Lecture 16: Multi-Version Concurrency Control

Recap

Optimistic Concurrency Control

- The DBMS creates a private workspace for each txn. trasaction
  - Any object read is copied into workspace.
  - Modifications are applied to workspace.
- When a txn commits, the DBMS compares workspace **write set** to see whether it conflicts with other txns.
- If there are no conflicts, the write set is installed into the **global database**.

OCC Phases

- **Phase 1 – Read**:
  - Track the read/write sets of txns and store their writes in a private workspace.
- **Phase 2 – Validation**:
  - When a txn commits, check whether it conflicts with other txns.
- **Phase 3 – Write**:
  - If validation succeeds, apply private changes to database. Otherwise abort and restart the txn.

Today's Agenda

- Multi-Version Concurrency Control
- Design Decisions
  - Concurrency Control Protocol
  - Version Storage
  - Garbage Collection
  - Index Management

Multi-Version Concurrency Control

Multi-Version Concurrency Control

- The DBMS maintains multiple **physical versions** of a single **logical object** in the database:
  - When a txn writes to an object, the DBMS creates a new version of that object (instead of private workspace in OCC)
  - When a txn reads an object, it reads the newest version that existed when the txn started.

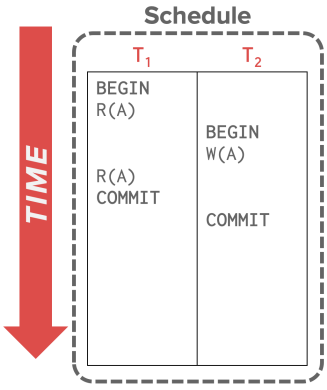
MVCC HISTORY

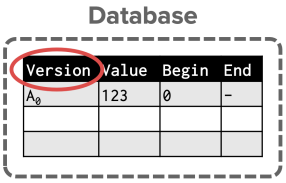
- Protocol was first proposed in 1978 MIT PhD dissertation.
- First implementations was Rdb/VMS and InterBase at DEC in early 1980s.
  - Both were by Jim Starkey, co-founder of NuoDB.
  - DEC Rdb/VMS is now "Oracle Rdb"
  - InterBase was open-sourced as Firebird.

Multi-Version Concurrency Control

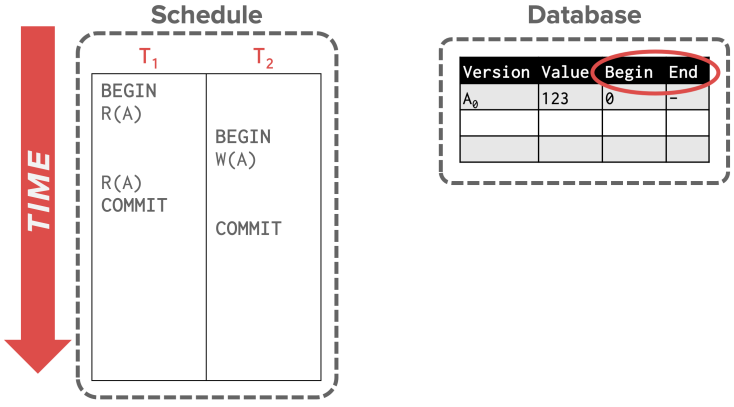
- Writers don't block readers. Readers don't block writers.
- Read-only txns can read a **consistent snapshot** without acquiring locks.
  - Use timestamps to determine visibility.
- Easily support **time-travel queries**.

MVCC – Example 1





MVCC – Example 1



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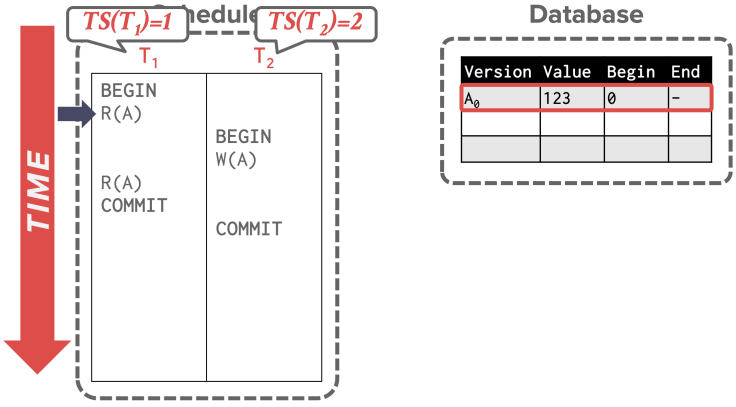

