L-Store: Towards a Unified OLTP and OLAP over a Secure Platform

Mohammad Sadoghi

Exploratory Systems Lab
University of California, Davis

University of Waterloo

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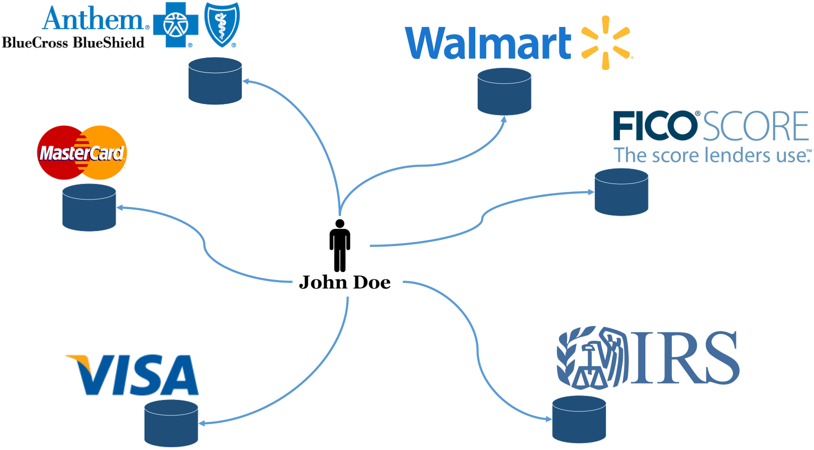
Data Management at Macroscale



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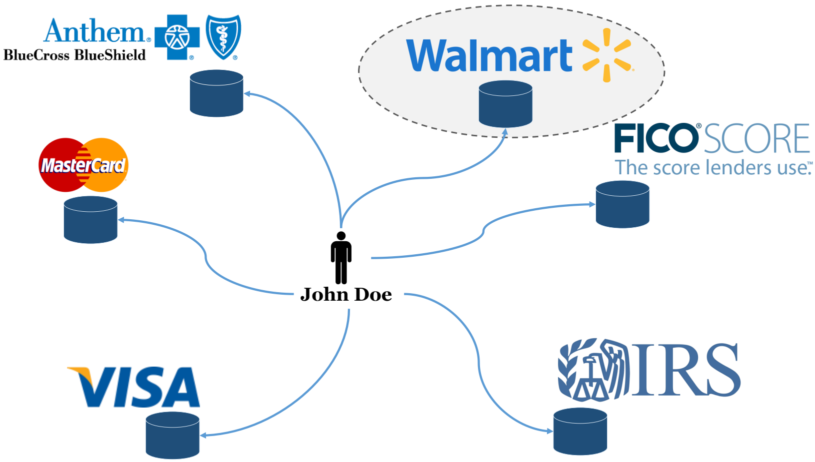
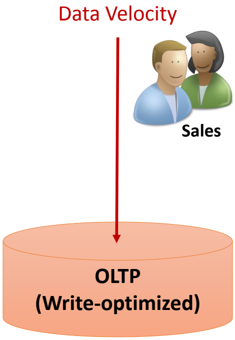


Data Management at Microscale: Volume & Velocity



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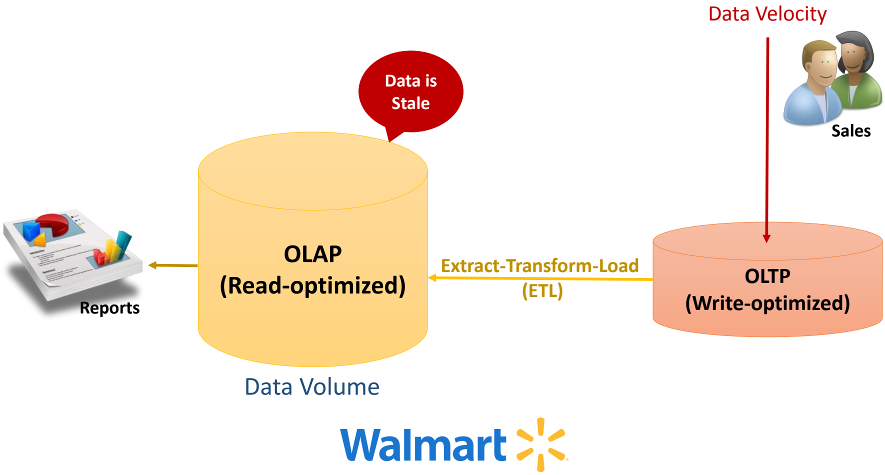

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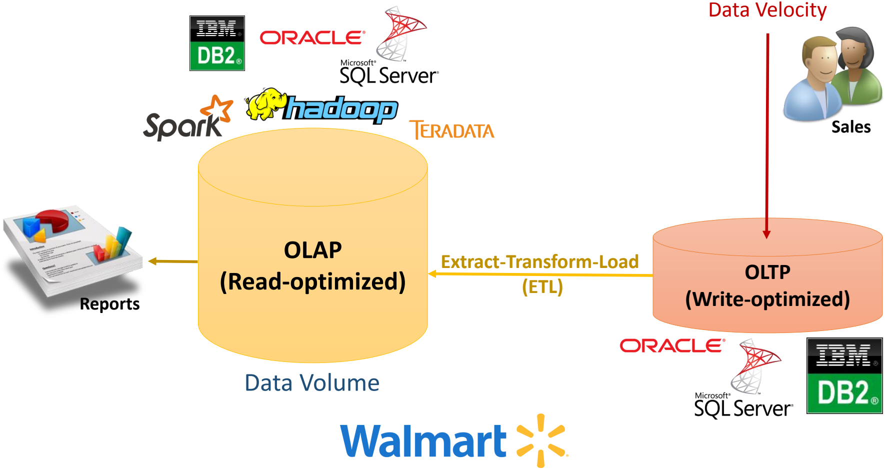
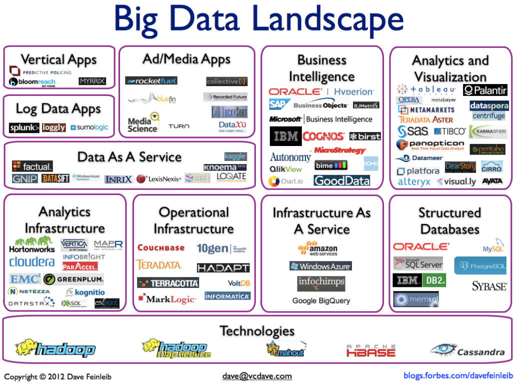


One Size Does not Fit All As of 2012



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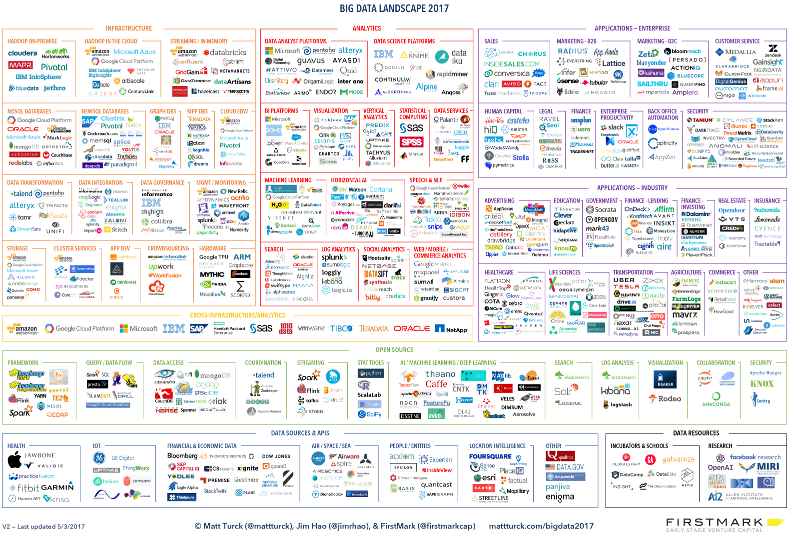

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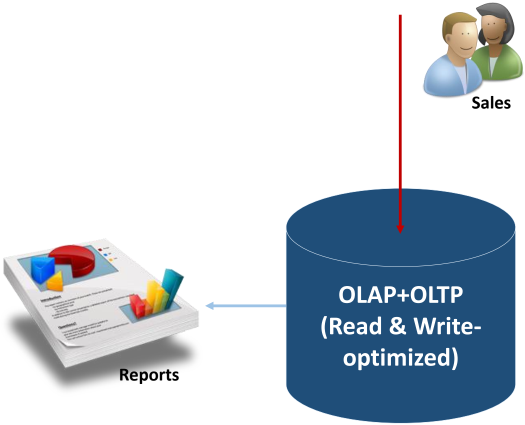

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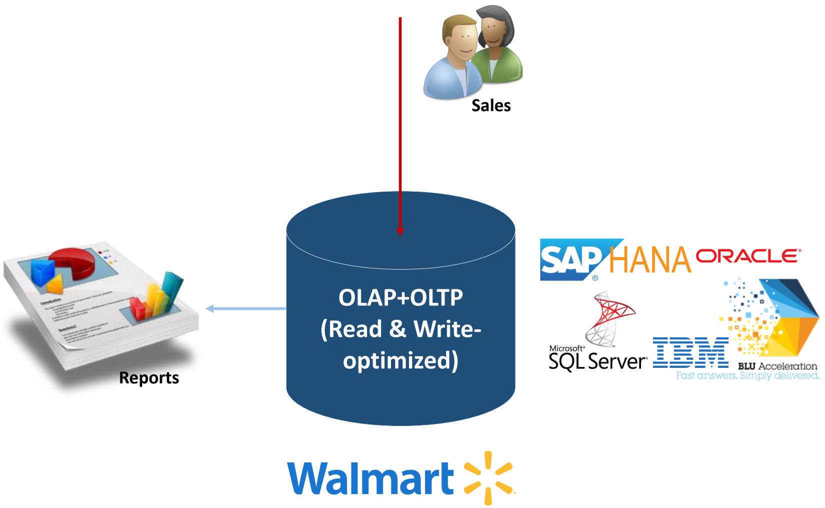

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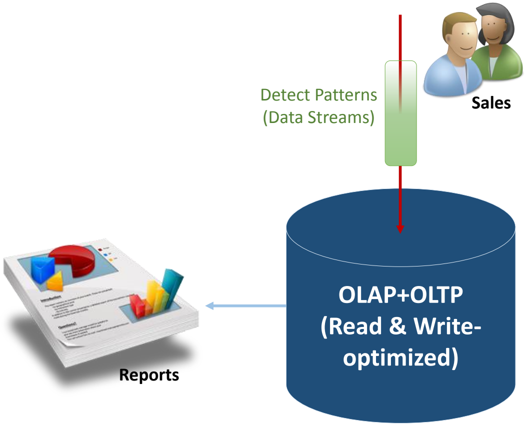

