TreeLine: An Update-In-Place Key-Value Store for Modern Storage

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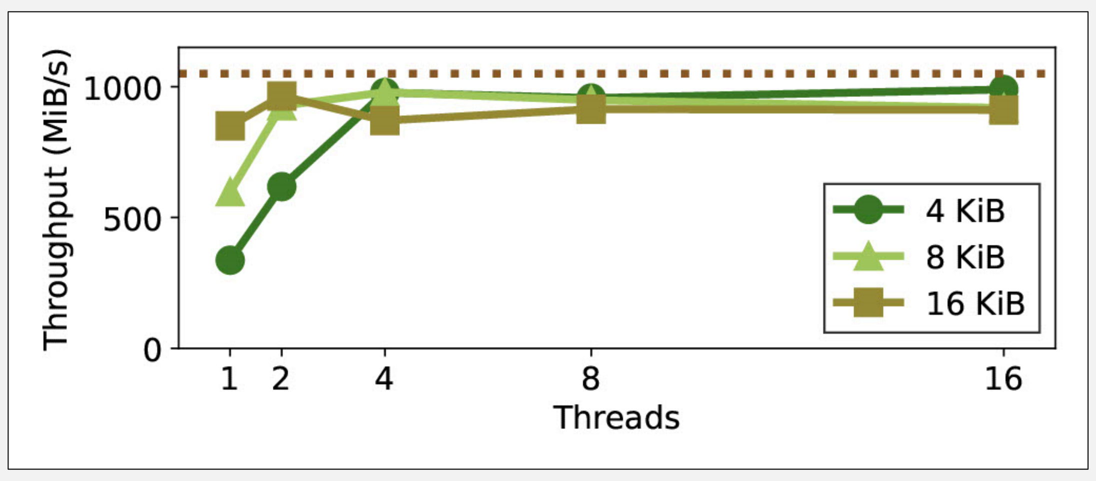
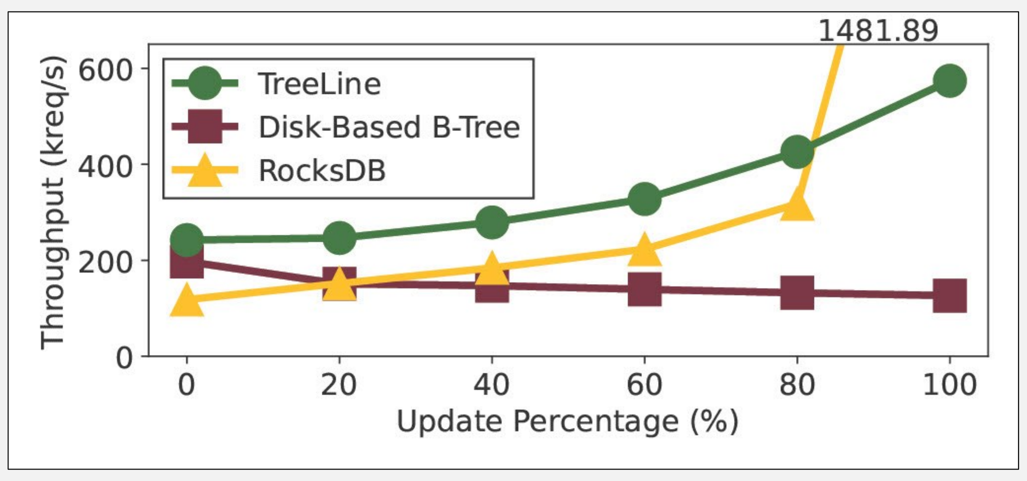
Motivation





Both experiments on an Intel DC P4510 NVMe SSD.

- Modern persistent key-value stores, such as RocksDB [1] and LevelDB [2], typically use log-structured merge trees (LSMs) [3].
- Stellar write performance: large sequential writes exploit the high sequential throughput.
- Slow read performance: need caches, Bloom filters [4,5], compaction strategies [6,7,8]—complex and hard-to-tune. [9]

Random Writes ≈ Sequential Writes on NVMe SSDs

- Random write throughput across (i) request sizes, and (ii) number of writing threads.
- With high parallelism, can reach advertised peak sequential write throughput [10].