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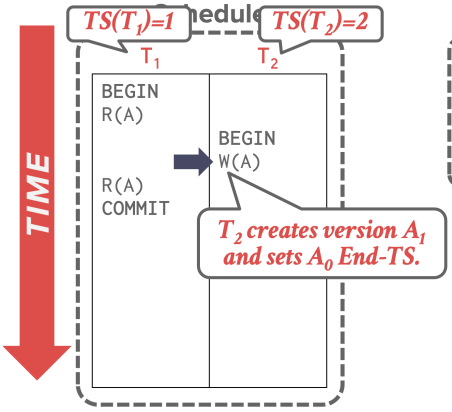
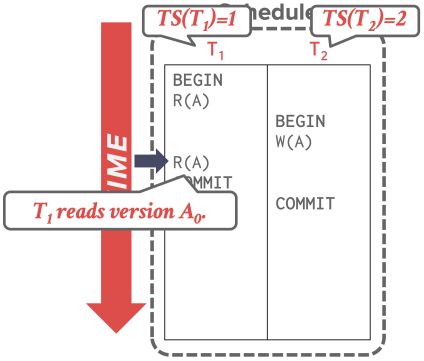


Database

Version	Value	Begin	End
A_0	123	0	-
A_1	456	2	-

MVCC – Example 1



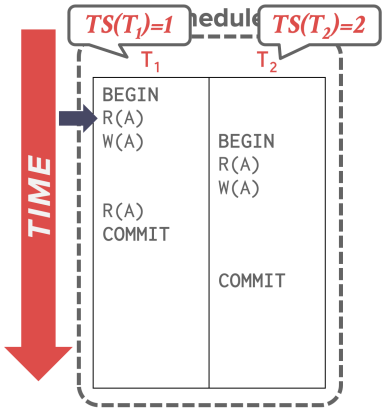
Database

Version	Value	Begin	End
A_0	123	0	2
A_1	456	2	–

Txn Status Table

TxnId	Timestamp	Status
T_1	1	Active
T_2	2	Active

MVCC – Example 2



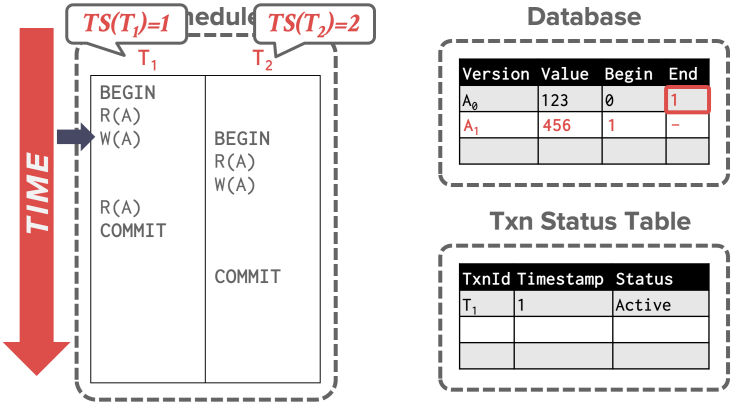
Database

Version	Value	Begin	End
A_0	123	0	

Txn Status Table

TxnId	Timestamp	Status
T_1	1	Active

MVCC – Example 2



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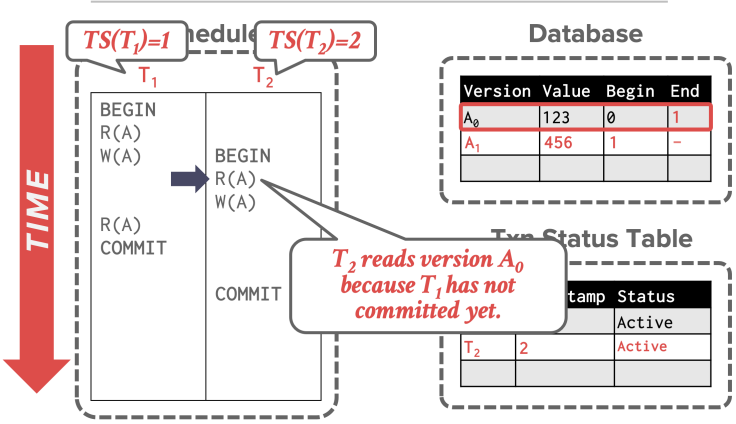

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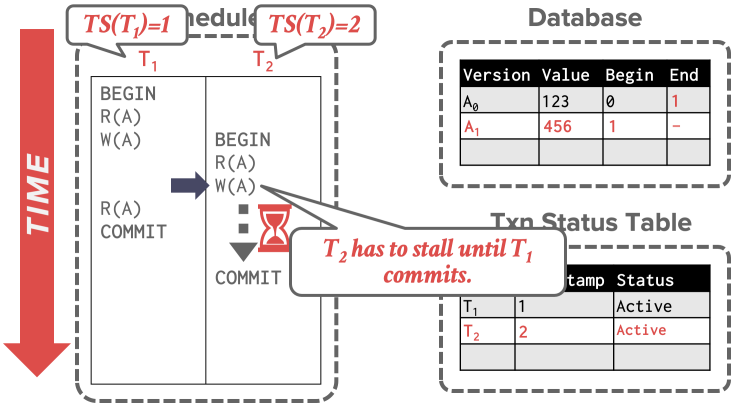

