Intro to Database Systems (15-445/645)

17 Timestamp Ordering Concurrency Control

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CONCURRENCY CONTROL APPROACHES

Two-Phase Locking (2PL)

→ Determine serializability order of conflicting operations at runtime while txns execute.

Timestamp Ordering (T/O)

→ Determine serializability order of txns before they execute.

T/O CONCURRENCY CONTROL

Use timestamps to determine the serializability order of txns.

If $\mathtt{TS}(T_i) < \mathtt{TS}(T_j)$, then the DBMS must ensure that the execution schedule is equivalent to a serial schedule where T_i appears before T_j.

TIMESTAMP ALLOCATION

Each txn T_i is assigned a unique fixed timestamp that is monotonically increasing.

→ Let $TS(T_i)$ be the timestamp allocated to txn T_i.

→ Different schemes assign timestamps at different times during the txn.

Multiple implementation strategies:

→ System/Wall Clock.

→ Logical Counter.

→ Hybrid.

TODAY'S AGENDA

Basic Timestamp Ordering (T/O) Protocol

Optimistic Concurrency Control

Isolation Levels

BASIC T/O

Txns read and write objects without locks.

Every object **X** is tagged with timestamp of the last txn that successfully did read/write:
- → `W-TS(X)` – Write timestamp on **X**
- → `R-TS(X)` – Read timestamp on **X**

Check timestamps for every operation:
- → If txn tries to access an object "from the future", it aborts and restarts.

BASIC T/O – READS

If $TS(T_i)$ < $W\text{-}TS(X)$, this violates timestamp order of T_i with regard to the writer of **X**.

→ Abort T_i and restart it with a new TS.

Else:

→ Allow T_i to read **X**.

→ Update $R\text{-}TS(X)$ to $\max(R\text{-}TS(X), TS(T_i))$

→ Make a local copy of **X** to ensure repeatable reads for T_i.

BASIC T/O – WRITES

If $TS(T_i) < R\text{-}TS(X)$ or $TS(T_i) < W\text{-}TS(X)$

→ Abort and restart T_i.

Else:

→ Allow T_i to write X and update $W\text{-}TS(X)$

→ Also make a local copy of X to ensure repeatable reads.

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	0	0

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	0	0

BASIC T/O – EXAMPLE #1

Schedule

$TS(T_1)=1$

TIME

T_1	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	1	0

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

$TS(T_2)=2$

	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	1	0

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

$TS(T_2)=2$

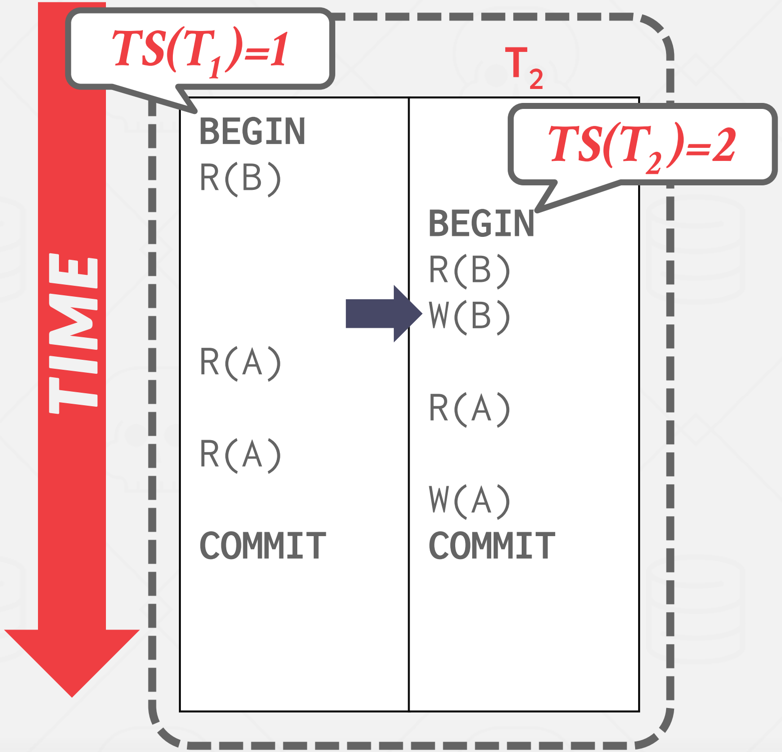
	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	0	0
B	1	0

BASIC T/O – EXAMPLE #1

Schedule



Database

Object	R-TS	W-TS
A	0	0
B	2	2

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

$TS(T_2)=2$

T_1	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	1	0
B	2	2

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

$TS(T_2)=2$

	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	2	0
B	2	2

BASIC T/O – EXAMPLE #1

TIME

Schedule

$TS(T_1)=1$

$TS(T_2)=2$

T_1	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

$TS(T_1) < TS(T_2)$

Object	R-TS	W-TS
A	2	0
B	2	2

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

$TS(T_2)=2$

	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

Database

Object	R-TS	W-TS
A	2	2
B	2	2

BASIC T/O – EXAMPLE #1

Schedule

TIME

$TS(T_1)=1$

T_2

$TS(T_2)=2$

T_1	T_2
BEGIN	
R(B)	
	BEGIN
	R(B)
	W(B)
R(A)	
	R(A)
R(A)	
	W(A)
COMMIT	COMMIT

No violations so both txns are safe to commit.

Database

Object	R-TS	W-TS
A	2	2
B	2	2

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN	
R(A)	
	BEGIN
	W(A)
	COMMIT
W(A)	
R(A)	
COMMIT	

Database

Object	R-TS	W-TS
A	1	0
B	0	0

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN	
R(A)	
	BEGIN
	W(A)
	COMMIT
W(A)	
R(A)	
COMMIT	

Database

Object	R-TS	W-TS
A	1	2
B	0	0

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN	
R(A)	
	BEGIN
	W(A)
	COMMIT
W(A)	
R(A)	
COMMIT	

T_1 cannot overwrite update by T_2, so the DBMS must abort it!

Database

Object	R-TS	W-TS
A	1	2
B	0	0

Violation:
$TS(T_1) < W\text{-}TS(A)$

THOMAS WRITE RULE

If $TS(T_i) < R\text{-}TS(X)$:

→ Abort and restart T_i.

If $TS(T_i) < W\text{-}TS(X)$:

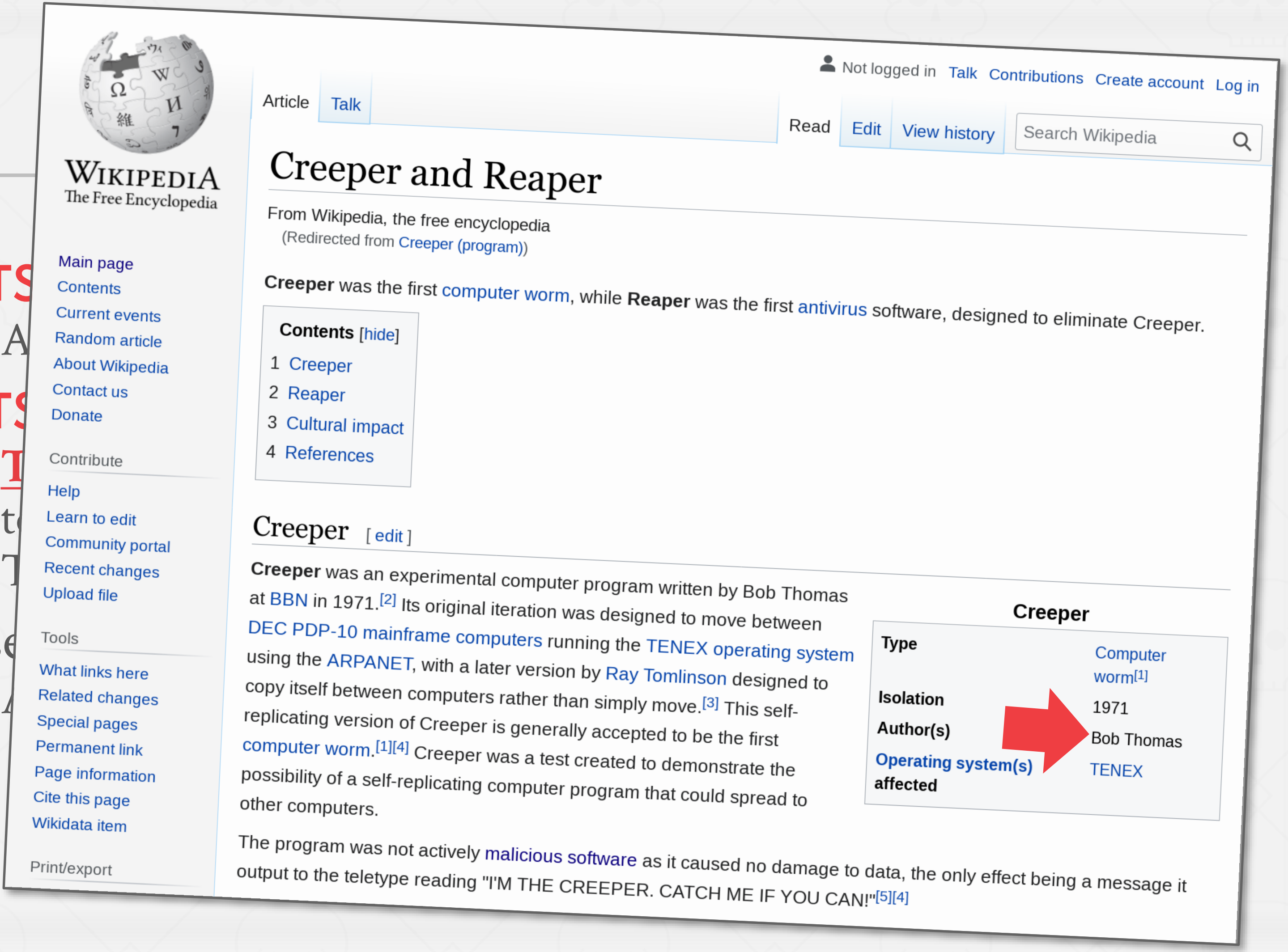
→ **Thomas Write Rule**: Ignore the write to allow the txn to continue executing without aborting.

→ This violates timestamp order of T_i.

Else:

→ Allow T_i to write X and update $W\text{-}TS(X)$

If TS
→ A
If TS
→ T
t
→ T
Else
→ A



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Creeper and Reaper

From Wikipedia, the free encyclopedia
(Redirected from Creeper (program))

Creeper was the first computer worm, while **Reaper** was the first antivirus software, designed to eliminate Creeper.

Contents [hide]

Creeper [edit]

Creeper was an experimental computer program written by Bob Thomas at BBN in 1971.[2] Its original iteration was designed to move between DEC PDP-10 mainframe computers running the TENEX operating system using the ARPANET, with a later version by Ray Tomlinson designed to copy itself between computers rather than simply move.[3] This self-replicating version of Creeper is generally accepted to be the first computer worm.[1][4] Creeper was a test created to demonstrate the possibility of a self-replicating computer program that could spread to other computers.

Creeper

Type	Computer worm[1]
Isolation	1971
Author(s)	Bob Thomas
Operating system(s) affected	TENEX

The program was not actively malicious software as it caused no damage to data, the only effect being a message it output to the teletype reading "I'M THE CREEPER. CATCH ME IF YOU CAN!"[5][4]

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN	
R(A)	
	BEGIN
	W(A)
	COMMIT
W(A)	
R(A)	
COMMIT	

Database

Object	R-TS	W-TS
A	1	0
B	0	0

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN	
R(A)	
	BEGIN
	W(A)
	COMMIT
W(A)	
R(A)	
COMMIT	

Database

Object	R-TS	W-TS
A	1	2
B	0	0

BASIC T/O – EXAMPLE #2

Schedule

TIME

T_1	T_2
BEGIN R(A)	
	BEGIN W(A) COMMIT
W(A) R(A) COMMIT	

Ignore the write and allow T_1 to commit.

Database

Object	R-TS	W-TS
A	1	2
B	0	0

We do not update W-TS(A)

BASIC T/O

Generates a schedule that is conflict serializable if you do **not** use the Thomas Write Rule.

→ No deadlocks because no txn ever waits.

→ Possibility of starvation for long txns if short txns keep causing conflicts.

Andy is not aware of any DBMS that uses the basic T/O protocol described here.

→ It provides the building blocks for OCC / MVCC.

BASIC T/O – PERFORMANCE ISSUES

High overhead from copying data to txn's workspace and from updating timestamps.

→ Every read requires the txn to write to the database.

Long running txns can get starved.

→ The likelihood that a txn will read something from a newer txn increases.

OBSERVATION

If you assume that conflicts between txns are **rare** and that most txns are **short-lived**, then forcing txns to acquire locks or update timestamps adds unnecessary overhead.

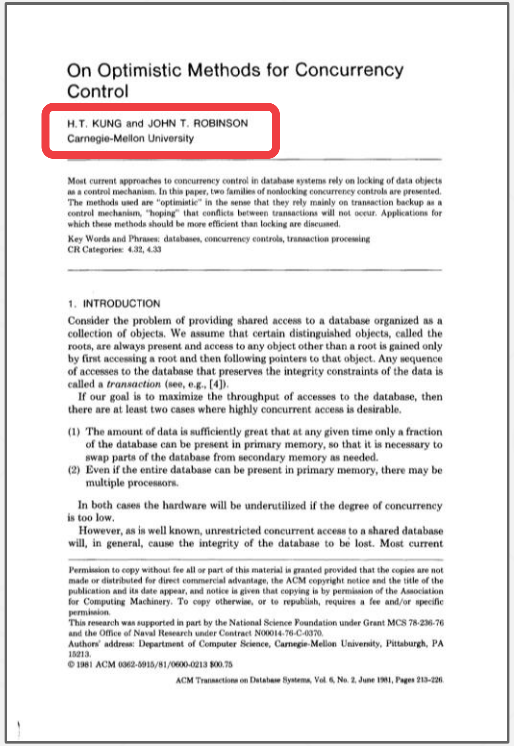
A better approach is to optimize for the no-conflict case.

OPTIMISTIC CONCURRENCY CONTROL

The DBMS creates a private workspace for each txn.
→ 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.



On Optimistic Methods for Concurrency Control

H.T. KUNG and JOHN T. ROBINSON
Carnegie-Mellon University

Most current approaches to concurrency control in database systems rely on locking of data objects as a control mechanism. In this paper, two families of nonlocking concurrency controls are presented. The methods used are "optimistic" in the sense that they rely mainly on transaction backup as a control mechanism, "hoping" that conflicts between transactions will not occur. Applications for which these methods should be more efficient than locking are discussed.

Key Words and Phrases: databases, concurrency controls, transaction processing
CR Categories: 4.32, 4.33

1. INTRODUCTION

Consider the problem of providing shared access to a database organized as a collection of objects. We assume that certain distinguished objects, called the roots, are always present and access to any object other than a root is gained only by first accessing a root and then following pointers to that object. Any sequence of accesses to the database that preserves the integrity constraints of the data is called a *transaction* (see, e.g., [4]).

If our goal is to maximize the throughput of accesses to the database, then there are at least two cases where highly concurrent access is desirable.

(1) The amount of data is sufficiently great that at any given time only a fraction of the database can be present in primary memory, so that it is necessary to swap parts of the database from secondary memory as needed.
(2) Even if the entire database can be present in primary memory, there may be multiple processors.

In both cases the hardware will be underutilized if the degree of concurrency is too low.

However, as is well known, unrestricted concurrent access to a shared database will, in general, cause the integrity of the database to be lost. Most current

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ACM Transactions on Database Systems, Vol. 6, No. 2, June 1981, Pages 213-226.

OCC PHASES

#1 – Read Phase:

→ Track the read/write sets of txns and store their writes in a private workspace.

