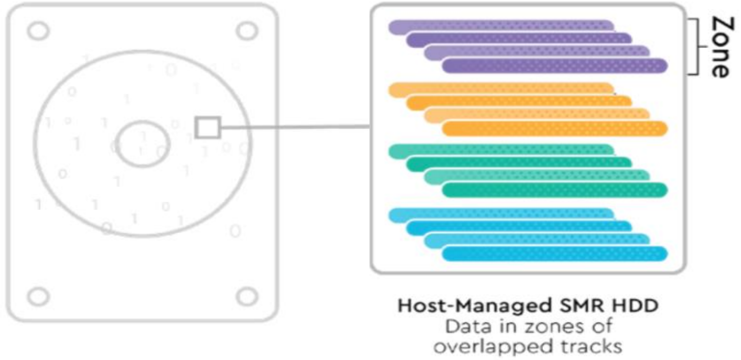
Zoned Namespace (ZNS)

- The logical address space is divided into fixed-size zones.
- Each zone must be written sequentially and reset explicitly for reuse
- No SSD-side garbage collection

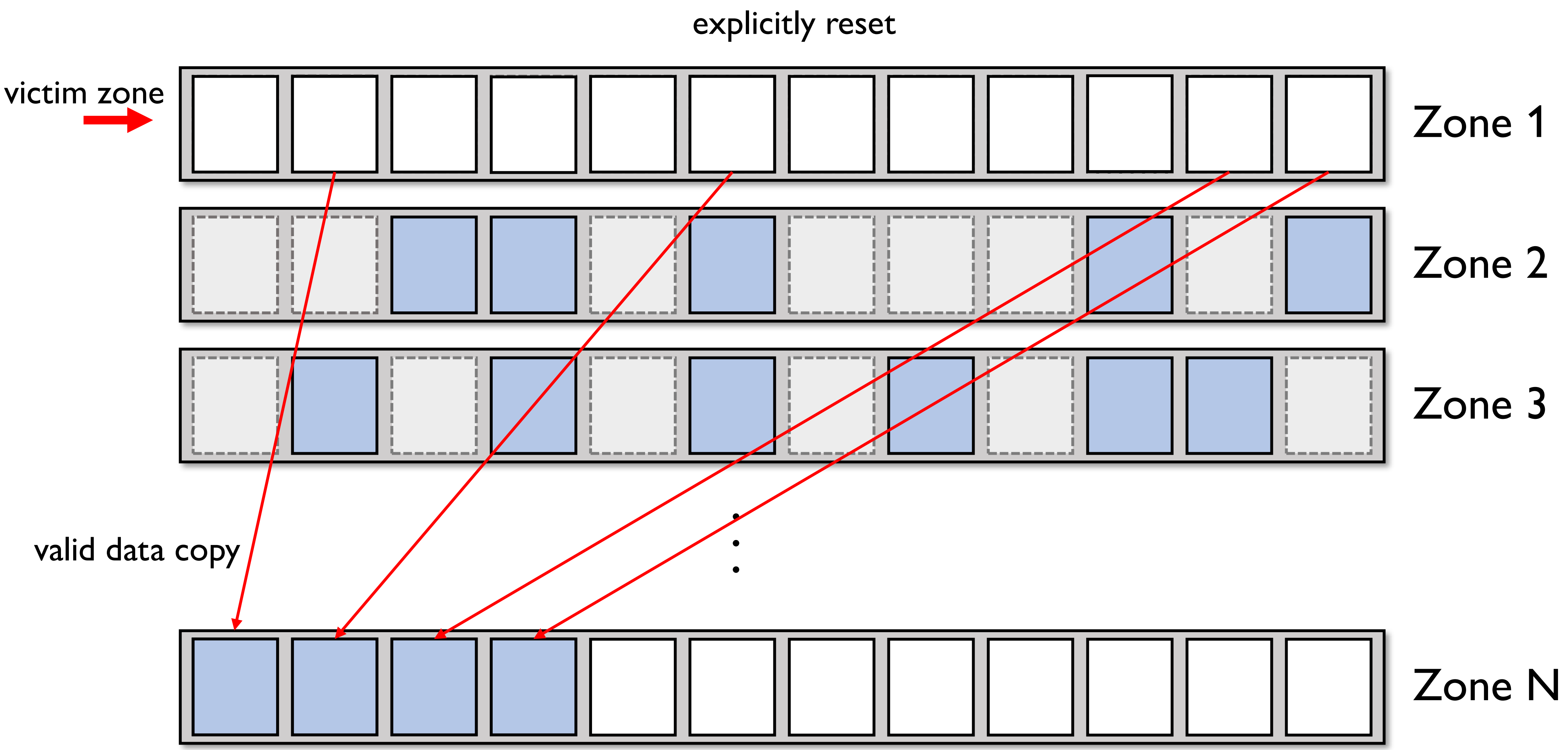




HM-SMR HDD

ZNS SSD

Host-managed GC on ZNS



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LSM-tree SST at ZNS

Large SST

Zone0	Zone1	Zone2	Zone3

- Large Compaction Cost
- High memory pressure

Large Zone

SST0	SST1	SST2	SST3

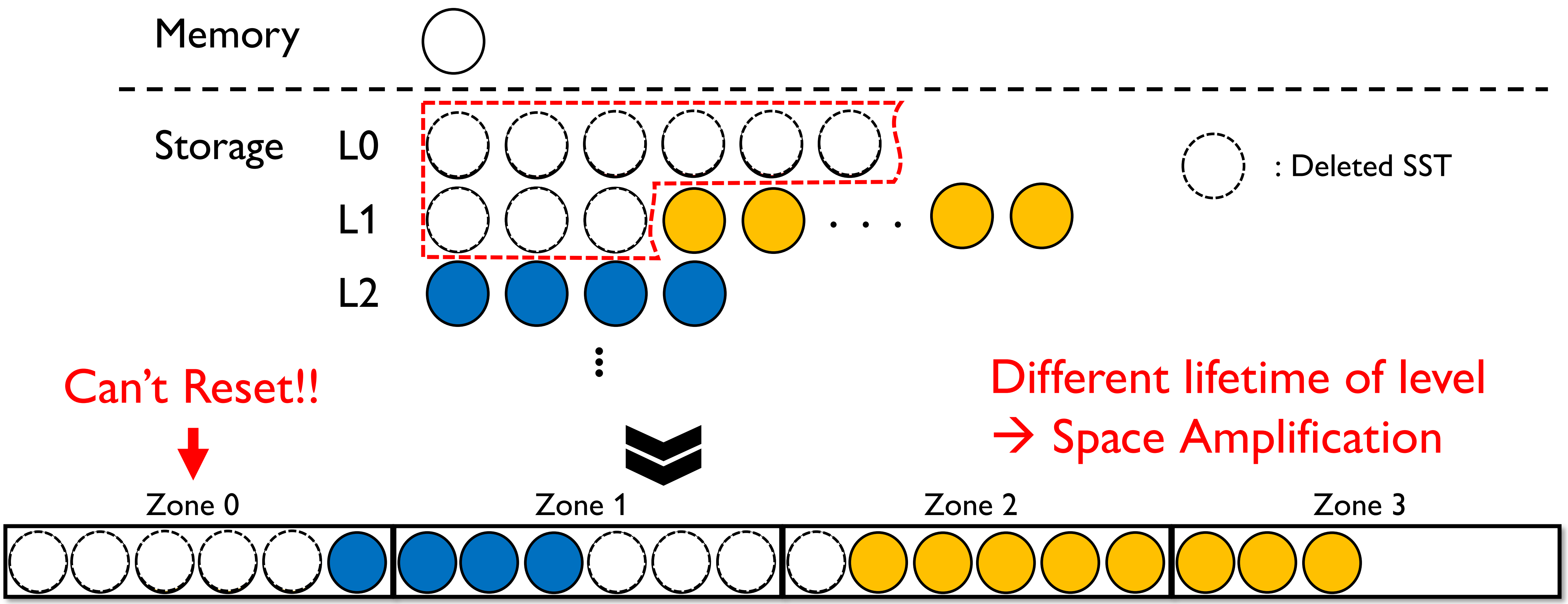
- Small Compaction Cost
- Low memory Size