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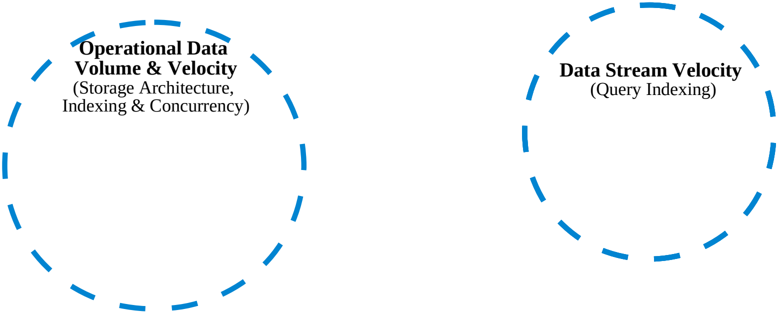
Data Management at Microscale: Volume & Velocity

Big Picture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Volume & Velocity
(Storage Architecture,
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Data Stream Velocity
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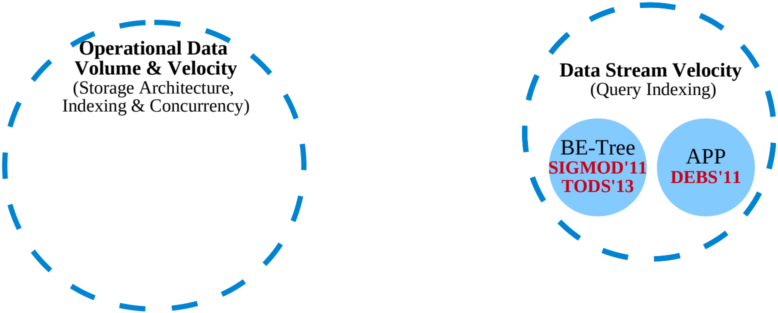
Big Picture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TODS'13
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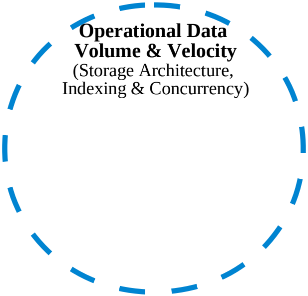

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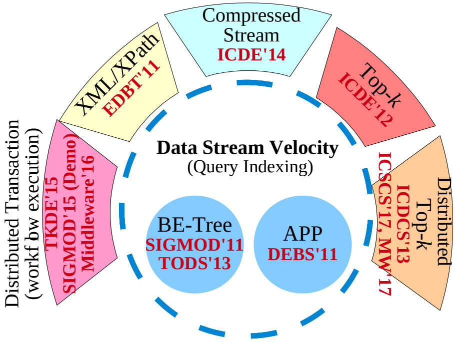

Compressed
Stream
ICDE'14
XML/XPath
EDBT'11
Top-k
ICDE'12
Distributed Transaction
(workf bw execution)
TKDE'15
SIGMOD'15 (Demo)
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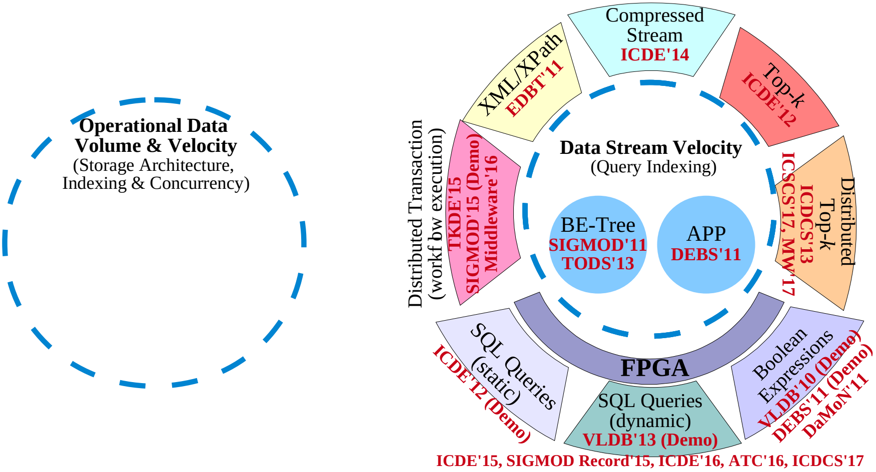
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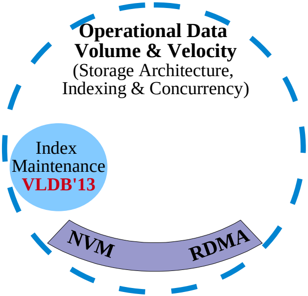

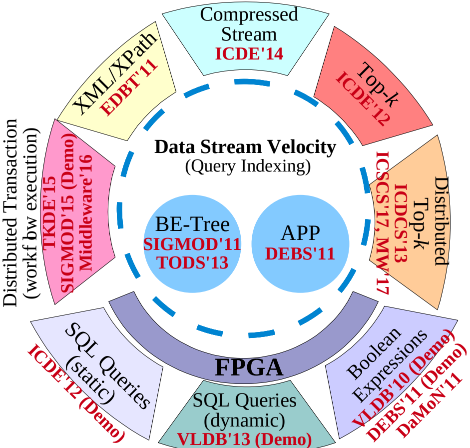

ICDE'15, SIGMOD Record'15, ICDE'16, ATC'16, ICDCS'17

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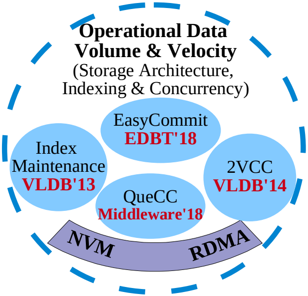
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Index
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VLDB'14
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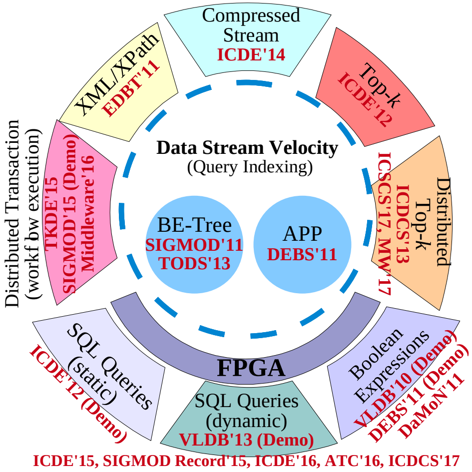
NVM
RDMA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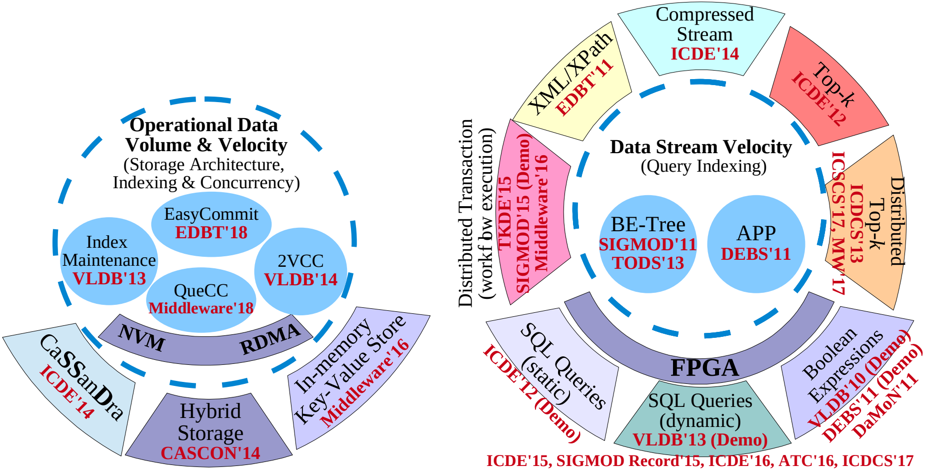
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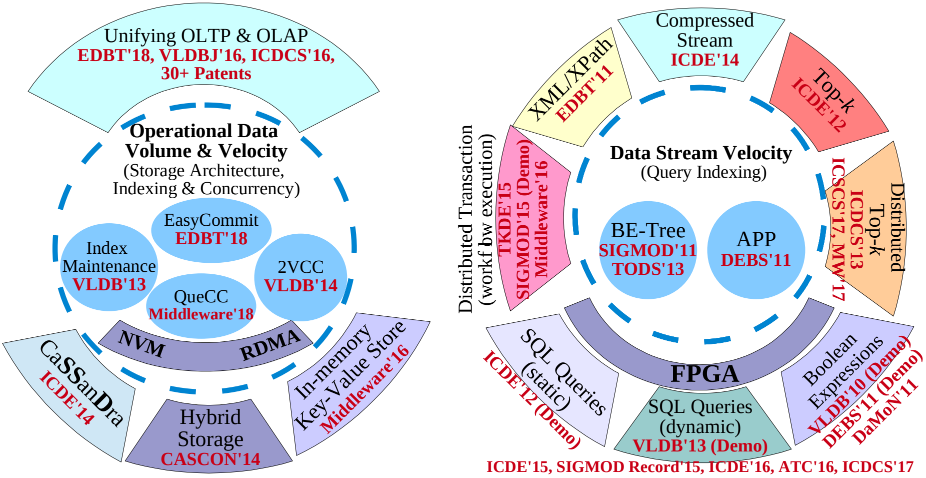
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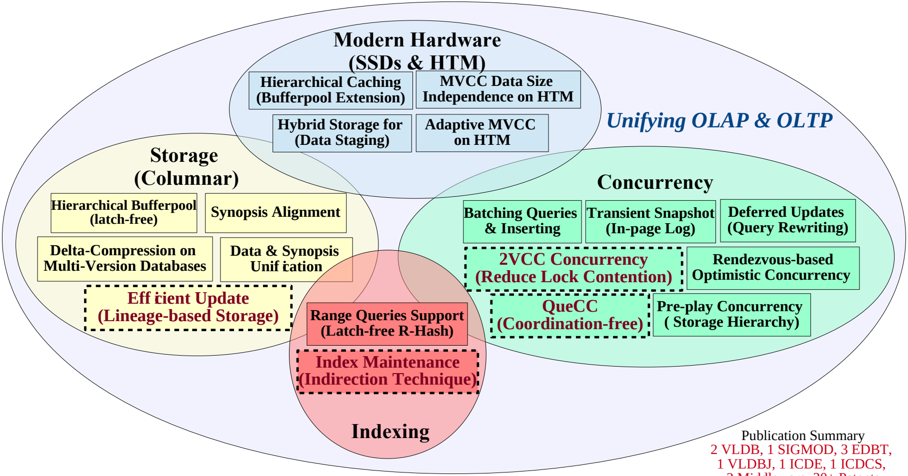
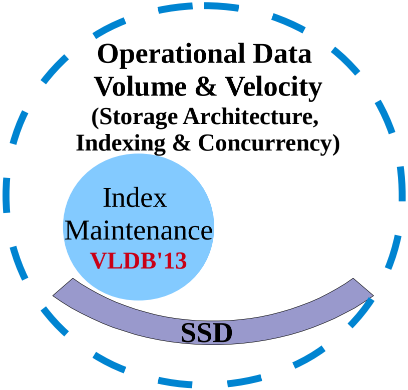
Deep Dive: Unifying OLTP & OLTP



