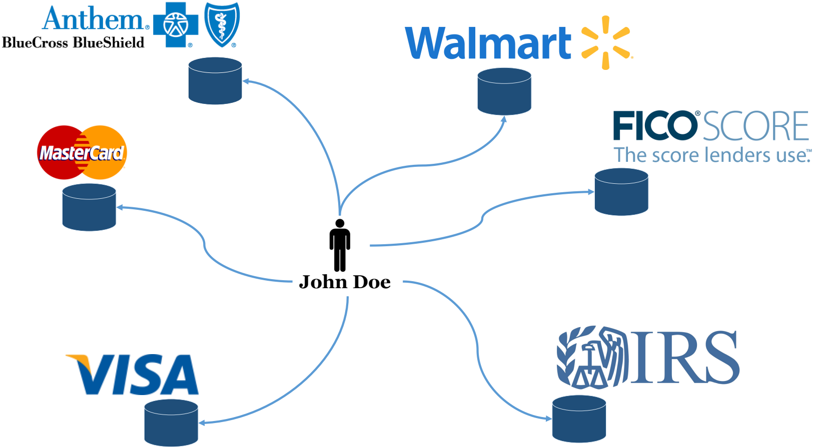
L-Store: Lineage-based Storage Architectures

ECS165A: Winter 2023

Slides are adopted from Sadoghi, et al.

L-Store: A Real-time OLTP and OLAP System, EDBT'18

Data Management at Macroscale: The Four V's of Big Data



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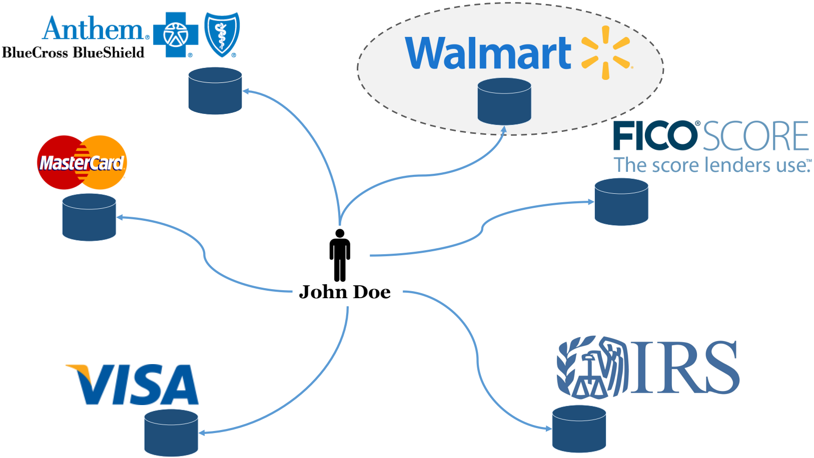
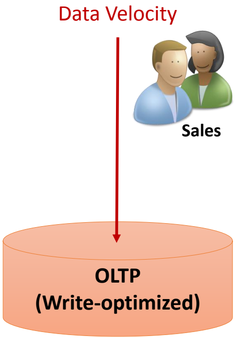


Data Management at Microscale: Volume & Velocity



Walmart

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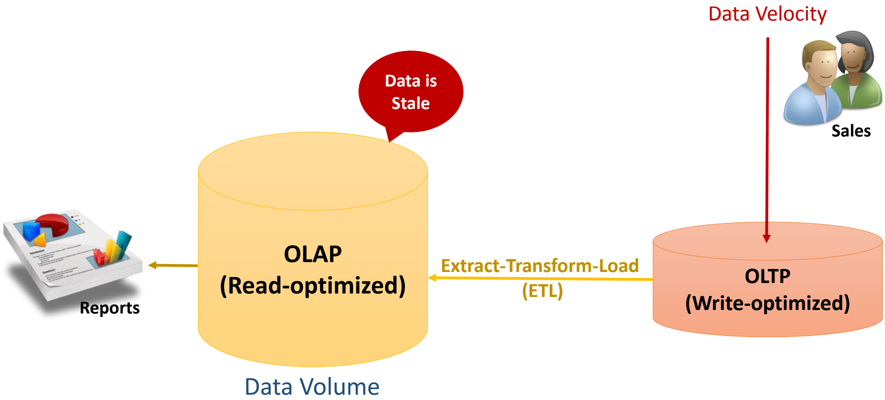