Target of this paper

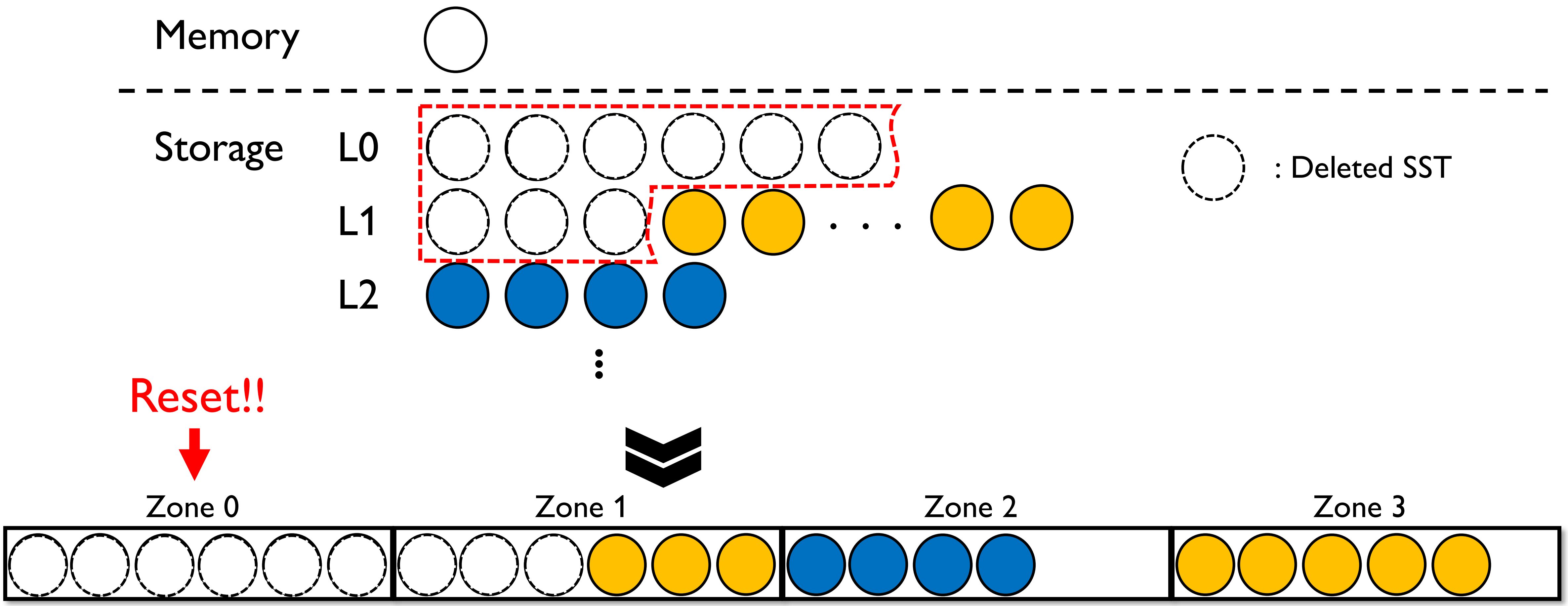
- **Space Amplification**

→ Host-managed GC

Level Separation

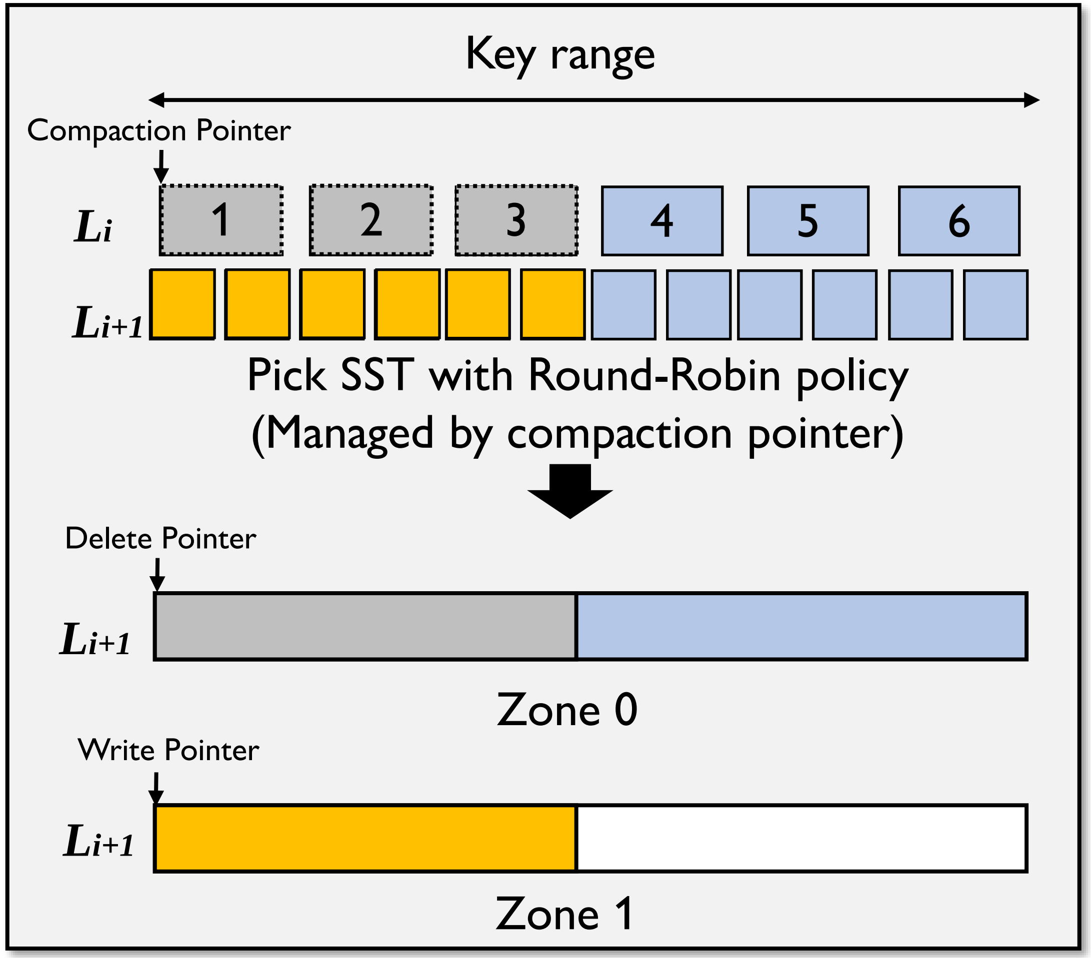


Level Separation (GearDB)