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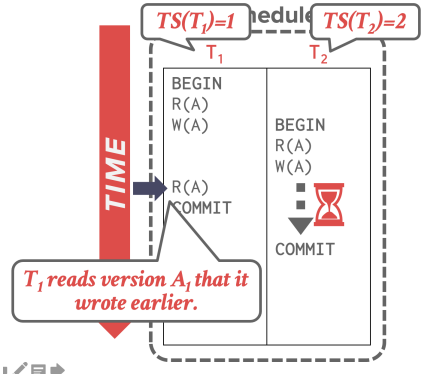


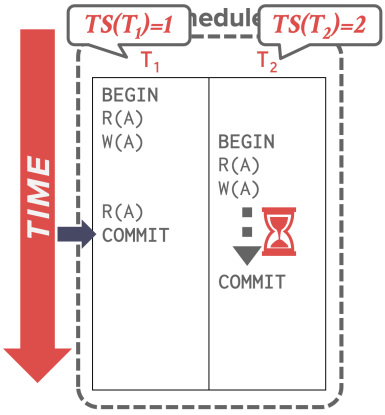
Database

Version	Value	Begin	End
A_0	123	0	1
A_1	456	1	-

Txn Status Table

TxnId	Timestamp	Status
T_1	1	Active
T_2	2	Active

MVCC – Example 2



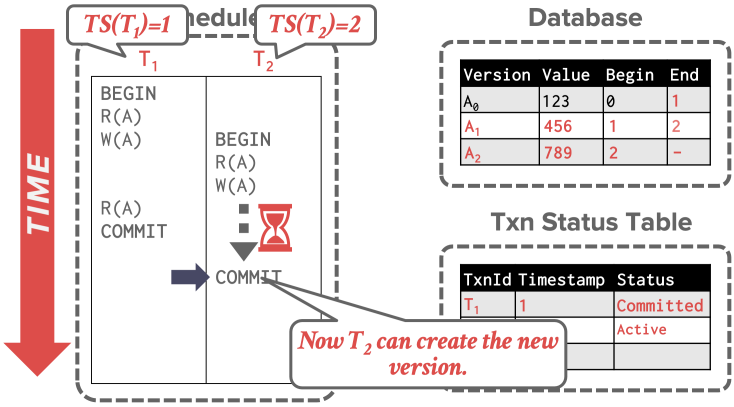
Database

Version	Value	Begin	End
A_0	123	0	1
A_1	456	1	–

Txn Status Table

TxnId	Timestamp	Status
T_1	1	Committed
T_2	2	Active

MVCC – Example 2



Multi-Version Concurrency Control

- MVCC is more than just a Concurrency Control protocol.
- It completely affects how the DBMS manages transactions and the database.
- **Examples:** Oracle, SAP HANA, PostgreSQL, CockroachDB