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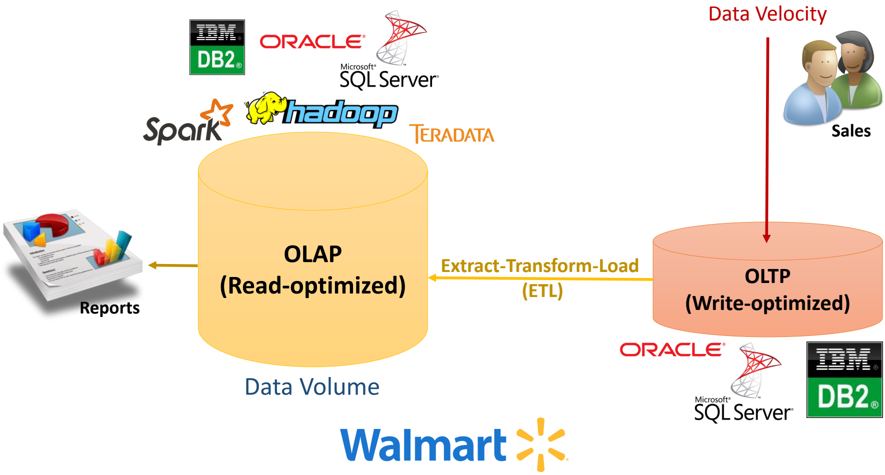
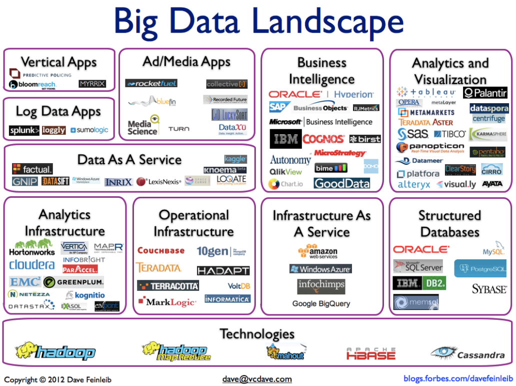


One Size Does not Fit All As of 2012



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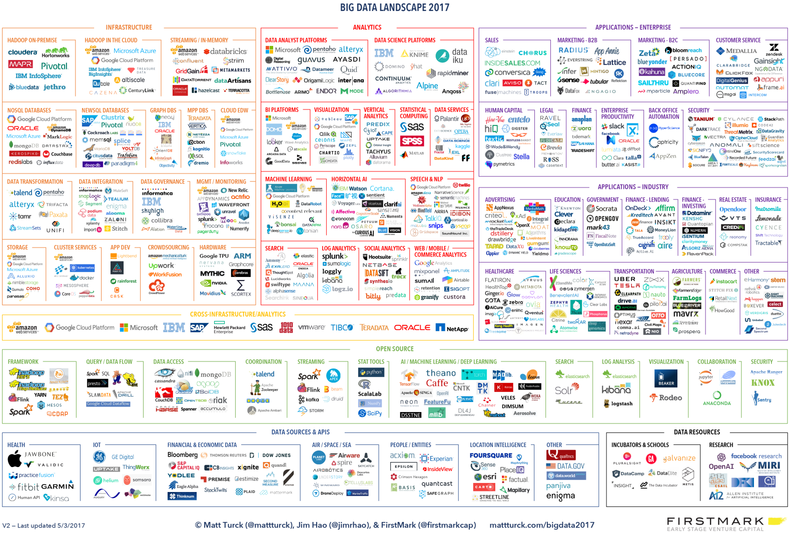

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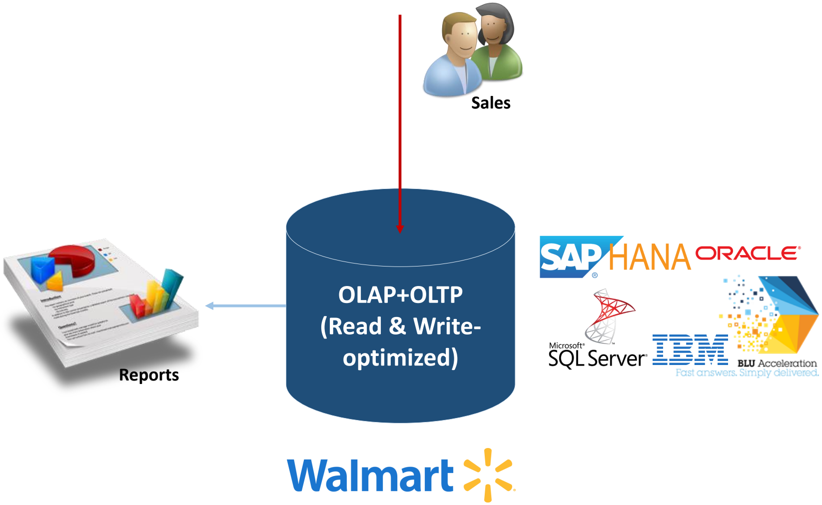
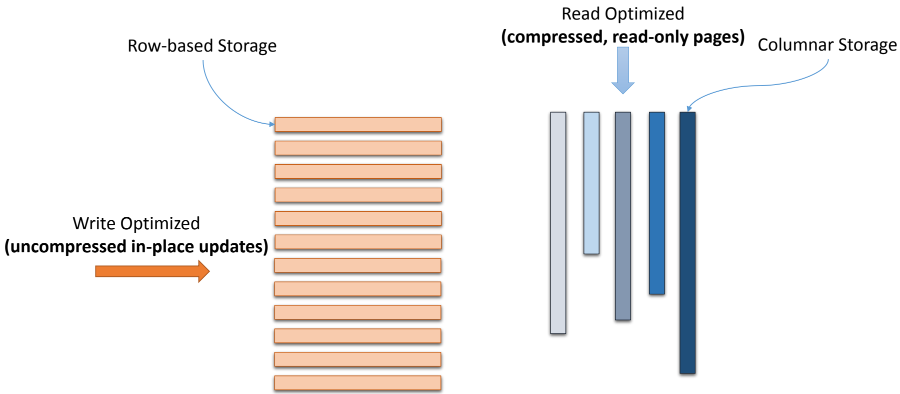