Publication Summary
2 VLDB, 1 SIGMOD, 3 EDBT,
1 VLDBJ, 1 ICDE, 1 ICDCS,
2 Middleware, 30+ Patents

Extending Storage Hierarchy with Indirection Layer



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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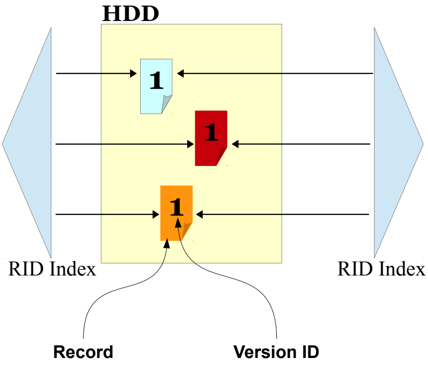
Decouple Logical and Physical Locations of Records to Reduce Index Maintenance

Traditional Multi-version Indexing: Updating Records



Updating random leaf pages

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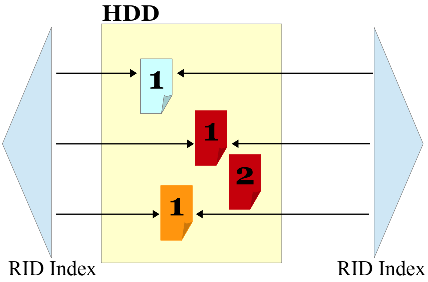

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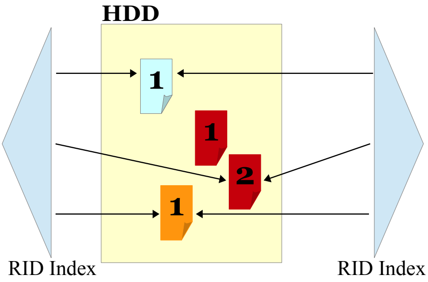

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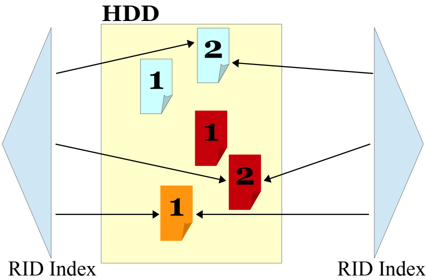

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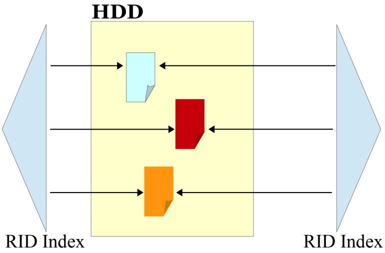

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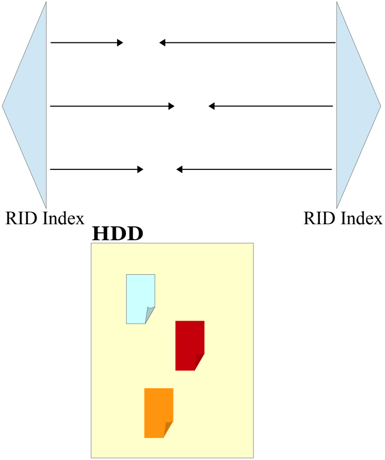

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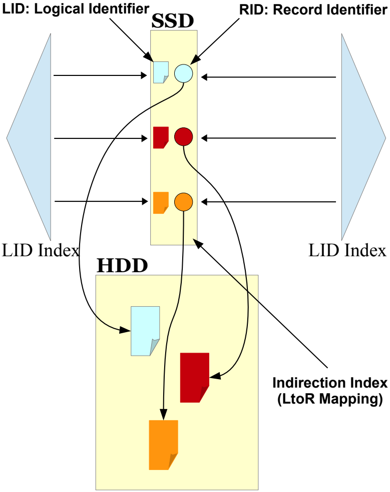

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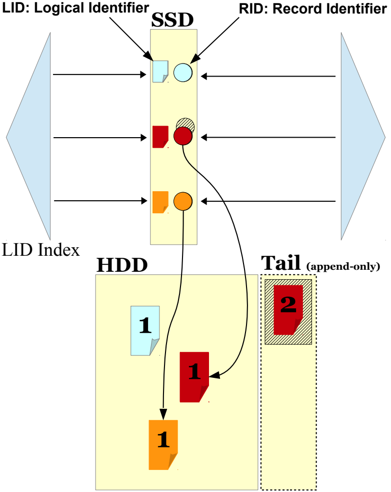

Eliminating random leaf-page updates

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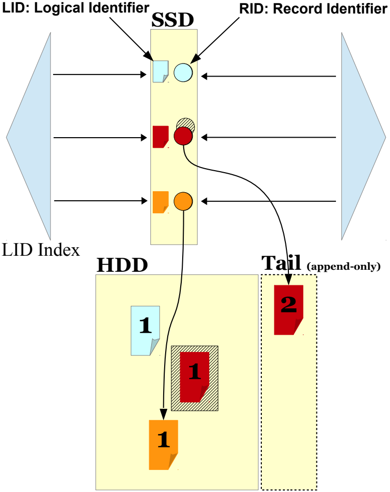

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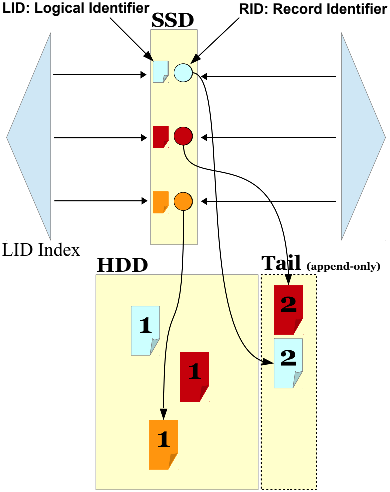


Eliminating random leaf-page updates

Analytical & Experimental Evaluations

Indirection Time Complexity Analysis

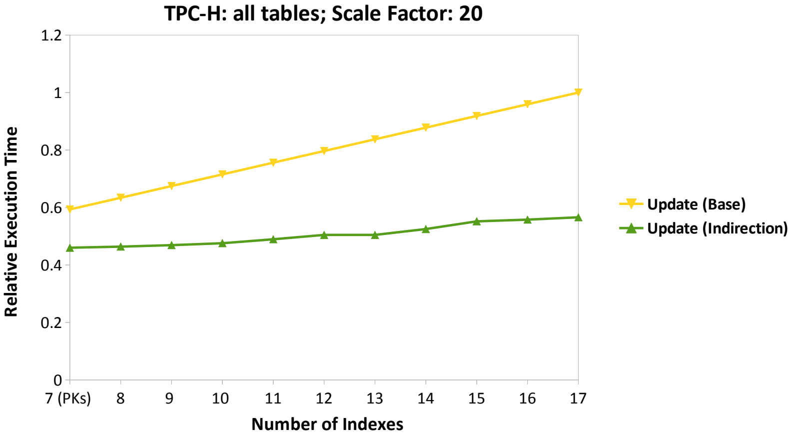
	Legend
K	Number of indexes
LB	LIDBlock size
M	Number of matching records

Method	Type	Imm. SSD	Def. SSD	Imm. HDD	Def. HDD
Base	Deletion	0	0	$2+K$	$\leq 1+K$
	Single-attr. update	**0**	**0**	$3+K$	$\leq 2+K$
	Insertion	0	0	$1+K$	$\leq 1+K$
	Search Uniq.	0	0	2	0
	Search Mult.	0	0	$1+M$	0
Indirection	Deletion	2	0	2	≤ 3
	Single-attr. update	**2**	**0**	**4**	≤ 3
	Insertion	$2+2K$	$2K/LB$	1	$\leq 1+2K/LB$
	Search Uniq.	2	0	2	0
	Search Mult.	$1+M$	0	$1+M$	0

Experimental Setting

- Hardware:
  - (2 × 8-core) Intel(R) Xeon(R) CPU E7-4820 @ 2.00GHz, 32GB, 2 × HDD, SSD Fusion-io
- Software:
  - Database: IBM DB2 9.7
  - Prototyped in a commercial proprietary database
  - Prototyped in Apache Spark by UC Berkeley
  - LIBGist v.1.0: Generalized Search Tree C++ Library by UC Berkeley (**5K LOC**) (Predecessor of Generalized Search Tree (GiST) access method for PostgreSQL)
  - **LIBGist^{mv} Prototype:** Multi-version Generalized Search Tree C++ Library over LIBGist supporting Indirection/LIDBlock/DeltaBlock (**3K LOC**)
- Data:
  - TPC-H benchmark
  - Microsoft Hekaton micro benchmark

Indirection: Effect of Indexes in Operational Data Stores



Substantially improving the update time ...

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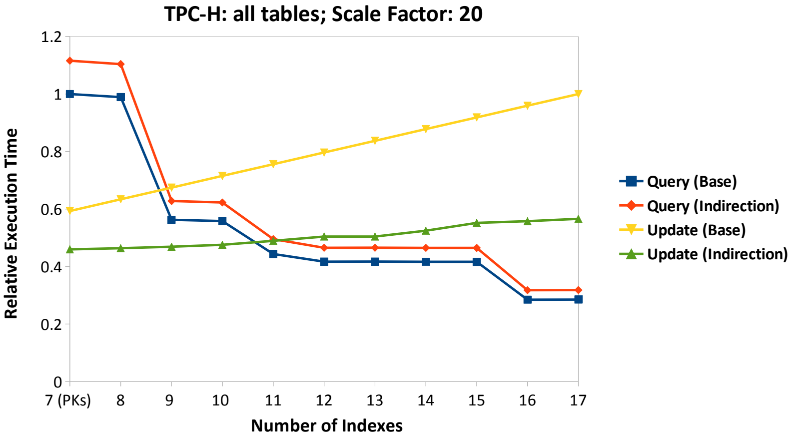
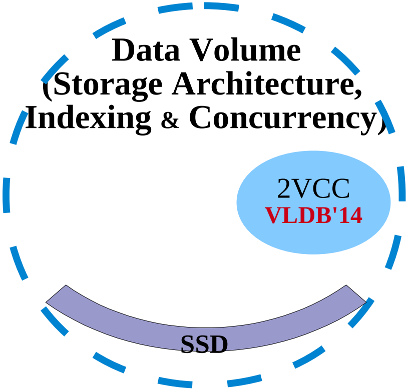


... Consequently affording more indexes and significantly reducing the query time

Introducing Multi-version Concurrency Control



Generalized Concurrency Control: Volume Dimension

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In operational multi-version databases, there is a tremendous opportunity to avoid clashes between readers (scanning a large volume of data) and writers (frequent updates).

