Concurrency control

Apr 6th&7th, 2022
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) \hspace{2cm} W(B), Commit
T2: R(A) \hspace{2cm} 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

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

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

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

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

T2: \( R(A), \quad R(B), \quad W(B) \) Commit
Testing for serializability

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

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

T1: \( R(A), W(A), \text{Commit} \)

T2: \( R(A), R(B), W(B), \text{Commit} \)

Serializable
Testing for serializability

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

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

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

T1: R(A), W(A) \hspace{2cm} W(B), \text{Commit}

T2: R(B), W(B), R(A) \text{ Commit}
Testing for serializability

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

T1: \[ R(A), W(A), W(B), \text{Commit} \]

T2: \[ R(B), W(B), R(A) \text{ Commit} \]

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

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
Implementing serializability: 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

Lock_X(A)  Lock_X(B)
T1: R(A), W(A),  W(B), Commit  DEADLOCK!
T2:  R(B), W(B), R(A)  Commit

Lock_X(B)  Lock_S(A)

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

Lock_X(B)  Lock_S(A)

time

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
Two ways of implementing serializability: 2PL, OCC

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
Optimistic concurrency control

**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

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

- **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
<table>
<thead>
<tr>
<th>Lock_X(A) &lt;granted&gt;</th>
<th>Read(A)</th>
<th>Lock_S(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Read(A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A := A - 50</td>
<td>Write(A)</td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lock_S(B) &lt;granted&gt;</td>
</tr>
<tr>
<td>Lock_X(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Read(B)</td>
<td>Unlock(B)</td>
<td></td>
</tr>
<tr>
<td>Read(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B := B + 50</td>
<td>Write(B)</td>
<td></td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Is this a 2PL schedule?  
No

Is this a serializable schedule?  
No
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)

Is this a 2PL schedule?
Yes, and it is serializable

Is this a Strict 2PL schedule?
No, cascading aborts possible
<table>
<thead>
<tr>
<th>Lock_X(A) &lt;granted&gt;</th>
<th>Read(A)</th>
<th>Lock_S(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A := A -50</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lock_X(B) &lt;granted&gt;</td>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B := B +50</td>
<td></td>
</tr>
<tr>
<td>Write(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td></td>
<td>&lt;granted&gt;</td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock_S(B) &lt;granted&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlock(B)</td>
<td></td>
</tr>
</tbody>
</table>

Is this a 2PL schedule?  
Yes, and it is serializable

Is this a Strict 2PL schedule?  
Yes, cascading aborts not possible

---

### Diagram

<table>
<thead>
<tr>
<th>Lock_X(A) &lt;granted&gt;</th>
<th>Read(A)</th>
<th>Lock_S(A)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A := A -50</td>
<td></td>
</tr>
<tr>
<td>Write(A)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lock_X(B) &lt;granted&gt;</td>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>B := B +50</td>
<td></td>
</tr>
<tr>
<td>Write(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unlock(A)</td>
<td></td>
<td>&lt;granted&gt;</td>
</tr>
<tr>
<td>Unlock(B)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lock_S(B) &lt;granted&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Read(B)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlock(A)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Unlock(B)</td>
<td></td>
</tr>
</tbody>
</table>