Storage Layout Conflict



Write-optimized (i.e., uncompressed & row-based) vs. read-optimized (i.e., compressed & column-based) layouts

Reducing Index maintenance: Velocity Dimension

Observed Trends

In the absence of in-place updates in operational multi-version databases, the cost of index maintenance becomes a major obstacle to cope with data velocity.

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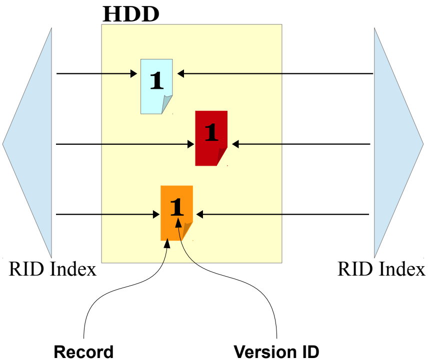
Decouple Logical and Physical Locations of Records to Reduce Index Maintenance

Traditional Multi-version Indexing: Updating Records



Updating random leaf pages

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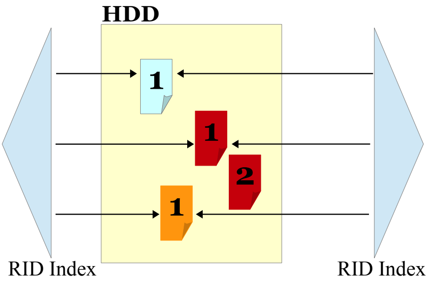

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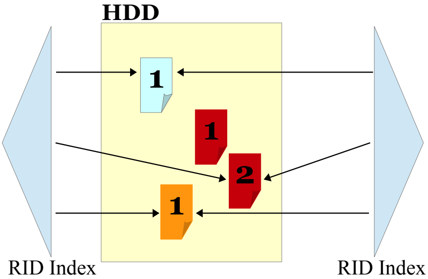

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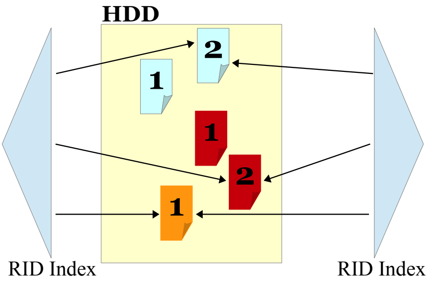

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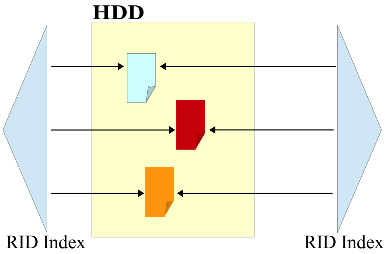

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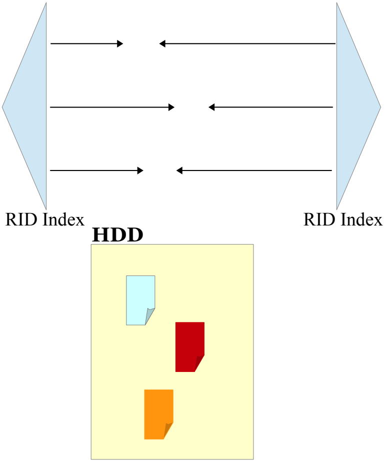

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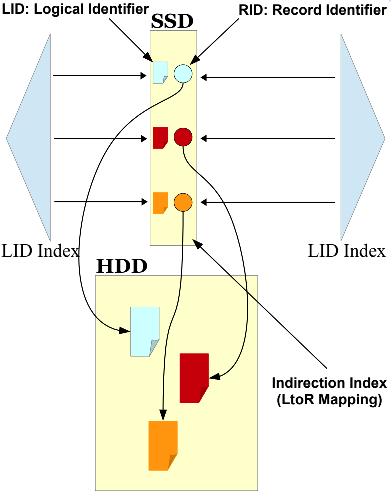

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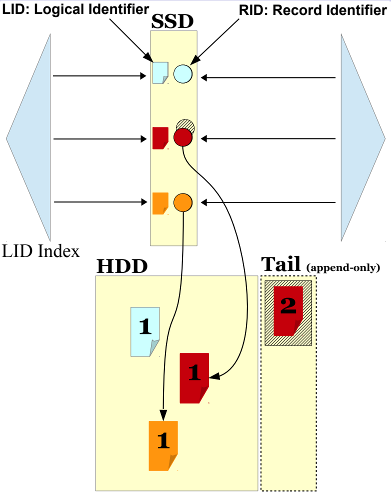

