# CSE 444: Database Internals

Lectures 14
Transactions: Locking



## Announcements

- Quiz 1+2 Friday in class
  - Last quarter's quiz linked in calendar
  - 1 page (2 sides) of notes allowed
  - Most important things to study are labs, including your implementation choices and the related material
- HW 5 due tonight
- Lab 3 part 1 due *Saturday* 11pm
  - Less times for labs in general



## Scheduler

- The scheduler:
- Module that schedules the transaction's actions, ensuring serializability
- Two main approaches
- Pessimistic: locks
- Optimistic: timestamps, multi-version, validation



## Pessimistic Scheduler

Simple idea:

- Each element has a unique lock
- Each transaction must first acquire the lock before reading/writing that element
- If the lock is taken by another transaction, then wait
- The transaction must release the lock(s)



## Notation

$L_i(A)$ = transaction $T_i$ acquires lock for element A

$U_i(A)$ = transaction $T_i$ releases lock for element A



## A Non-Serializable Schedule

| T1 | T2 |
|---|---|
| READ(A, t) | |
| t := t+100 | |
| WRITE(A, t) | |
| | READ(A,s) |
| | s := s*2 |
| | WRITE(A,s) |
| | READ(B,s) |
| | s := s*2 |
| | WRITE(B,s) |
| READ(B, t) | |
| t := t+100 | |
| WRITE(B,t) | |

## Example

| T1 | T2 |
|---|---|
| $L_1(A)$; READ(A, t) | |
| t := t+100 | |
| WRITE(A, t); $U_1(A)$; $L_1(B)$ | |
| | $L_2(A)$; READ(A,s) |
| | s := s*2 |
| | WRITE(A,s); $U_2(A)$; |
| | $L_2(B)$; DENIED… |
| READ(B, t) | |
| t := t+100 | |
| WRITE(B,t); $U_1(B)$; | |
| | …GRANTED; READ(B,s) |
| | s := s*2 |
| | WRITE(B,s); $U_2(B)$; |

Scheduler has ensured a conflict-serializable schedule



## But…

| T1 | T2 |
|---|---|
| $L_1(A)$; READ(A, t) | |
| t := t+100 | |
| WRITE(A, t); $U_1(A)$; | |
| | $L_2(A)$; READ(A,s) |
| | s := s*2 |
| | WRITE(A,s); $U_2(A)$; |
| | $L_2(B)$; READ(B,s) |
| | s := s*2 |
| | WRITE(B,s); $U_2(B)$; |
| $L_1(B)$; READ(B, t) | |
| t := t+100 | |
| WRITE(B,t); $U_1(B)$; | |

Locks did not enforce conflict-serializability !!! What's wrong ?

## Two Phase Locking (2PL)

The 2PL rule:

- In every transaction, all lock requests must precede all unlock requests
- This ensures conflict serializability ! (will prove this shortly)



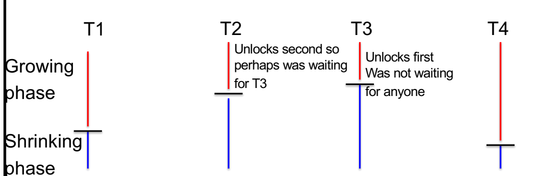
## Example: 2PL transactions

| T1 | T2 |
|---|---|
| $L_1(A)$; $L_1(B)$; READ(A, t) | |
| t := t+100 | |
| WRITE(A, t); $U_1(A)$ | |
| | $L_2(A)$; READ(A,s) |
| | s := s*2 |
| | WRITE(A,s); |
| | $L_2(B)$; DENIED… |
| READ(B, t) | |
| t := t+100 | |
| WRITE(B,t); $U_1(B)$; | |
| | …GRANTED; READ(B,s) |
| | s := s*2 |
| | WRITE(B,s); $U_2(A)$; $U_2(B)$; |

Now it is conflict-serializable



## Example with Multiple Transactions




Equivalent to each transaction executing entirely the moment it enters shrinking phase



## Two Phase Locking (2PL)

**Theorem**: 2PL ensures conflict serializability

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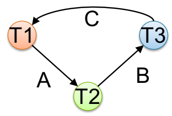
**Proof**. Suppose not: then there exists a cycle in the precedence graph.



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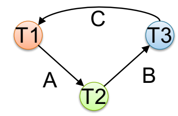


Then there is the following **temporal** cycle in the schedule:



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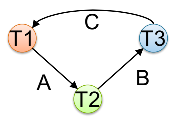


Then there is the following **temporal** cycle in the schedule:
$U_1(A) \rightarrow L_2(A)$ why?



