MaSM: Efficient Online Updates in Data Warehouses

by

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Introduction

Background

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- When did the inserting and updating take place?
- Why does this not meet business needs anymore?

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↓

Solution: Active Data Warehousing

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- There are 2 main approaches for supporting online updates:
  - In-Place Updates
    - Traditional
    - Straightforward
    - SLOW

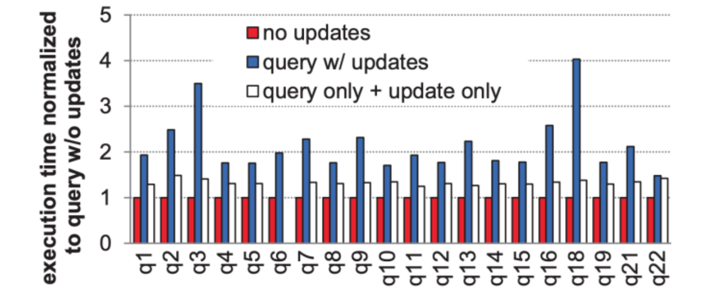

Figure 3: TPC-H queries with random updates on a row store.

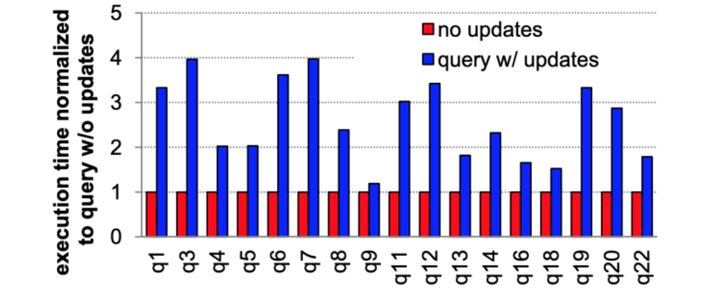

Figure 4: TPC-H queries with emulated random updates on a column store.

What is the current situation?

- The main issue: How to efficiently execute analysis queries in the presence of online updates
- There are 2 main approaches for supporting online updates:
  - In-Place Updates
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    - Straightforward
    - SLOW
  - Differential Updates

Differential Updates - Basics

- Cache incoming updates in an in-memory buffer
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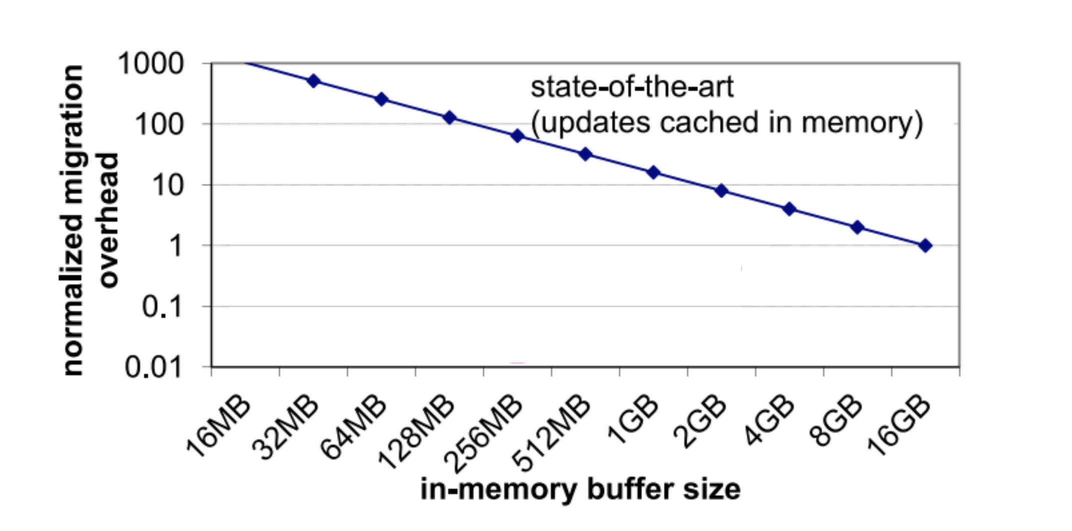
- Any problems? If not, congrats we get to go home!

Differential Updates – The big problem

- If the cache is in memory, you have to choose
  - Small buffers: Small memory requirements -> you can use memory for something else. -> Many migrations
  - Big buffers: Few migrations -> memory will be occupied but you don't have to introduce updates into the main data disks until later.



Is there a better way?

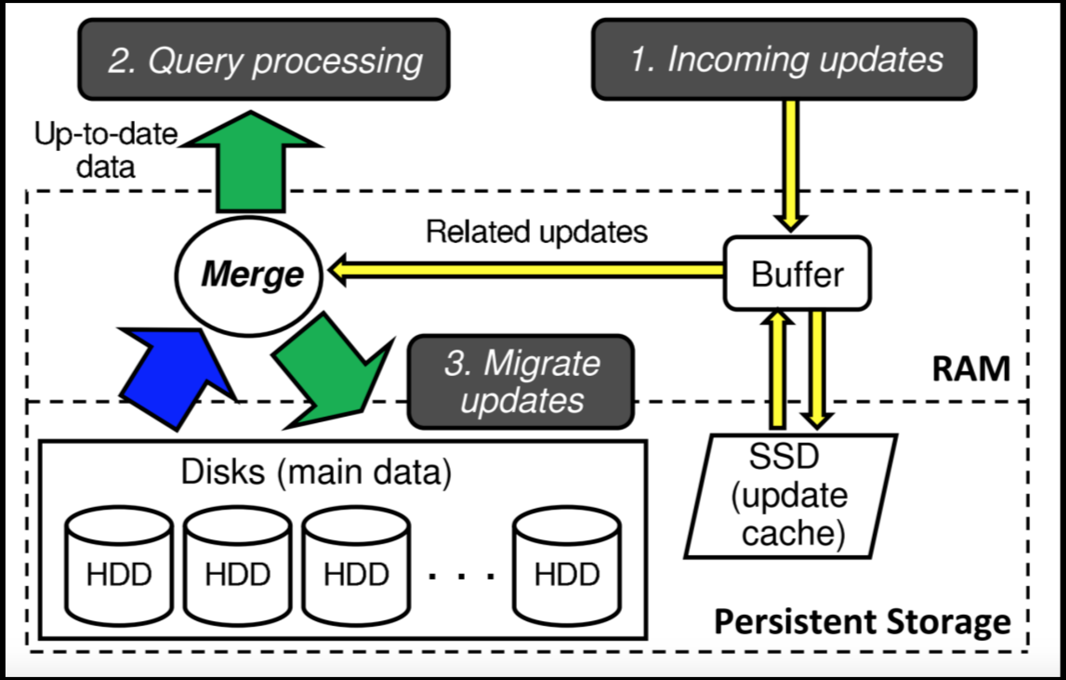
Summary of the Problem

- We want differential updates to match business needs
- We don't want to have to compromise between memory requirements and migration overhead in the incredibly expensive way that current systems make us.

