# Concurrency control

12/1/17

# Bag of words...

Isolation

Linearizability

Consistency

Strict serializability

Durability

Snapshot isolation

Conflict equivalence

Serializability

Atomicity

Optimistic concurrency control

Multiversion concurrency control

Two-phase locking

Conflict serializability

# ACID semantics

Relevant in the context of database transactions (txn)

Atomicity: Either all ops happen or no ops happen

Consistency: Application constraints are not violated

Isolation: Concurrent txns appear as if executed serially

Durability: Results of committed txns survive failures

# Consistency disambiguation

Consistency in ACID refers to integrity constraints in applications

e.g. Bank account balance should always be >= 0

Consistency in context of availability refers to linearizability

Linearizability: once a write completes, all later reads should see that value

Consistency here describes guarantees about a *single item*

e.g. CAP theorem, Dynamo

# Isolation

How to ensure *correctness* when running concurrent txns?

# Problems caused by concurrency?

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

Dirty read: uncommitted results can be read by a txn

Non-repeatable read: two reads in the same txn can return different results

Phantom read: later reads in the same txn can return extra rows

```
BEGIN TRANSACTION
SELECT * FROM students
SELECT * FROM students
COMMIT
```

```
BEGIN TRANSACTION
UPDATE students SET gpa = 3.6 WHERE id = 1
INSERT INTO students VALUES (2, "Jack", 4.0)
COMMIT
```

# 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

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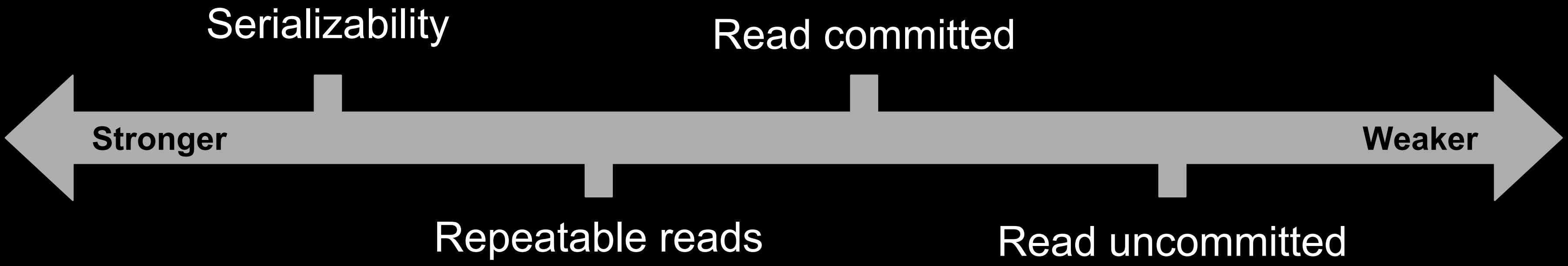
Dirty read

# Levels of isolation



# Levels of isolation

Read uncommitted: no restrictions on reads

Read committed: no dirty reads

Repeatable reads: rows returned by two reads in the same txn are unchanged

Serializability: txns behave as if executed one after another (strongest)

# Levels of isolation

| Isolation level | Dirty read | Nonrepeatable read | Phantom |
|---|---|---|---|
| **Read uncommitted** | Yes | Yes | Yes |
| **Read committed** | No | Yes | Yes |
| **Repeatable read** | No | No | Yes |
| **Snapshot** | No | No | No |
| **Serializable** | No | No | No |

# Fixing concurrency problems

Strawman: Just run txns serially — prohibitive performance

Observation: Problems only arise when

1. Two txns touch the same table
2. At least one of these txns involve a *write* to the table

Key idea: Permit schedules whose effects are *equivalent* to serial schedules

# Conflict serializability

Two operations conflict if

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

Two operations are conflict equivalent if

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

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

# Testing for conflict serializability

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

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NOT conflict serializable

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Another way to test conflict serializability:

- Draw arrows between conflicting operations
- Arrow points in the direction of time
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No cycles,
conflict serializable

