Concurrency Control

Spring 2024

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

time

Quiz: Which concurrency problem is this?

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

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

→ time

Dirty read

Quiz: Which concurrency problem is this?

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

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

time

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

time

Lost update

Quiz: Which concurrency problem is this?

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

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

time

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

time

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

time

Testing for serializability - Example 1

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

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time

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

time

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

time

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

time

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

time

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

time

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

time

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

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

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

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

→ time

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

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

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

time

No cycles, 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

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

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

Cycle exists (T1 ⇄ T2), NOT serializable

time

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

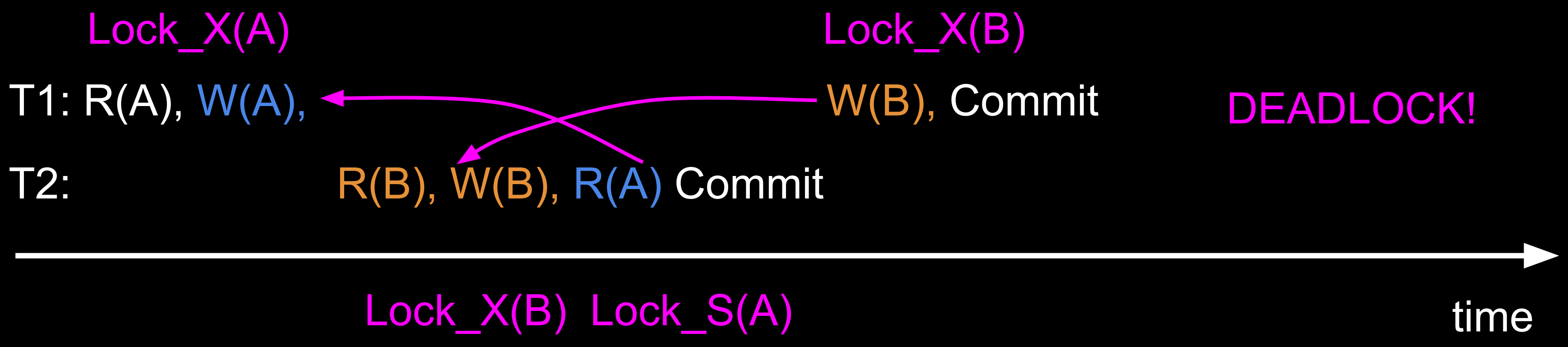
2PL

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?

Lock_X(A) Unlock_X(A)

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

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

time

Lock_X(B) Lock_S(A)

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. Send *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

TXN 1	TXN 2
Lock_X(A) <granted>	
Read(A)	Lock_S(A)
A := A-50	
Write(A)	
Lock_X(B) <granted>	
Unlock(A)	<granted>
	Read(A)
	Lock_S(B)
Read(B)	
B := B +50	
Write(B)	
Unlock(B)	<granted>
	Unlock(A)
	Read(B)
	Unlock(B)

time

Is this a 2PL schedule?

Yes, and it is serializable

Is this a Strict 2PL schedule?

No, cascading aborts possible

TXN 1	TXN 2
Lock_X(A) <granted>	
Read(A)	Lock_S(A)
A := A-50	
Write(A)	
Lock_X(B) <granted>	
Read(B)	
B := B +50	
Write(B)	
Unlock(A)	
Unlock(B)	<granted>
	Read(A)
	Lock_S(B) <granted>
	Read(B)
	Unlock(A)
	Unlock(B)

time

Is this a 2PL schedule?

Yes, and it is serializable

Is this a Strict 2PL schedule?

Yes, cascading aborts not possible