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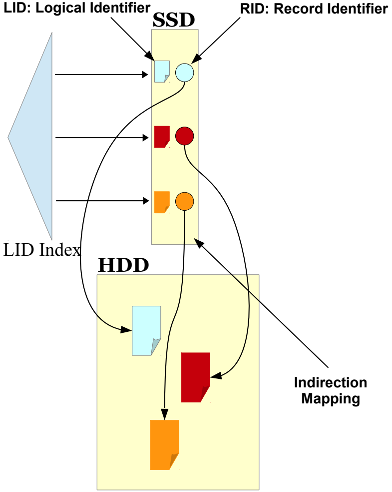
Decouple Readers/Writers to Reduce Contention

(Pessimistic and Optimistic Concurrency Control Coexistence)

2V-Indirection Indexing: Updating Records



Recap: Indirection technique for reducing index maintenance

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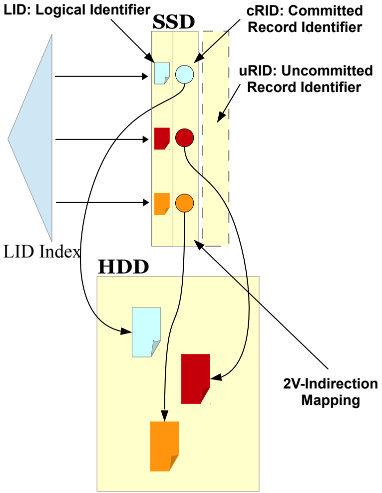

Extending the indirection to committed/uncommitted records

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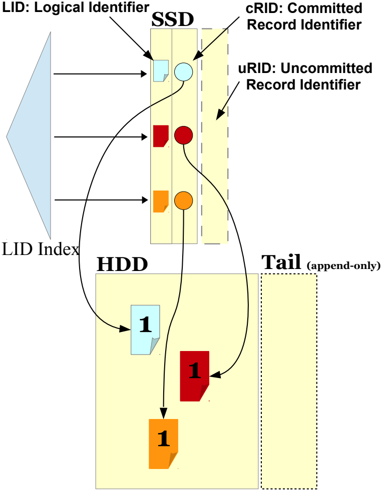

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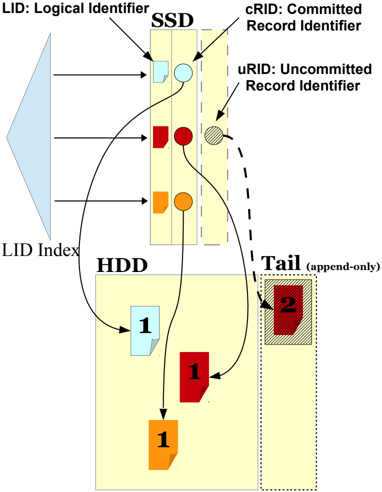

Decoupling readers/writers to eliminate contention

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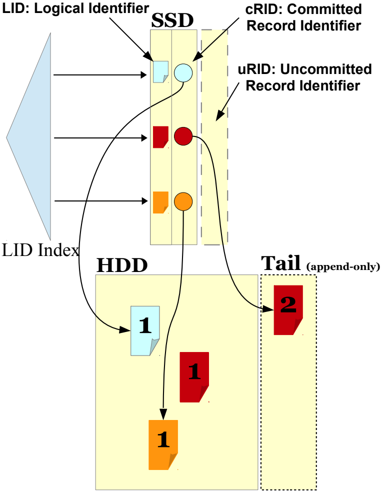

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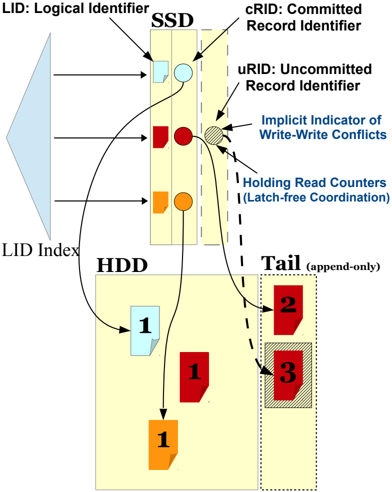

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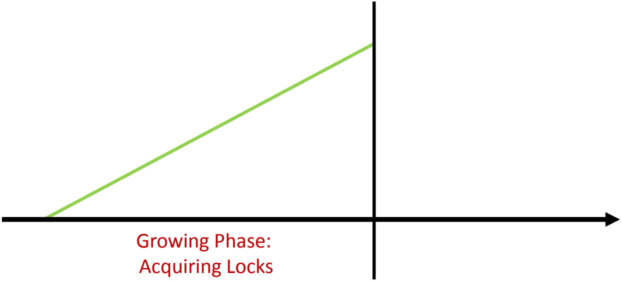

Two-phase locking (2PL) consisting of growing and shrinking phases

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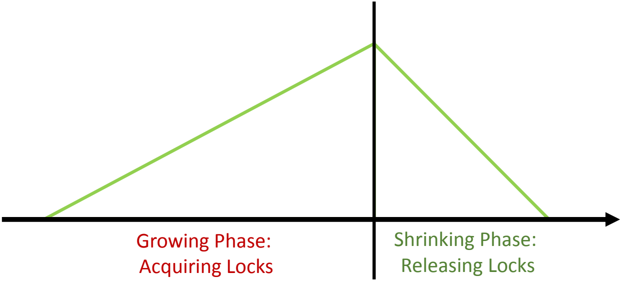

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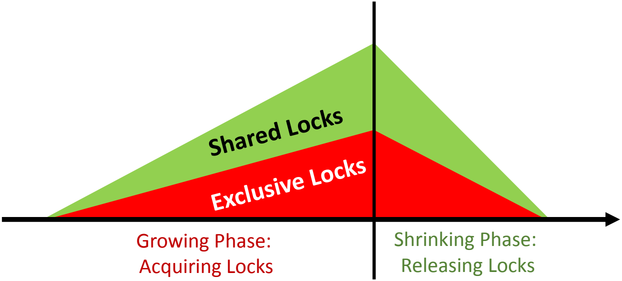

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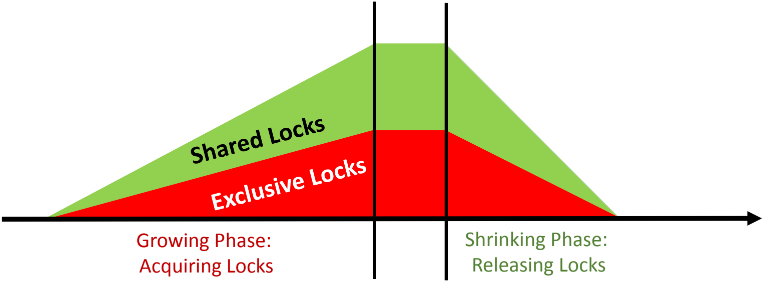
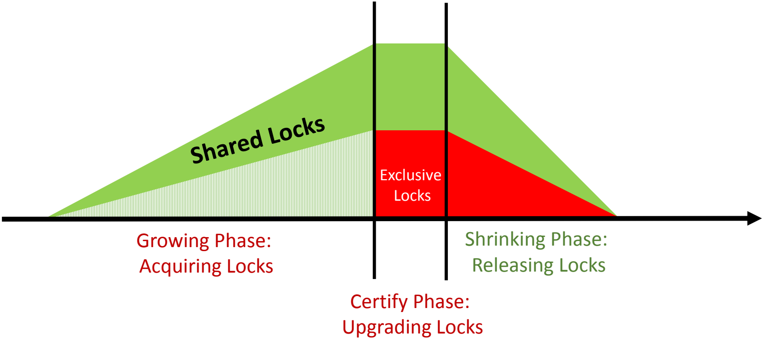


Extending 2PL with certify phase

Overview of Two-version Concurrency Control Protocol



Exclusive locks held for shorter period (inherently optimistic)

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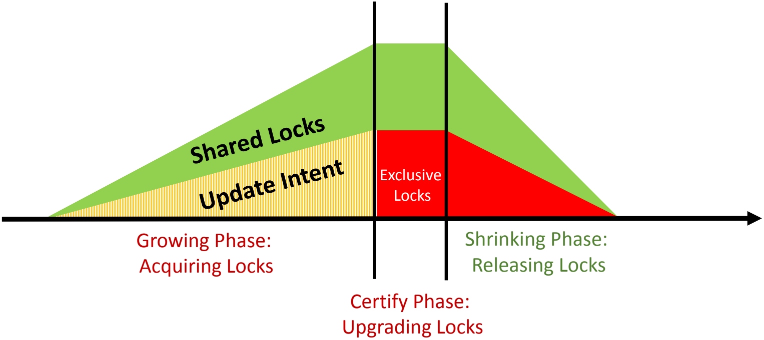

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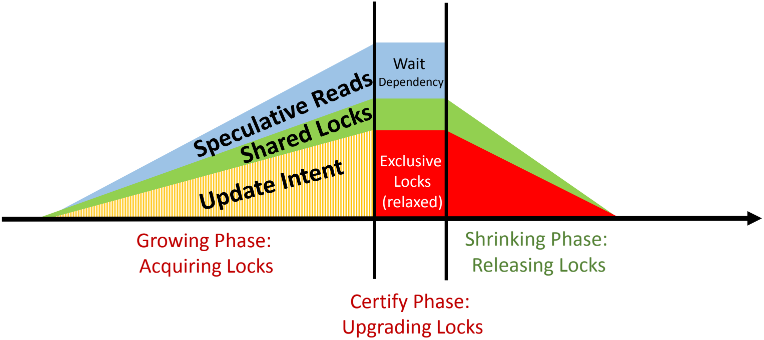
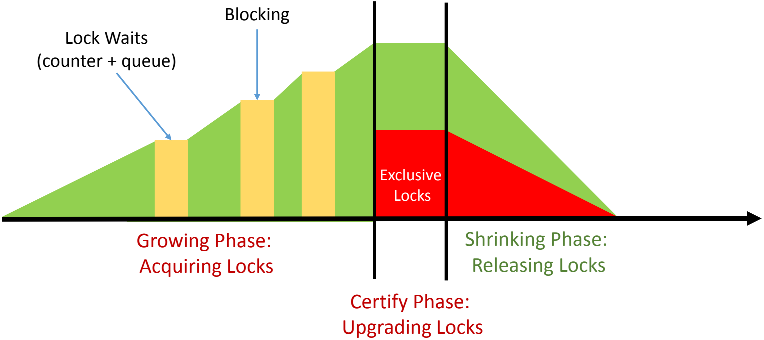


Relaxed exclusive locks to allow speculative reads (increased optimism)