#2 – Validation Phase:

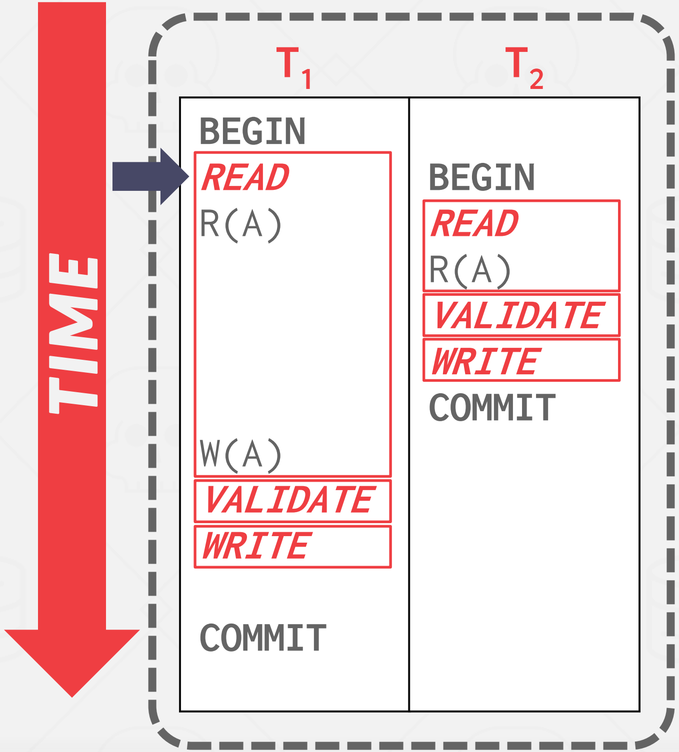
→ When a txn commits, check whether it conflicts with other txns.

#3 – Write Phase:

→ If validation succeeds, apply private changes to database. Otherwise abort and restart the txn.

OCC – EXAMPLE

Schedule



Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
–	–	–
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	BEGIN
R(A)	*READ*
	R(A)
	VALIDATE
	WRITE
	COMMIT
W(A)	
VALIDATE	
WRITE	
COMMIT	

Database

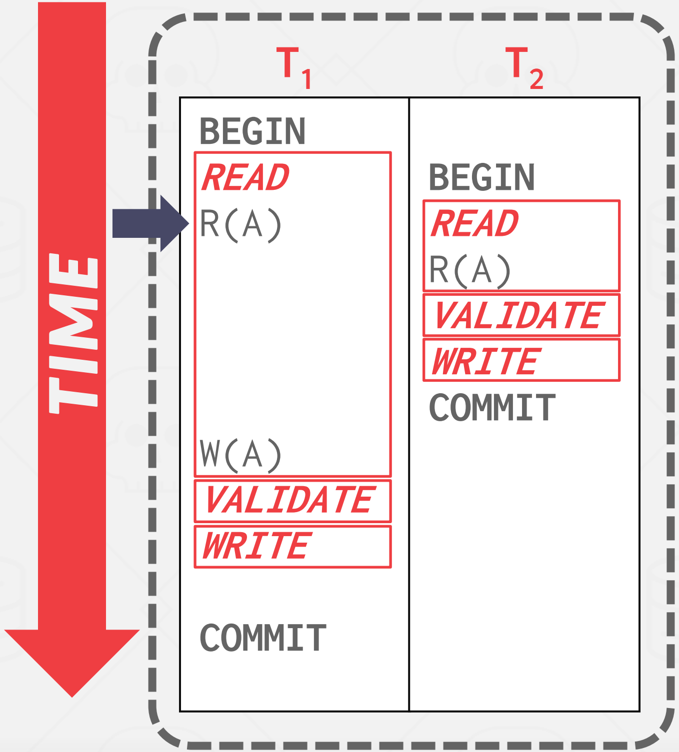
Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
–	–	–
–	–	–

OCC – EXAMPLE

Schedule



Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	BEGIN
R(A)	*READ*
	R(A)
	VALIDATE
	WRITE
	COMMIT
W(A)	
VALIDATE	
WRITE	
COMMIT	

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	123	0
–	–	–

T_2 Workspace

Object	Value	W-TS
–	–	–
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	
R(A)	BEGIN
	READ
	R(A)
	VALIDATE
	WRITE
	COMMIT
W(A)	
VALIDATE	
WRITE	
COMMIT	

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	123	0
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	
R(A)	
	BEGIN
	READ
	R(A)
	VALIDATE
	WRITE
	COMMIT
W(A)	
VALIDATE	
WRITE	
COMMIT	

$TS(T_2)=1$

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	123	0
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	
R(A)	
	BEGIN
	READ
	R(A)
	VALIDATE
	WRITE
	COMMIT
W(A)	
VALIDATE	
WRITE	
COMMIT	

$TS(T_2)=1$

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

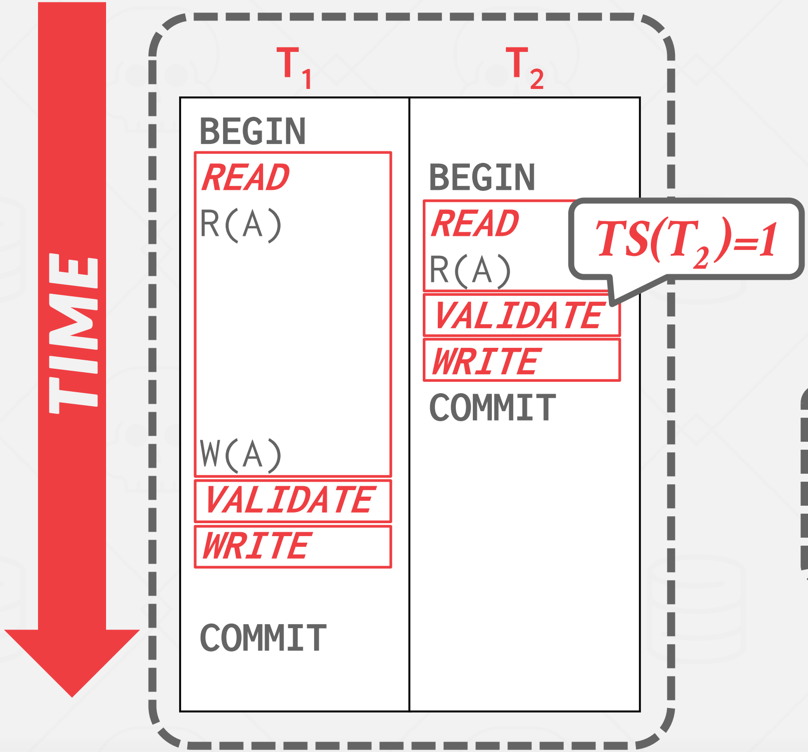
Object	Value	W-TS
A	123	0
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – EXAMPLE

Schedule



Database

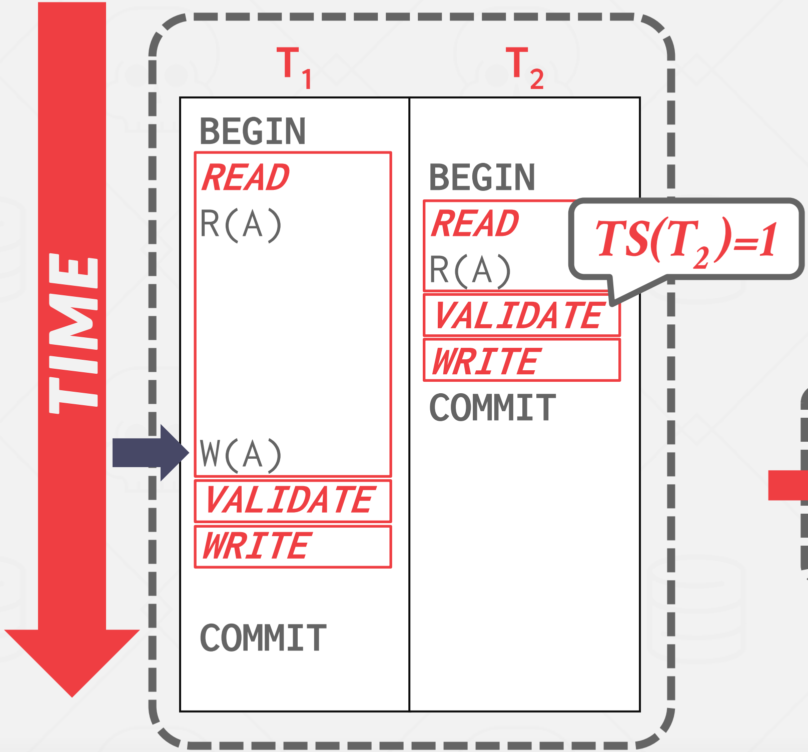
Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – EXAMPLE

