2PL and OCC

CS 475: Concurrent & Distributed Systems (Fall 2021)

Lecture 15

Yue Cheng

Some material taken/derived from:

- Princeton COS-418 materials created by Michael Freedman and Kyle Jamieson.
- MIT 6.824 by Robert Morris, Frans Kaashoek, and Nickolai Zeldovich.

Recap: Transaction serializability

Serializability:

Execution of a set of transactions over multiple items is equivalent to ***some*** serial execution of transactions

Some new terms

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

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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 problem

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

Lost update Dirty read Non-repeatable read Phantom read ??

Quiz: Which concurrency problem is this?

T1: R(A)		R(A), W(A), Commit
T2:	R(A), W(A), Commit	

time →

Lost update   Dirty read   Non-repeatable read   Phantom read   ??

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time

Lost update Dirty read Non-repeatable read Phantom read ??

Q: How to ensure *correctness* when running concurrent transactions?

What does correctness mean?

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

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We need serializability

Fixing concurrency problems

Strawman: Just run transactions serially — prohibitively bad performance

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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

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

Serializability of schedules

Two operations conflict if

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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

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

time

Serializable

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

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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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time

Cycle exists

(T1 ⇄ T2),

NOT serializable

Linearizability vs. Serializability

- **Linearizability:** a guarantee about **single** operations on **single** objects
  - Once write completes, all later reads (by wall clock) should reflect that write
- **Serializability** is a guarantee about **transactions** over **one or more** objects
  - Doesn't impose real-time constraints

- Linearizability + serializability = **strict serializability**
  - Transaction behavior equivalent to some serial execution
    - And that serial execution agrees with real-time

Lock-based concurrency control

- Big Global Lock: Results in a **serial** transaction schedule at the cost of performance

- 2PL: Two-phase locking with finer-grain locks:
  - Growing phase when txn acquires locks
  - Shrinking phase when txn releases locks (typically commit)
  - Allows txns to execute concurrently, improving performance

2PL

- 2PL guarantees serializability by disallowing cycles between txns

- There could be dependencies in the waits-for graph among txns waiting for locks:
  - Edge from T2 to T1 means T1 acquired lock first and T2 has to wait
  - Edge from T1 to T2 means T1 acquired lock first and T1 has to wait
  - Cycles mean DEADLOCK, and in that case 2PL won't proceed

2PL

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

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

time

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

2PL

Lock_X(A)

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

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

time

2PL

Lock_X(A)

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

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

Lock_X(B)

time

2PL

Lock_X(A)

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

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

Lock_X(B) Lock_S(A)

time

2PL

Lock_X(A) Lock_X(B)

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

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

Lock_X(B) Lock_S(A)

time

2PL

Lock_X(A) Lock_X(B)

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

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

Lock_X(B) Lock_S(A)

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2PL

Lock_X(A) Lock_X(B)

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

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

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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?

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Lock_X(A) Unlock_X(A)

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Lock_X(B)

time

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2PL: Releasing locks too soon?

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Lock_X(A)   Unlock_X(A)

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time

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

2PL: Releasing locks too soon?

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Lock_X(A) Unlock_X(A)

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

Lock_X(B) Lock_S(A)

time

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

Cascading aborts: the rollback of one txn causes rollback of another

Strict 2PL

- Release locks at the end of the transaction

- Variant of 2PL implemented by most DBs in practice

Q: What if access patterns rarely, if ever, conflict?

Today

- Optimistic concurrency control (OCC)
  - Be optimistic, or opportunistic that conflicts rarely happen

Be optimistic!

- Goal: Low overhead for non-conflicting txns
- Assume success!
  - Process transaction as if would succeed
  - Check for serializability only at commit time
  - If fails, abort transaction
- Optimistic Concurrency Control (OCC)
  - **Higher performance** when few conflicts vs. locking
  - **Lower performance** when many conflicts vs. locking

OCC: Three-phase approach

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- Validate phase

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- Begin: Record timestamp marking the transaction's beginning
- Modify phase:
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  - Updates only to local copies (versions) of items (in DB cache)
- Validate phase
- Commit phase
  - If validates, transaction's updates applied to DB
  - Otherwise, transaction restarted
  - Care must be taken to avoid "TOCTTOU" issues

OCC: Three-phase approach

- **Begin:** Record timestamp marking the transaction's beginning
- Modify phase: Execute optimistically!
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- **Begin:** Record timestamp marking the transaction's beginning
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Execute optimistically!