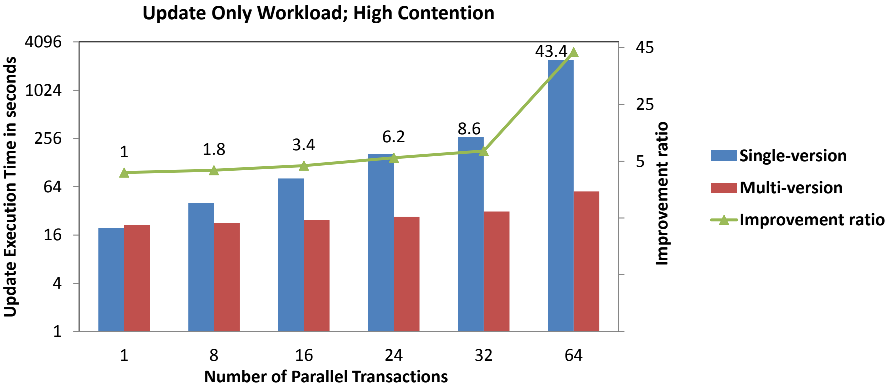
Overview of Two-version Concurrency Control Protocol



Trade-offs between blocking (i.e., locks) vs. non-blocking (i.e., read counters)

Experimental Analysis

2VCC: Effect of Parallel Update Transactions



Substantial gain by reducing the read/write contention & using non-blocking operations

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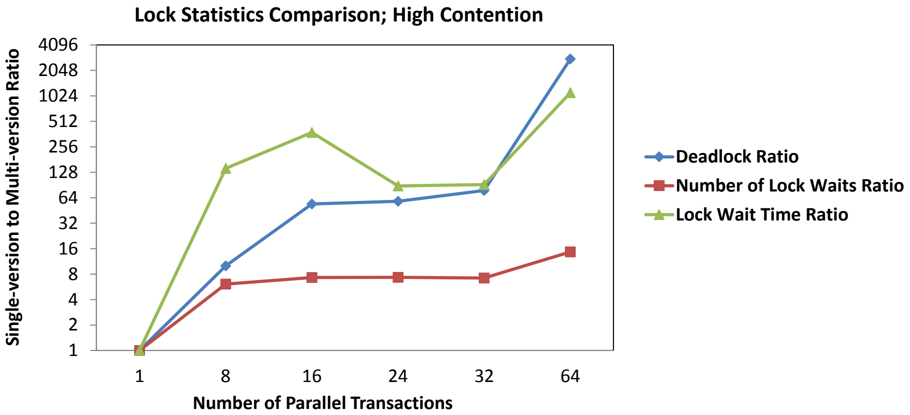

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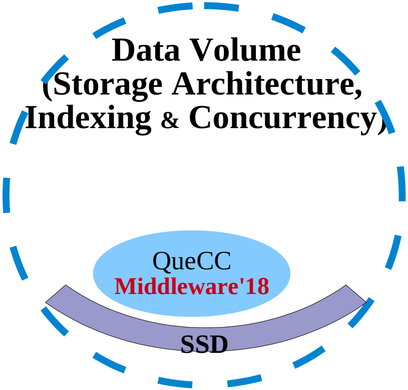
Introducing Coordination-free Concurrency Control



Confrontation-free Concurrency Control

Observed Trends

In operational databases, the use of pre-compiled stored procedures is predominant. There is a tremendous opportunity to exploit transaction prior knowledge to eliminate the need for coordination.

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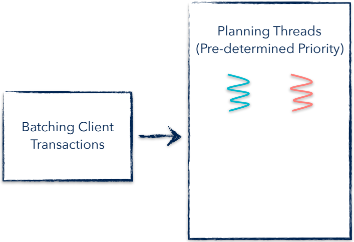
Execution and Synchronization Decoupling

Queue-oriented, Control-free Concurrency (QueCC)

Execution & Synchronization Decoupling: Deterministic priority-based planning followed by queue-oriented execution

Queue-oriented, Control-free Concurrency (QueCC)



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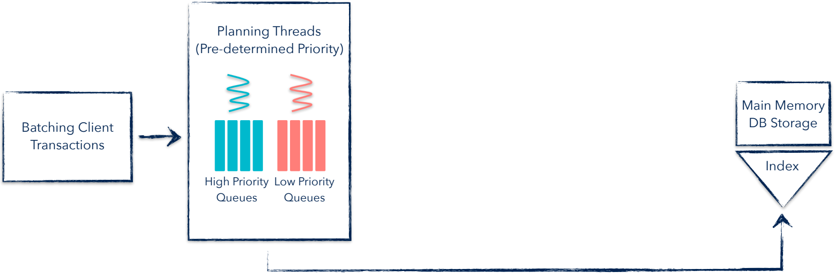

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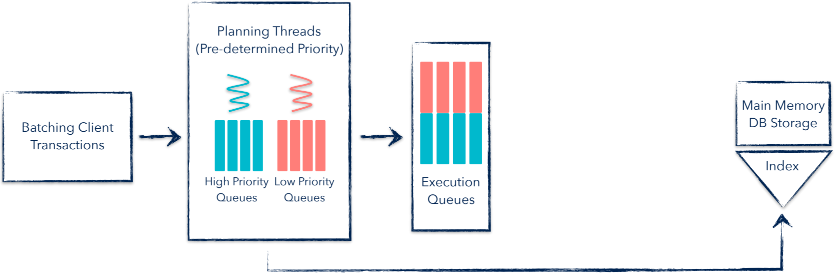

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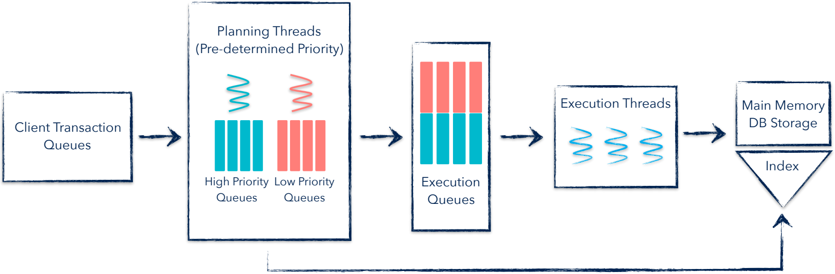

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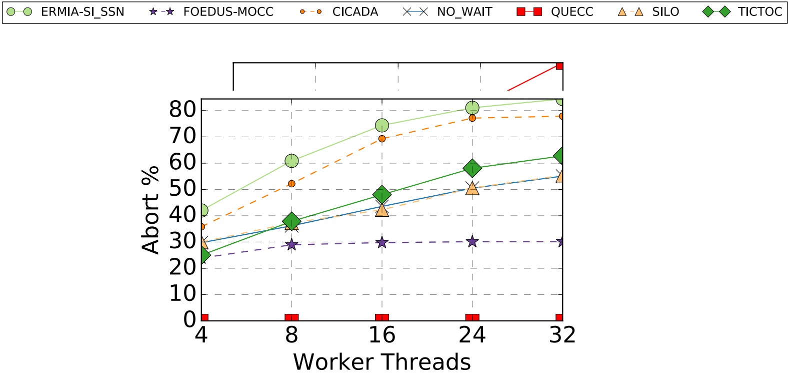
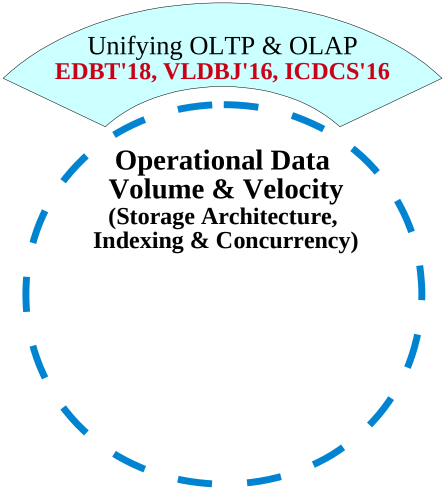


Avoiding thread coordination & eliminating all execution-induced aborts

Unifying OLTP and OLAP



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).

Unifying OLTP and OLAP: Velocity & Volume Dimensions

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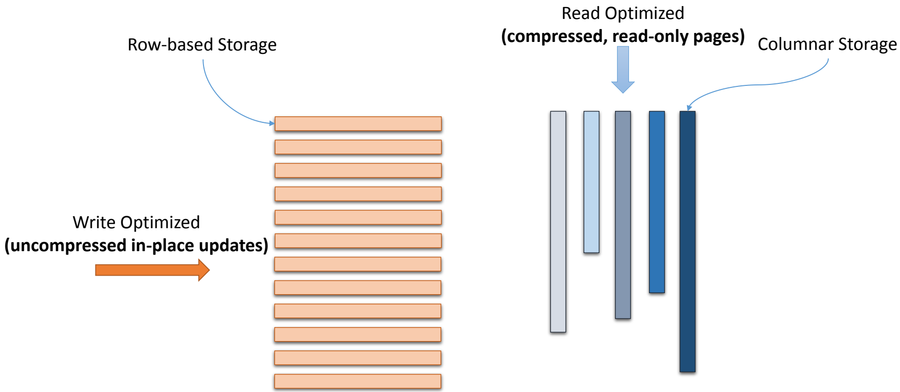
Introducing a *lineage-based storage architecture*, a contention-free update mechanism over a native columnar storage in order to

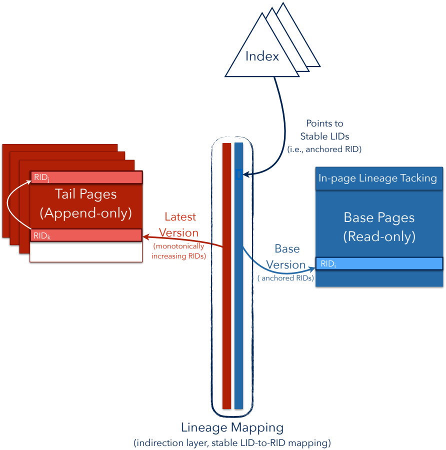
lazily and independently stage stable data from a write-optimized layout (i.e., OLTP) into a read-optimized layout (i.e., OLAP)

Storage Layout Conflict



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

Lineage-based Storage Architecture (LSA): Intuition



Physical Update Independence: De-coupling data & its updates
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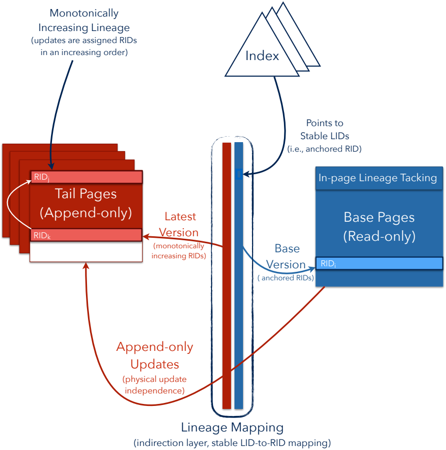