Update Approach	Freshness	Performance	↓ mem overhead
Batched	X	☺	☺
In place	☺	X	☺
In-memory differential	☺	☺	X

Cache Updates in SSDs instead of RAM

- A few Specs:
  - Cache size is 1% – 10% of main data size
  - Both the disks and the SSD cache are searched when queries are received.
  - Data is migrated to main disks when:
    - Load on the system is low
    - The SSD cache is almost full



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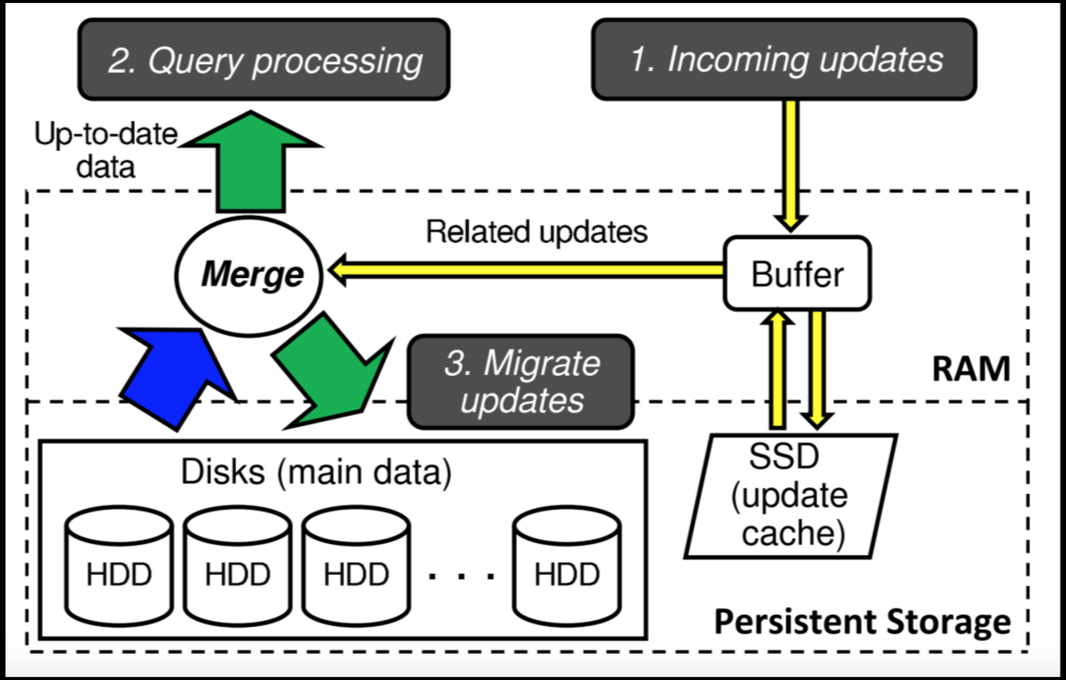

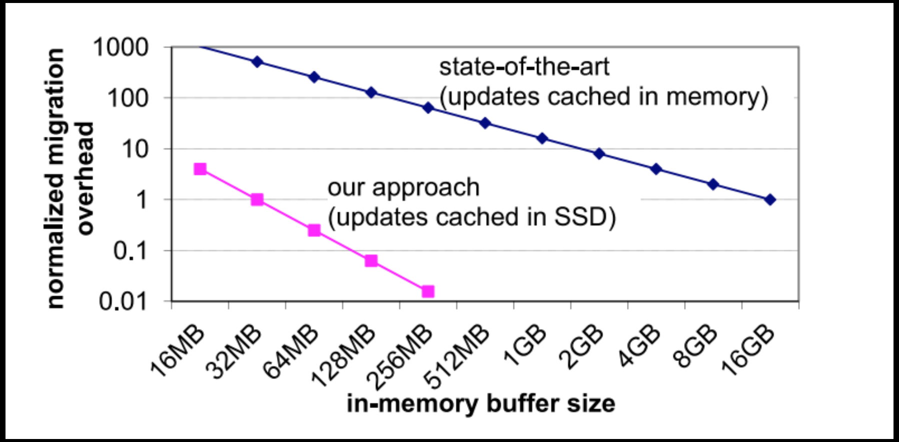

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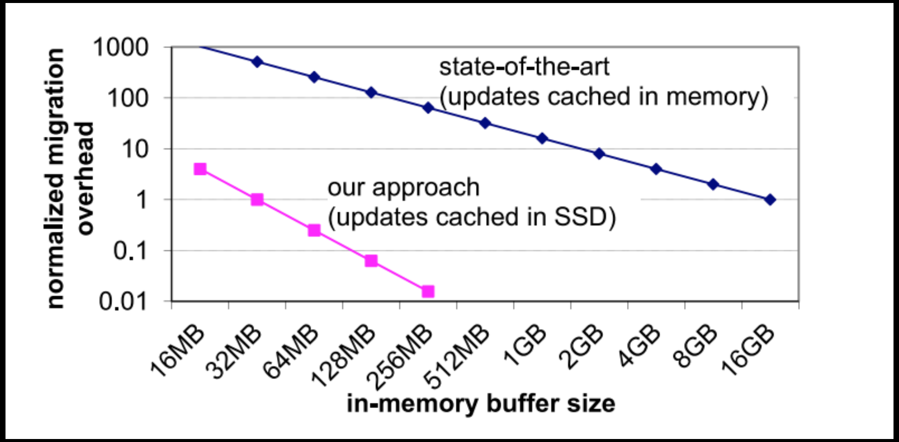
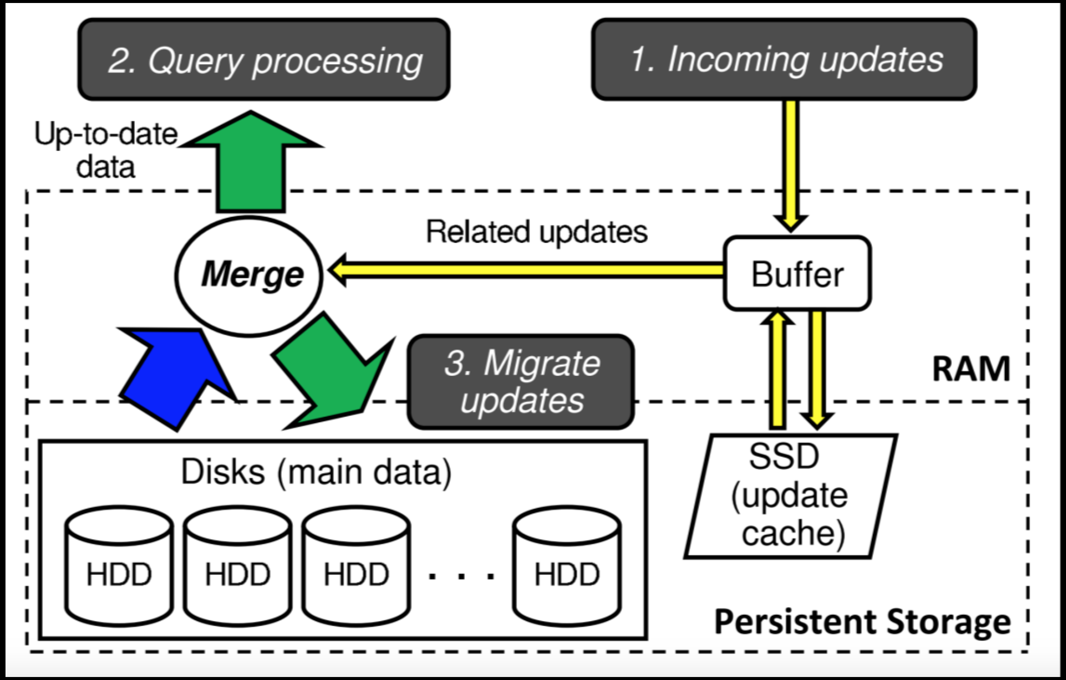