Eliminating random leaf-page updates

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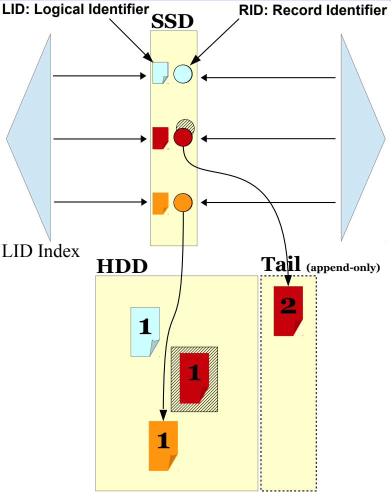

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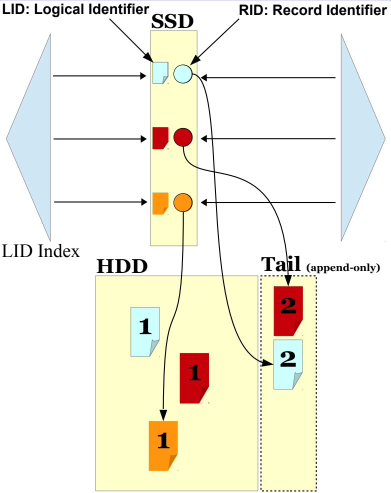

Eliminating random leaf-page updates

Unifying OLTP and OLAP: Velocity & Volume Dimensions

Observed Trends

In operational databases, there is a pressing need to close the gap between the write-optimized layout for OLTP (i.e., row-wise) and the read-optimized layout for OLAP (i.e., column-wise).

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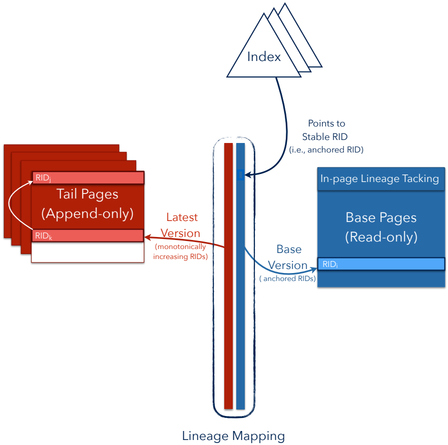
Introducing a *lineage-based storage architecture*, a contention-free update mechanism over a native columnar storage in order to

lazily and independently stage stable data from a write-optimized layout (i.e., OLTP) into a read-optimized layout (i.e., OLAP)

Lineage-based Storage Architecture (LSA): Intuition



Physical Update Independence: De-coupling data & its updates
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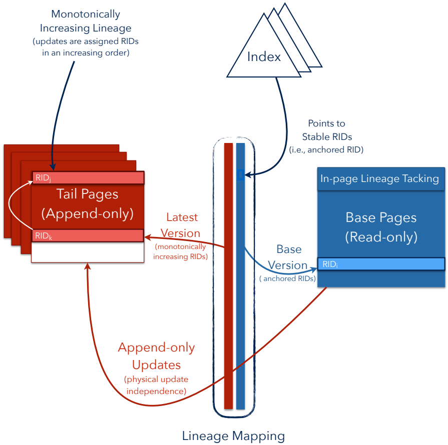

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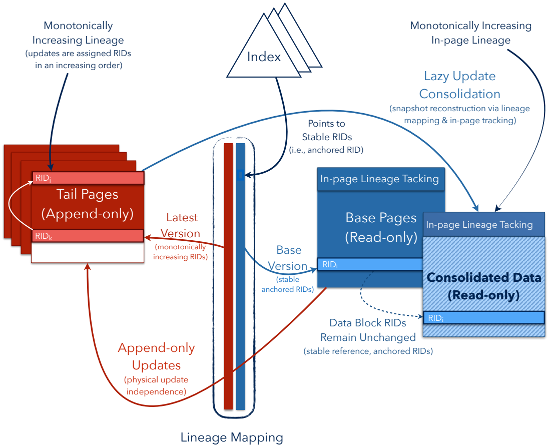

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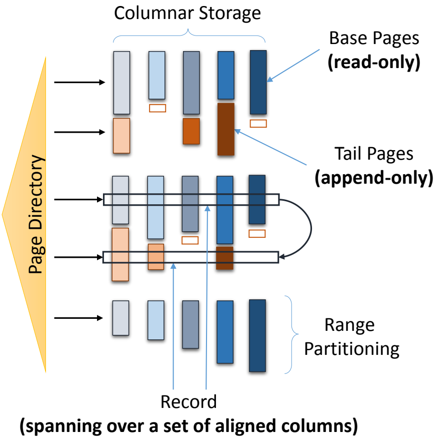
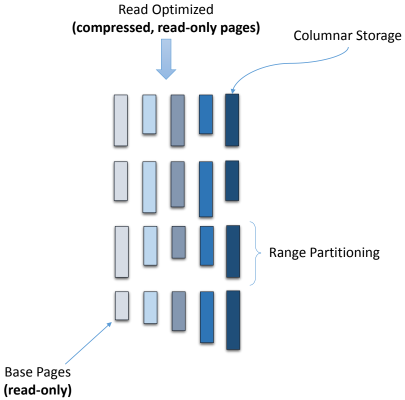
Lineage-based Storage Architecture (LSA): Overview



