HashKV: Enabling Efficient Updates in KV Storage via Hashing

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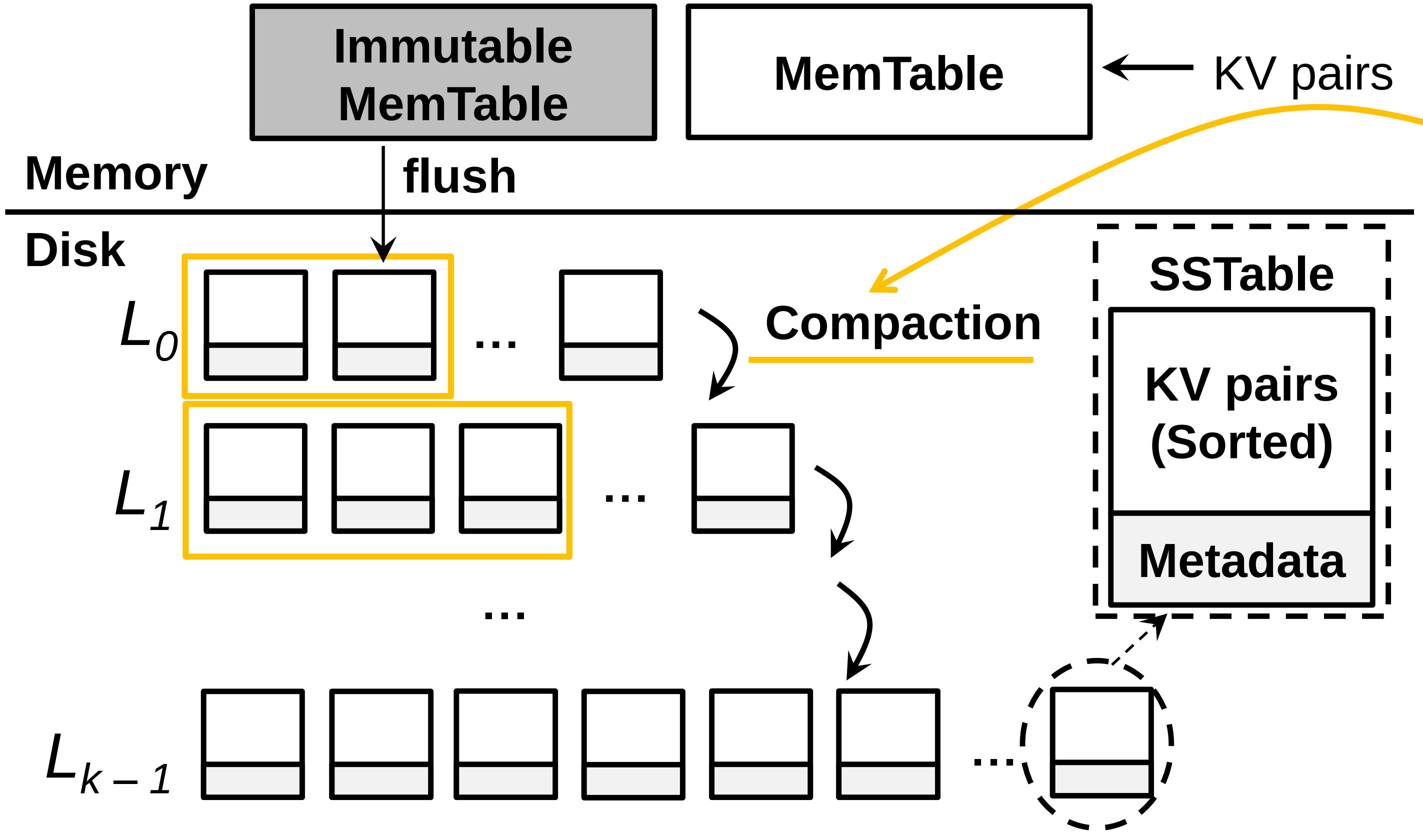
Background

- Update-intensive workloads are common in key-value (KV) stores
  - Online transaction processing (OLTP)
  - Enterprise servers
  - Yahoo's workloads are shifting from reads to writes [*]

- **Log-structured merge (LSM) tree**
  - Transform random writes into sequential writes
  - Support efficient range scans
  - **Limitation**: high read and write amplifications during compaction

[*] Sears et al., "bLSM: A General Purpose Log Structured Merge Tree", SIGMOD 2012