- **Validate** phase
- **Commit** phase
  - If validates, transaction's updates applied to DB
  - Otherwise, transaction restarted
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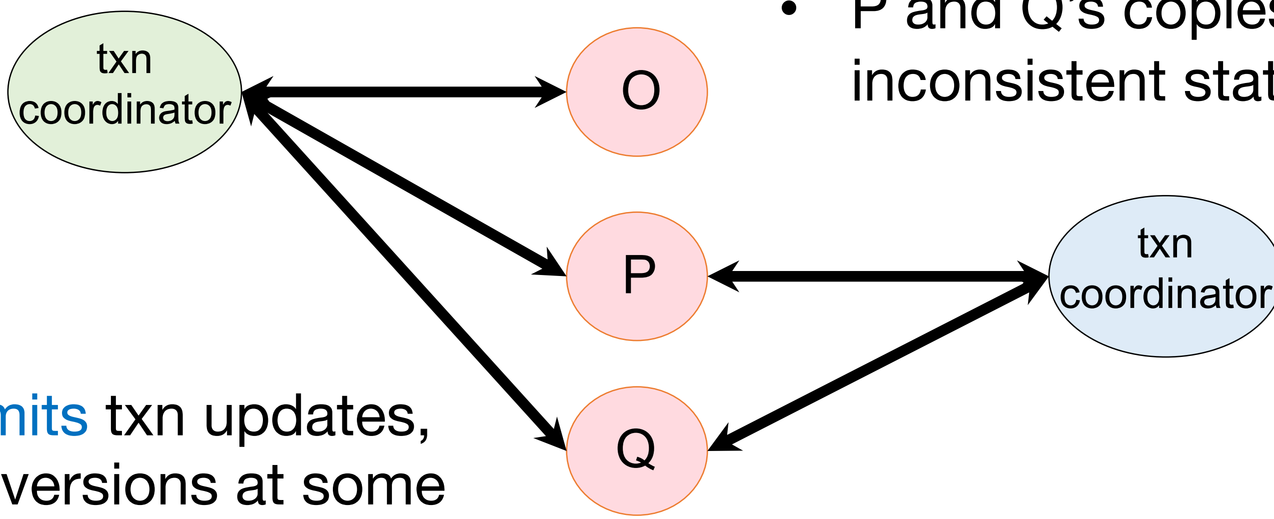
These should happen together!

OCC: Why validation is necessary!

- New txn creates shadow copies of P and Q
- P and Q's copies at inconsistent state



When commits txn updates, create new versions at some timestamp t

OCC: Validate phase

- Transaction is about to commit. System must ensure:
  - Initial consistency: Versions of accessed objects at start consistent
  - No conflicting concurrency: No other txn has committed an operation at object that conflicts with one of this txn's invocations

- Consider transaction 1: For all other txns N either committed or in validation phase, one of the following holds:
  A. N completes commit before 1 starts modify
  B. 1 starts commit after N completes commit, and ReadSet 1 and WriteSet N are disjoint
  C. Both ReadSet 1 and WriteSet 1 are disjoint from WriteSet N, and N completes modify phase

- When validating 1, first check (A), then (B), then (C). If all fail, validation fails and 1 aborted

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

Atomic commit for 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

Phase 1

Phase 2

Atomic commit for OCC

- 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*

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  - 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

Two ways of implementing serializability: 2PL, OCC

- 2PL (pessimistic):
  - Assume conflict, always lock
  - High overhead for non-conflicting txn
  - Must check for deadlock

- OCC (optimistic):
  - Assume no conflict
  - Low overhead for low-conflict workloads (but high for high-conflict workloads)
  - Ensure correctness by aborting txns if conflict occurs

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)	

Is this a 2PL schedule?

No

Is this a serializable schedule?

No

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A := A-50	
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	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

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Write(B)	
Unlock(A)	
Unlock(B)	<granted>
	Read(A)
	Lock_S(B) <granted>
	Read(B)
	Unlock(A)
	Unlock(B)

Is this a 2PL schedule?

Yes, and it is serializable

Is this a Strict 2PL schedule?

Yes, cascading aborts not possible