MVCC Design Decisions

- Concurrency Control Protocol
- Version Storage
- Garbage Collection
- Index Management

Concurrency Control Protocol

Concurrency Control Protocol

- **Approach 1:** Timestamp Ordering
  - Assign txns timestamps that determine serial order.
- **Approach 2:** Optimistic Concurrency Control
  - Three-phase protocol from last class.
  - Use private workspace for new versions.
- **Approach 3:** Two-Phase Locking
  - Txns acquire appropriate lock on physical version before they can read/write a logical tuple.

Version Storage

Version Storage

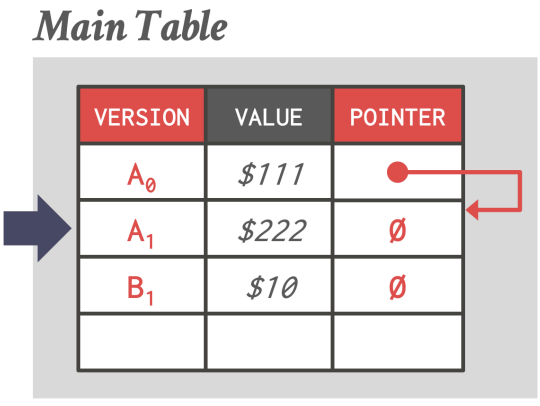
- The DBMS uses the tuples' pointer field to create a **version chain** per logical tuple.
  - This allows the DBMS to find the version that is visible to a particular txn at runtime.
  - Indexes always point to the **head** of the chain.
- Different storage schemes determine where/what to store for each version.

Version Storage

- **Approach 1:** Append-Only Storage
  - New versions are appended to the same table space.
- **Approach 2:** Time-Travel Storage
  - Old versions are copied to separate table space.
- **Approach 3:** Delta Storage
  - The original values of the modified attributes are copied into a separate delta record space.

Append-Only Storage

- All of the physical versions of a logical tuple are stored in the same table space. The versions are mixed together.
- On every update, append a new version of the tuple into an empty space in the table.



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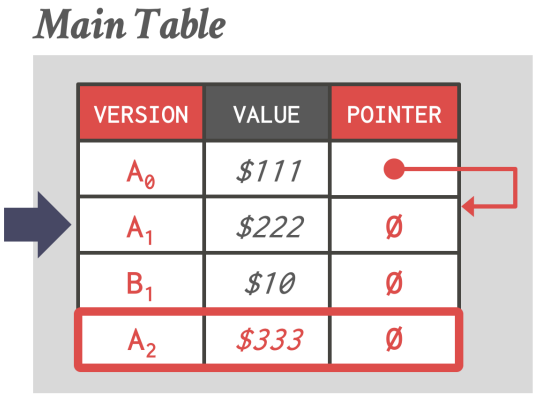

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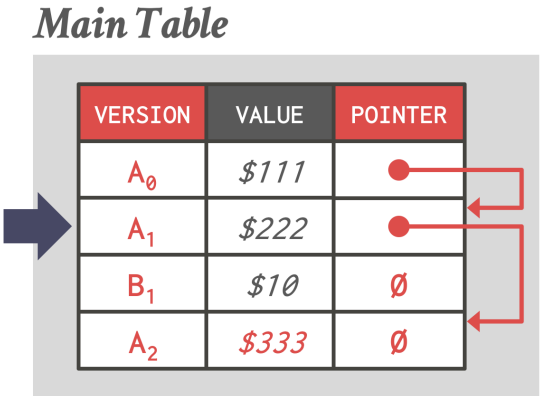
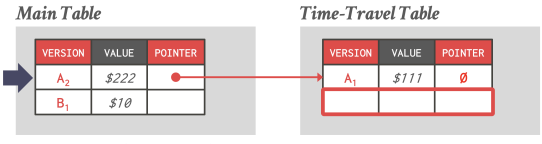


Version Chain Ordering

- **Approach 1:** Oldest-to-Newest (O2N)
  - Just append new version to end of the chain.
  - Have to traverse chain on look-ups.
- **Approach 2:** Newest-to-Oldest (N2O)
  - Have to update index pointers for every new version.
  - Don't have to traverse chain on look ups.