Schedule



Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

OCC – EXAMPLE

Schedule

TIME

T_1	T_2
BEGIN	
READ	BEGIN
R(A)	*READ*
	R(A)
	VALIDATE
	WRITE
W(A)	
VALIDATE	
WRITE	
COMMIT	

$TS(T_2)$=1

$TS(T_1)$=2

Database

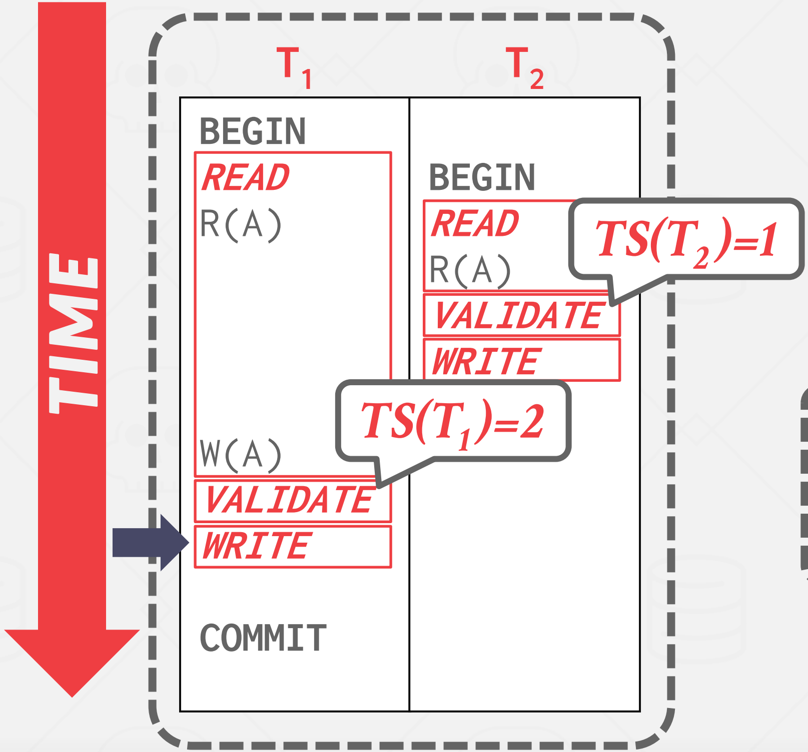
Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

OCC – EXAMPLE

Schedule



Database

Object	Value	W-TS
A	456	2
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

OCC – READ PHASE

Track the read/write sets of txns and store their writes in a private workspace.

The DBMS copies every tuple that the txn accesses from the shared database to its workspace ensure repeatable reads.

→ We can ignore for now what happens if a txn reads/writes tuples via indexes.

OCC – VALIDATION PHASE

When txn T_i invokes **COMMIT**, the DBMS checks if it conflicts with other txns.

→ The DBMS needs to guarantee only serializable schedules are permitted.

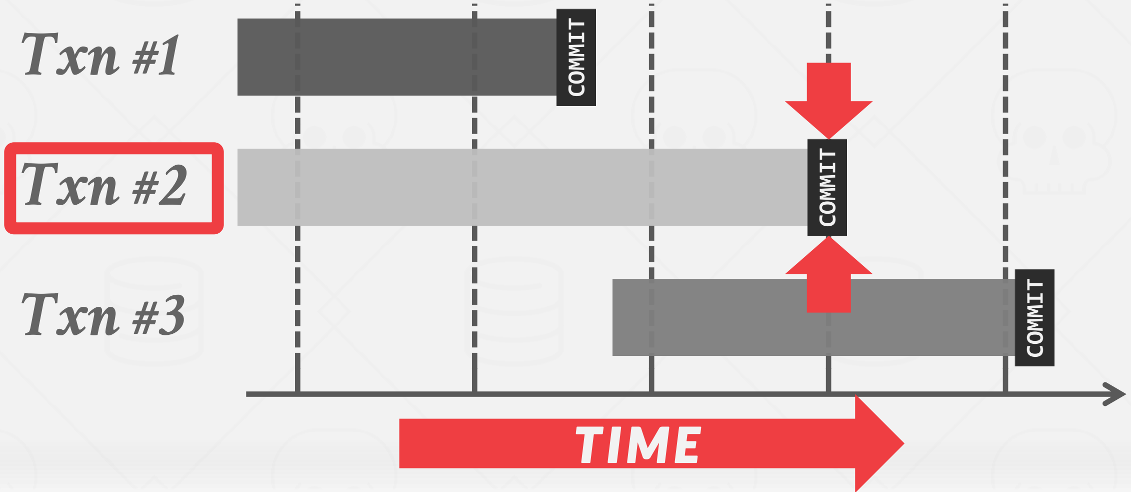
→ Checks other txns for RW and WW conflicts and ensure that conflicts are in one direction (e.g., older→younger).

Approach #1: Backward Validation

Approach #2: Forward Validation

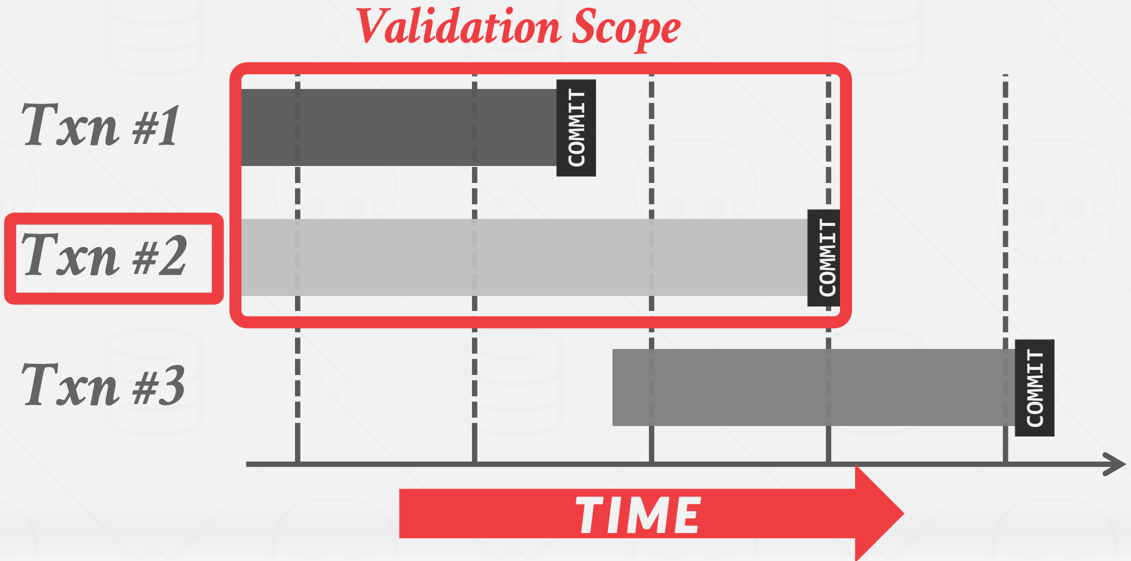
OCC – BACKWARD VALIDATION

Check whether the committing txn intersects its read/write sets with those of any txns that have **already** committed.