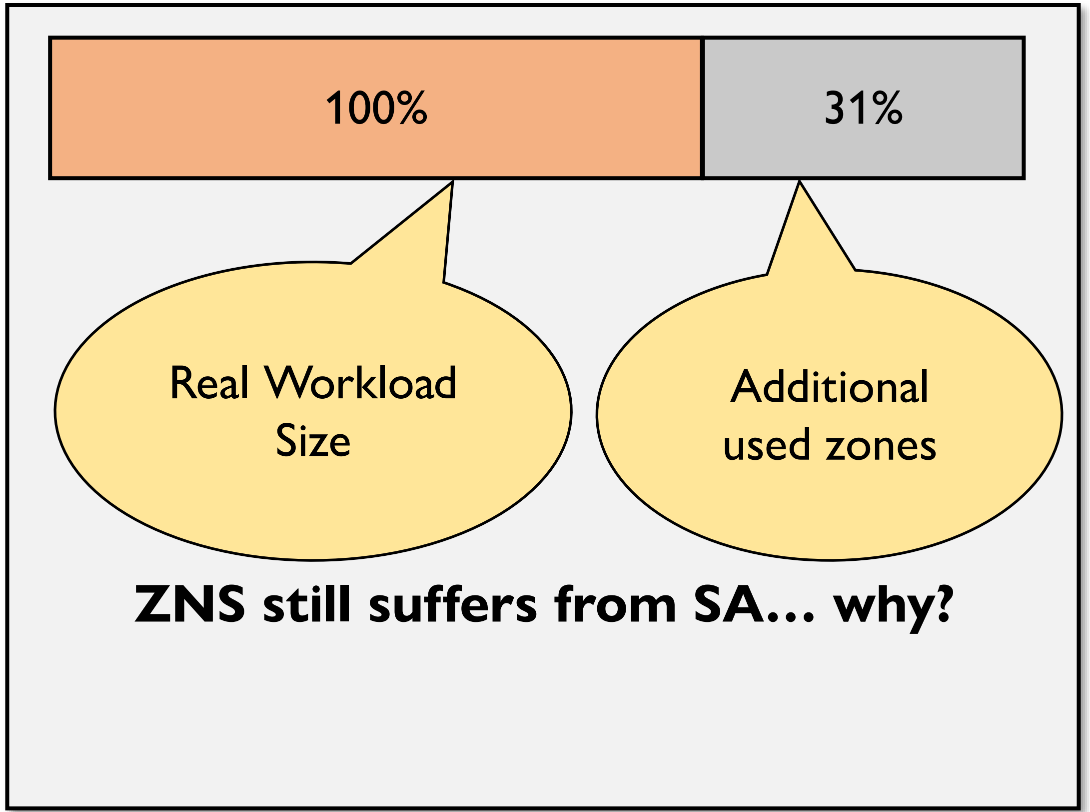


Space Amplification

Current LevelDB Compaction Algorithm



Even with level separation



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