Time-Travel Storage

- On every update, copy the current version to the time-travel table. Update pointers.
- Overwrite master version in the main table. Update pointers.



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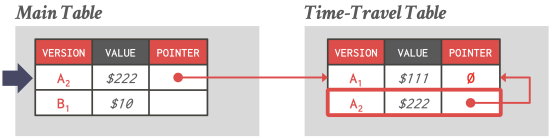

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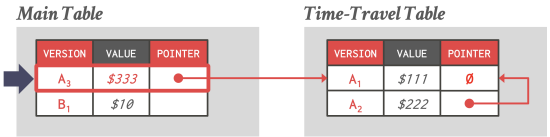

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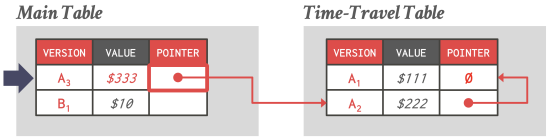
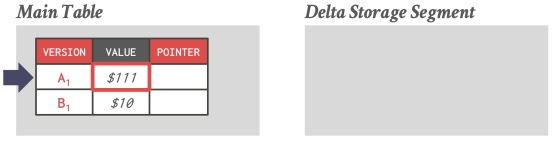


Delta Storage

- On every update, copy only the values that were modified to the delta storage and overwrite the master version.
- Txns can recreate old versions by applying the delta in reverse order.



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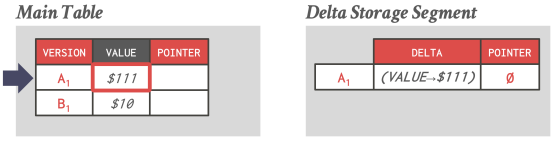

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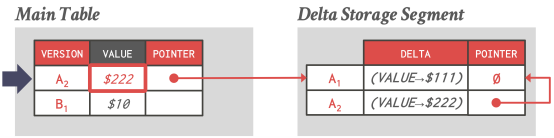

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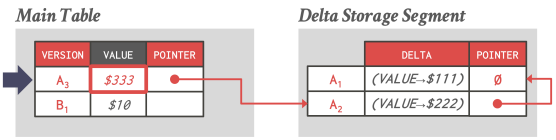


Garbage Collection

Garbage Collection

- The DBMS needs to remove **reclaimable** physical versions from the database over time.
  - No active txn in the DBMS can **see** that version (SI).
  - The version was created by an aborted txn.
- Two additional design decisions:
  - How to look for expired versions?
  - How to decide when it is safe to reclaim memory?

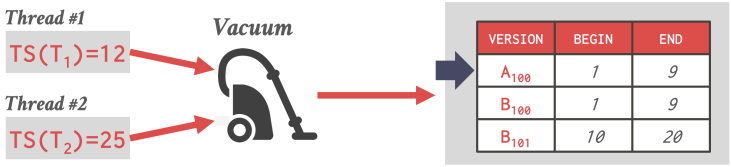
Garbage Collection

- **Approach 1:** Tuple-level
  - Find old versions by examining tuples directly.
  - **Background Vacuuming** vs. **Cooperative Cleaning**
- **Approach 2:** Transaction-level
  - Txns keep track of their old versions so the DBMS does not have to scan tuples to determine visibility.

Tuple-level GC

- **Background Vacuuming:**
- Separate thread(s) periodically scan the table and look for reclaimable versions.
- Works with any storage.