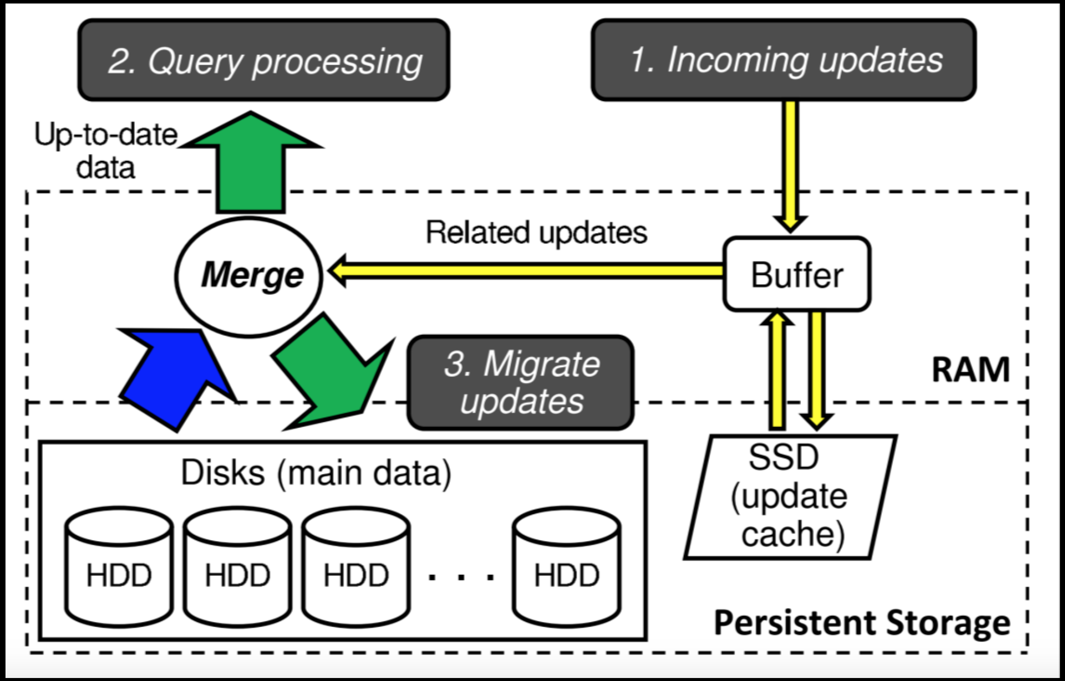
- But, what are the limitations of SSDs?

Implementation

System Goals

1. Low Query Overhead & Small Memory Footprint:
   - Avoid having to make a lot of migrations and also avoid taking up RAM
2. No Random SSD writes:
   - Often leads to expensive additional operations and can degrade performance of SSD.
3. Low total SSD writes per update:
   - Since eventually the SSD memory will wear out, it is good to minimize writes per update to decrease wear out rate.
4. Efficient in place migration:
   - Previous approaches make a copy of the entire disk and then add updates, which requires twice as much disk space.
5. ACID:
   - Ensure that traditional concurrency control and crash recovery techniques still work.

Implementation

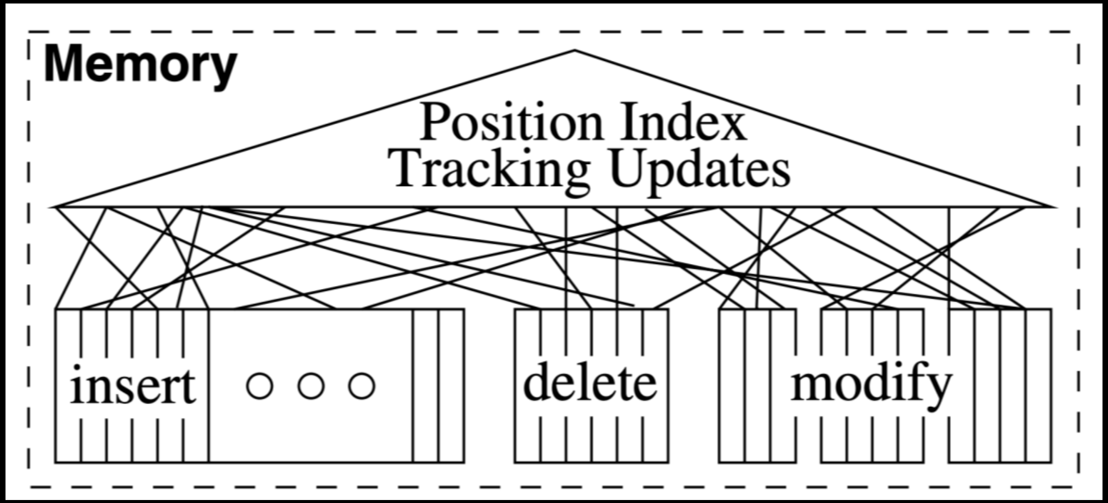


- What must be implemented:
  - Merging: Essentially an outer join
  - Caching: Coordinate Buffer and SSD
  - Migrating: Placing Updates in Disks

All of this must be done taking the 5 goals into account.

Prior Proposals to enable Indexed Updates

- In-Memory Indexed Updates(IU): Keep cache in memory and index it.
  - During Query time: Random access to find relevant cached updates
  - During Migration: Make a copy of the entire disk then make it available when migration is completed.