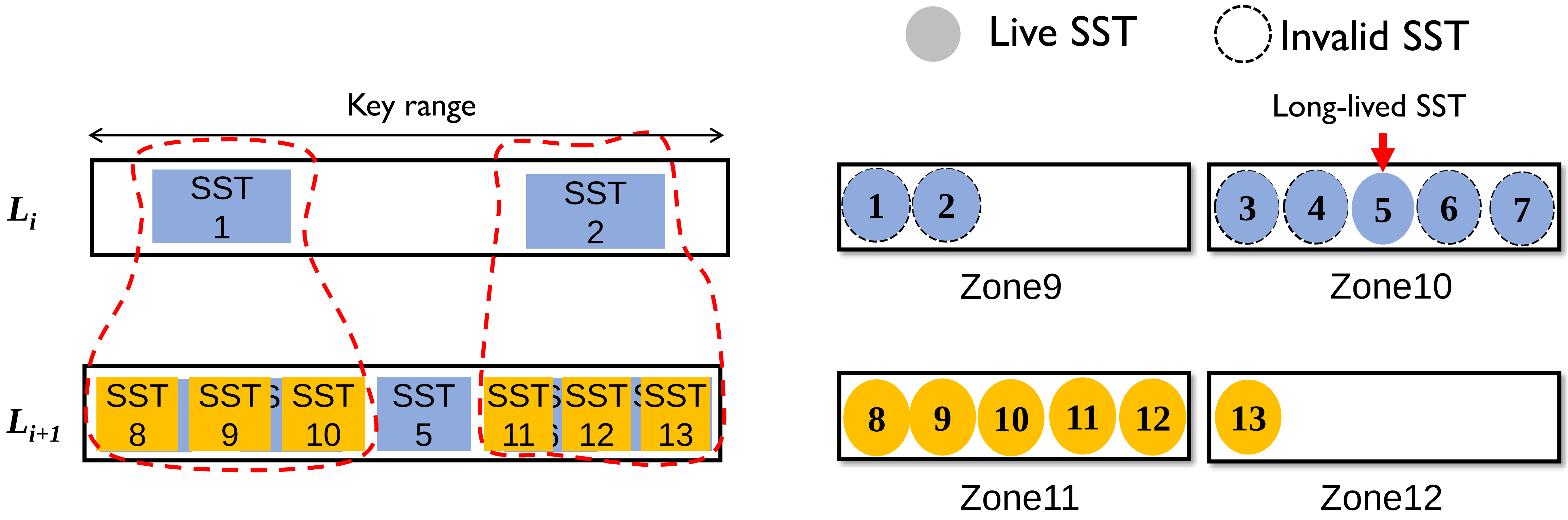
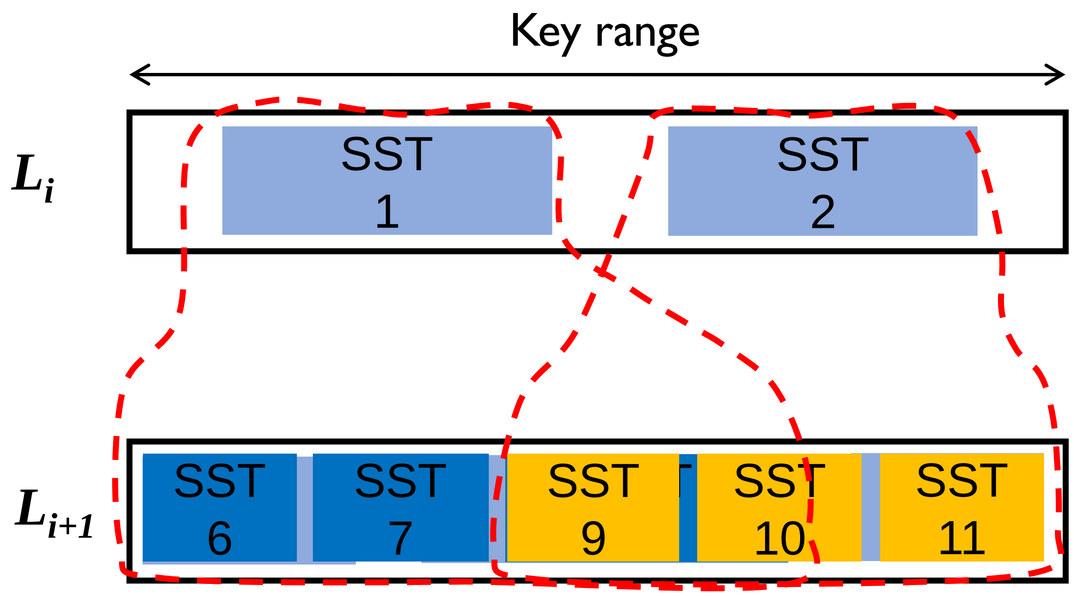
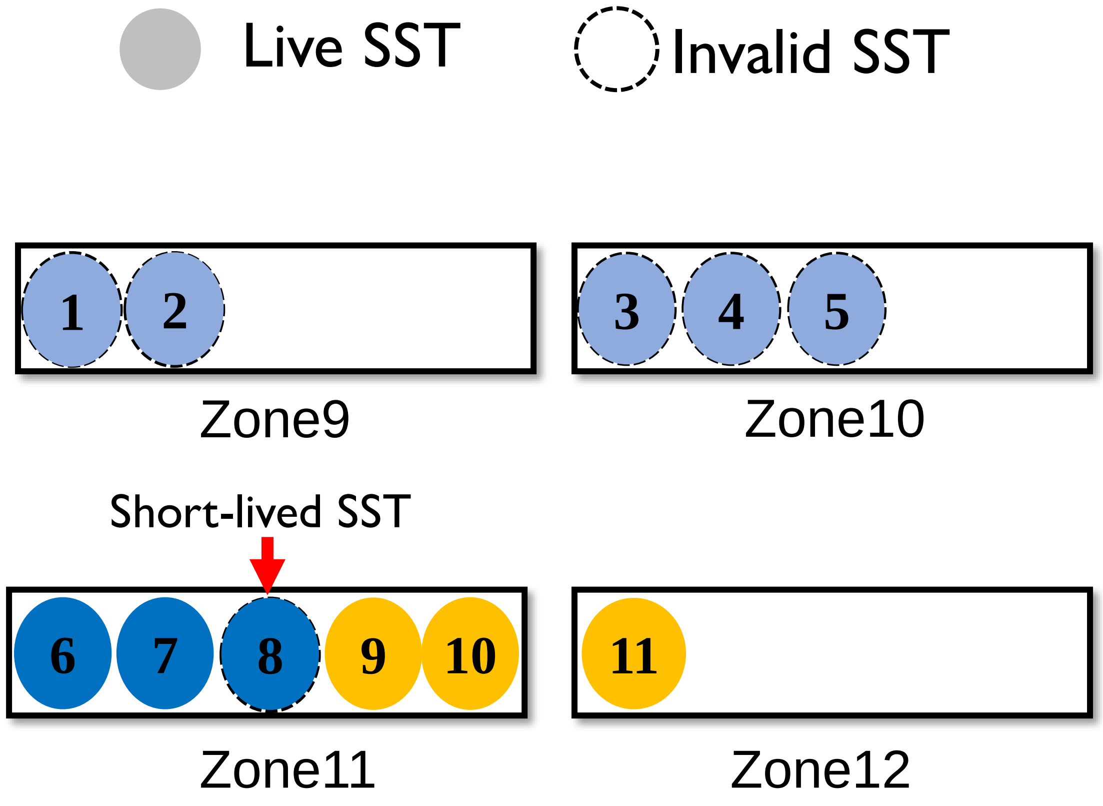
Long-lived SST