LSM-tree in LevelDB

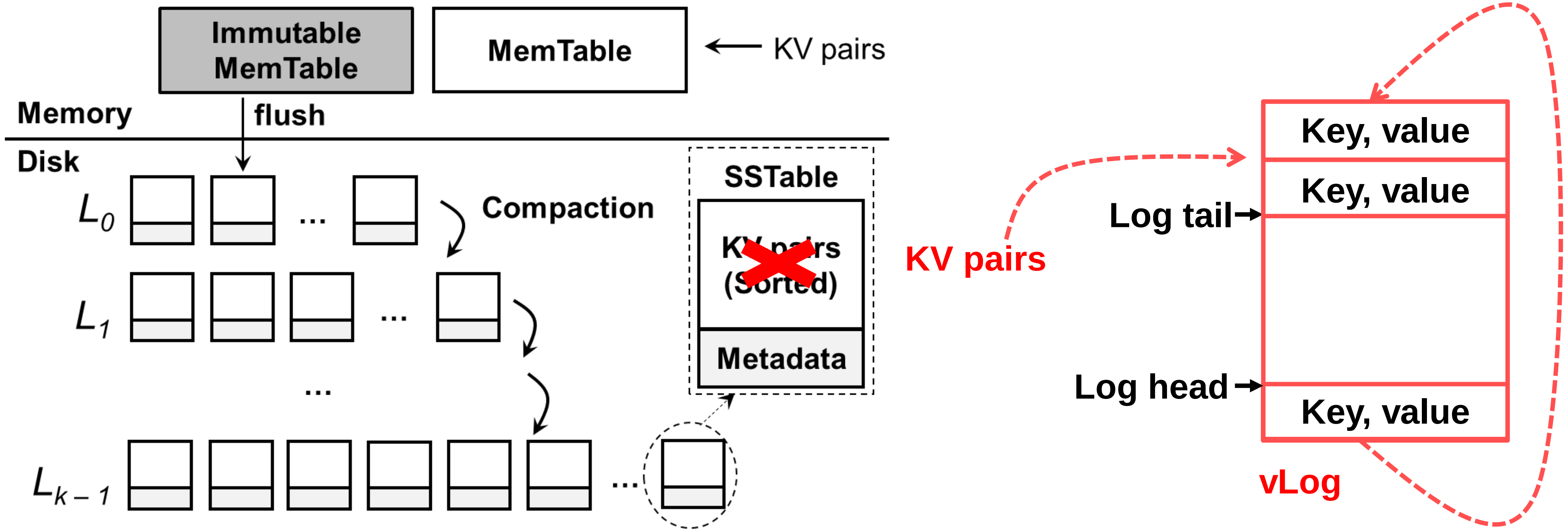


1. Read SSTables
2. Merge and sort by keys
3. Split into new SSTables

High I/O amplifications!

KV Separation[*]

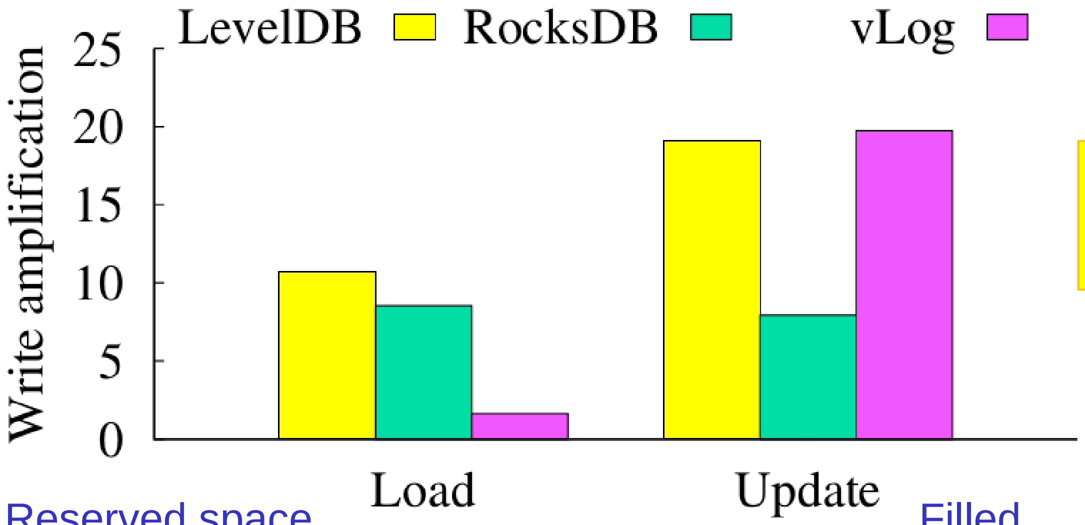
- Store values separately to reduce LSM-tree size
  - LSM-tree: keys and metadata for indexing
  - **vLog**: circular log for KV pairs



[*] Lu et al., "WiscKey: Separating Keys from Values in SSD-Conscious Storage", FAST 2016

KV Separation

- Does KV separation solve all problems?
  - **High garbage collection (GC) overhead in vLog management**
    - More severe if reserved space is limited
    - Update-intensive workloads aggravate GC overhead
  - GC needs to query the LSM-tree to check if KV pairs are valid