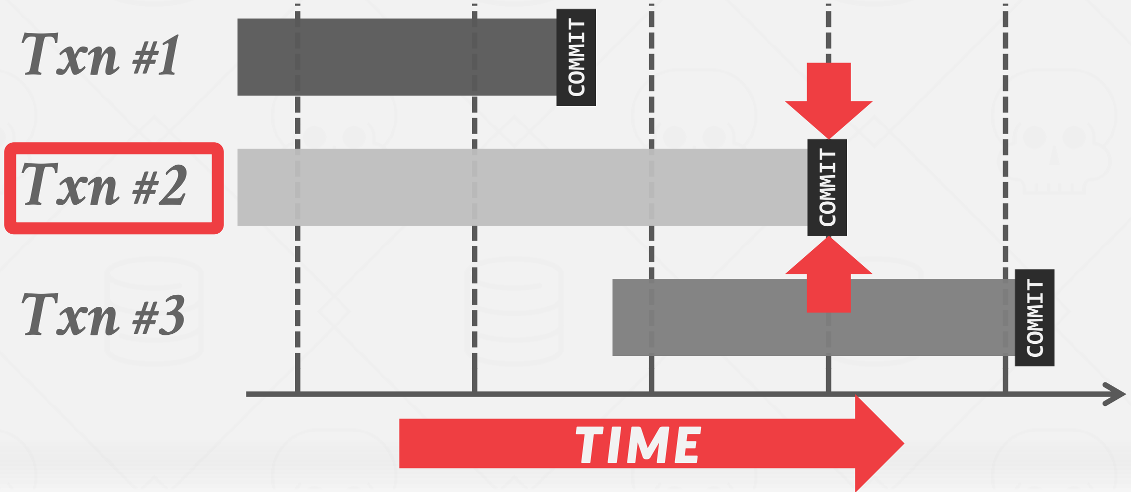
OCC – BACKWARD VALIDATION

Check whether the committing txn intersects its read/write sets with those of any txns that have **already** committed.



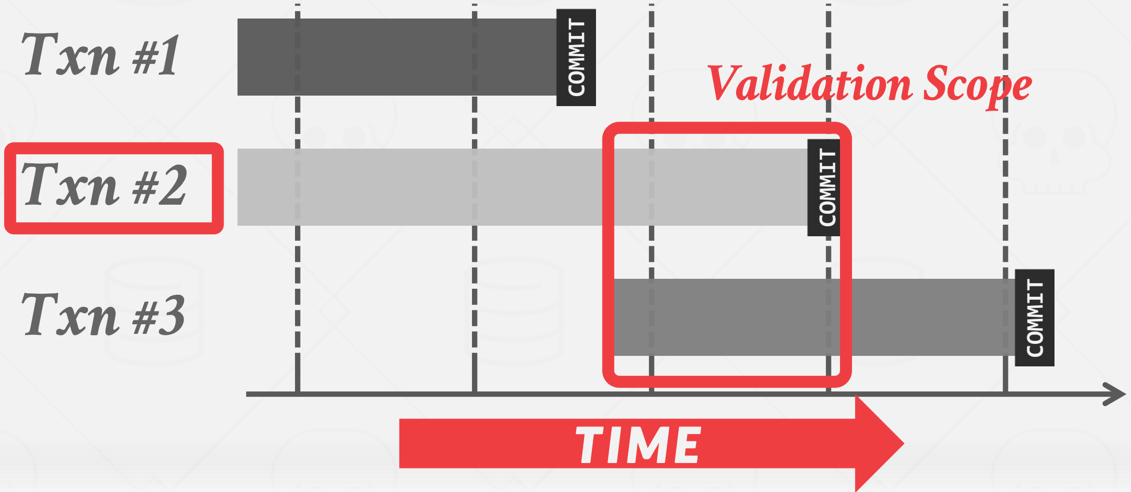
OCC – FORWARD VALIDATION

Check whether the committing txn intersects its read/write sets with any active txns that have **not** yet committed.



OCC – FORWARD VALIDATION

Check whether the committing txn intersects its read/write sets with any active txns that have **not** yet committed.



OCC – FORWARD VALIDATION

Each txn's timestamp is assigned at the beginning of the validation phase.

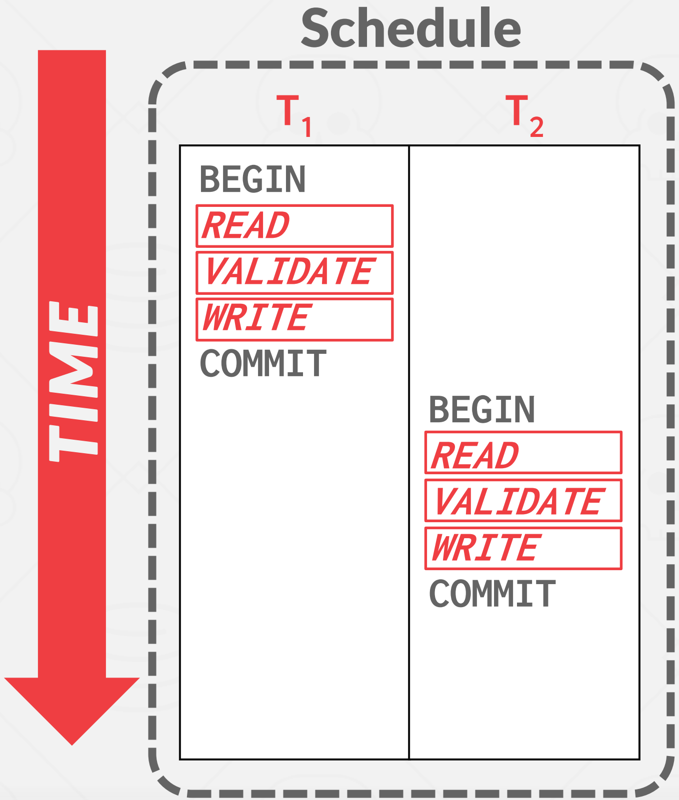
Check the timestamp ordering of the committing txn with all other running txns.

If $TS(T_i) < TS(T_j)$, then one of the following three conditions must hold…

OCC – FORWARD VALIDATION STEP #1

T_i completes all three phases before T_j begins its execution.

This just means that there is serial ordering.



OCC – FORWARD VALIDATION STEP #2

T_i completes before T_j starts its **Write** phase, and T_i does not write to any object read by T_j.

→ $\texttt{WriteSet}(T_i) \cap \texttt{ReadSet}(T_j) = \emptyset$

OCC – FORWARD VALIDATION STEP #2

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	
	READ
	R(A)
VALIDATE	
	VALIDATE
	WRITE
	COMMIT

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – FORWARD VALIDATION STEP #2

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	*READ*
	R(A)
VALIDATE	
	VALIDATE
	WRITE
	OMMIT

T_1 must abort even though T_2 will never write to the database.

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – FORWARD VALIDATION STEP #2

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ R(A) W(A)	
	READ R(A)
	VALIDATE
VALIDATE	
WRITE	
COMMIT	*WRITE*
	COMMIT

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – FORWARD VALIDATION STEP #2

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	
	READ
	R(A)
	VALIDATE
VALIDATE	
WRITE	
COMMIT	
	WRITE

Safe to commit T_1 because T_2 commits logically before T_1

Database

Object	Value	W-TS
A	123	0
–	–	–

T_1 Workspace

Object	Value	W-TS
A	456	∞
–	–	–

T_2 Workspace

Object	Value	W-TS
A	123	0
–	–	–

OCC – FORWARD VALIDATION STEP #3

T_i completes its **Read** phase before T_j completes its **Read** phase

And T_i does not write to any object that is either read or written by T_j:

→ `WriteSet(`T_i`)` ∩ `ReadSet(`T_j`)` = Ø

→ `WriteSet(`T_i`)` ∩ `WriteSet(`T_j`)` = Ø

OCC – FORWARD VALIDATION STEP #3

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	
	READ
	R(B)
VALIDATE	
WRITE	
COMMIT	
	R(A)
	VALIDATE
	WRITE
	COMMIT