Tuple-level GC



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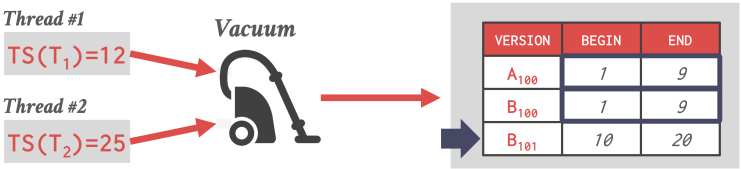
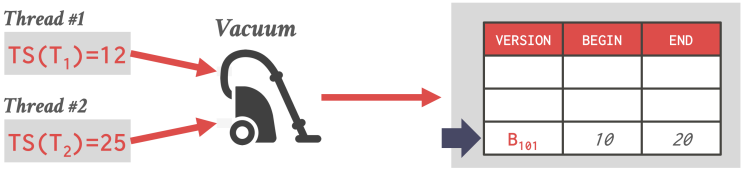


Tuple-level GC



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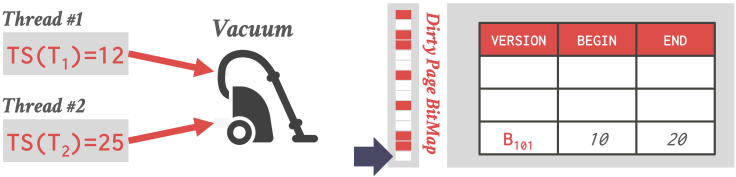


Tuple-level GC

- **Cooperative Cleaning:**
- Worker threads identify reclaimable versions as they traverse version chain.
- Only works with O2N.

Tuple-level GC

Tuple-level GC

Tuple-level GC

Tuple-level GC

Transaction-level GC

- Each txn keeps track of its read/write set.
- The DBMS determines when all versions created by a finished txn are no longer visible.

Index Management

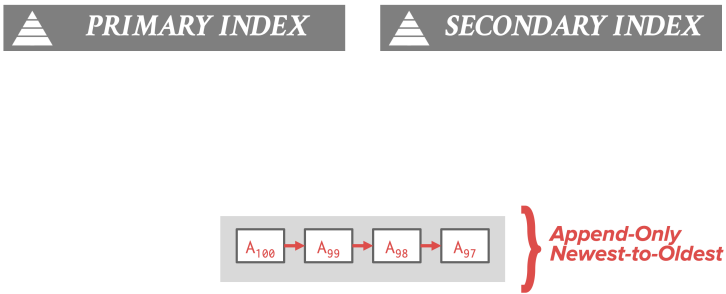
Index Management

- Primary key indexes point to version chain head.
  - How often the DBMS has to update the pkey index depends on whether the system creates new versions when a tuple is updated.
  - If a txn updates a tuple's pkey attribute(s), then this is treated as an `DELETE` followed by an `INSERT`.
- Secondary indexes are more complicated...

Secondary Indexes

- **Approach 1:** Physical Pointers
  - Use the physical address to the version chain head.
- **Approach 2:** Logical Pointers
  - Use a fixed identifier per tuple that does not change.
  - Requires an extra indirection layer.
  - Primary Key vs. Tuple Id

Physical Pointers



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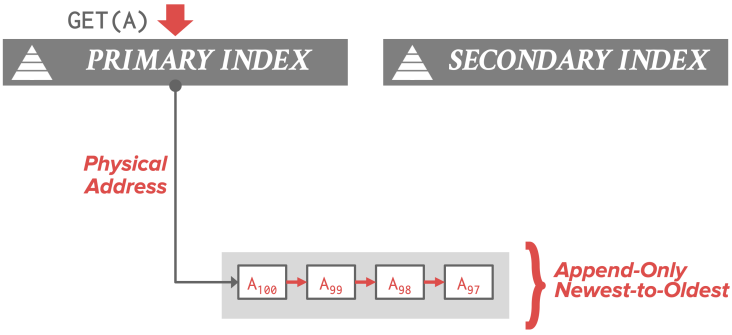