Overview of the lineage-based storage architecture
(**base pages** and **tail pages** are handled identically at the storage layer)

L-Store: Detailed Design



Records are range-partitioned and compressed into a set of ready-only **base pages** (accelerating analytical queries)

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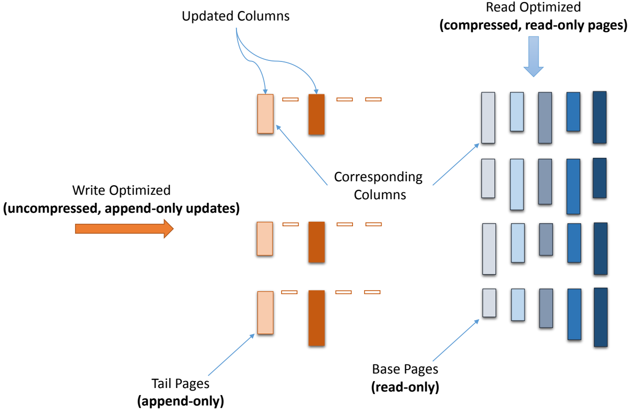

Recent updates for a range of records are clustered in their **tails pages** (transforming costly point updates into an amortized analytical-like query)

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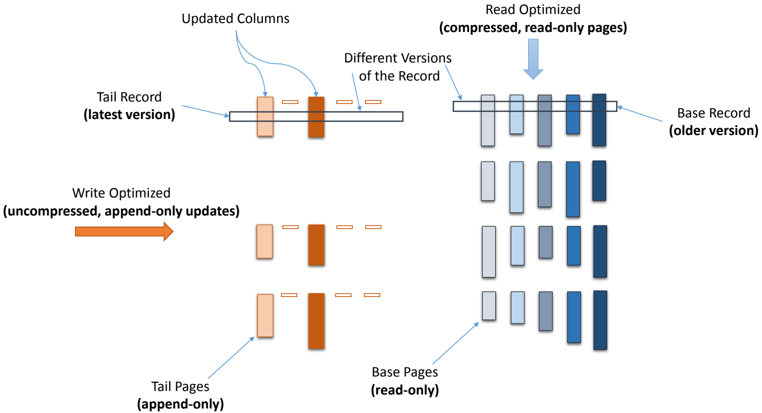

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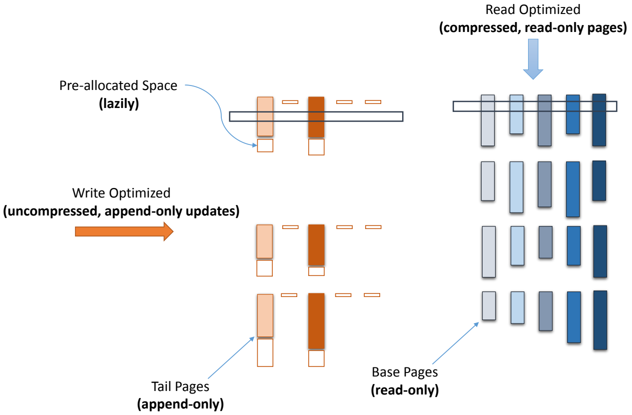

Recent updates are strictly appended, uncompressed in the pre-allocated space (eliminating the read/write contention)

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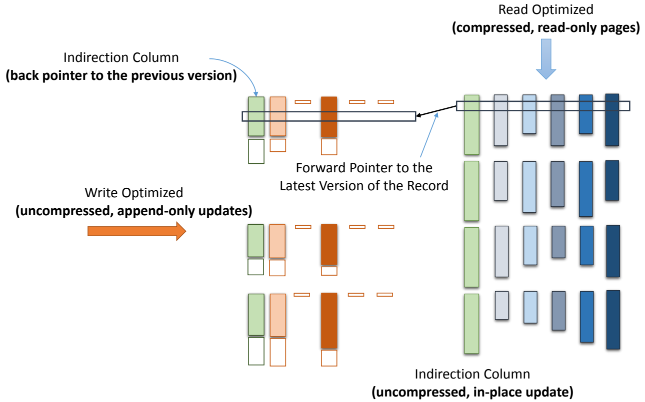

Achieving (at most) 2-hop access to the latest version of any record
(avoiding read performance deterioration for point queries)

