

# Concurrency Control

Spring 2025

Why concurrency control is important?

# Problems Caused By Concurrency

**Lost update:** the result of a transaction is overwritten by another transaction

**Dirty read:** uncommitted results are read by a transaction

**Non-repeatable read:** two reads in the same transaction return different results

**Phantom read:** later reads in the same transaction return extra rows

# Serial schedule — no problems

T1: R(A), W(A), R(B), W(B), Abort

T2: R(A), W(A), Commit



# Quiz: Which concurrency problem is this?

T1: R(A), W(A)

R(B), W(B), Abort

T2: R(A), W(A), Commit



Dirty read

# Quiz: Which concurrency problem is this?

T1: R(A)

R(A), W(A), Commit

T2: R(A), W(A), Commit



Non-repeatable read

# Quiz: Which concurrency problem is this?

T1: R(A), W(A)

W(B), Commit

T2: R(A)

W(A), W(B), Commit



Lost update

# Quiz: Which concurrency problem is this?

T1: R(A), W(A)

W(A), Commit

T2: R(A), R(B), W(B) Commit



Dirty read



How to ensure *correctness* when running concurrent transactions?

# What does correctness mean?

Transactions should have property of *isolation*, i.e., where all operations in a transaction appear to happen together at the same time

Today, we'll review serializability

Weaker isolation levels exist in the literature but we'll ignore them in this class

# Fixing concurrency problems

Strawman: Just run transactions serially — prohibitively bad performance

Observation: Problems only arise when

1. Two transactions touch the same data
2. At least one of these transactions involves a *write* to the data

Key idea: Only **permit** schedules whose effects are guaranteed to be *equivalent* to serial schedules

# Serializability of schedules

Two operations **conflict** if

1. They belong to different transactions
2. They operate on the same data
3. One of them is a write

Two schedules are **equivalent** if

1. They involve the same transactions and operations
2. All *conflicting* operations are ordered the same way

A schedule is **serializable** if it is equivalent to a serial schedule

# Testing for serializability

Intuition: **Swap** non-conflicting operations until you reach a serial schedule

# Testing for serializability - Example 1

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A), Commit

T2: R(A), R(B), W(B) Commit



# Testing for serializability - Example 1

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

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# Testing for serializability - Example 1

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

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T2: R(A), R(B) W(B) Commit



# Testing for serializability - Example 1

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A), Commit

T2: R(A), R(B), W(B) Commit



Serializable

# Testing for serializability - Example 2

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A), W(B), Commit

T2: R(B), W(B), R(A) Commit



# Testing for serializability - Example 2

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A), W(B), Commit

T2: R(B), W(B), R(A) Commit



# Testing for serializability - Example 2

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A) W(B), Commit

T2: R(B), W(B), R(A) Commit



# Testing for serializability - Example 2

Intuition: Swap *non-conflicting* operations until you reach a serial schedule

T1: R(A), W(A), W(B), Commit

T2: R(B), W(B), R(A) Commit



NOT serializable

# Testing for serializability

Another way to test serializability:

- Draw arrows between conflicting operations

- Arrow points in the direction of time

- If no cycles between transactions, the schedule is serializable

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T1: R(A), W(A), Commit

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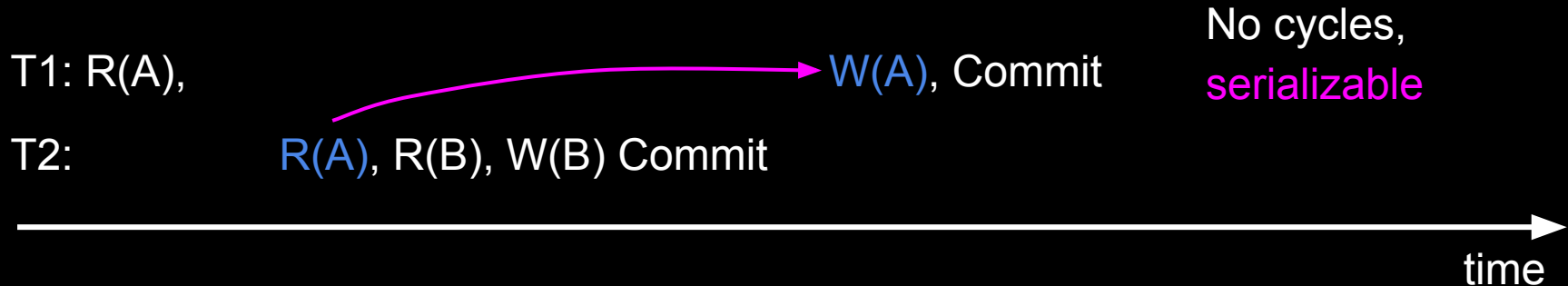
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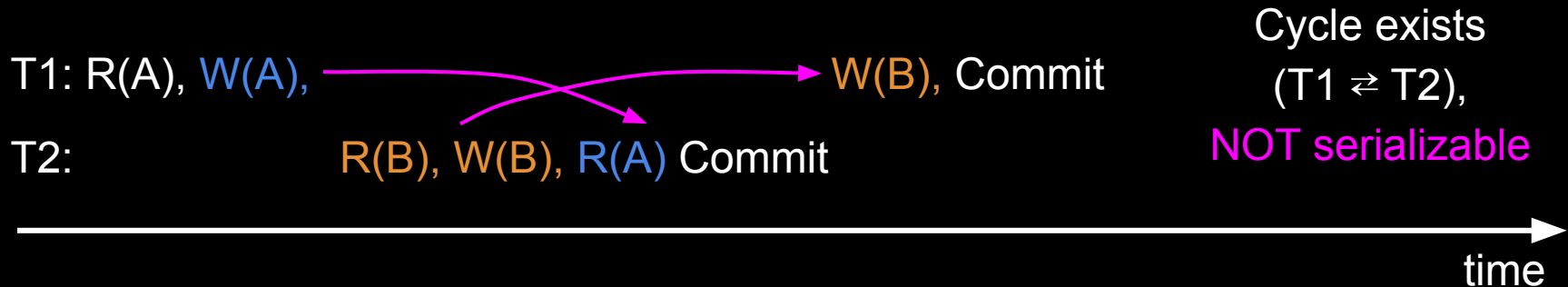
# Testing for serializability

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Draw arrows between conflicting operations

Arrow points in the direction of time

If no cycles between transactions, the schedule is serializable



How to implement serializability?

# Overview: Different Ways to Implementing Serializability

## Two-phase Locking - 2PL (**pessimistic**):

1. Assume conflict, always lock
2. High overhead for non-conflicting txn
3. Must check for deadlock

## **Optimistic** Concurrency Control - OCC:

1. Assume no conflict
2. Low overhead for low-conflict workloads (but high for high-conflict workloads)
3. Ensure correctness by aborting transactions if conflict occurs

# Method 1 - Two-phase Locking (2PL)

**Two-phase locking** (2PL): acquire all locks before releasing any locks

Each txn acquires shared locks (S) for reads and exclusive locks (X) for writes

- Growing phase: transaction acquires all necessary locks
- Shrinking phase: transaction releases all locks

Cannot acquire more locks after *any* locks are released

# 2PL

2PL guarantees **serializability** by disallowing cycles between transactions

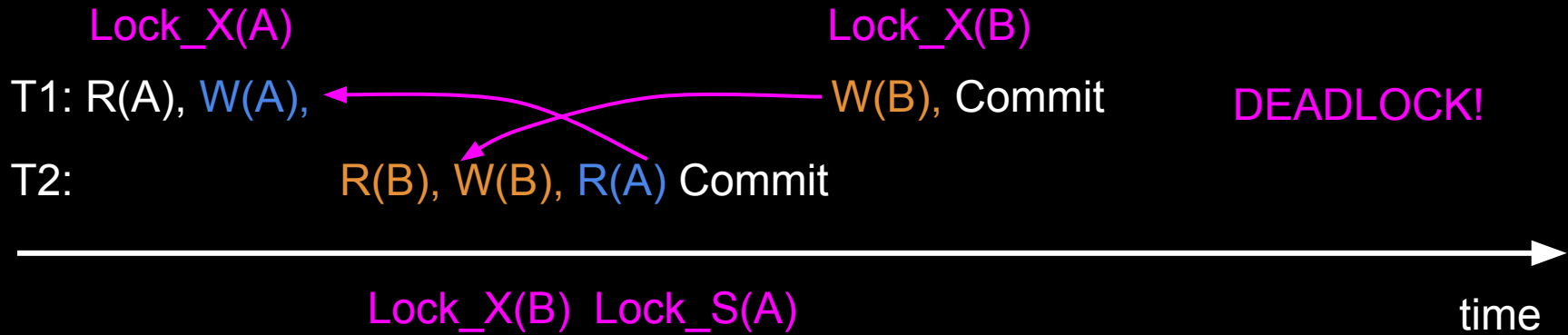
There could be dependencies in the waits-for graph among transactions waiting for locks:

Edge from T2 to T1 means T1 acquired lock first and T2 has to wait

Edge from T1 to T2 means T2 acquired lock first and T1 has to wait

Cycles mean DEADLOCK, and in this case 2PL won't proceed

# 2PL



Deal with deadlocks by aborting one of the two txns (e.g., detect with timeout)

## 2PL: Releasing locks too soon?

*What if we release the lock as soon as we can?*



Rollback of T1 requires rollback of T2, since T2 read a value written by T1

**Cascading aborts:** the rollback of one transaction causes the rollback of another



# Strict 2PL

Release locks at the *end* of the transaction

Variant of 2PL implemented by most databases in practice

# Method 2: Optimistic Concurrency Control (OCC)

**Execute optimistically:** Read committed values, write changes locally

**Validate:** Check if data has changed since original read

**Commit (Write):** Commit if no change, else abort

These should happen together!

# Atomic commit for OCC

Use **two-phase commit (2PC)** to achieve atomic commit (validate + commit writes)

Recall 2PC protocol:

1. Coordinator sends *prepare* messages to all nodes, other nodes vote *yes* or *no*
  - a. If all nodes accept, proceed
  - b. If **any** node declines, abort
2. Coordinator sends *commit* or *abort* messages to all nodes, and all nodes act accordingly

# Optimistic Concurrency Control

**Execute optimistically:** Read committed values, write changes locally

**Validate:** Check if data has changed since original read

Phase 1

**Commit (Write):** Commit if no change, else abort

Phase 2

- **Phase 1:** send *prepare* to each shard: include buffered write + original reads for that shard
  - Shards **validate reads and acquire locks** (exclusive for write locations, shared for read locations)
  - If this succeeds, respond with *yes*; else respond with *no*
- **Phase 2:** collect votes, send result (*abort* or *commit*) to all shards
  - If *commit*, **shards apply buffered writes**
  - All shards release locks

# Exercises

TXN 1

TXN 2

Lock_X(A) <granted>	
Read(A)	Lock_S(A)
A := A-50	
Write(A)	
Unlock(A)	<granted>
	Read(A)
	Unlock(A)
	Lock_S(B) <granted>
Lock_X(B)	
	Read(B)
<granted>	Unlock(B)
Read(B)	
B := B +50	
Write(B)	
Unlock(B)	