Reserved space not filled up yet

Filled reserved space

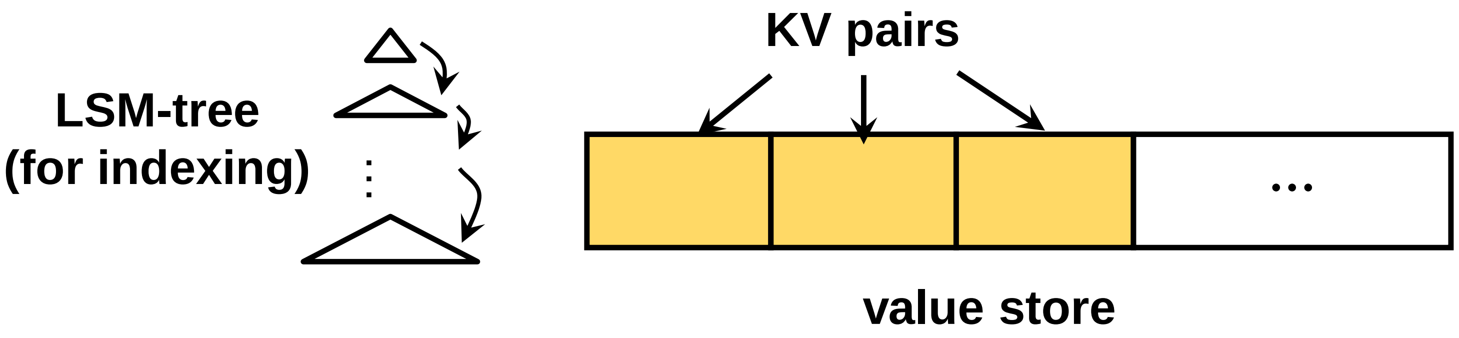
High write amplification of vLog if reserved space is filled

Our Contributions

- **HashKV**, an efficient KV store for update-intensive workloads
  - Extend KV separation with **hash-based data grouping** for value storage
  - Mitigate GC overhead with smaller I/O amplifications and without LSM-tree queries
- Three extensions that adapt to workload characteristics
  - E1: Dynamic reserved space allocation
  - E2: Hotness awareness
  - E3: Selective KV separation
- Extensive prototype experiments
  - 4.6x throughput and 53.4% less write traffic over circular log

Hash-based Data Grouping

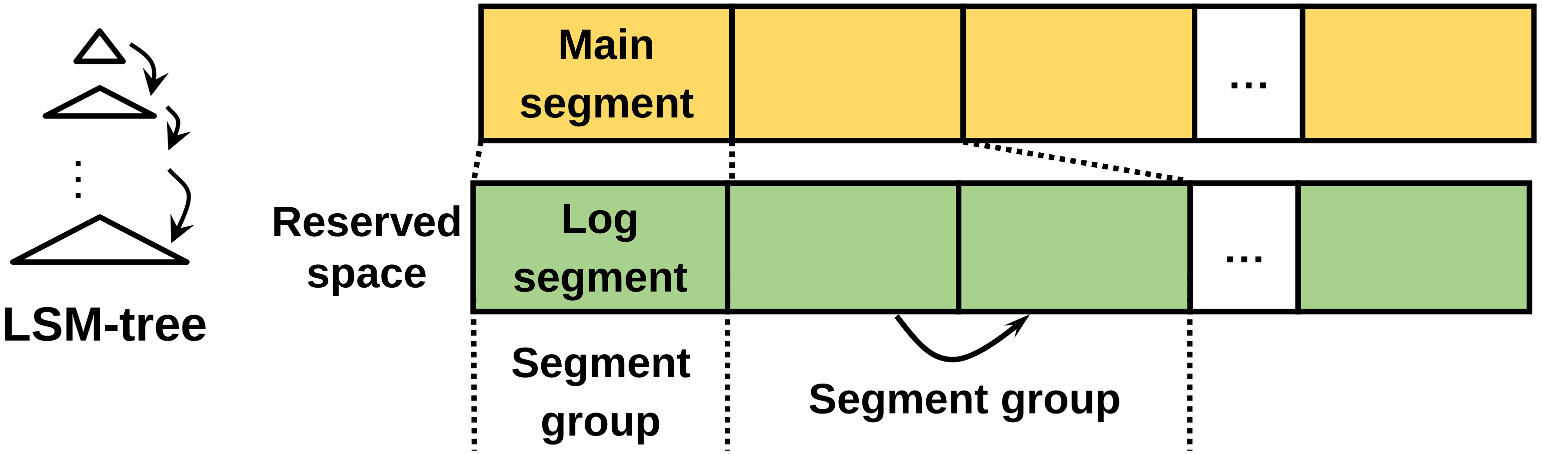
- Hash values into fixed-size partitions by keys
  - **Partition isolation**: all value updates of the same key must go to the same partition in a log-structured manner
  - **Deterministic grouping**: instantly locate the partition of a given key
- Allow flexible and lightweight GC
  - Localize all updates of a key in the same partition