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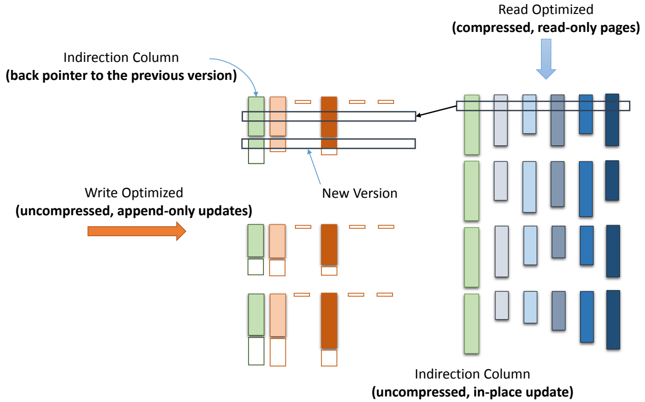

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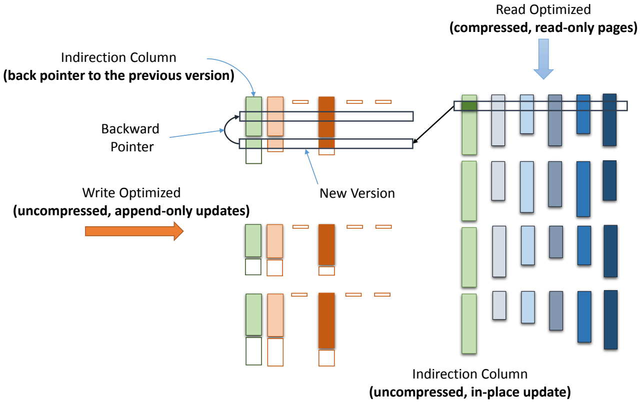

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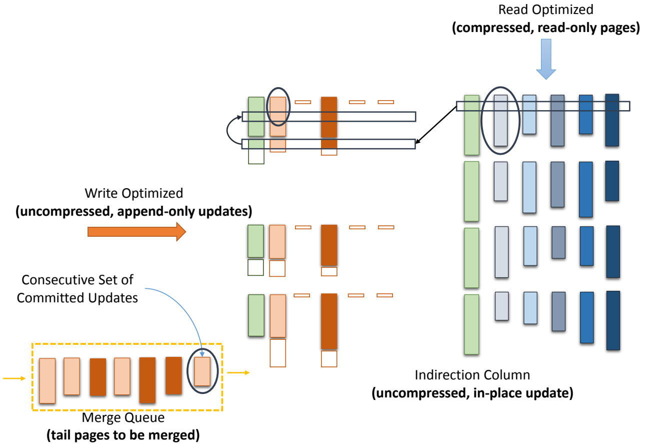
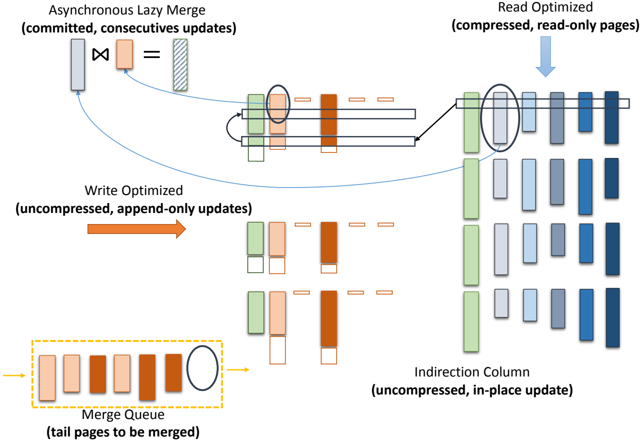
L-Store: Contention-free Merge



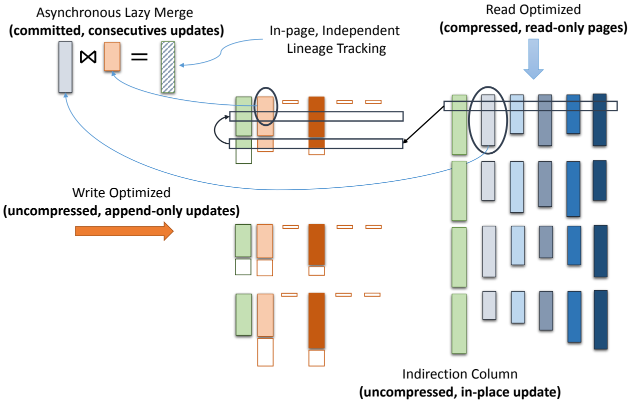
Contention-free merging of only stable data: read-only and committed data (no need to block on-going and new transactions)

L-Store: Contention-free Merge



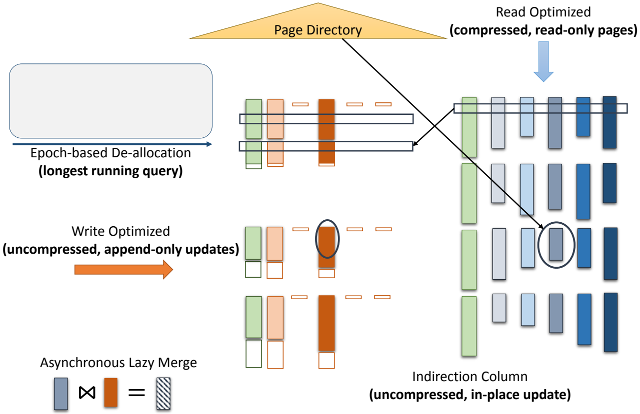
Lazy independent merging of **base pages** with their corresponding **tail pages** (resembling a local left outer-join of the base and tail pages)