Additional 2% zones are allocated by Long-lived SST

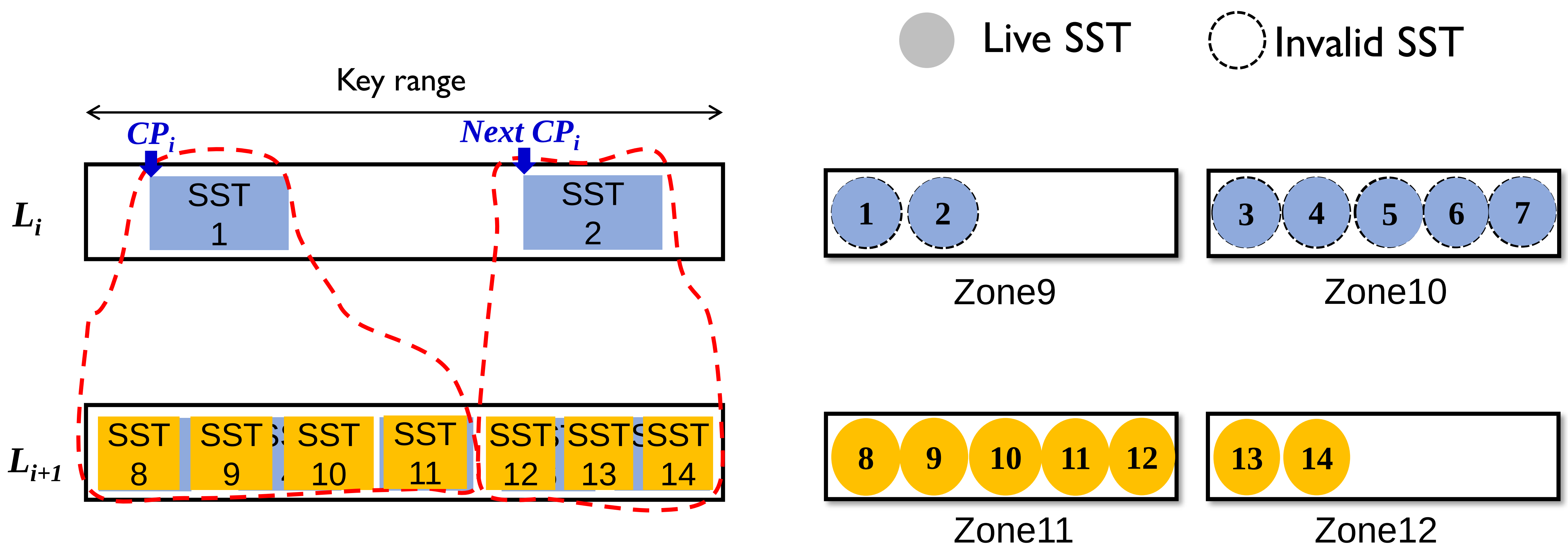
Short-lived SST





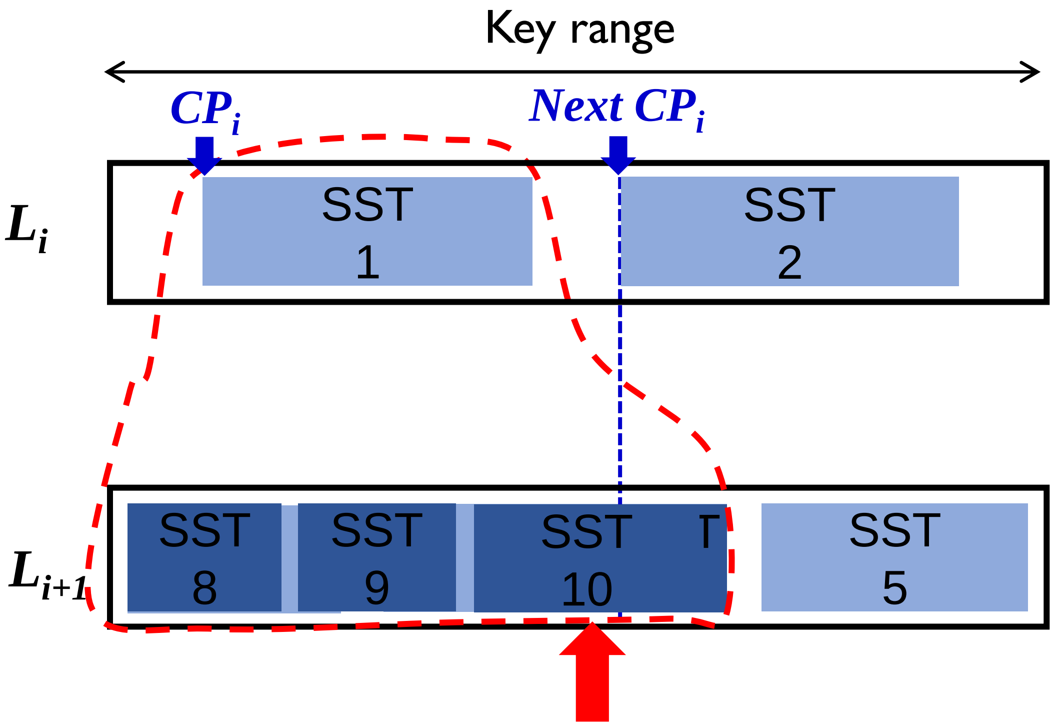
Additional 30% zones are allocated by Short-lived SST