- *What if a partition is full?*

E1: Dynamic Reserved Space Allocation

- Layout:
  - Logical address space: **main segments** (e.g., 64 MiB)
  - Reserved space: **log segments** (e.g., 1 MiB)
  - **Segment group**: 1 main segment + multiple log segments
- In-memory **segment table** tracks all segment groups
  - Checkpointed for fault tolerance

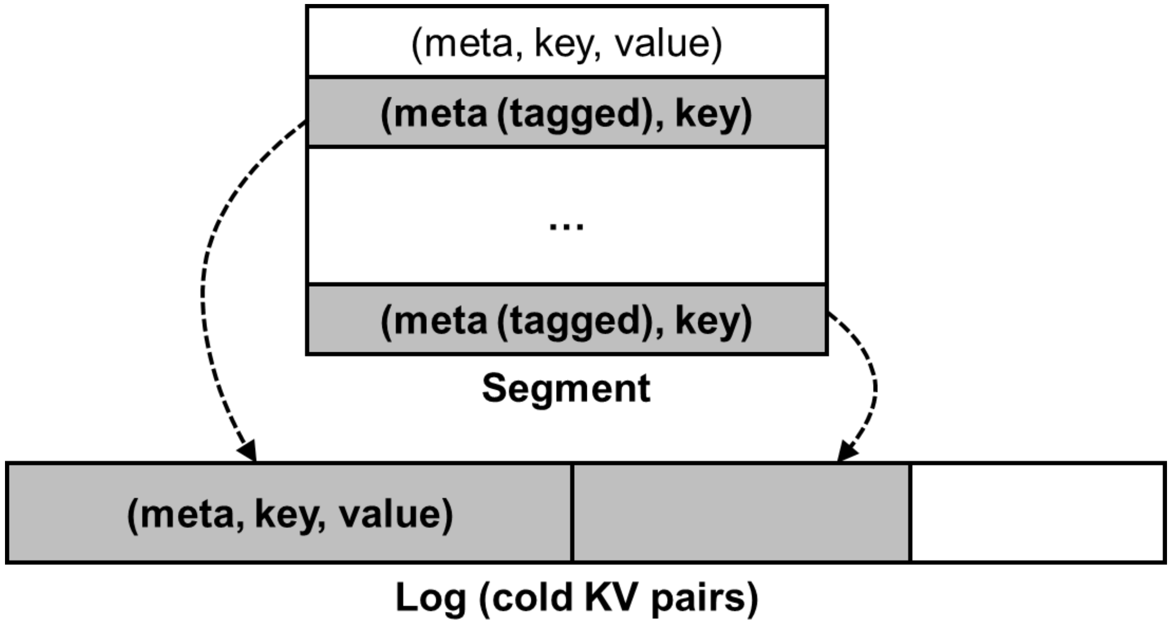


Group-Based Garbage Collection

- Select a segment group for GC
  - e.g., the one with largest amount of writes
  - Likely to have many invalid KV pairs to reclaim free space
- Identify all valid KV pairs in selected group
  - Since each group stores updates in a log-structured manner, the latest version of each key must reside at the end of the group
  - **No LSM-tree queries required**
- Write all valid KV pairs to new segments
- Update LSM-tree

E2: Hotness Awareness

- ➢ Problem: mix of hot and cold KV pairs
  - Unnecessary rewrites for cold KV pairs
- ➢ **Tagging**:
  - Add a tag in metadata to indicate presence of cold values
  - Cold values are separately stored
    - Hot-cold value separation
- ➢ GC rewrites small tags instead of values