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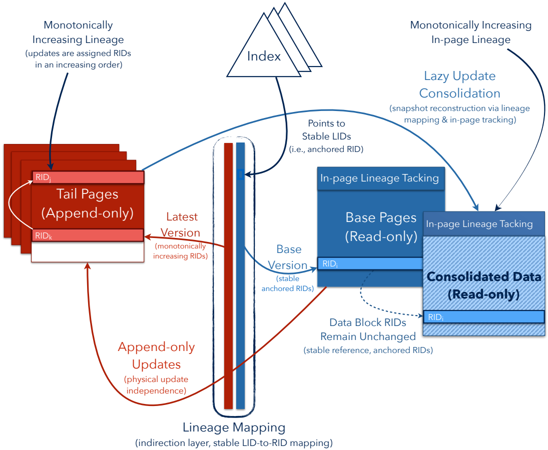

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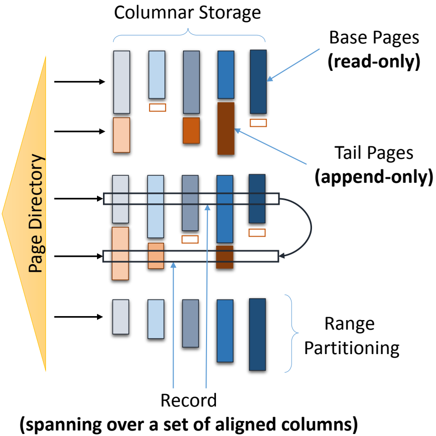
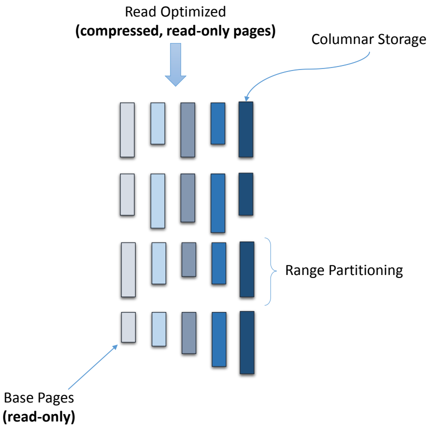
Lineage-based Storage Architecture (LSA): Overview



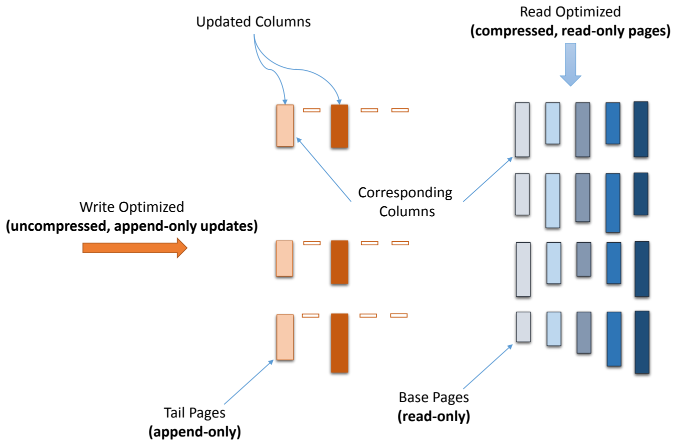
Overview of the lineage-based storage architecture
(**base pages** and **tail pages** are handled identically at the storage layer)

L-Store: Detailed Design



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

L-Store: Detailed Design



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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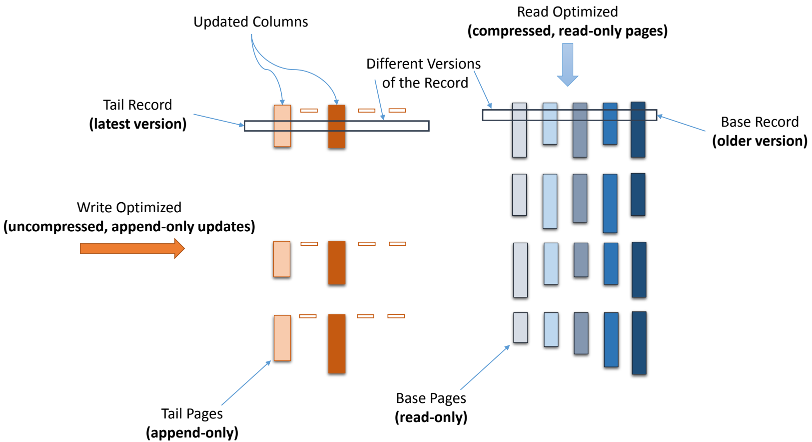

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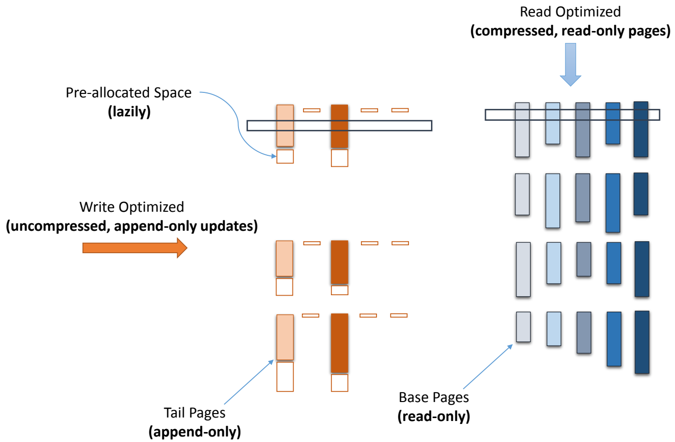
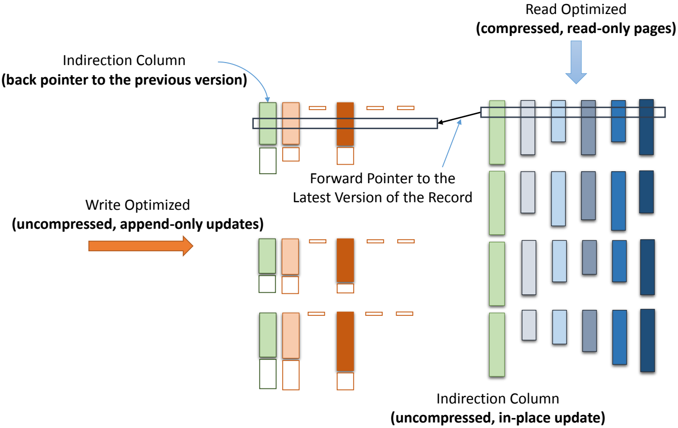


Recent updates are strictly appended, uncompressed in the pre-allocated space (eliminating the read/write contention)

L-Store: Detailed Design



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

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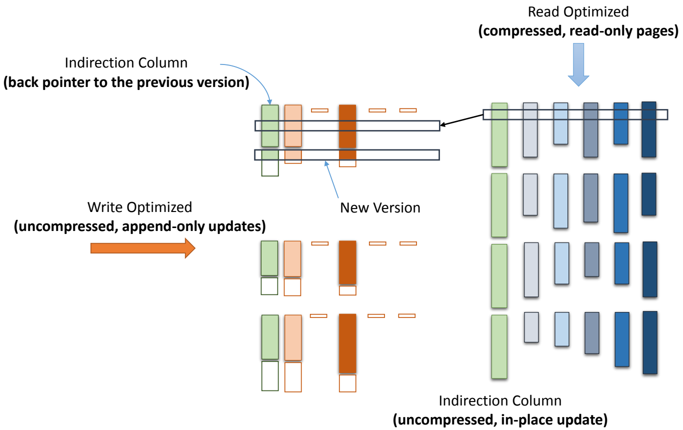

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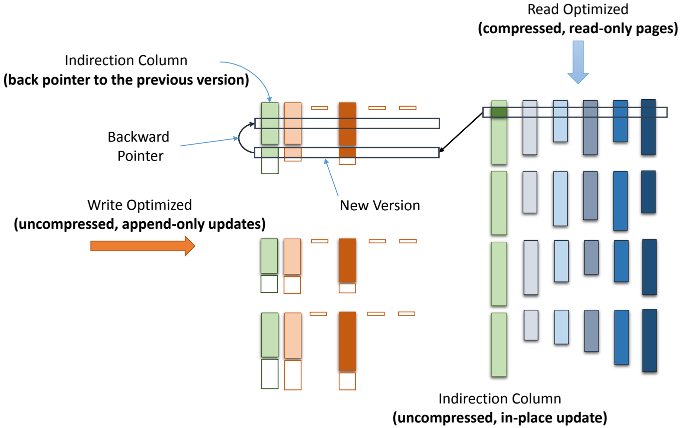

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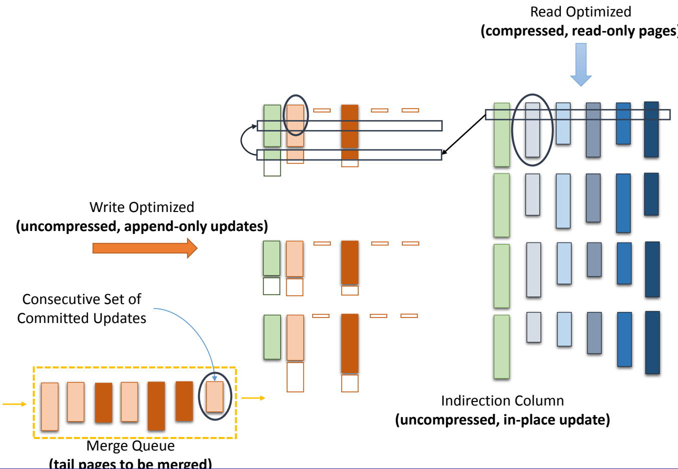
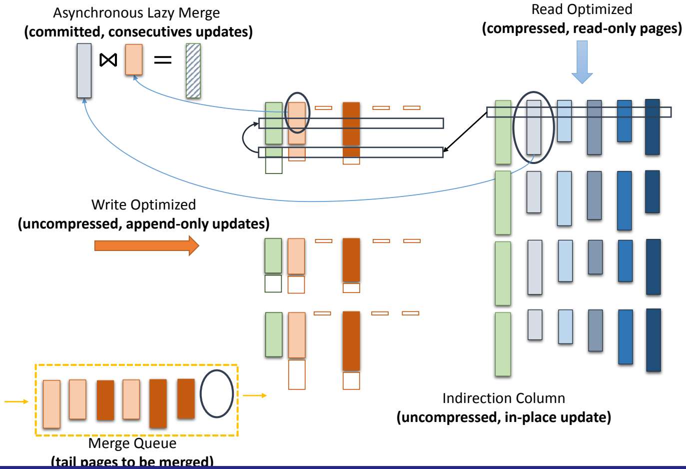
L-Store: Contention-free Merge