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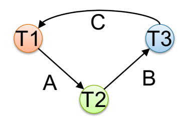


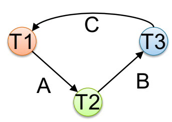

Then there is the following **temporal** cycle in the schedule:
$U_1(A) \rightarrow L_2(A)$
$L_2(A) \rightarrow U_2(B)$ why?



## Two Phase Locking (2PL)

**Theorem**: 2PL ensures conflict serializability

**Proof**. Suppose not: then there exists a cycle in the precedence graph.




Then there is the following **temporal** cycle in the schedule:
$U_1(A) \rightarrow L_2(A)$
$L_2(A) \rightarrow U_2(B)$
$U_2(B) \rightarrow L_3(B)$
$L_3(B) \rightarrow U_3(C)$
$U_3(C) \rightarrow L_1(C)$
$L_1(C) \rightarrow U_1(A)$

Contradiction

## A New Problem: Non-recoverable Schedule

| T1 | T2 |
|---|---|
| $L_1(A)$; $L_1(B)$; READ(A, t) | |
| t := t+100 | |
| WRITE(A, t); $U_1(A)$ | |
| | $L_2(A)$; READ(A,s) |
| | s := s*2 |
| | WRITE(A,s); |
| | $L_2(B)$; DENIED… |
| READ(B, t) | |
| t := t+100 | |
| WRITE(B,t); $U_1(B)$; | |
| | …GRANTED; READ(B,s) |
| | s := s*2 |
| | WRITE(B,s); $U_2(A)$; $U_2(B)$; |
| | **Commit** |
| **Abort** | |

## Strict 2PL

- Strict 2PL: All locks held by a transaction are released when the transaction is completed; release happens at the time of COMMIT or ROLLBACK
- Schedule is recoverable
- Schedule avoids cascading aborts



## Strict 2PL

| T1 | T2 |
|---|---|
| $L_1(A)$; READ(A)<br>A :=A+100<br>WRITE(A); | |
| | $L_2(A)$; DENIED… |
| $L_1(B)$; READ(B)<br>B :=B+100<br>WRITE(B);<br>$U_1(A)$,$U_1(B)$; Rollback | |
| | …GRANTED; READ(A)<br>A := A*2<br>WRITE(A);<br>$L_2(B)$; READ(B)<br>B := B*2<br>WRITE(B);<br>$U_2(A)$; $U_2(B)$; Commit |



## Summary of Strict 2PL

- Ensures serializability, recoverability, and avoids cascading aborts
- Issues?



## Summary of Strict 2PL

- Ensures serializability, recoverability, and avoids cascading aborts
- Issues: implementation, lock modes, granularity, deadlocks, performance



## The Locking Scheduler

Task 1: -- act on behalf of the transaction

Add lock/unlock requests to transactions

- Examine all READ(A) or WRITE(A) actions
- Add appropriate lock requests
- On COMMIT/ROLLBACK release all locks
- Ensures Strict 2PL !



## The Locking Scheduler

Task 2: -- act on behalf of the system
Execute the locks accordingly

- Lock table: a big, critical data structure in a DBMS !
- When a lock is requested, check the lock table
  - Grant, or add the transaction to the element's wait list
- When a lock is released, re-activate a transaction from its wait list
- When a transaction aborts, release all its locks
- Check for deadlocks occasionally

## Lock Modes

- S = shared lock (for READ)
- X = exclusive lock (for WRITE)

Lock compatibility matrix:

| | None | S | X |
|---|---|---|---|
| None | OK | OK | OK |
| S | OK | OK | Conflict |
| X | OK | Conflict | Conflict |



## Lock Granularity

- Fine granularity locking (e.g., tuples)
  - 
  - 
- Coarse grain locking (e.g., tables, predicate locks)
  - 
  - 



## Lock Granularity

- Fine granularity locking (e.g., tuples)
  - High concurrency
  - High overhead in managing locks
- Coarse grain locking (e.g., tables, predicate locks)
  - 
  - 



## Lock Granularity

- Fine granularity locking (e.g., tuples)
  - High concurrency
  - High overhead in managing locks
- Coarse grain locking (e.g., tables, predicate locks)
  - Many false conflicts
  - Less overhead in managing locks