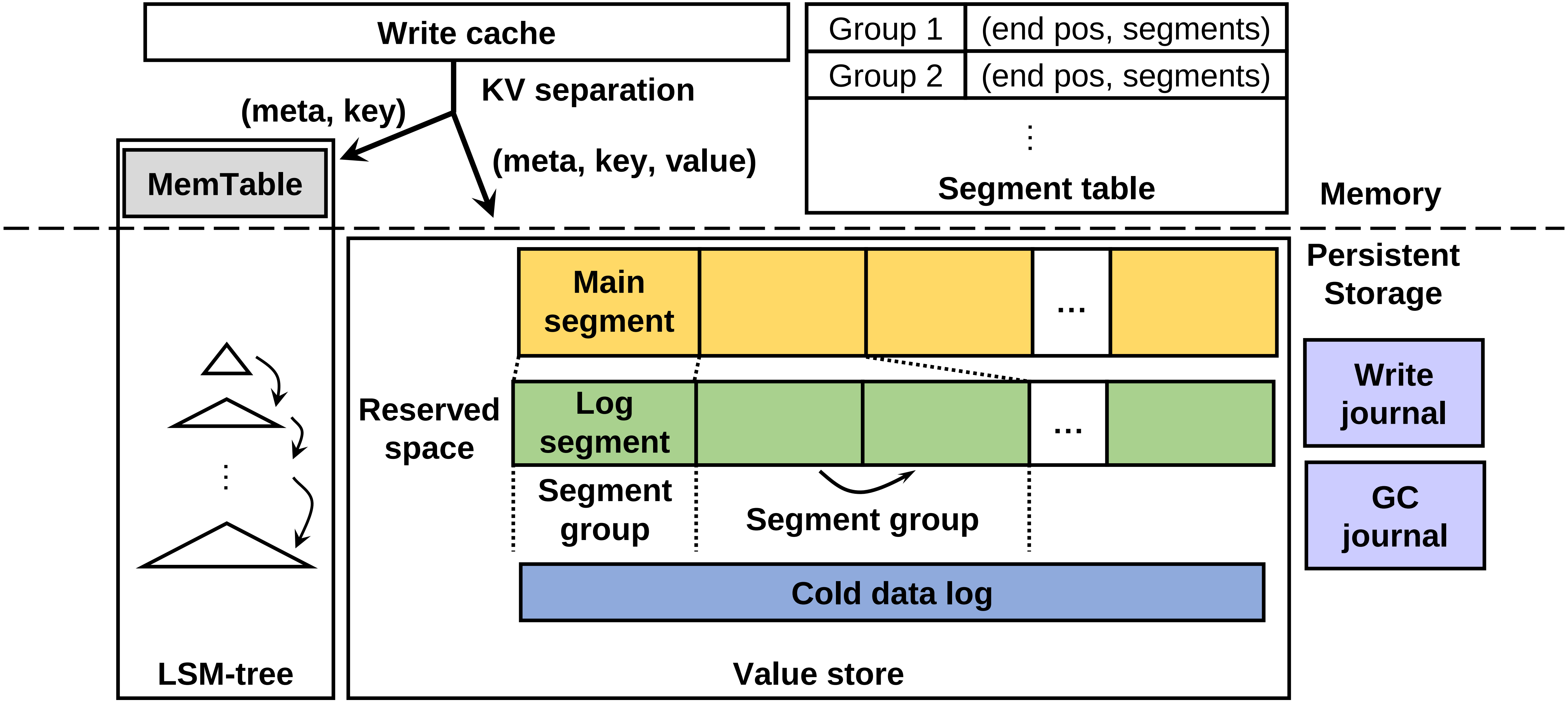
E3: Selective KV Separation

- KV separation for small values incurs extra costs to access both LSM-tree and value store
- Selective approach:
  - Large values: KV separation
  - Small values: stored entirely in LSM-tree
- Open issue: how to distinguish between small and large values?

Other Issues

- Range scans:
  - Leverage read-ahead (via `posix_fadvise`) for speedup
- Metadata journaling:
  - Crash consistency for both write and GC operations
- Implementation:
  - Multi-threading for writes and GC
  - Batched writes for KV pairs in the same segment group
  - Built on SSDs

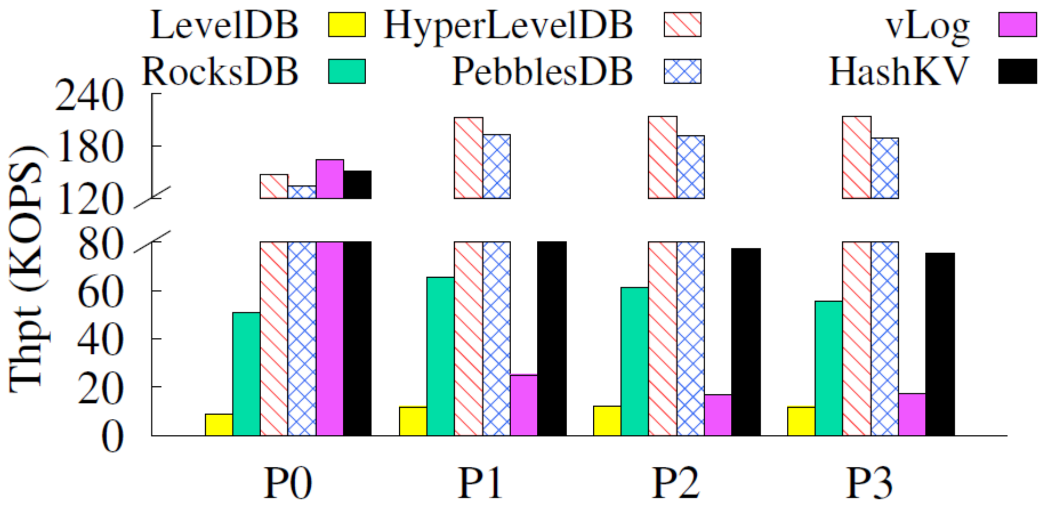
Putting It All Together: HashKV Architecture