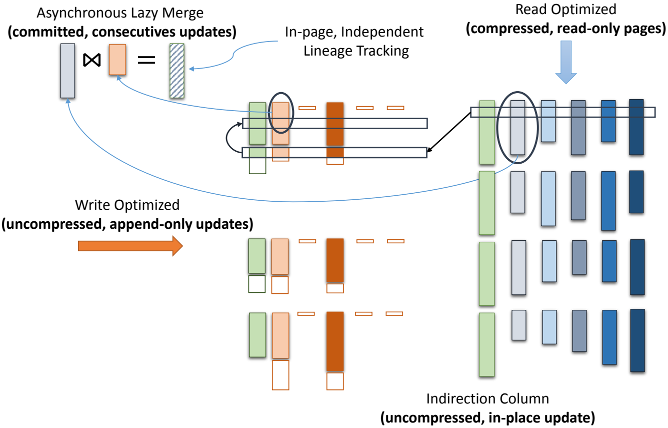
Contention-free merging of only stable data: read-only and committed data (no need to block on-going and new transactions)

L-Store: Contention-free Merge



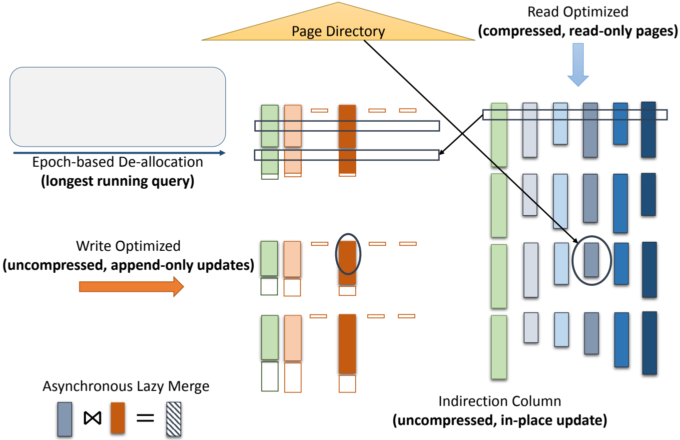
Lazy independent merging of **base pages** with their corresponding **tail pages** (resembling a local left outer-join of the base and tail pages)

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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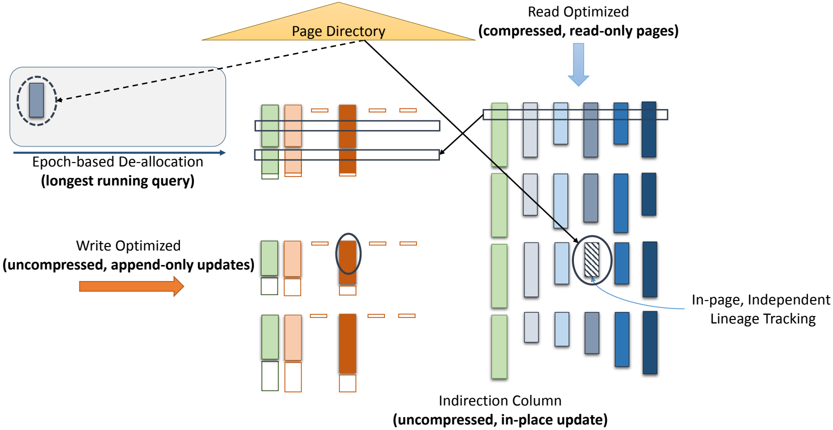

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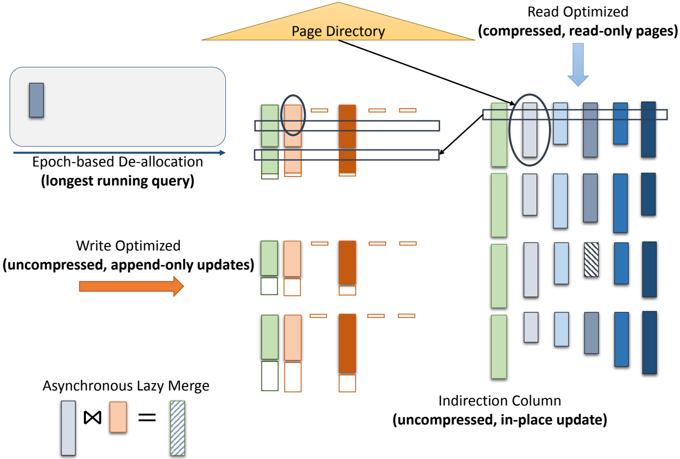

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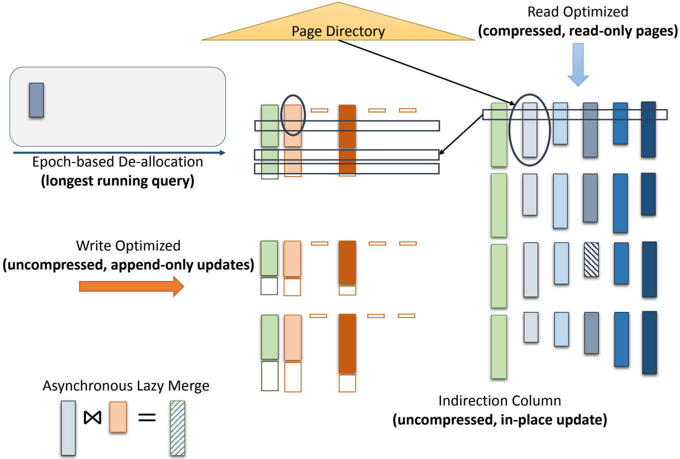

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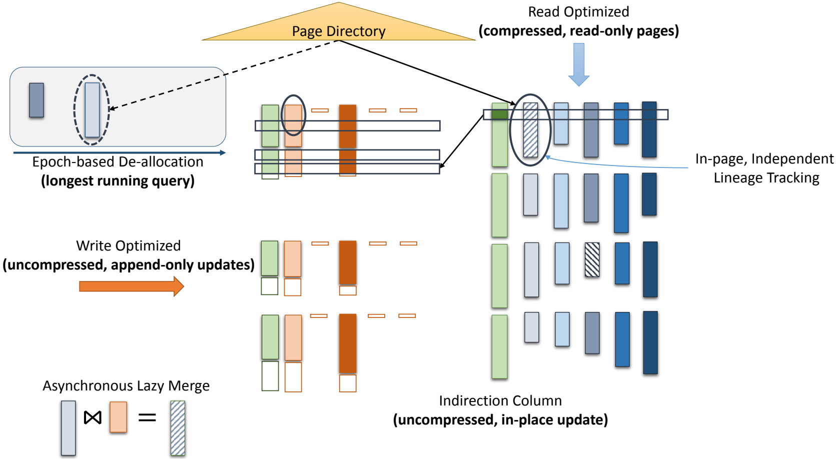

Contention-free page de-allocation using an epoch-based approach
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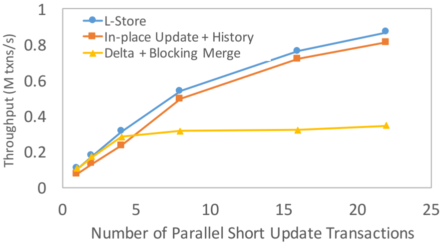
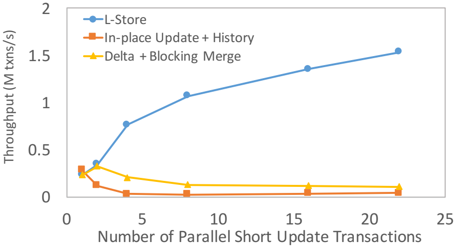
Experimental Analysis

Experimental Settings

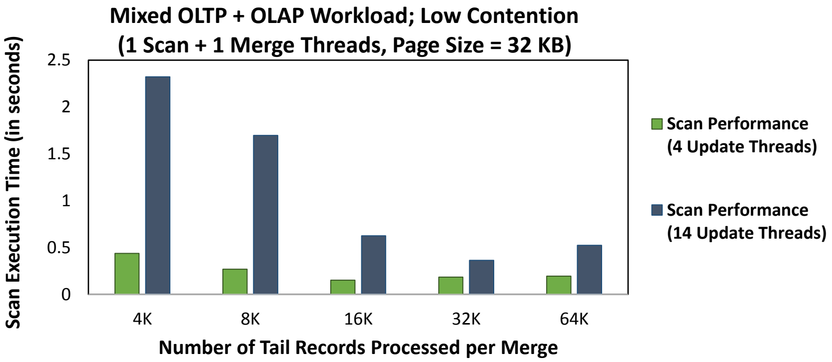
- Hardware:
  - 2 × 6-core Intel(R) Xeon(R) CPU E5-2430 @ 2.20GHz, 64GB, 15 MB L3 cache
- Workload: Extended Microsoft Hekaton Benchmark
  - Comparison with *In-place Update + History* and *Delta + Blocking Merge*
  - Effect of varying contention levels
  - Effect of varying the read/write ratio of short 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



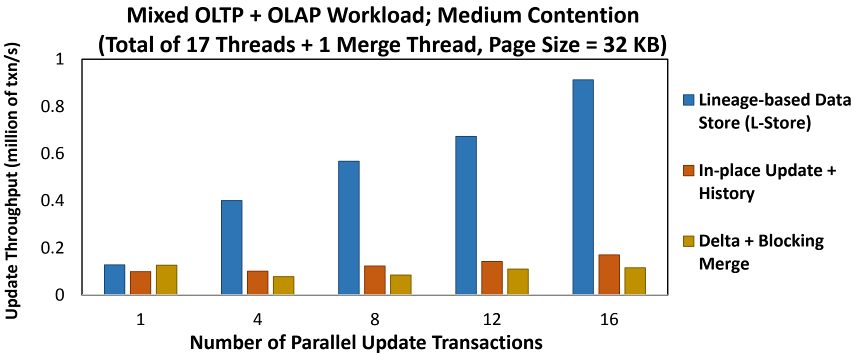


Effect of Merge Frequency on Scan Performance



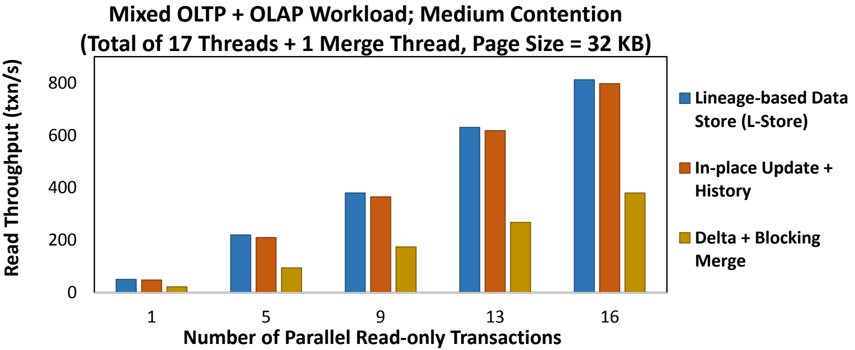
Merge process is essential in maintaining efficient scan performance