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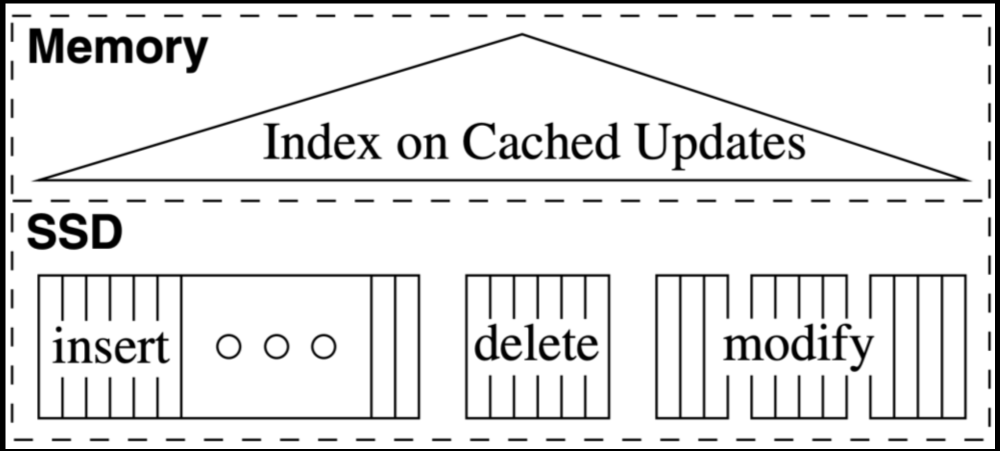
- Simply extended IU to SSDs:
  - Adds random access to SSDs
  - An entire SSD page must be read for retrieving each entry



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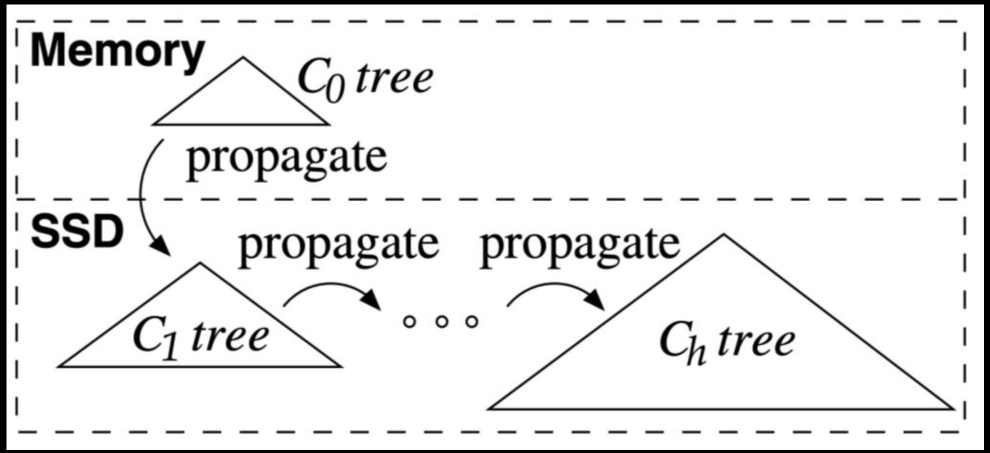
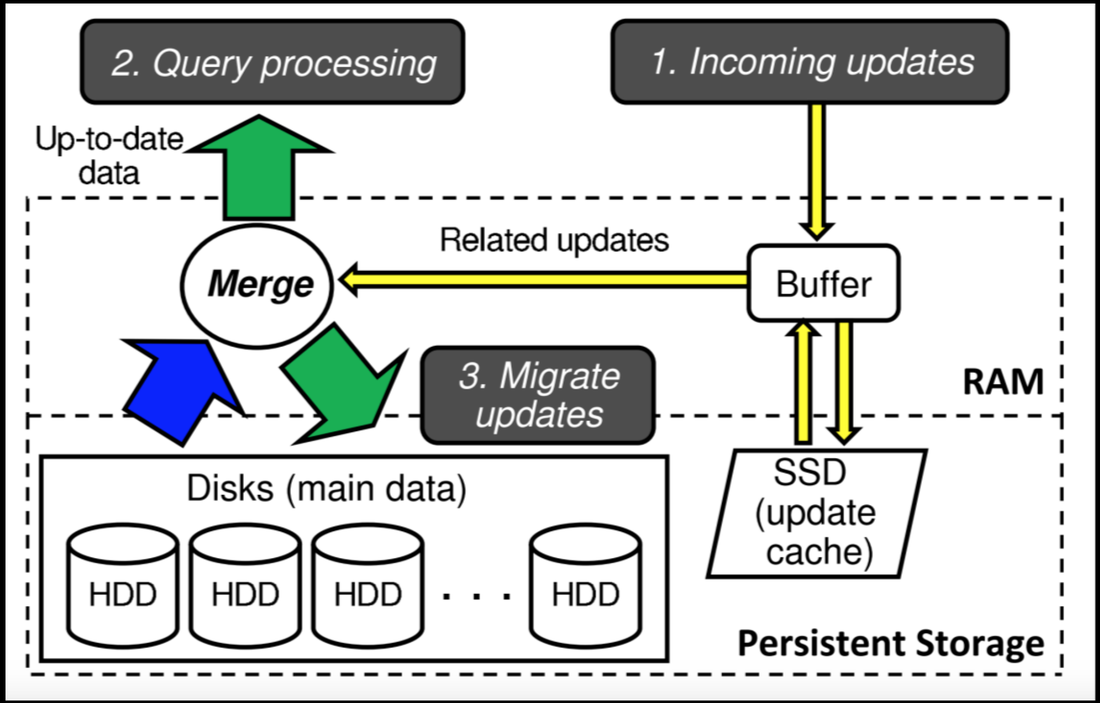
- Use log-structured merge trees:
  - We reduce random reads
  - We increase writes per update