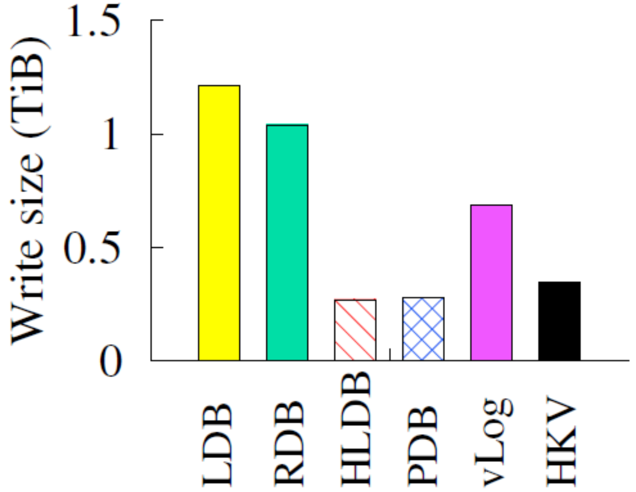
Experiments

- Testbed backed with an SSD RAID array
- KV stores
  - LevelDB, RocksDB, HyperLevelDB, PebblesDB (default parameters)
  - vLog (circular log) and HashKV: built on LevelDB for KV separation
- Workloads
  - 40 GiB for main segments + 12 GiB (30%) reserved space for log segments
  - Load: 40 GiB of 1-KiB KV pairs (Phase P0)
  - Update: 40 GiB of updates for three phases (Phases P1, P2, P3)
    - P1: reserved space gradually filled up
    - P2 & P3: reserved space fully filled (stabilized performance)

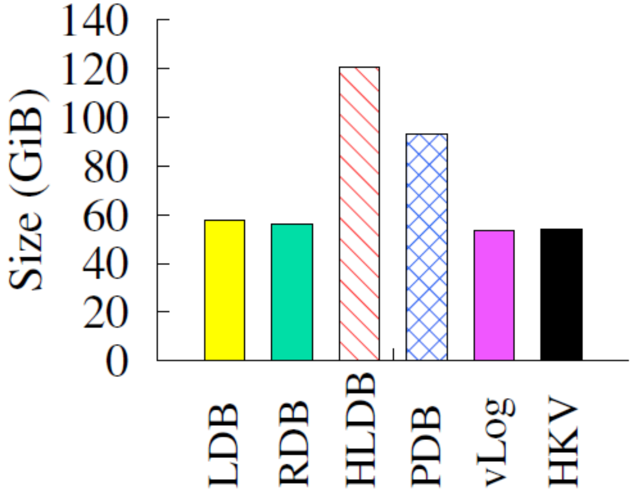
Update Performance of HashKV



Throughput



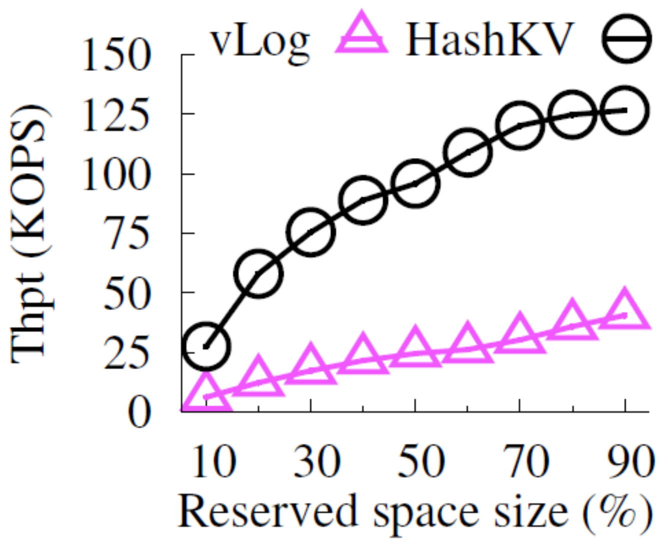
Write size



KV store size

- Compared to LevelDB, RocksDB, and vLog:
  - 6.3-7.9x , 1.3-1.4x, and 3.7-4.6x throughput, resp.
  - 49.6-71.5% lower write size
- Much lower KV store size than HyperLevelDB and PebblesDB