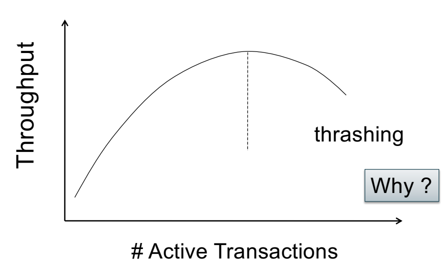


## Deadlocks

- Cycle in the wait-for graph:
  - T1 waits for T2
  - T2 waits for T3
  - T3 waits for T1
- Deadlock detection
  - Timeouts
  - Wait-for graph
- Deadlock avoidance
  - Acquire locks in pre-defined order
  - Acquire all locks at once before starting



## Lock Performance



## Phantom Problem

- So far we have assumed the database to be a *static* collection of elements (=tuples)
- If tuples are inserted/deleted then the *phantom problem* appears



## Phantom Problem

| T1 | T2 |
| --- | --- |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |
| | INSERT INTO Product(name, color)<br>VALUES ('gizmo','blue') |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |

Is this schedule serializable ?



## Phantom Problem

| T1 | T2 |
| --- | --- |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |
| | INSERT INTO Product(name, color)<br>VALUES ('gizmo','blue') |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |

Suppose there are two blue products, X1, X2:

R1(X1),R1(X2),W2(X3),R1(X1),R1(X2),R1(X3)



## Phantom Problem

| T1 | T2 |
| --- | --- |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |
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Suppose there are two blue products, X1, X2:

R1(X1),R1(X2),W2(X3),R1(X1),R1(X2),R1(X3)

This is conflict serializable ! What's wrong ??



## Phantom Problem

| T1 | T2 |
| --- | --- |
| SELECT *<br>FROM Product<br>WHERE color='blue' | |
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Suppose there are two blue products, X1, X2:

R1(X1),R1(X2),W2(X3),R1(X1),R1(X2),R1(X3)

Not serializable due to ***phantoms***



## Phantom Problem

- A "phantom" is a tuple that is invisible during part of a transaction execution but not invisible during the entire execution
- In our example:
  - T1: reads list of products
  - T2: inserts a new product
  - T1: re-reads: a new product appears !

## Phantom Problem

- In a ***static*** database:
  - Conflict serializability implies serializability
- In a ***dynamic*** database, this may fail due to phantoms
- Strict 2PL guarantees conflict serializability, but not serializability



## Dealing With Phantoms

- Lock the entire table, or
- Lock the index entry for 'blue'
  - If index is available
- Or use predicate locks
  - A lock on an arbitrary predicate

Dealing with phantoms is expensive !



## Isolation Levels in SQL

1. "Dirty reads"
   SET TRANSACTION ISOLATION LEVEL READ UNCOMMITTED
2. "Committed reads"
   SET TRANSACTION ISOLATION LEVEL READ COMMITTED
3. "Repeatable reads"
   SET TRANSACTION ISOLATION LEVEL REPEATABLE READ
4. Serializable transactions
   SET TRANSACTION ISOLATION LEVEL SERIALIZABLE

ACID



## 1. Isolation Level: Dirty Reads

- "Long duration" WRITE locks
  - Strict 2PL
- No READ locks
  - Read-only transactions are never delayed

Possible pbs: dirty and inconsistent reads



## 2. Isolation Level: Read Committed

- "Long duration" WRITE locks
  - Strict 2PL
- "Short duration" READ locks
  - Only acquire lock while reading (not 2PL)

Unrepeatable reads
When reading same element twice,
may get two different values



## 3. Isolation Level: Repeatable Read

- "Long duration" WRITE locks
  - Strict 2PL
- "Long duration" READ locks
  - Strict 2PL

This is not serializable yet !!!

Why ?

## 4. Isolation Level Serializable

- "Long duration" WRITE locks
  - Strict 2PL
- "Long duration" READ locks
  - Strict 2PL
- Predicate locking
  - To deal with phantoms



## READ-ONLY Transactions

```
Client 1: START TRANSACTION
          INSERT INTO SmallProduct(name, price)
                   SELECT pname, price
                   FROM Product
                   WHERE price <= 0.99

          DELETE  FROM Product
                    WHERE price <=0.99
          COMMIT

Client 2: SET TRANSACTION READ ONLY
          START TRANSACTION
          SELECT count(*)
          FROM Product

          SELECT count(*)
          FROM SmallProduct
          COMMIT
```

May improve performance



## Commercial Systems

Always check documentation!

- DB2: Strict 2PL
- SQL Server:
  - Strict 2PL for standard 4 levels of isolation
  - Multiversion concurrency control for snapshot isolation
- PostgreSQL: Snapshot isolation; recently: seralizable Snapshot isolation (!)
- Oracle: Snapshot isolation