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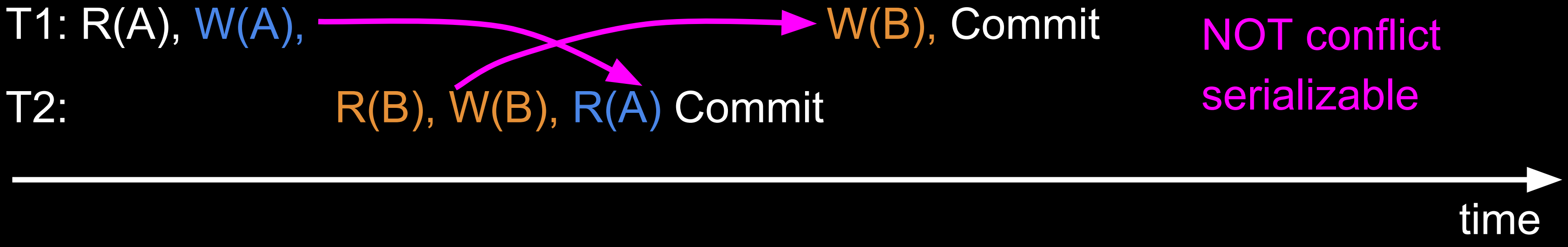


Cycles exist, NOT conflict serializable

# Implementing conflict serializability

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

2PL guarantees conflict serializability by disallowing cycles

- Edge from Ti to Tj means Ti acquired lock first and Tj has to wait
- Edge from Tj to Ti means Tj acquired lock first and Ti has to wait
- Cycles mean DEADLOCK

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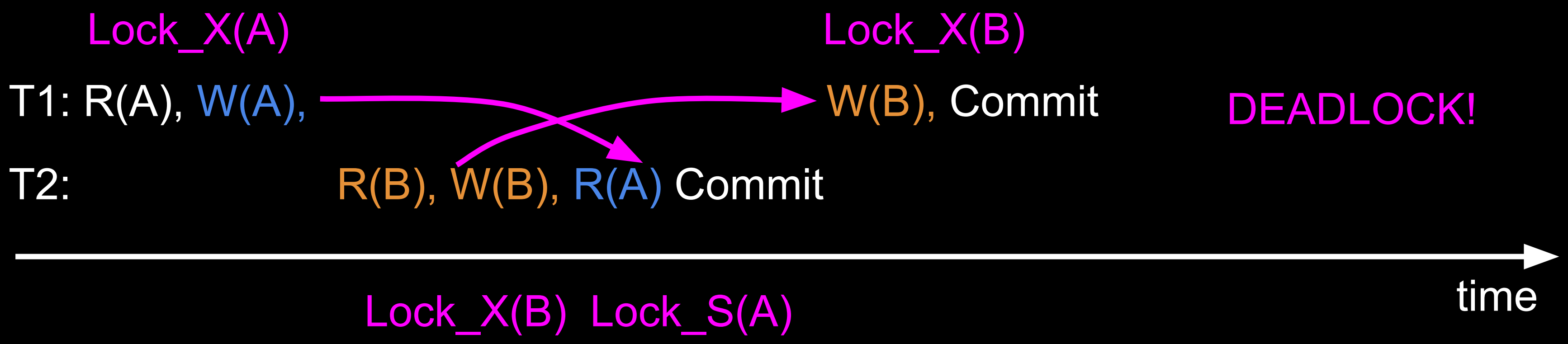

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2PL guarantees conflict serializability by disallowing cycles

- Edge from Ti to Tj means Ti acquired lock first and Tj has to wait
- Edge from Tj to Ti means Tj acquired lock first and Ti has to wait
- Cycles mean DEADLOCK
- Deal with deadlocks by aborting one of the two txns (e.g. detect + 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 txn causes the rollback of another

# Strict 2PL

Release locks at the end of the txn

Variant of 2PL implemented by most databases in practice

| | |
|---|---|
| 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) |
| | PRINT(A+B) |
| Read(B) | |
| B := B +50 | |
| Write(B) | |
| Unlock(B) | |

Is this a 2PL schedule?

No, and it is not conflict serializable

| | |
|---|---|
| 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) |
| | PRINT(A+B) |

Is this a 2PL schedule?

Yes, and it is conflict serializable

Is this a Strict 2PL schedule?