Impact of Reserved Space



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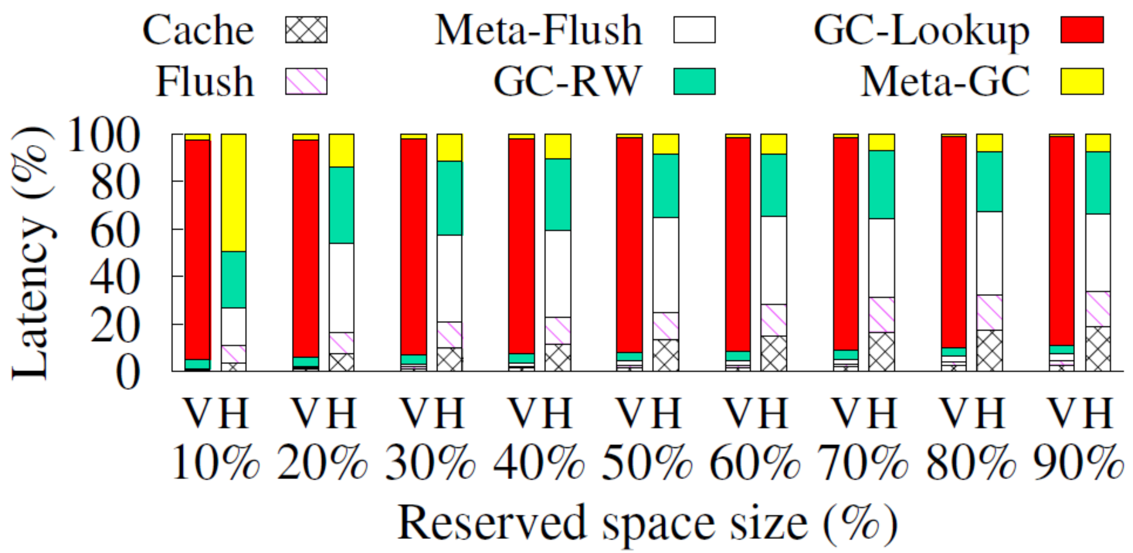
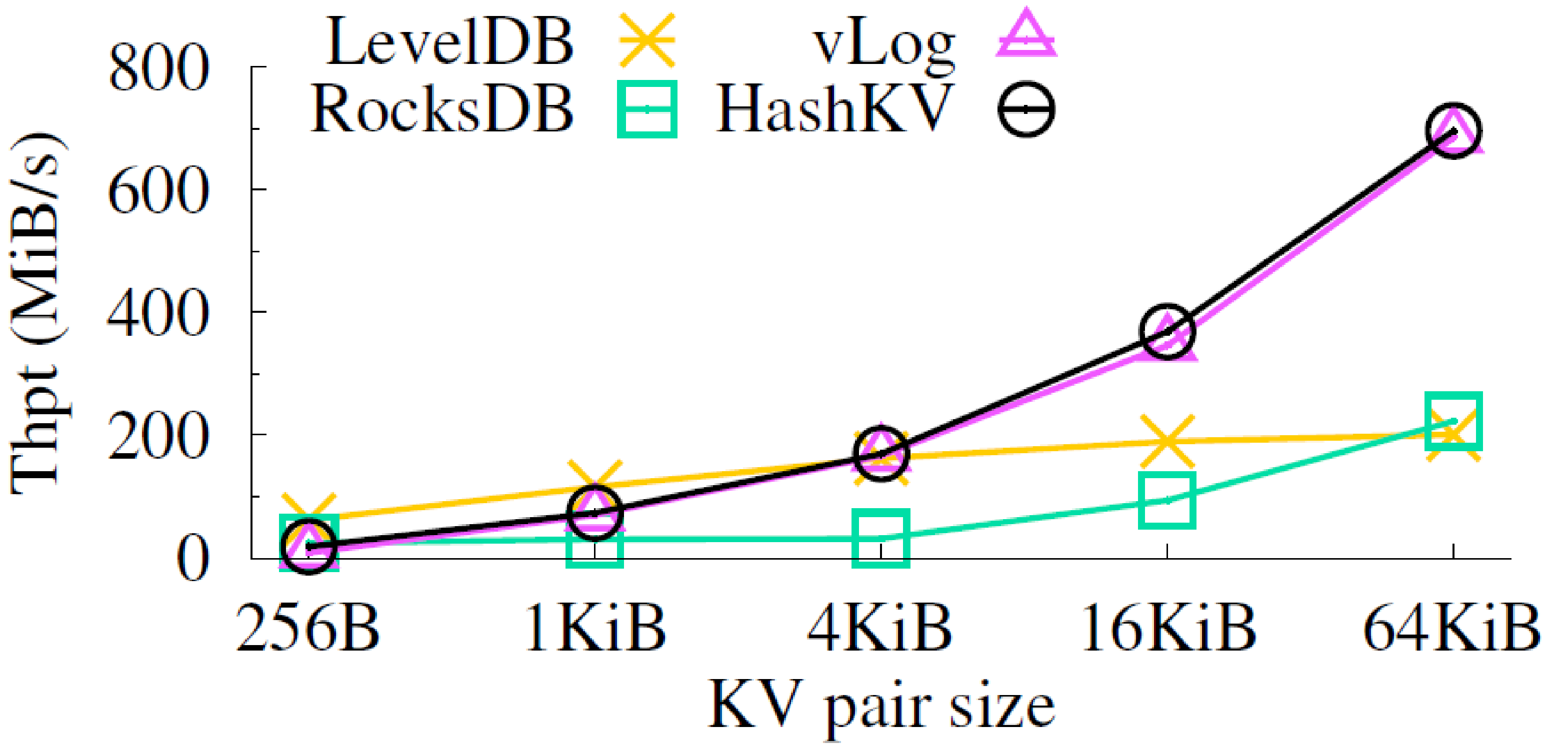