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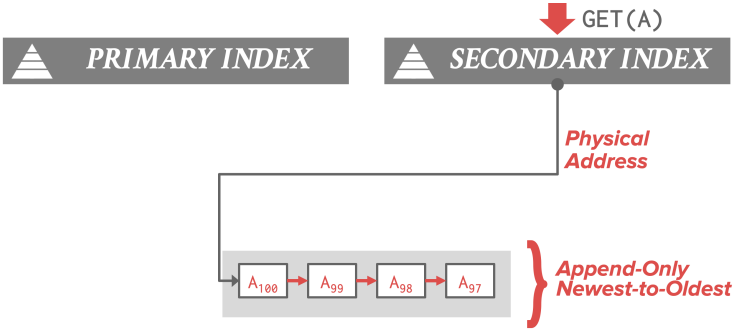

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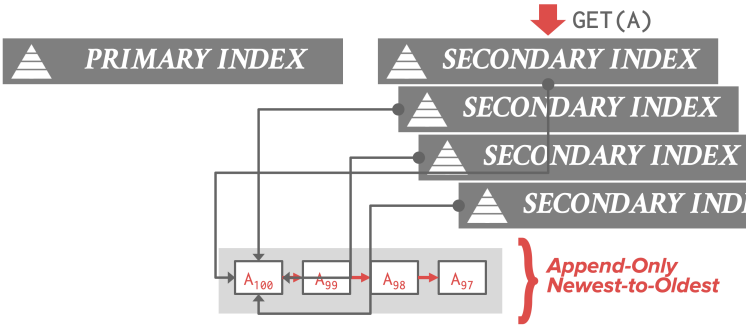
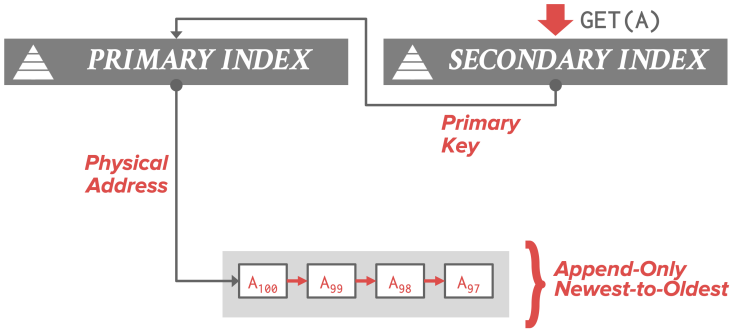
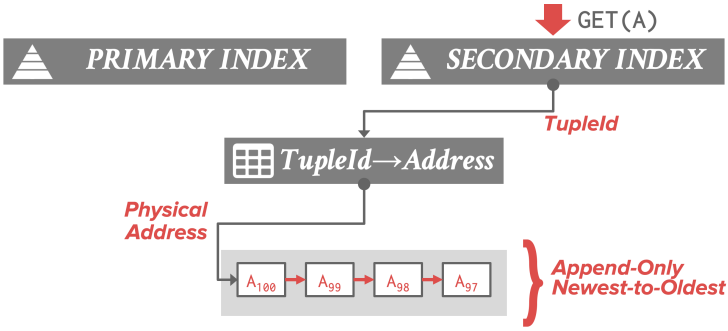


Logical Pointers



Logical Pointers



MVCC Implementations

DBMS	Protocol	Version Storage	Garbage Collection	Indexes
Oracle	MV2PL	Delta	Vacuum	Logical
Postgres	MV-2PL/MV-TO	Append-Only	Vacuum	Physical
MySQL-InnoDB	MV-2PL	Delta	Vacuum	Logical
HYRISE	MV-OCC	Append-Only	–	Physical
Hekaton	MV-OCC	Append-Only	Cooperative	Physical
MemSQL	MV-OCC	Append-Only	Vacuum	Physical
SAP HANA	MV-2PL	Time-travel	Hybrid	Logical
NuoDB	MV-2PL	Append-Only	Vacuum	Logical
HyPer	MV-OCC	Delta	Txn-level	Logical

Conclusion

- MVCC is the widely used scheme in DBMSs.
- Even systems that do not support multi-statement txns (*e.g.*, NoSQL) use it.

Next Class

- Advanced topics in Concurrency Control