No, cascading aborts possible

| | |
|---|---|
| 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) |
| | PRINT(A+B) |
| | Unlock(A) |
| | Unlock(B) |

Is this a 2PL schedule?

Yes, and it is conflict serializable

Is this a Strict 2PL schedule?

Yes, cascading aborts not possible

# Recap

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# Two ways of implementing serializability

Issues with 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
3. Ensure correctness by aborting txns if conflict occurs

# Optimistic concurrency control

Modify (Read): Read committed values, write changes locally

Verify: Check if a conflict would occur at commit

Commit (Write): If no conflict, commit, else abort

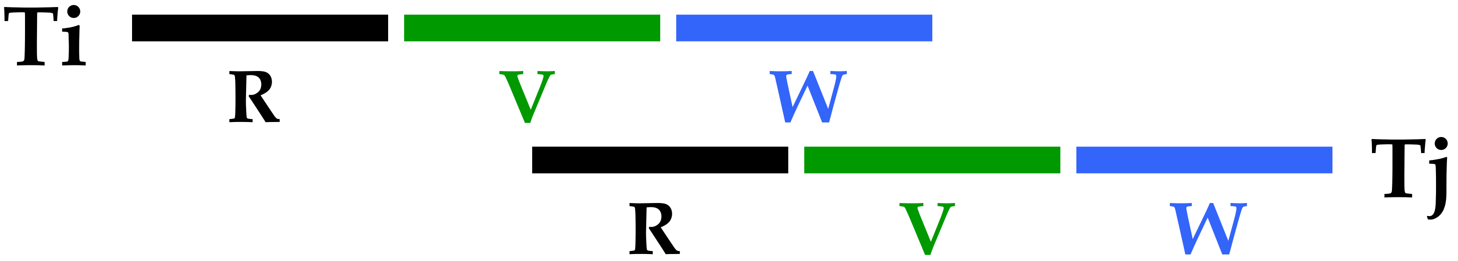
# Test 1

**For all i and j such that Ti < Tj, check that Ti completes before Tj begins**

# Test 2

**For all i and j such that Ti < Tj, check that:**

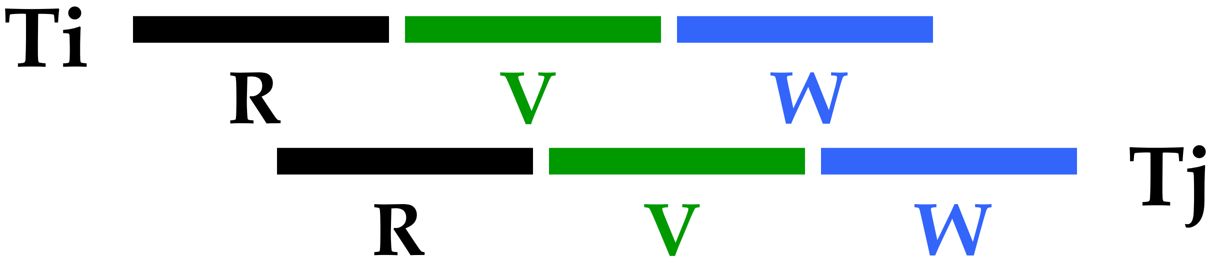
- Ti completes before Tj begins its Write phase
- WriteSet(Ti) ∩ ReadSet(Tj) is empty