Latency breakdown (V = vLog; H = HashKV)

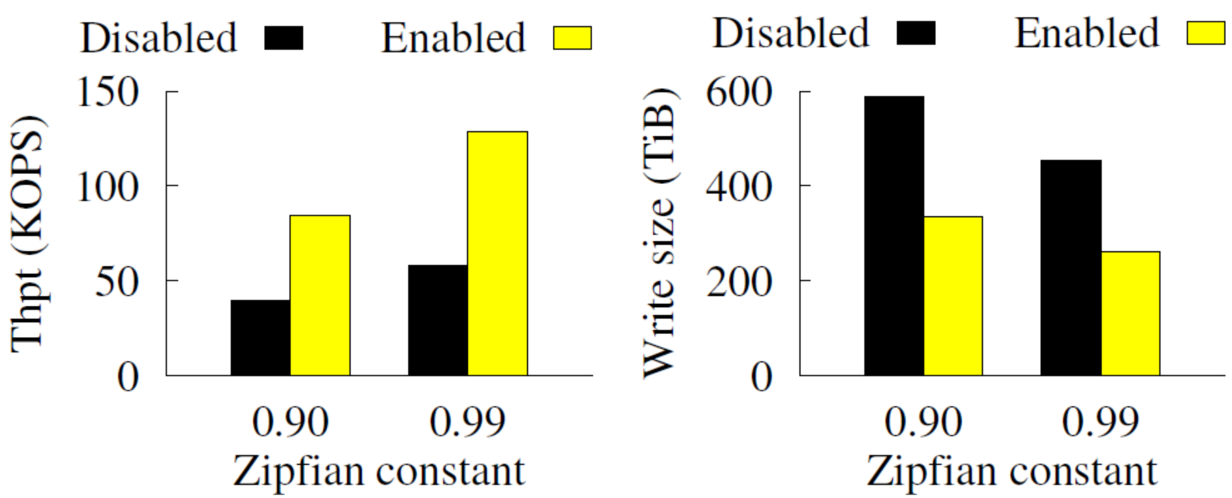
- HashKV's throughput increases with reserved space size
- vLog has high LSM-tree query overhead (80% of latency)

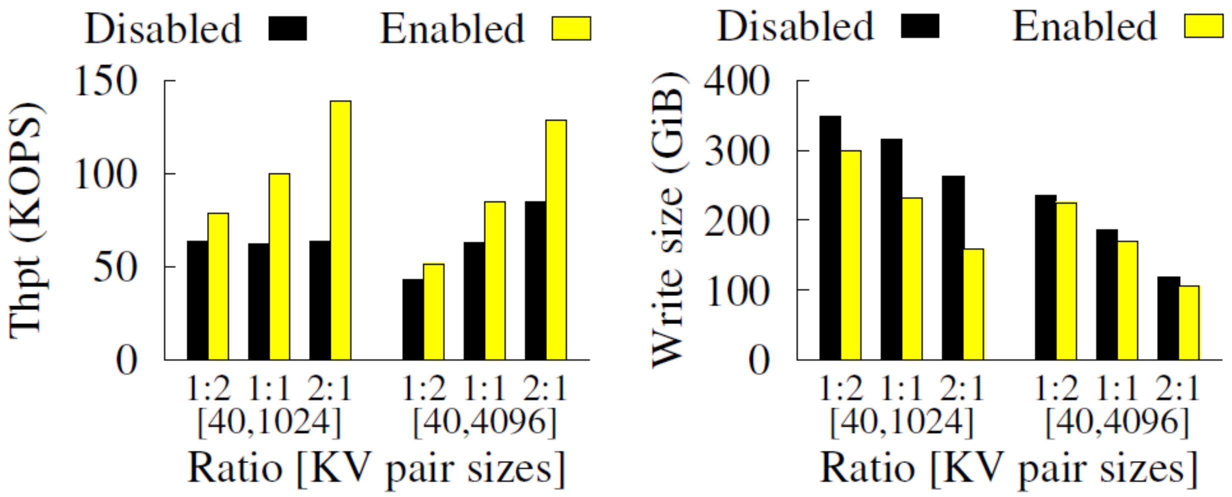
Range Scans



➢ HashKV maintains high range scan performance

Optimization Features





Hotness awareness **Selective KV separation**

- Higher throughput and smaller write size with optimization features enabled

Conclusions

- HashKV: hash-based data grouping for efficient updates
  - Dynamic reserved space allocation
  - Hotness awareness via tagging
  - Selective KV separation
- More evaluation results and analysis in paper and technical report
- Source code: http://adslab.cse.cuhk.edu.hk/software/hashkv