LSMs Leave Read Performance on the Table

- Zipfian-distributed (θ = 0.79) workload of reads, updates, and scans on 64 B records.
- Of the requests that are not updates, 10% are range scans and the rest are point reads.
- For read-heavy, the disk-based B-tree outperforms/is competitive against RocksDB.
- TreeLine can outperform both systems all the way up to 80% updates.

Design Overview

Key Idea A: Record Caching

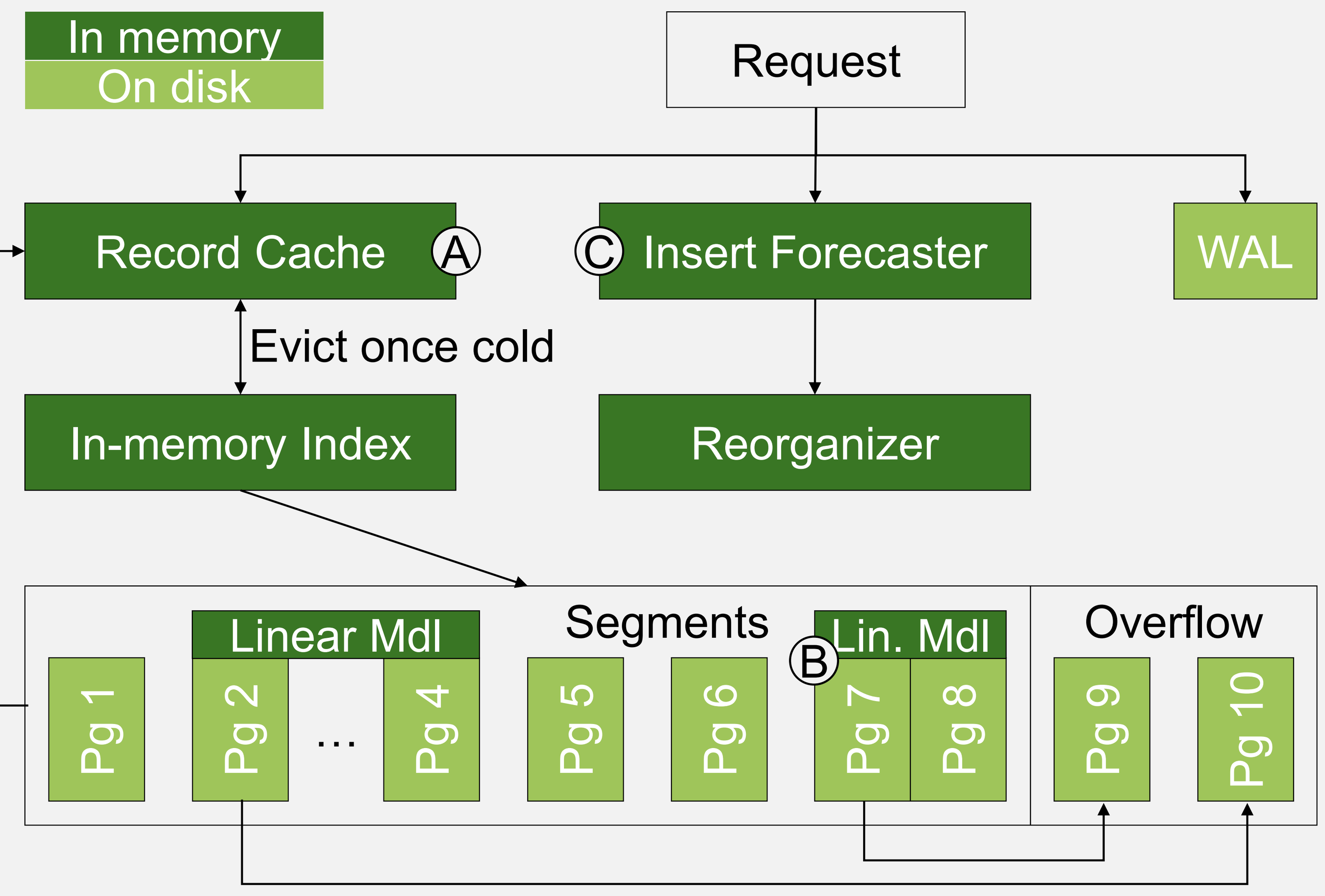
- Key-to-page mapping is expensive to change in update-in-place design.
- But variable hotness among records on the same page.
- **Solution:** Only cache records, to increase memory efficiency.