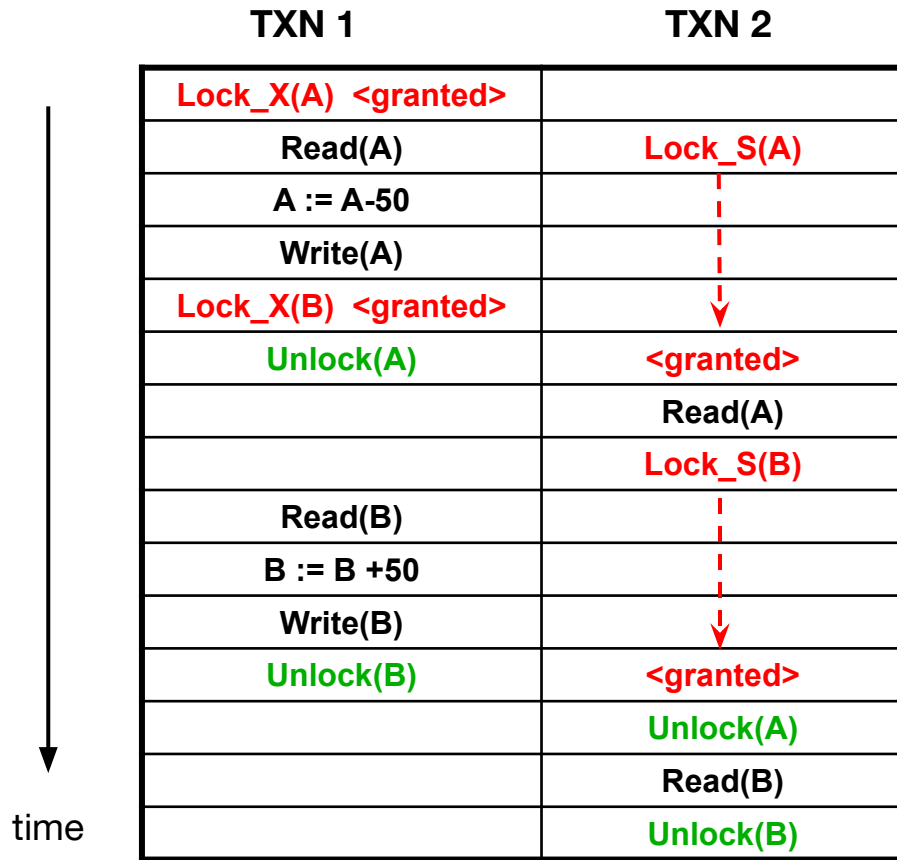
time

Is this a 2PL schedule?

No

Is this a serializable schedule?

No

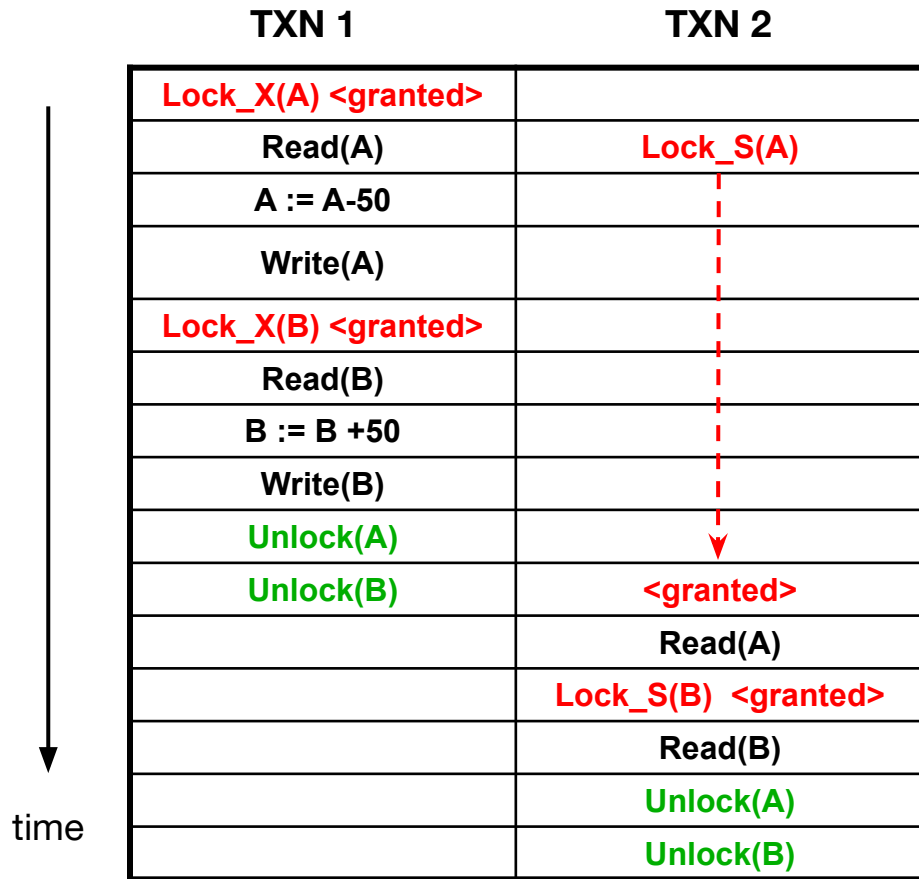


Is this a 2PL schedule?

Yes, and it is serializable

Is this a Strict 2PL schedule?

No, cascading aborts possible



Is this a 2PL schedule?

Yes, and it is serializable

Is this a Strict 2PL schedule?

Yes, cascading aborts not possible