Database

Object	Value	W-TS
A	123	0
B	XYZ	0

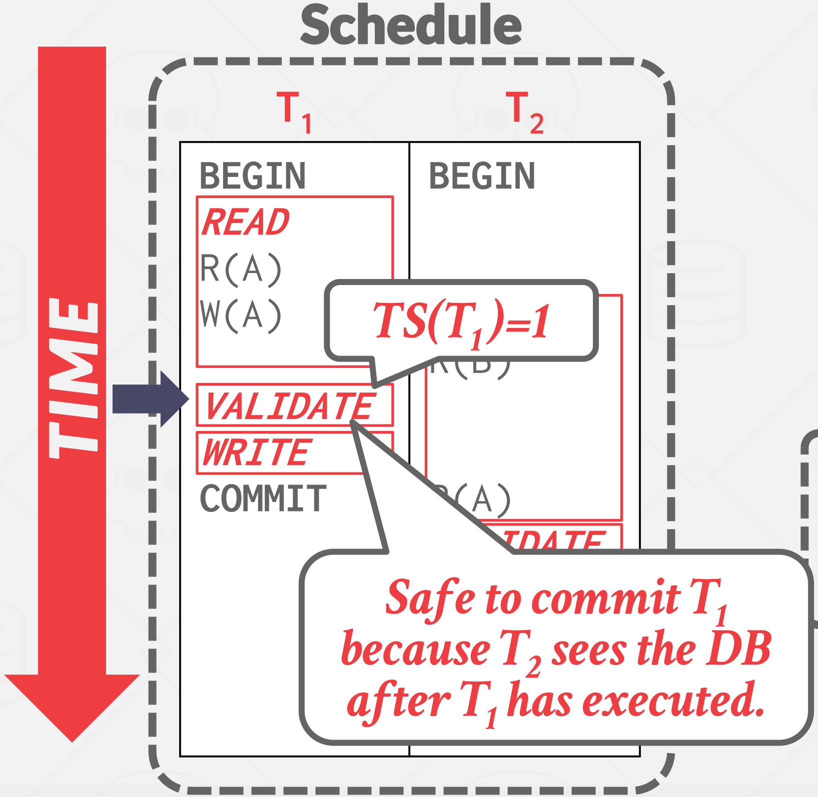
T_1 Workspace

Object	Value	W-TS
A	456	∞
-	-	-

T_2 Workspace

Object	Value	W-TS
B	XYZ	0
-	-	-

OCC – FORWARD VALIDATION STEP #3



Database

Object	Value	W-TS
A	123	0
B	XYZ	0

T_1 Workspace

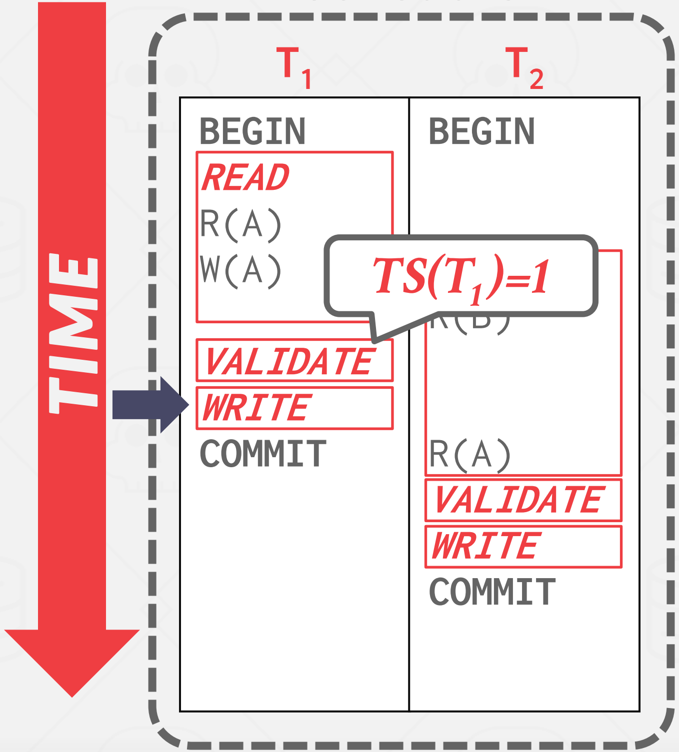
Object	Value	W-TS
A	456	∞
-	-	-

T_2 Workspace

Object	Value	W-TS
B	XYZ	0
-	-	-

OCC – FORWARD VALIDATION STEP #3

Schedule



Database

Object	Value	W-TS
A	456	1
B	XYZ	0

T_1 Workspace

Object	Value	W-TS
A	456	∞
-	-	-

T_2 Workspace

Object	Value	W-TS
B	XYZ	0
-	-	-

OCC – FORWARD VALIDATION STEP #3

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	
	READ
	R(B)
VALIDATE	
WRITE	
COMMIT	
	R(A)
	VALIDATE
	WRITE
	COMMIT

Database

Object	Value	W-TS
A	456	1
B	XYZ	0

T_2 Workspace

Object	Value	W-TS
B	XYZ	0
-	-	-

OCC – FORWARD VALIDATION STEP #3

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
READ	
R(A)	
W(A)	
	READ
	R(B)
VALIDATE	
WRITE	
COMMIT	R(A)
	VALIDATE
	WRITE
	COMMIT

Database

Object	Value	W-TS
A	456	1
B	XYZ	0

T_2 Workspace

Object	Value	W-TS
B	XYZ	0
A	456	1

OCC – WRITE PHASE

Propagate changes in the txn's write set to database to make them visible to other txns.

Serial Commits:

→ Use a global latch to limit a single txn to be in the **Validation/Write** phases at a time.

Parallel Commits:

→ Use fine-grained write latches to support parallel **Validation/Write** phases.

→ Txns acquire latches in primary key order to avoid deadlocks.

OCC – OBSERVATIONS

OCC works well when the # of conflicts is low:

→ All txns are read-only (ideal).

→ Txns access disjoint subsets of data.

If the database is large and the workload is not skewed, then there is a low probability of conflict, so again locking is wasteful.

OCC – PERFORMANCE ISSUES

High overhead for copying data locally.

Validation/Write phase bottlenecks.

Aborts are more wasteful than in 2PL because they only occur after a txn has already executed.

DYNAMIC DATABASES

Recall that so far, we have only dealt with transactions that read and update existing objects in the database.

But now if txns perform insertions, updates, and deletions, we have new problems…

THE PHANTOM PROBLEM

Schedule

TIME

T_1	T_2
BEGIN	BEGIN
`SELECT MAX(age) FROM people WHERE status='lit'` → 72	
	`INSERT INTO people (age=96, status='lit')`
	COMMIT
`SELECT MAX(age) FROM people WHERE status='lit'` → 96	
COMMIT	

```
CREATE TABLE people (
  id SERIAL,
  name VARCHAR,
  age INT,
  status VARCHAR
);
```

WTF?

How did this happen?

→ Because T_1 locked only existing records and not ones under way!

Conflict serializability on reads and writes of individual items guarantees serializability **only** if the set of objects is fixed.

THE PHANTOM PROBLEM

Approach #1: Re-Execute Scans

→ Run queries again at commit to see whether they produce a different result to identify missed changes.

Approach #2: Predicate Locking

→ Logically determine the overlap of predicates before queries start running.

Approach #3: Index Locking

→ Use keys in indexes to protect ranges.

RE-EXECUTE SCANS

The DBMS tracks the **WHERE** clause for all queries that the txn executes.

→ Retain the scan set for every range query in a txn.

Upon commit, re-execute just the scan portion of each query and check whether it generates the same result.

→ Example: Run the scan for an **UPDATE** query but do not modify matching tuples.

PREDICATE LOCKING

Proposed locking scheme from System R.

→ Shared lock on the predicate in a **WHERE** clause of a **SELECT** query.