L-Store: Contention-free Merge



Independently tracking the lineage information within every page
(no need to coordinate merges among different columns of the same records)

L-Store: Epoch-based Contention-free De-allocation



Contention-free page de-allocation using an epoch-based approach (no need to drain the ongoing transactions)

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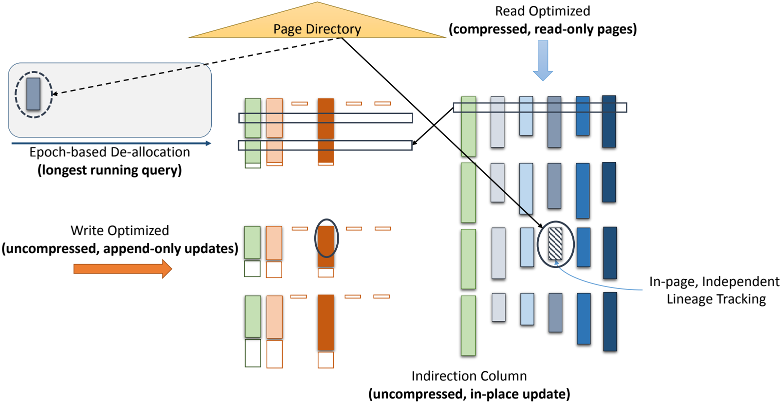

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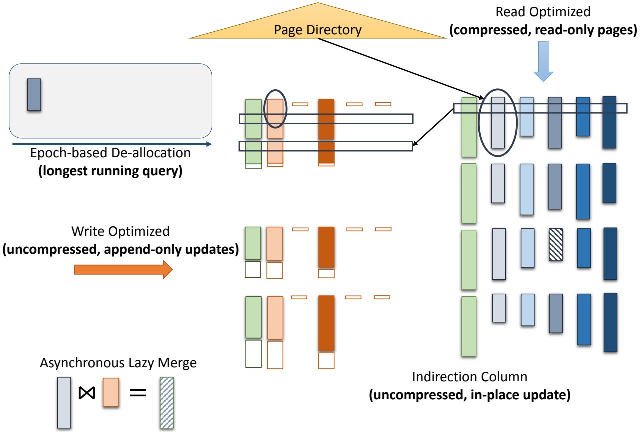

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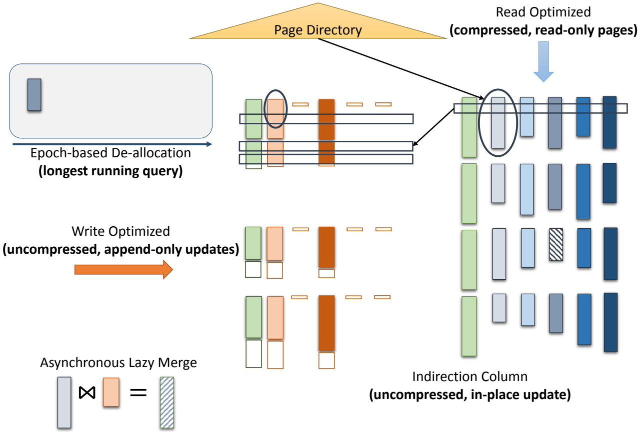

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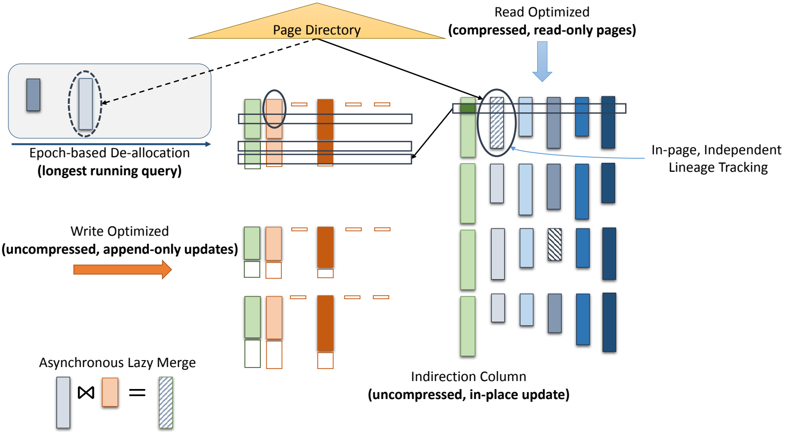

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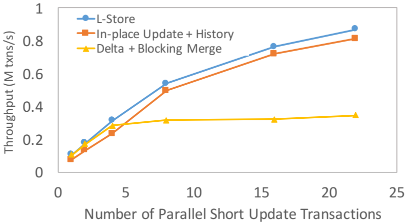
Experimental Analysis