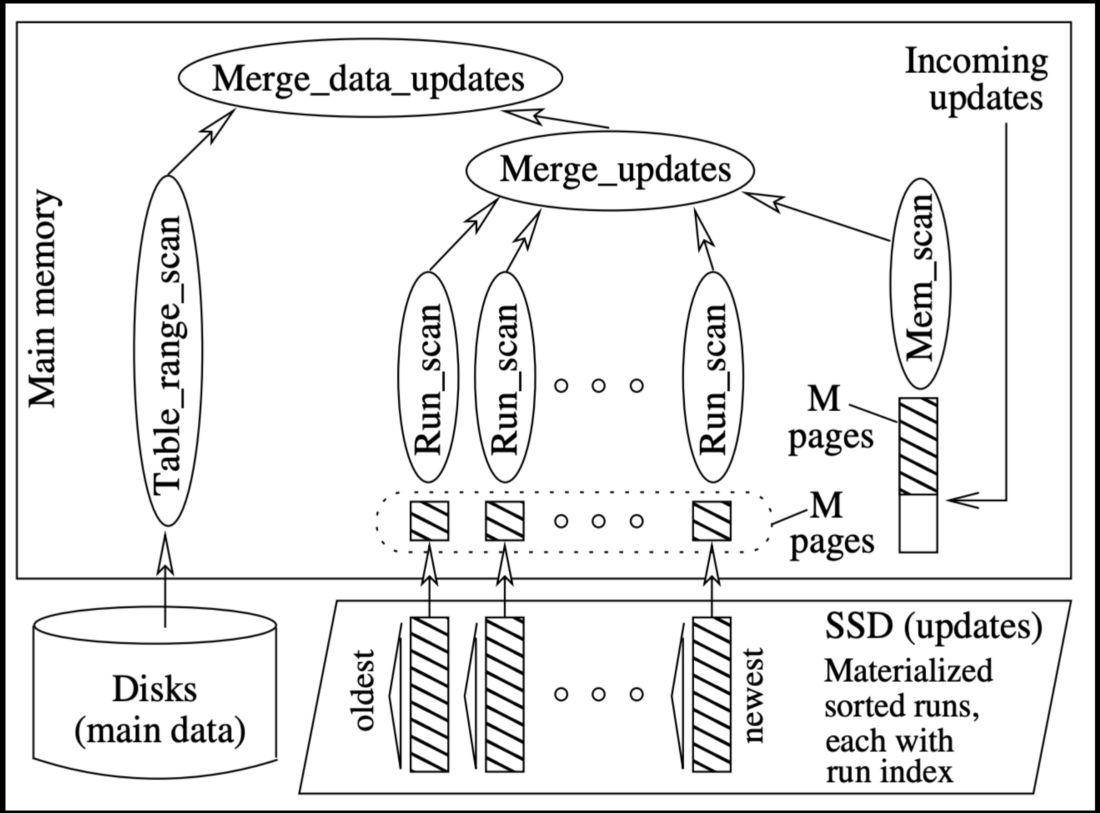


MaSM: Materialized Sort-Merge

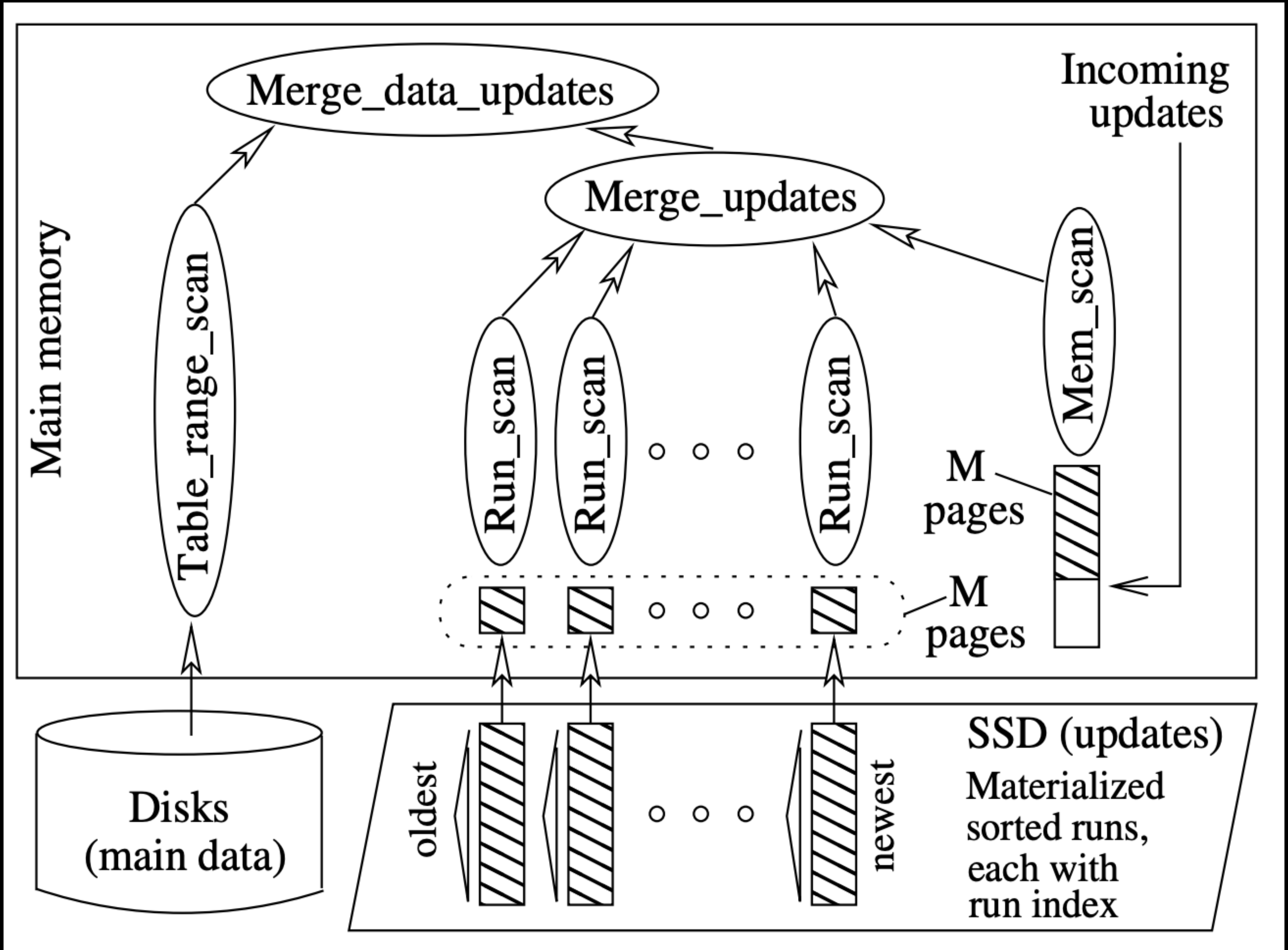


- How is Merging Handled?
  - Sort Merge:
    - Cheaper than hash-based alternatives
    - Preserve the record order
- How is Caching Handled?
  - SSD Storage and External Sorting:
    - SSD Storage reduces memory footprint
    - External sorting is expensive!
- How is Migration Handled?
  - Full table Scan and Write Back to Disk

MaSM – 2M: Minimizing SSD writes



- In-Memory Cache:
  - M pages to store new updates
  - When the buffer is full, create a materialized sorted run of size M in the SSD. (Add a read-only index)
- SSD:
  - Capacity: M^2 – At most M runs
- Query:
  - One page per run for each run in SSD
  - M pages for Table Range Scan