Key Idea B: Page Grouping

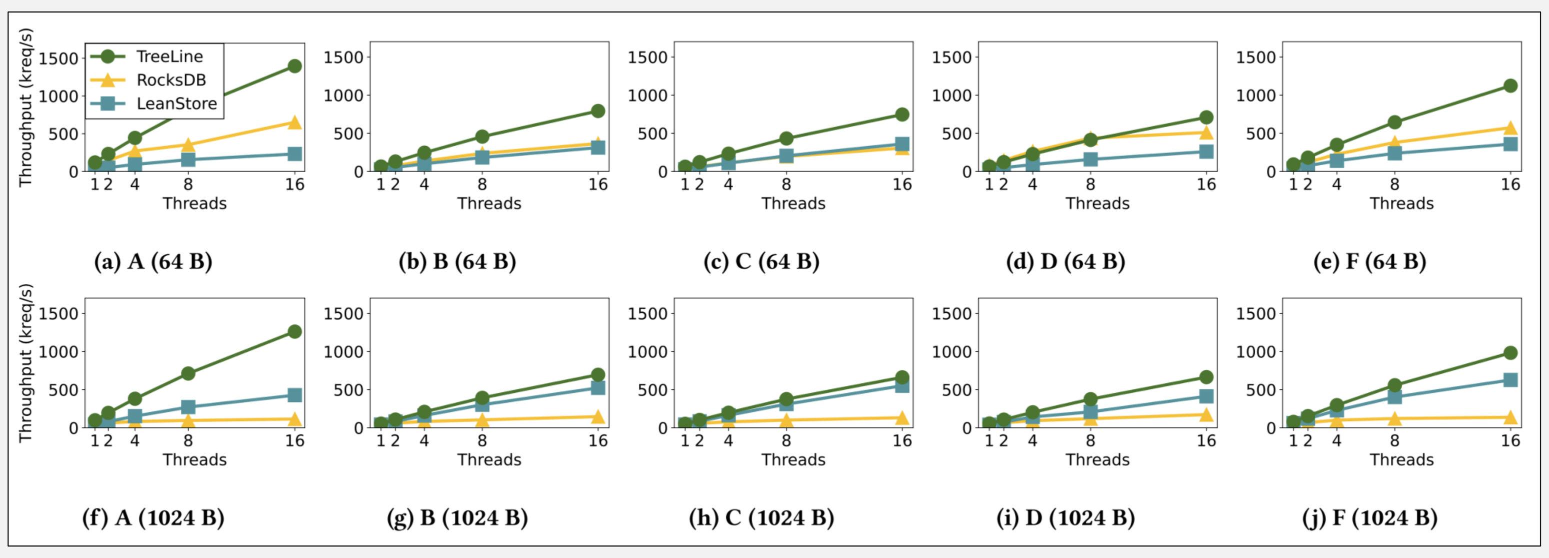
- Unlike writes, sequential reads still faster vs. random reads on modern SSDs.
- Pages must be sequential to make scans fast.
- **Solution:** Group pages into contiguous segments. Use linear models to index records within segments.

Key Idea C: Insert Forecasting

- To avoid constant reorganization, pages should have some empty space.
- But too much empty space increases I/O amplification.
- **Solution:** Leave empty space based on epoch-based insert forecast.