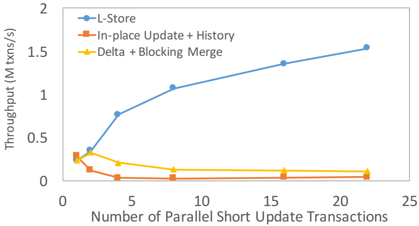
Experimental Settings

- Hardware:
  - 2 × 6-core Intel(R) Xeon(R) CPU E5-2430 @ 2.20GHz, 64GB, 15 MB L3 cache

- Workload: Extended Microsoft Hekaton Benchmark
  - Comparison with *In-place Update + History* and *Delta + Blocking Merge*
  - Effect of varying contention levels
  - Effect of varying the read/write ratio of short update transactions
  - Effect of merge frequency on scan
  - Effect of varying the number of short update vs. long read-only transactions
  - Effect of varying L-Store data layouts (row vs. columnar)
  - Effect of varying the percentage of columns read in point queries
  - Comparison with log-structured storage architecture (*LevelDB*)

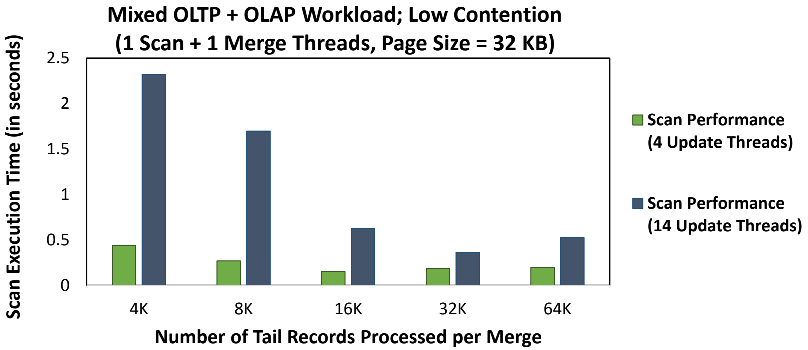
Effect of Varying Contention Levels





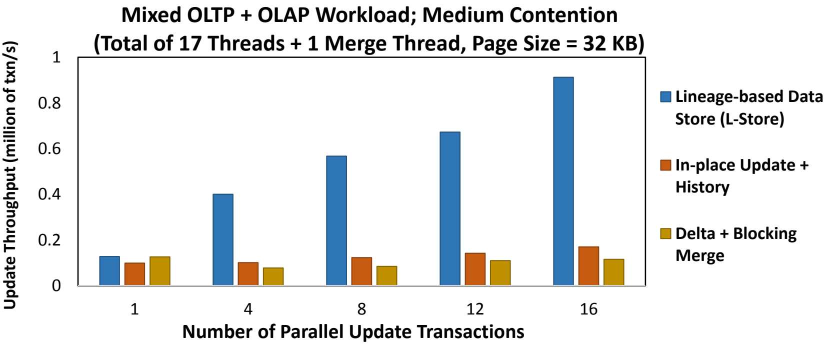
Achieving up to **40**× as increasing the update contention

Effect of Merge Frequency on Scan Performance



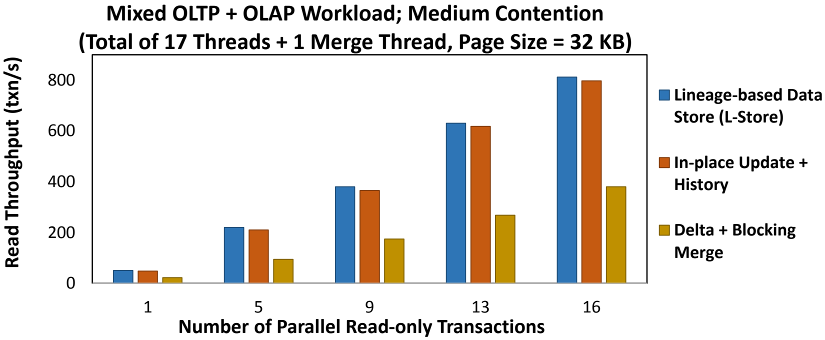
Merge process is essential in maintaining efficient scan performance

Effect of Mixed Workloads: Update Performance



Eliminating latching & locking results in a substantial performance improvement

Effect of Mixed Workloads: Read Performance



Coping with tens of update threads with a single merge thread

L-Store Key Contributions

- Unifying OLAP & OLTP by introducing lineage-based storage architecture (LSA)
- LSA is a native multi-version, columnar storage model that lazily & independently stages data from a write-optimized layout into a read-optimized one
- Contention-free merging of only stable data without blocking ongoing or incoming transactions
- Contention-free page de-allocation without draining ongoing transactions
- L-Store outperforms in-place update & delta approaches by factor of up to **8**× on mixed OLTP/OLAP workloads and up to **40**× on update-intensive workloads

Questions?

Thank you!

Exploratory Systems Lab (ExpoLab)
Website: https://expolab.org/

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ResilientDB Security, Privacy Reloaded