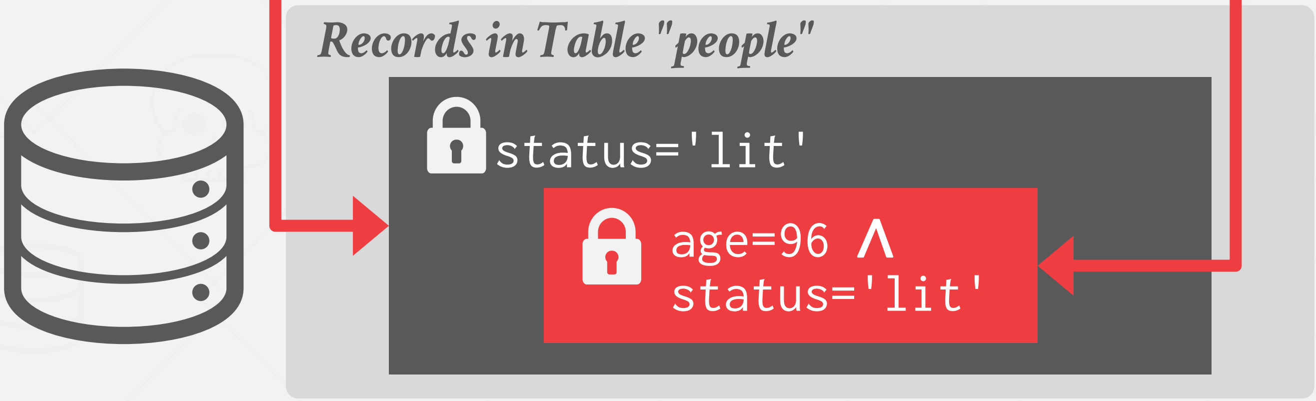
→ Exclusive lock on the predicate in a **WHERE** clause of any **UPDATE**, **INSERT**, or **DELETE** query.

Never implemented in any system except for HyPer (precision locking).

PREDICATE LOCKING

```
SELECT MAX(age)
  FROM people
 WHERE status='lit'
```

```
INSERT INTO people VALUES
(age=96, status='lit')
```

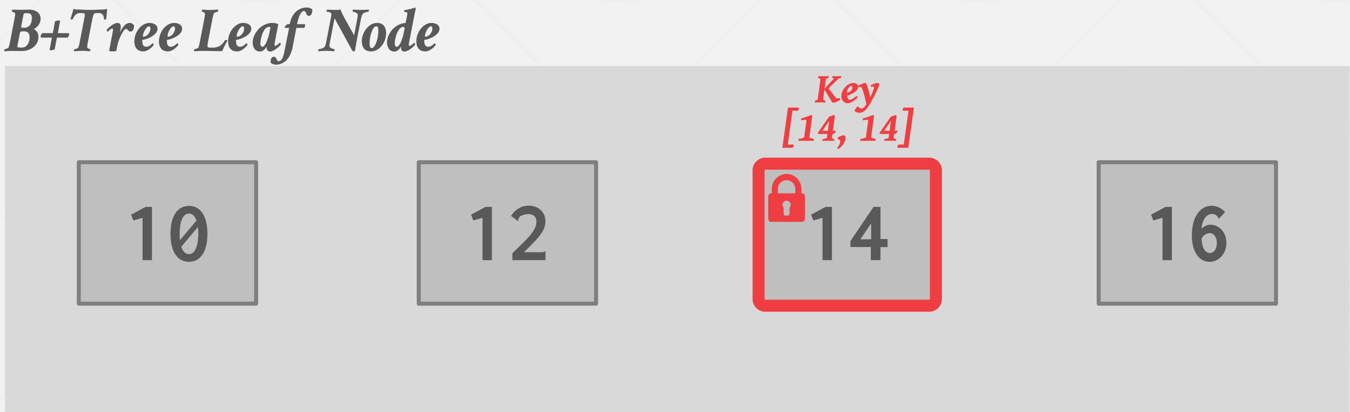


INDEX LOCKING SCHEMES

Key-Value Locks
Gap Locks
Key-Range Locks
Hierarchical Locking

KEY-VALUE LOCKS

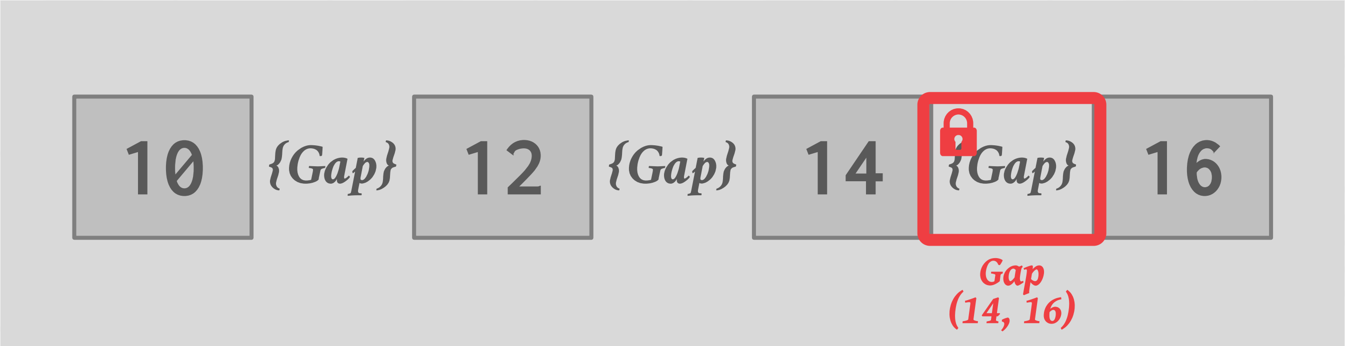
Locks that cover a single key-value in an index.
Need "virtual keys" for non-existent values.



GAP LOCKS

Each txn acquires a key-value lock on the single key that it wants to access. Then get a gap lock on the next key gap.

B+Tree Leaf Node



KEY-RANGE LOCKS

A txn takes locks on ranges in the key space.

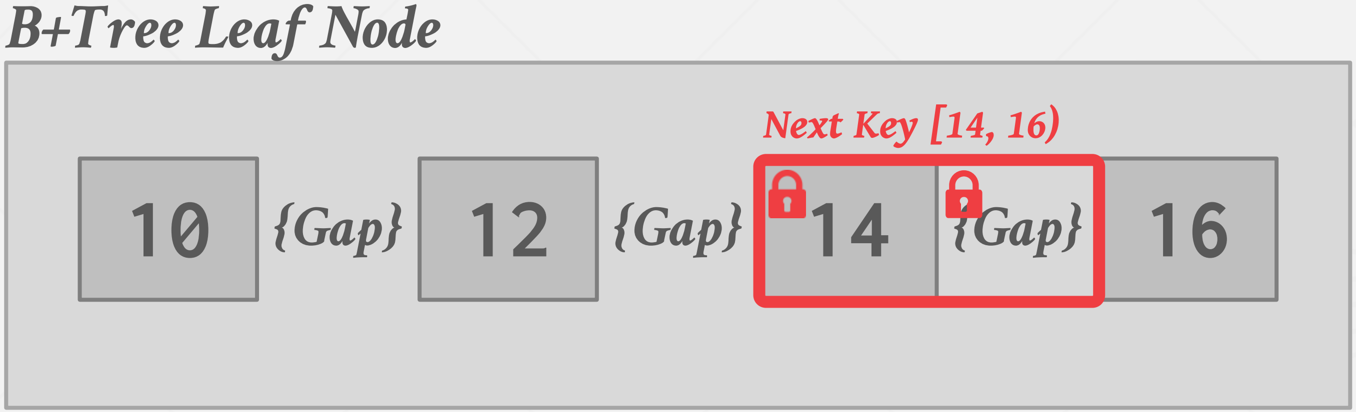
→ Each range is from one key that appears in the relation, to the next that appears.

→ Define lock modes so conflict table will capture commutativity of the operations available.