Effect of Mixed Workloads: Update Performance



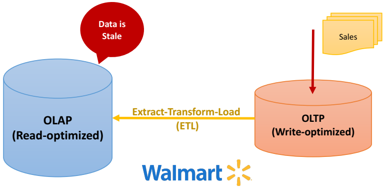
Eliminating latching & locking results in a substantial performance improvement

Effect of Mixed Workloads: Read Performance



Coping with tens of update threads with a single merge thread

Recap: Data Management Challenges at Microscale

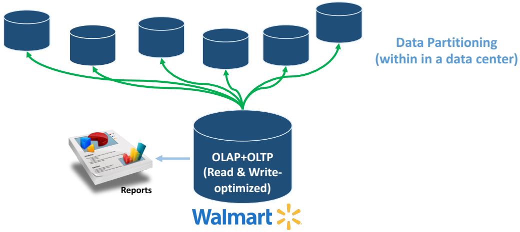


OLTP and OLAP data are isolated at microscale

Recap: Data Management Challenges at Microscale

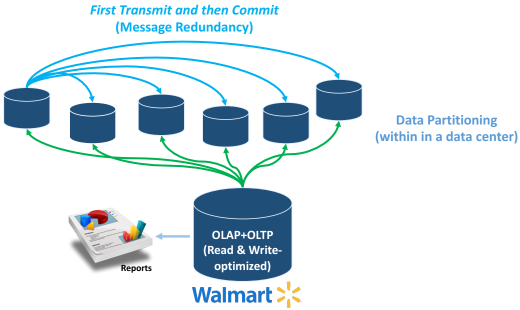
First step is to unify OLTP and OLAP

Platform Scaling: Data Partitioning



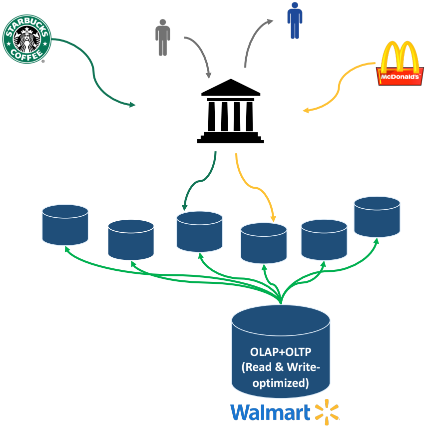
Moving towards distributed environment

Platform Scaling: Non-blocking Agreement Protocols



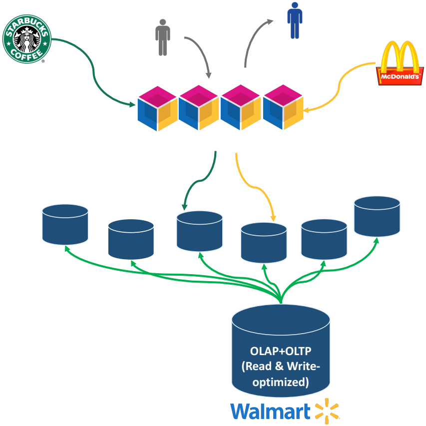
Message redundancy vs. latency trade-offs [EasyCommit, EDBT'18]

Central Control: Data Gate Keeper



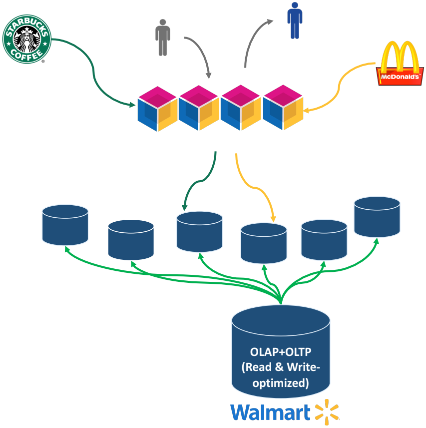
Conform to trusting the central authority and governance

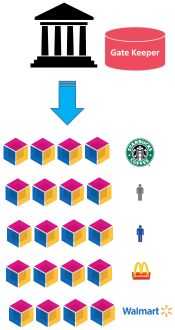
Decentralized Control: Removing Data Barrier



Seek trust in *decentralized* and *democratic* governance [PoE (under submission)]

Democratic Control: Removing Trust Barrier





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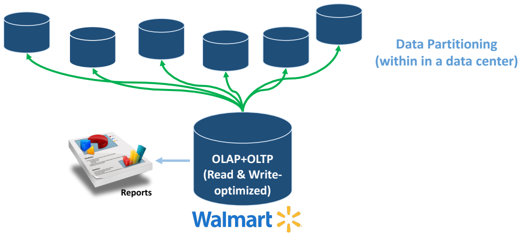
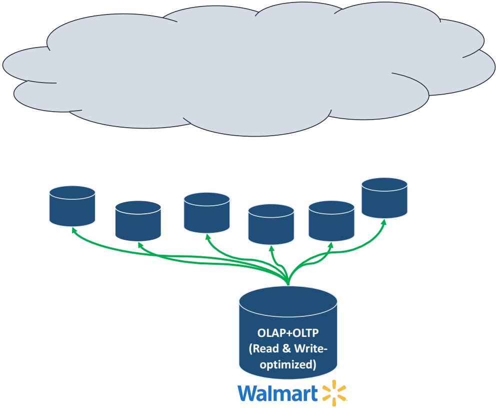
Global-scale Reliable Platform over Unreliable Hardware



Self-managed infrastructure

Global-scale Reliable Platform over Unreliable Hardware



Cloud-managed infrastructure (trust the provider)

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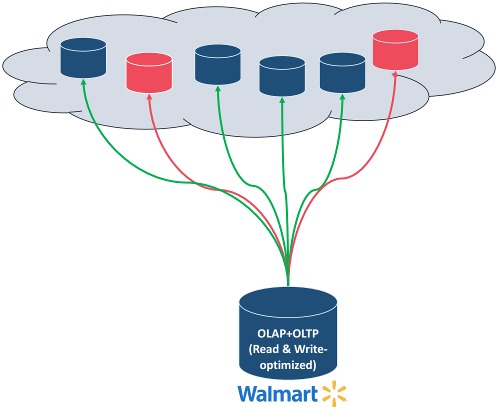

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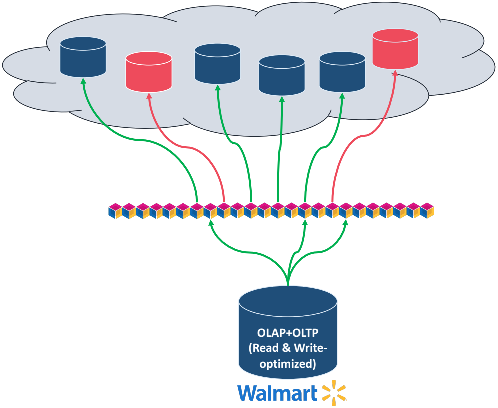
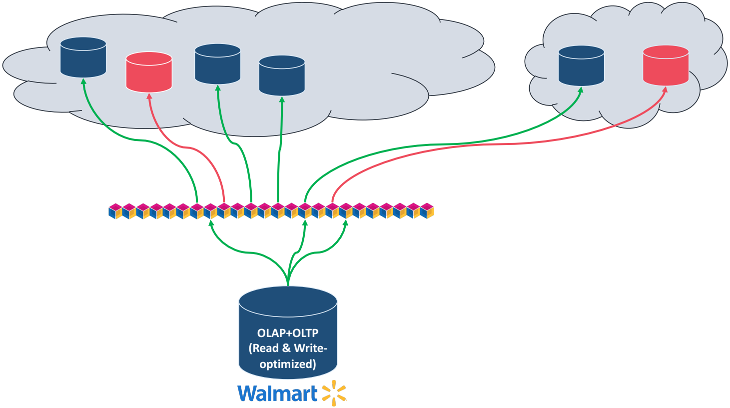


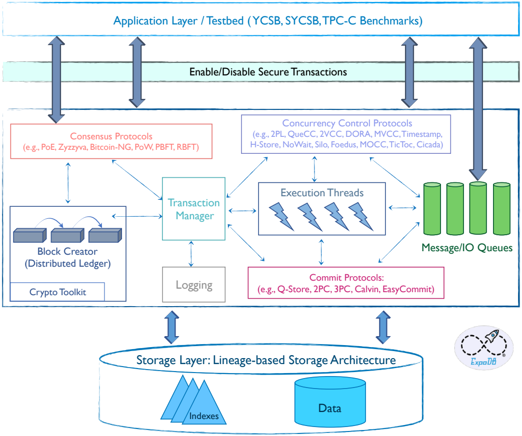
Light-weight, fault-tolerant, trusted middleware [Blockplane, (under submission)]

Global-scale Reliable Platform over Unreliable Hardware



Fault-tolerant protocols vs. consistency models [MultiBFT, GeoBFT (under submission)]

ExpoDB: Exploratory Data Platform Architecture



A decentralized & democratic platform to unify OLTP and OLAP

1. Data Management at Microscale
2. Data Management at Microscale
3. Data Velocity: Index Maintenance
4. Data Volume: MVCC Concurrency
5. Data Volume: Coordination-free Concurrency
6. Combining Volume & Velocity: Lineage-based Storage Architecture
7. Data at Macroscale: Decentralized & Democratic Data Platform
8. Conclusions
9. References

Contributions & Outlook

ExpoDB: Decentralized & Democratic Platform

- **Decentralized & Democratic Control**: PoE, MultiBFT, GeoBFT [under submission]
- **Reliability over Unreliable Hardware**: Blockplane [under submission]

Operational Data Stores: Velocity & Volume

- **Index Maintenance:** Indirection Technique [VLDB'13, VLDBJ'16]
- **Concurrency Control:** 2VCC Technique [VLDB'14, Middleware'16], EasyCommit [EDBT'18], QueCC [Middleware'18]
- **Hybrid Storage:** Enhancing Key-Value Store [VLDB'12, ICDE'14]
- **Real-time OLTP+OLAP:** Lineage-based Data Store (*L-Store*) [EDBT-18,ICDCS'16, 30+ Patents]

Stream Processing: Velocity

- **High-dimensional Indexing**: BE-Tree [SIGMOD'11, TODS'13], Compressed Stream Processing [ICDE'14]
- **(Distributed) Top-*k* Indexing**: BE*-Tree [ICDE'12, ICDCS'13, Middleware'17, ICDCS'17]
- **Hardware Acceleration**: FPGAs [VLDB'10, ICDE'12, VLDB'13, ICDE'15, SIGMOD Record'15, ICDE'16, USENIX ATC'16, ICDCS'17, ICDE'18]
- **Novel Mappings**: XML/XPath [EDBT'11], Distributed Workflow [TDKE'15, SIGMOD'15, ICDE'16, Middleware'16]

Questions?

Thank you!

Exploratory Systems Lab (ExpoLab)

Website: https://msadoghi.github.io/

Related Publications (Patents Omitted)

- I. Abdelaziz, A. Fokoue, O. Hassanzadeh, P. Zhang, M. Sadoghi.
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