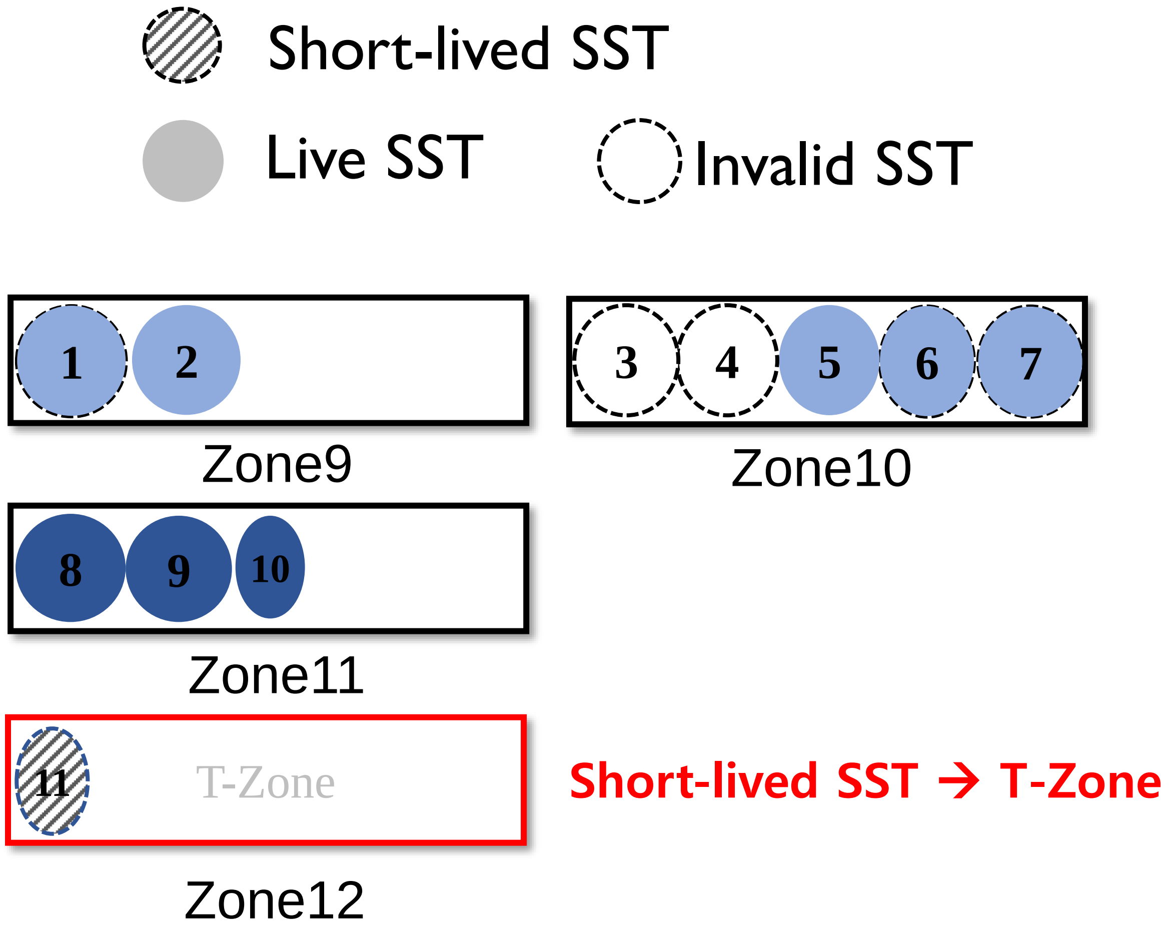
Solution for Long-Lived SST



Compaction involves all L_{i+1} SSTs between the current CP_i and the *Next* CP_i

Solution for Short-Lived SST

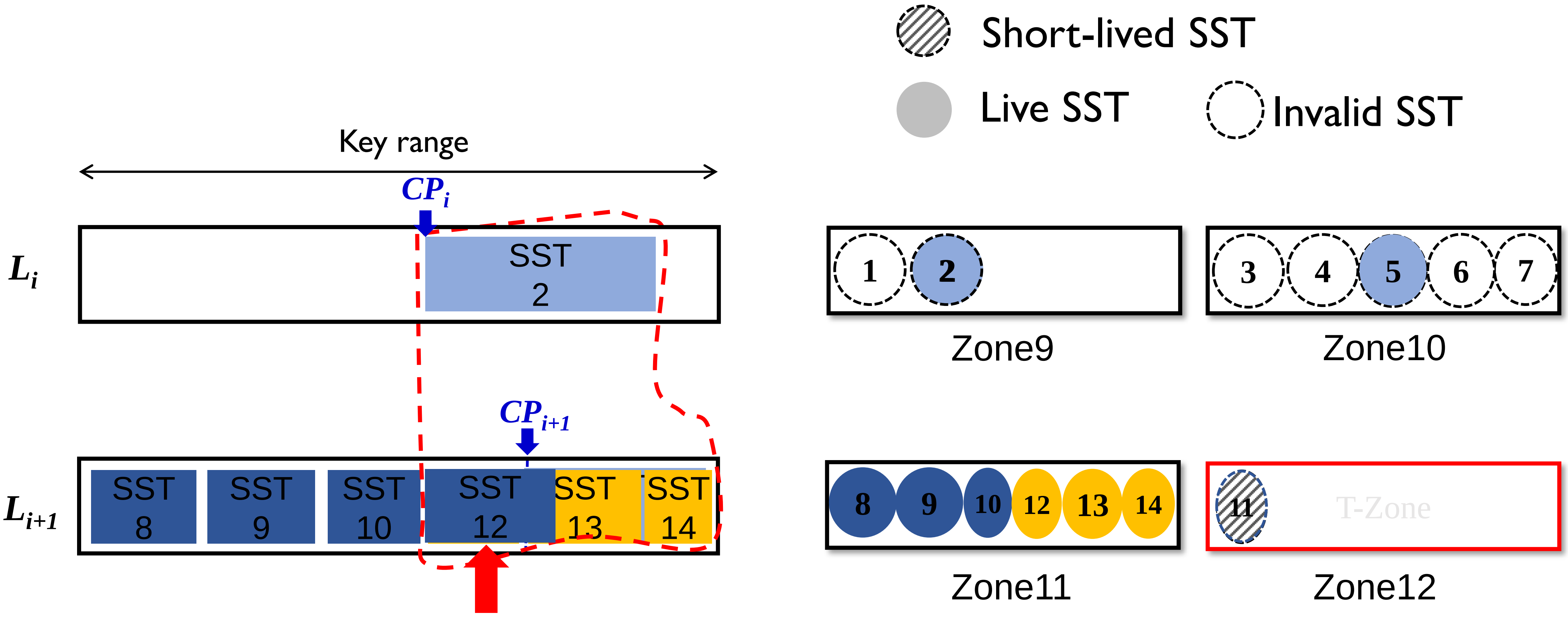




Split SST at *Next CP_i* to minimize the size of short-lived SST

Short-lived SST is written in T-Zone to prevent hole in normal Zone

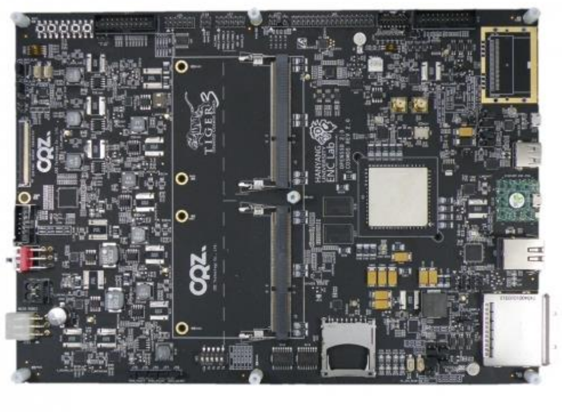
CP-Aware Split Algorithm



Split SST at CP_{i+1} to preserve compaction pointer

Evaluation Setup

- Comparisons
  - ➢BL : Baseline (use Infinite zone)
  - ➢GC : LevelDB + GC
  - ➢LS : LevelDB + Level Separation + GC
  - ➢Gear : GearDB
- Test environment