KEY-RANGE LOCKS

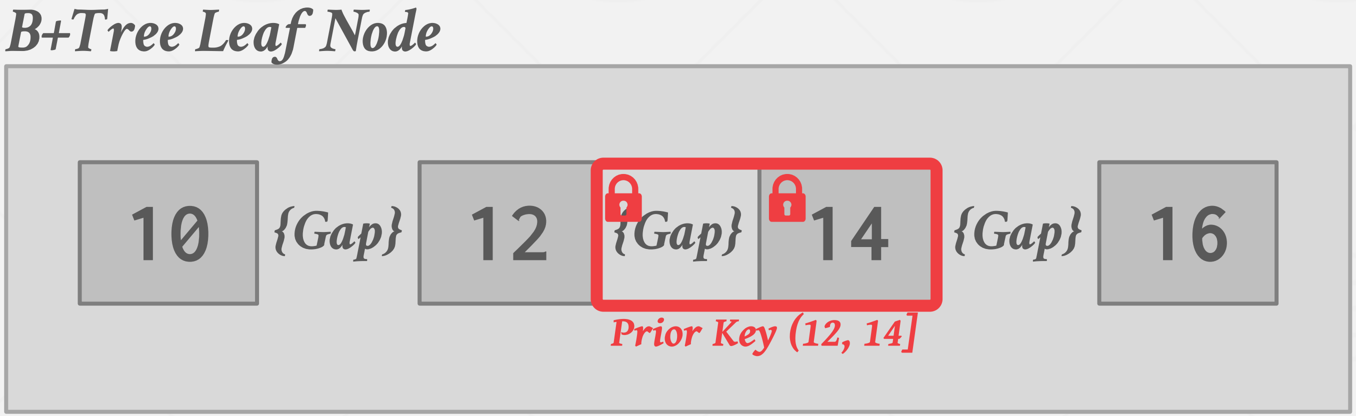
Locks that cover a key value and the gap to the next key value in a single index.

→ Need "virtual keys" for artificial values (infinity)



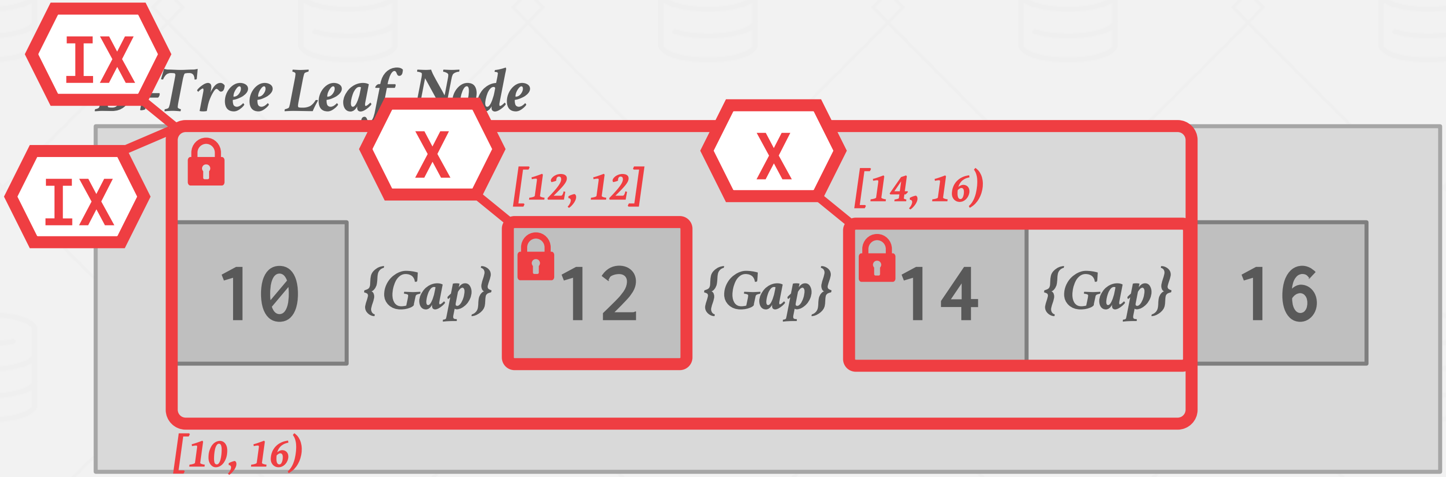
KEY-RANGE LOCKS

Locks that cover a key value and the gap to the next key value in a single index.
→ Need "virtual keys" for artificial values (infinity)



HIERARCHICAL LOCKING

Allow for a txn to hold wider key-range locks with different locking modes.
→ Reduces the number of visits to lock manager.



LOCKING WITHOUT AN INDEX

If there is no suitable index, then the txn must obtain:

- → A lock on every page in the table to prevent a record's `status='lit'` from being changed to `lit`.
- → The lock for the table itself to prevent records with `status='lit'` from being added or deleted.

WEAKER LEVELS OF ISOLATION

Serializability is useful because it allows programmers to ignore concurrency issues.

But enforcing it may allow too little concurrency and limit performance.

We may want to use a weaker level of consistency to improve scalability.

ISOLATION LEVELS

Controls the extent that a txn is exposed to the actions of other concurrent txns.

Provides for greater concurrency at the cost of exposing txns to uncommitted changes:
→ Dirty Reads
→ Unrepeatable Reads
→ Phantom Reads

ISOLATION LEVELS

Isolation (Low→High)

SERIALIZABLE: No phantoms, all reads repeatable, no dirty reads.

REPEATABLE READS: Phantoms may happen.

READ COMMITTED: Phantoms and unrepeatable reads may happen.

READ UNCOMMITTED: All of them may happen.

ISOLATION LEVELS

	Dirty Read	*Unrepeatable Read*	*Phantom*
SERIALIZABLE	No	No	No
REPEATABLE READ	No	No	Maybe
READ COMMITTED	No	Maybe	Maybe
READ UNCOMMITTED	Maybe	Maybe	Maybe

ISOLATION LEVELS

SERIALIZABLE: Obtain all locks first; plus index locks, plus strict 2PL.

REPEATABLE READS: Same as above, but no index locks.

READ COMMITTED: Same as above, but **S** locks are released immediately.

READ UNCOMMITTED: Same as above but allows dirty reads (no **S** locks).

SQL-92 ISOLATION LEVELS

You set a txn's isolation level before you execute any queries in that txn.

```
SET TRANSACTION ISOLATION LEVEL
  <isolation-level>;
```

```
BEGIN TRANSACTION ISOLATION LEVEL
  <isolation-level>;
```

Not all DBMS support all isolation levels in all execution scenarios

→ Replicated Environments

The default depends on implementation…

ISOLATION LEVELS (2013)

	Default	*Maximum*
Actian Ingres	SERIALIZABLE	SERIALIZABLE
IBM DB2	CURSOR STABILITY	SERIALIZABLE
CockroachDB	SERIALIZABLE	SERIALIZABLE
Google Spanner	STRONG SERIALIZABLE	STRONG SERIALIZABLE
MSFT SQL Server	READ COMMITTED	SERIALIZABLE
MySQL	REPEATABLE READS	SERIALIZABLE
Oracle	READ COMMITTED	SNAPSHOT ISOLATION
PostgreSQL	READ COMMITTED	SERIALIZABLE
SAP HANA	READ COMMITTED	SERIALIZABLE
VoltDB	SERIALIZABLE	SERIALIZABLE
YugaByte	SNAPSHOT ISOLATION	SERIALIZABLE

DATABASE ADMIN SURVEY

What isolation level do transactions execute at on this DBMS?

DATABASE ADMIN SURVEY

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What isolation level do transactions execute at on this DBMS?

SQL-92 ACCESS MODES

You can provide hints to the DBMS about whether a txn will modify the database during its lifetime.

Only two possible modes:
→ READ WRITE (Default)
→ READ ONLY

Not all DBMSs will optimize execution if you set a txn to in READ ONLY mode.

```
SET TRANSACTION <access-mode>;
```

```
BEGIN TRANSACTION <access-mode>;
```

CONCLUSION

Every concurrency control can be broken down into the basic concepts that I've described in the last two lectures.

Every protocol has pros and cons.

NEXT CLASS

Multi-Version Concurrency Control