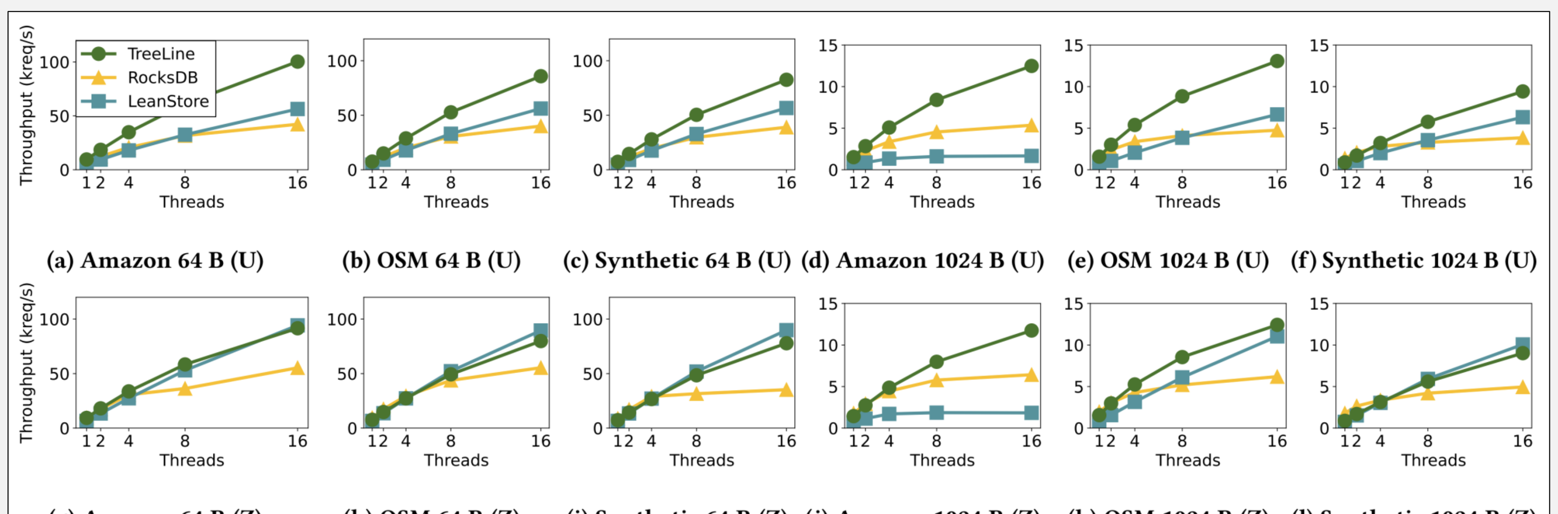


Evaluation



(a) A (64 B) (b) B (64 B) (c) C (64 B) (d) D (64 B) (e) F (64 B)

(f) A (1024 B) (g) B (1024 B) (h) C (1024 B) (i) D (1024 B) (j) F (1024 B)



(a) Amazon 64 B (U) (b) OSM 64 B (U) (c) Synthetic 64 B (U) (d) Amazon 1024 B (U) (e) OSM 1024 B (U) (f) Synthetic 1024 B (U)

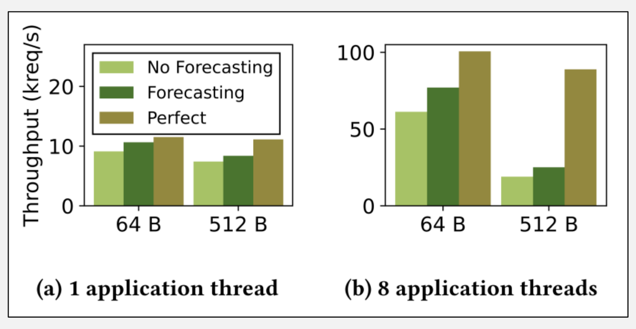
(g) Amazon 64 B (Z) (h) OSM 64 B (Z) (i) Synthetic 64 B (Z) (j) Amazon 1024 B (Z) (k) OSM 1024 B (Z) (l) Synthetic 1024 B (Z)

Point Workloads

- TreeLine outperforms RocksDB (LeanStore) by **1.62× (2.81×)** and **2.99× (1.53×)** on average for **64 B**/**1024 B** records.

Scans

- With 16 request threads, for uniform scans, TreeLine outperforms RocksDB (LeanStore) by **2.21× (1.58×)** and **2.50× (2.80×)** on average for **64 B**/**1024 B** records.
- With 16 request threads, for Zipfian-distributed scans, TreeLine outperforms RocksDB (LeanStore) by **1.74× (0.91×)** and **1.88× (1.86×)** on average for **64 B**/**1024 B** records.



(a) 1 application thread (b) 8 application threads

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