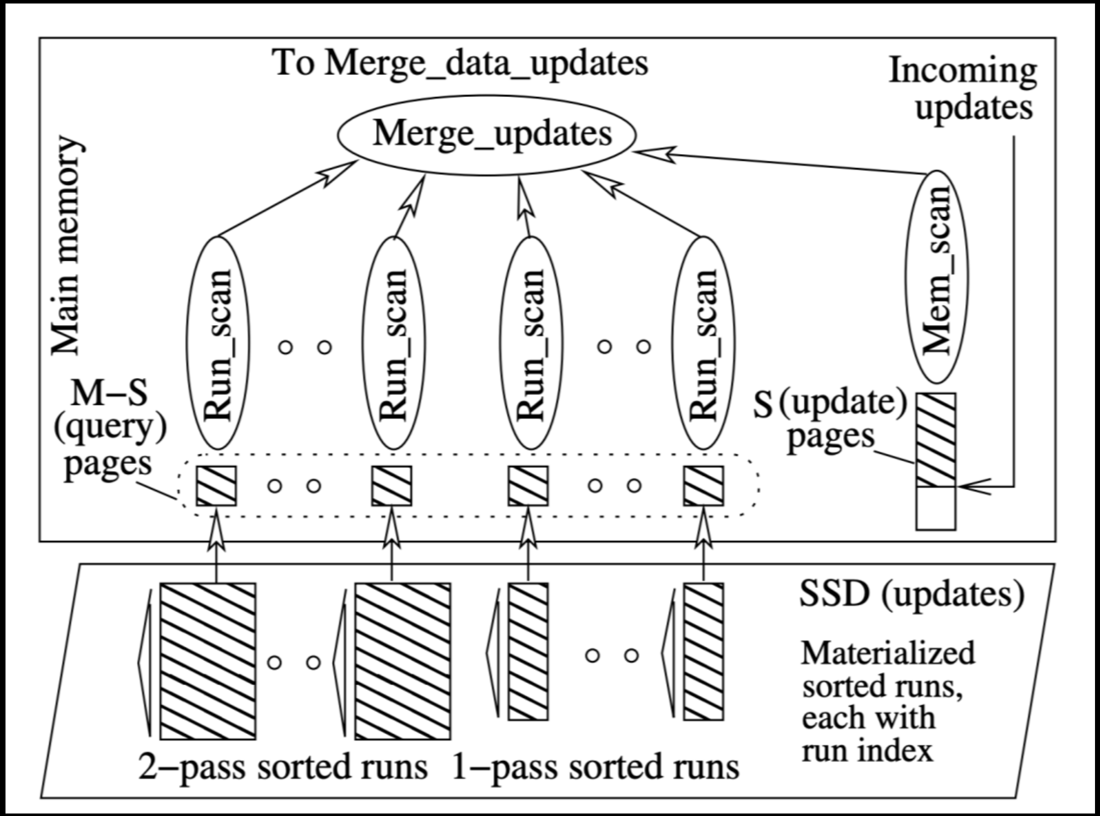


Merge_data_updates
Incoming updates
Merge_updates
Main memory
Table_range_scan
Run_scan
Run_scan
Run_scan
Mem_scan
M pages
M pages
Disks (main data)
SSD (updates)
oldest
newest
Materialized sorted runs, each with run index

MaSM – 2M: Details

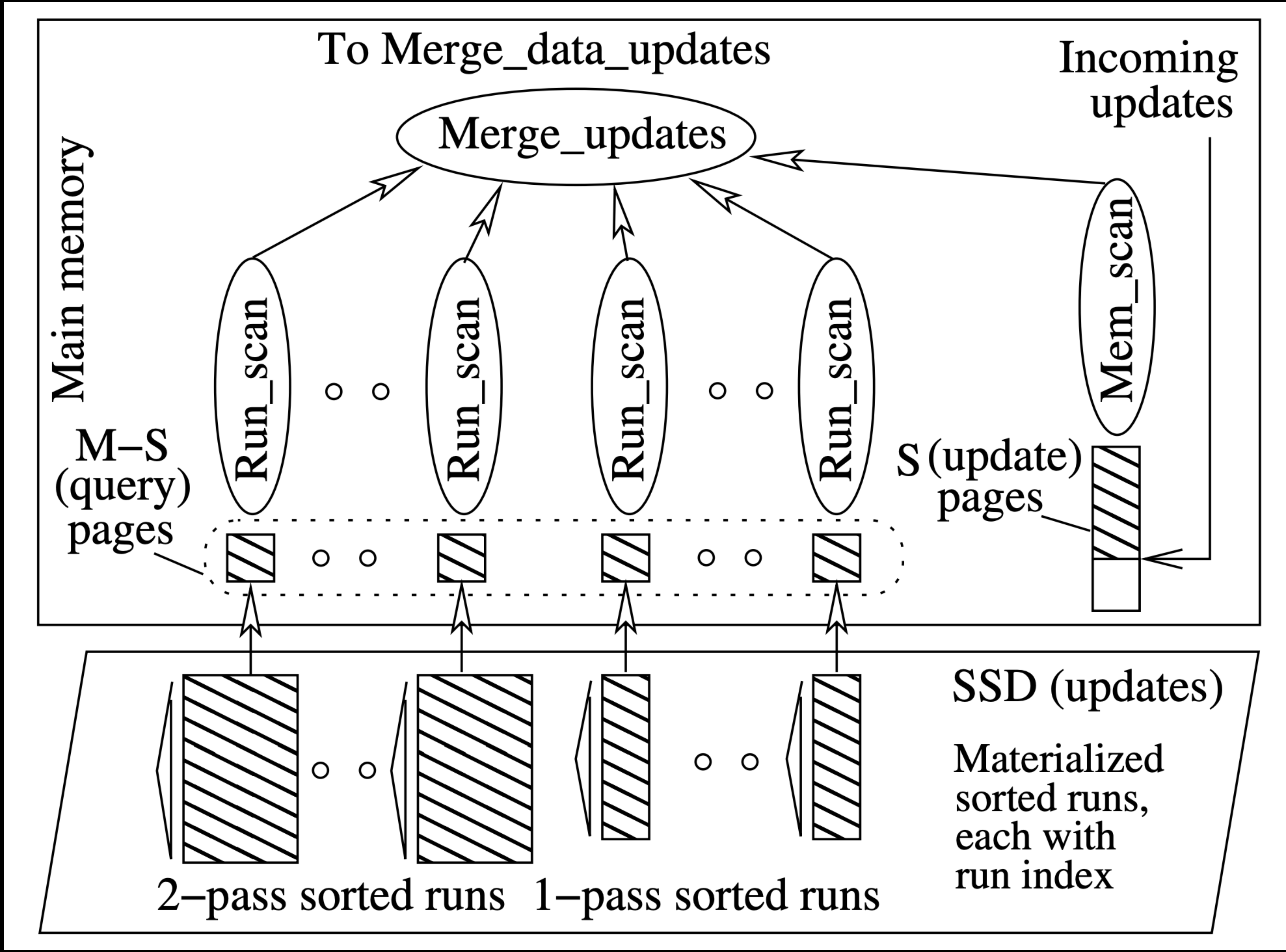
- Timestamps:
  - On Every Update and Every query -> Each query only sees previous updates
  - To support in place migration, each page has the last update timestamp.
- Update Record:
  - Format: (timestamp, key, type, content)
- Online Updates & Range Scan:
  - Thanks to timestamps, only case when online updates can generate issues on scans are when the cache must be flushed, so mutexes are used to protect the update buffer.
- Concurrent Range Scans:
  - Supported thanks read only indexes in SSDs and timestamps on cache
- In- Place Migration:
  - Perform a full range scan, returning pages instead of records. Apply the updates to the pages and write them back to the disk