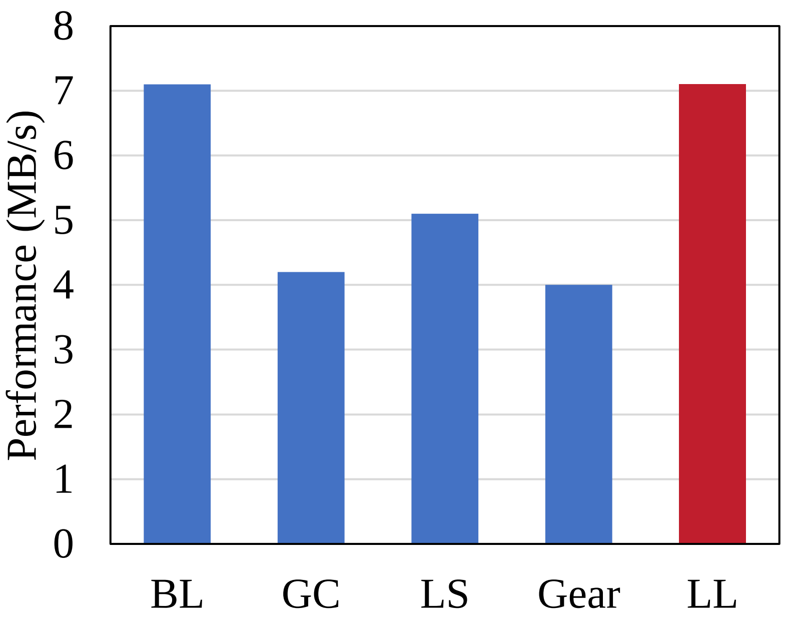


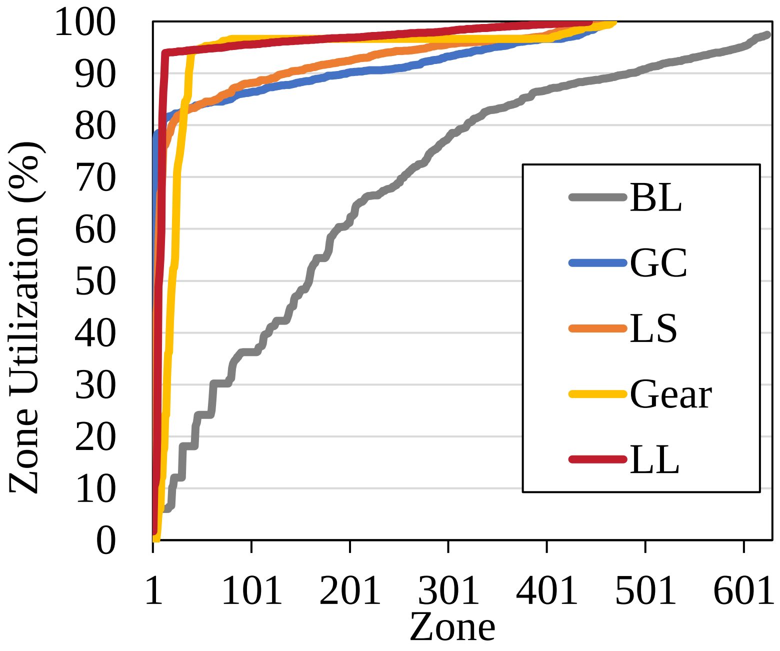
Cosmos+ OpenSSD

Linux	64-bit Linux 5.11.1
CPU	4GHz quad-core Intel i7-4790K CPU
Memory	16GB DDR4 , use 1.5GB user-level cache
ZNS	In-house ZNS SSD based on Cosmos+ OpenSSD
Defaults	LevelDB 1.19, key=16B, value=512B, SST size=4MB, GC=greedy, Zone=64MB

Performance & Zone utilization

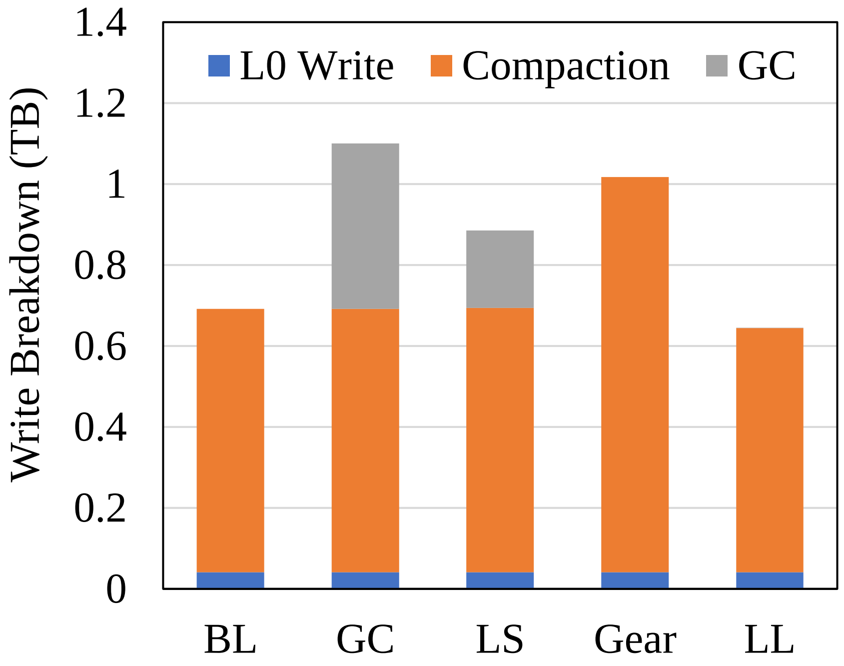
- BL and GC show trade off relationship between WA and SA
- LS has 1.3X better performance vs GC due to lower GC cost
- Gear has lower performance vs LS due to high-cost gear compaction
- LL-Compaction has 1.4X better performance vs LS, 1.8X better performance vs Gear