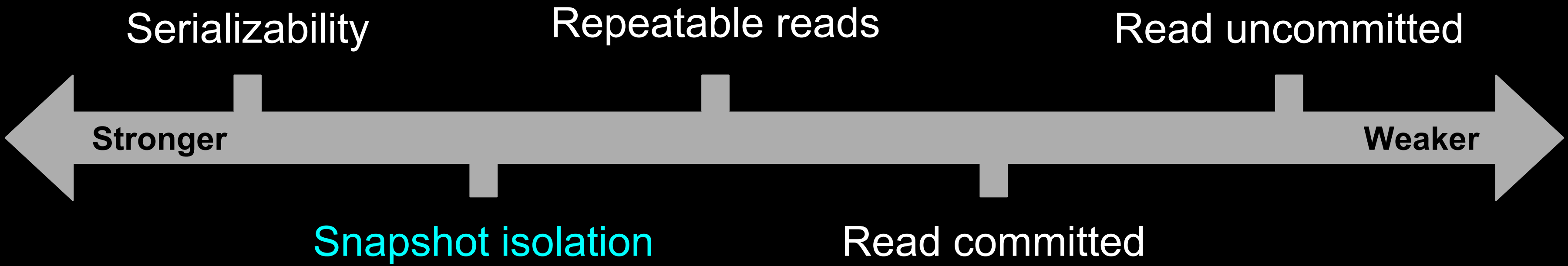
# Test 3

**For all i and j such that Ti < Tj, check that:**

- Ti completes Read phase before Tj does
- WriteSet(Ti) ∩ ReadSet(Tj) is empty
- WriteSet(Ti) ∩ WriteSet(Tj) is empty



# Levels of isolation



# Snapshot isolation

All reads see a consistent snapshot of the database

Commit only if no write-write conflicts with concurrent txns

Intuition: each write creates a new snapshot, and concurrent reads may return values from older snapshots

# Snapshot isolation advantages

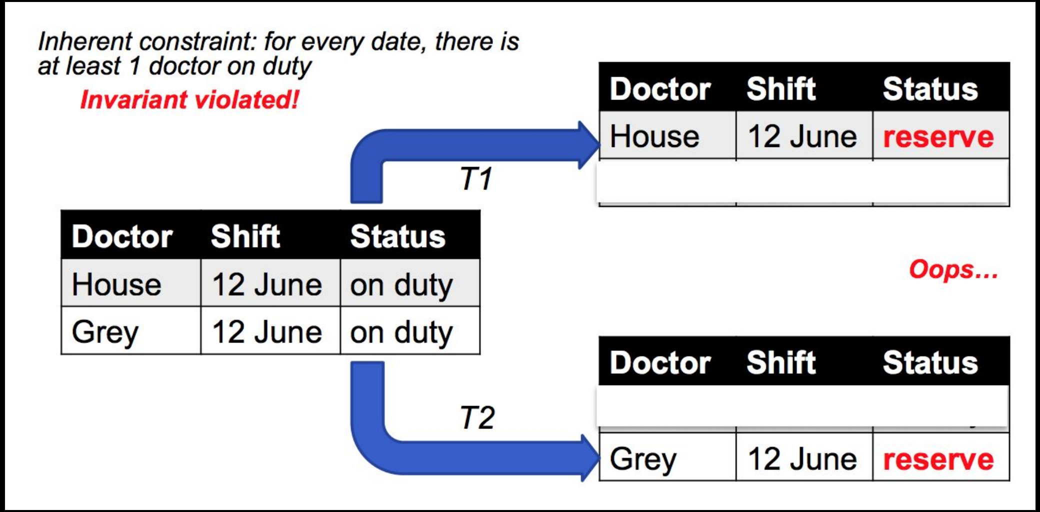
Super fast reads + most concurrency problems are solved

- No non-repeatable reads
- No dirty reads
- No lost updates
- (why?)

# Snapshot isolation < serializability

Write skew problem: txns modify different items (hence no write conflict) but violate integrity constraints

Rare in practice!



# Snapshot isolation implementation

Most popular implementation: multiversion concurrency control (MVCC)

Each txn T is assigned a timestamp TS

Reads return the latest value written before TS

Writes abort if another txn has updated the value in the same snapshot after TS

(Details in lecture)

# Further reading

https://inst.eecs.berkeley.edu/~cs186/fa05/lecs/17TransIntro-6up.pdf

https://inst.eecs.berkeley.edu/~cs186/fa05/lecs/18cc-6up.pdf

https://inst.eecs.berkeley.edu/~cs162/sp11/Lectures/lec18-transactionsx4.pdf

https://db.in.tum.de/teaching/ws1314/transactions/pdf/SnapshotIsolation.pdf?lang=de

https://courses.cs.washington.edu/courses/cse444/12sp/lectures/lecture16-transactions-snapshot.pdf

https://msdn.microsoft.com/en-us/library/ms189122(v=sql.105).aspx