MaSM – M: Reducing Memory Footprint



- 2 Main Differences:
  - Better Memory Management - M pages
    - S of the M pages: Updates
    - Rest: Queries
  - Not all SSD runs have equal size:
    - The query pages can only handle M-S materialized sorted runs

The algorithm merges multiple smaller runs (1 pass) into larger runs. (2 pass runs)



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Incoming updates
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Main memory
Run_scan
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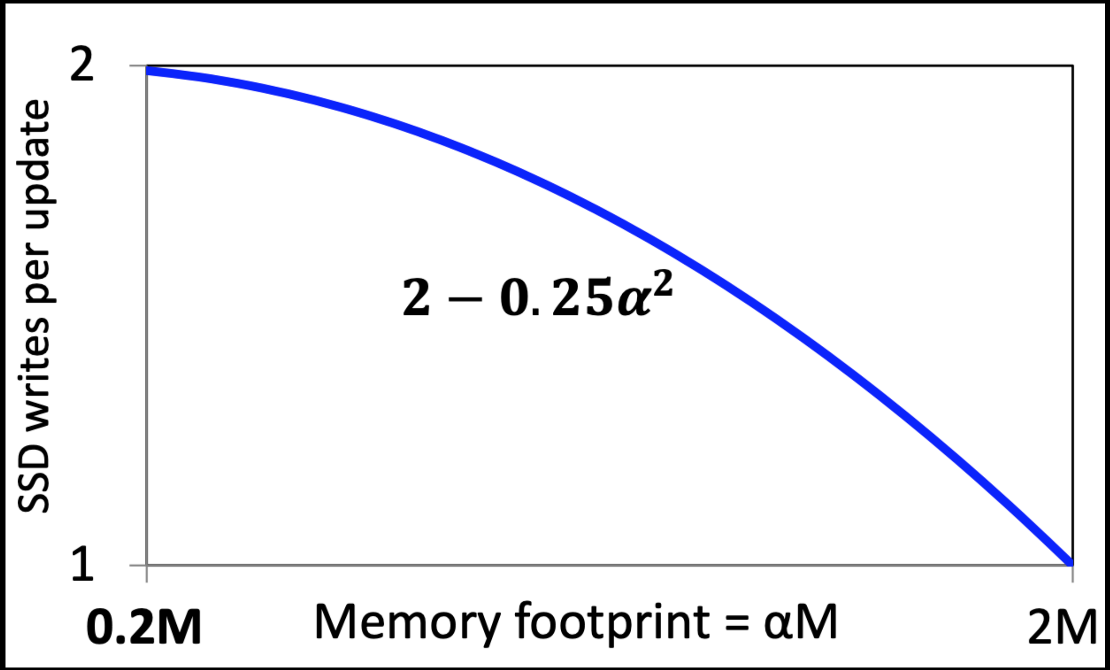
Mem_scan
M−S (query) pages
S (update) pages
SSD (updates)
Materialized sorted runs, each with run index
2−pass sorted runs
1−pass sorted runs

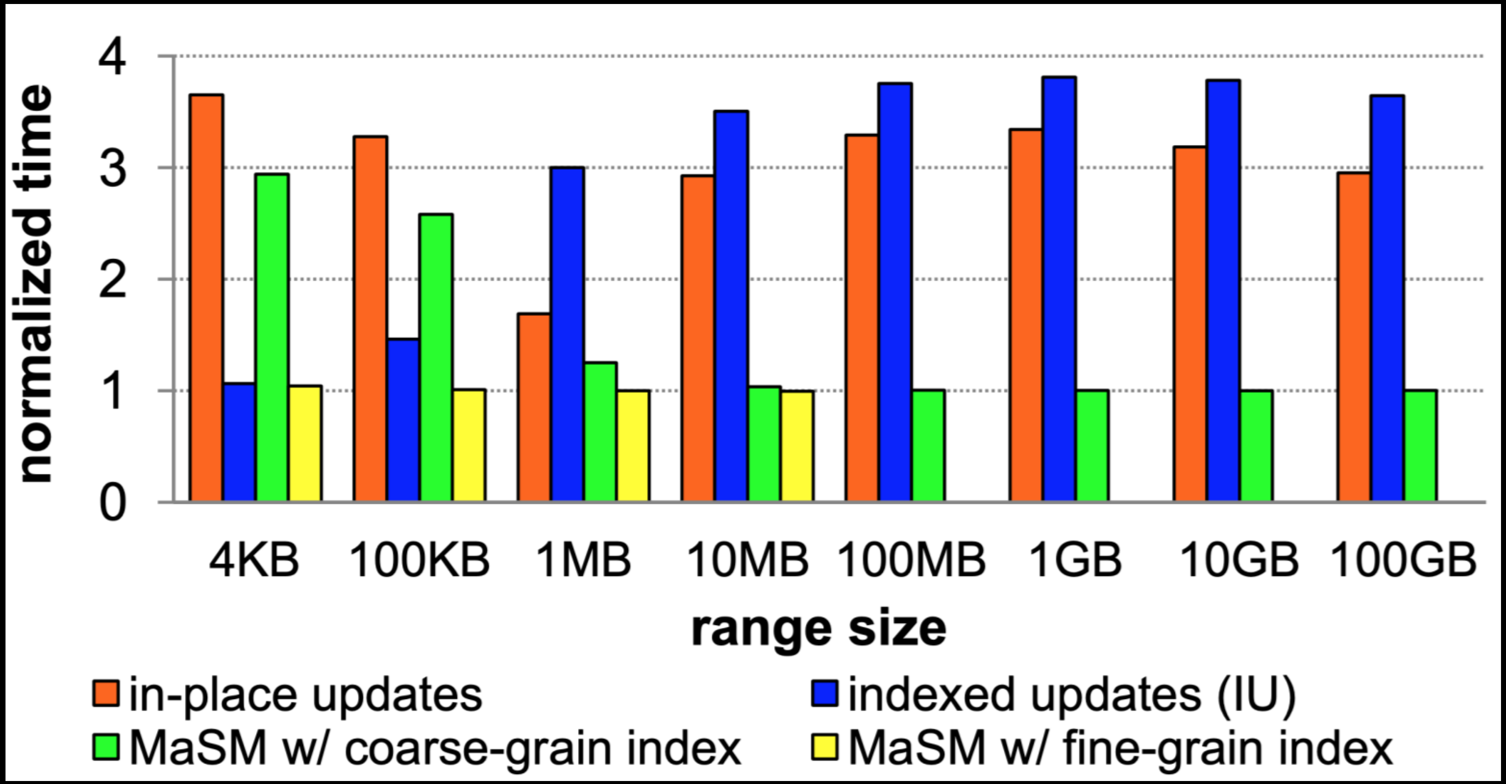
MaSM – αM: Generalizing MaSM



- Recall M is number of pages allocated to MaSM
- Details:
  - Tunable Memory Usage - αM pages
    - Range 2/√M³ to 2,
  - Think of previous as special cases:
    - MaSM – 2M: α = 2 (1 SSD write/update)
    - MaSM – M : α = 1 (1.75 SSD writes/update)