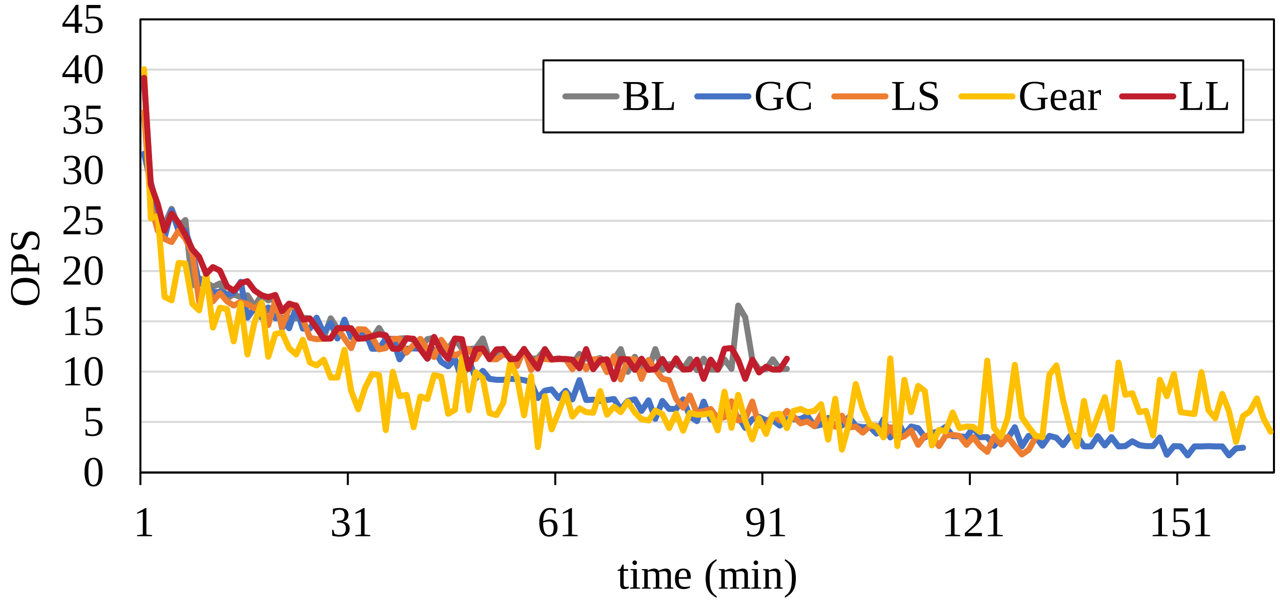
Write breakdown

- GC cost (LS, GC) makes write amplification
- Gear compaction needs more write than normal compaction
- LL-Compaction achieves less write cost vs BL → benefit by split policy



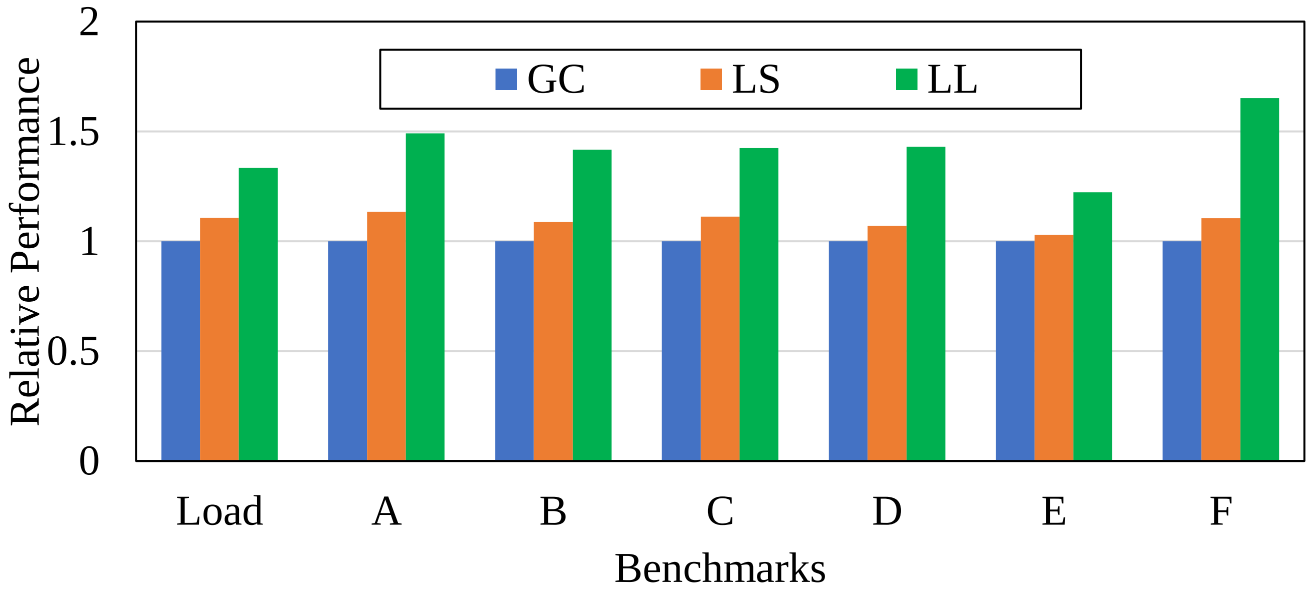
Incremental throughput

- BL & LL compaction achieve stable and fast performance
- Performance of GC & LS drops when GC occurred (55min GC, 75min LS)
- Performance of Gear compaction is not stable; compaction cost of Gear compaction is higher than normal compaction



Performance (Real workload)

- GearDB can't performs because GearDB needs more storage capacity
- LL-Compaction
  - 1.2~1.7X vs GC
  - 1.18~1.5X vs LS



Conclusion & Discussion

- **Current ZNS-unaware compaction can suffer from space amplification**
- **LL-Compaction**
  - ➢ Reduce space amplification without invoking host-managed garbage collection
  - ➢ 1.2~1.7X speed up for real workloads vs GC
- **Limitation of LL-Compaction**
  - ➢ Cannot use priority-driven compaction algorithms (e.g., RocksDB)
    - ➢ ex) Overlapping-key range (reduce compaction cost), age (reduce read cost)
  - ➢ We will analyze the impact of priority-driven compaction algorithms on GC

Thank You

Further Questions? wjdwldbs1@skku.edu