Testing

All Schemes for Handling Online Updates



Synthetic Data

- In-place Updates:
  - 1.7 – 3.7X slowdowns
- Indexed Updates:
  - 1.1 – 3.8X slowdowns
- MaSM w/ coarse-grain index:
  - incurs little overhead for 100MB to 100GB ranges
  - Bigger under 10mb
- MaSM w/ fine-grain index:
  - 4% overhead even at 4KB ranges

TPCH – Replay Experiment

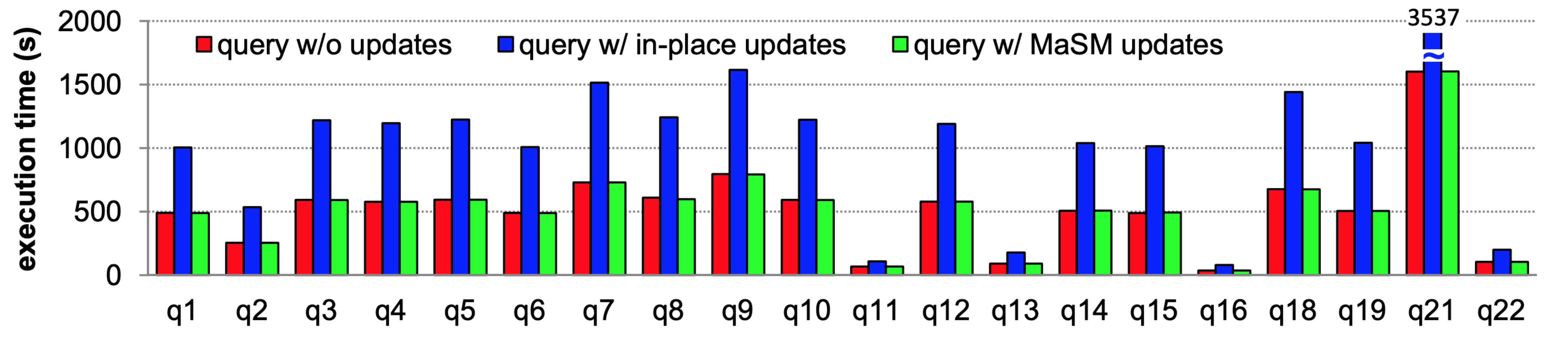
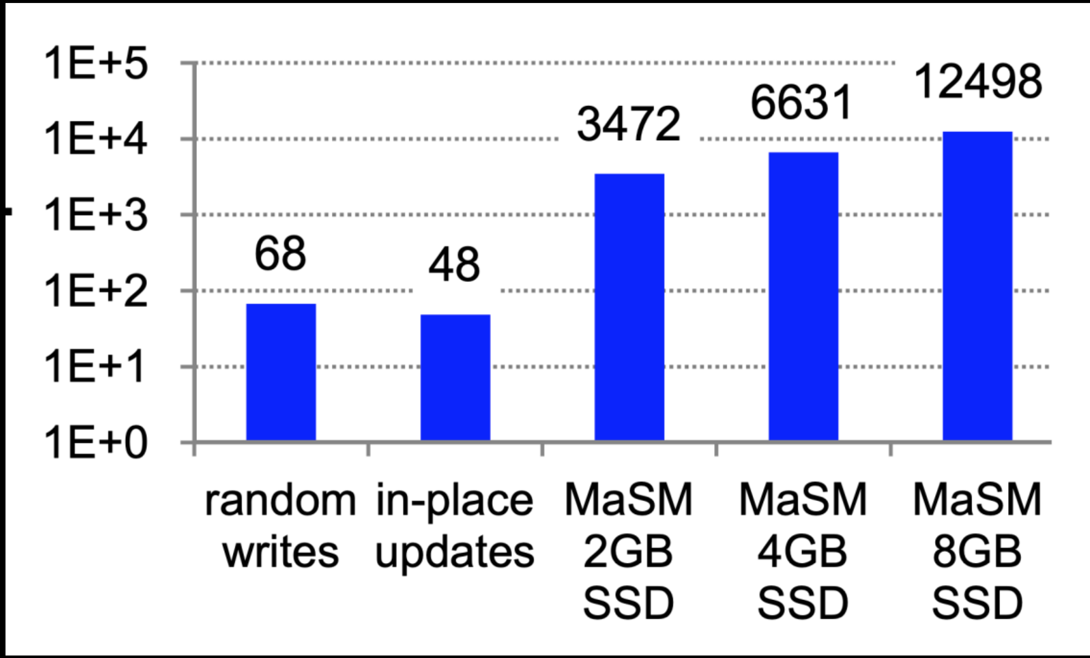


Figure 14: Replaying I/O traces of TPC-H queries on a real machine with online updates.

- In place updates:
    - 1.6 – 2.2X worse than no updates
- MaSM updates:
    - Less than 1% overhead

Sustained Update Rate



- 2 Main Points:
  - Comparison:
    - MaSM schemes achieve orders of magnitude higher sustained update rates
  - Scalability:
    - Doubling the flash space will roughly double the sustained update rate

Conclusion

System Goals

1. Low Query Overhead & Small Memory Footprint:
   - SSD reads can be completely overlapped with Disk reads
2. No Random SSD writes:
   - As described in the algorithm
3. Low total SSD writes per update:
   - Between 1 and 2 writes per update!
4. Efficient in place migration:
   - Thanks to large SSD size (1-10% of disk) we have low frequency and will likely affect all pages of disk.
5. ACID:
   - Timestamps enable serializability
   - Locking is supported
   - Crash Recovery: only in-memory buffer needs recovery.

Paper Did Well:

- Analyzed business needs
- Thoroughly discussed previous attempts
- Aimed to reduce the implementation impact
- Considered alternative or additional implementations
  - And showed why they may or may not work

I Wish the Paper had:

- Considered Full usage of SSDs:
  - Lower energy consumption
  - Leveraging main data storage as a cache extension
- Considered Additional Costs of SSDs Cache :
  - Power?
  - Investment?