Introduction to Database Systems
CSE 414

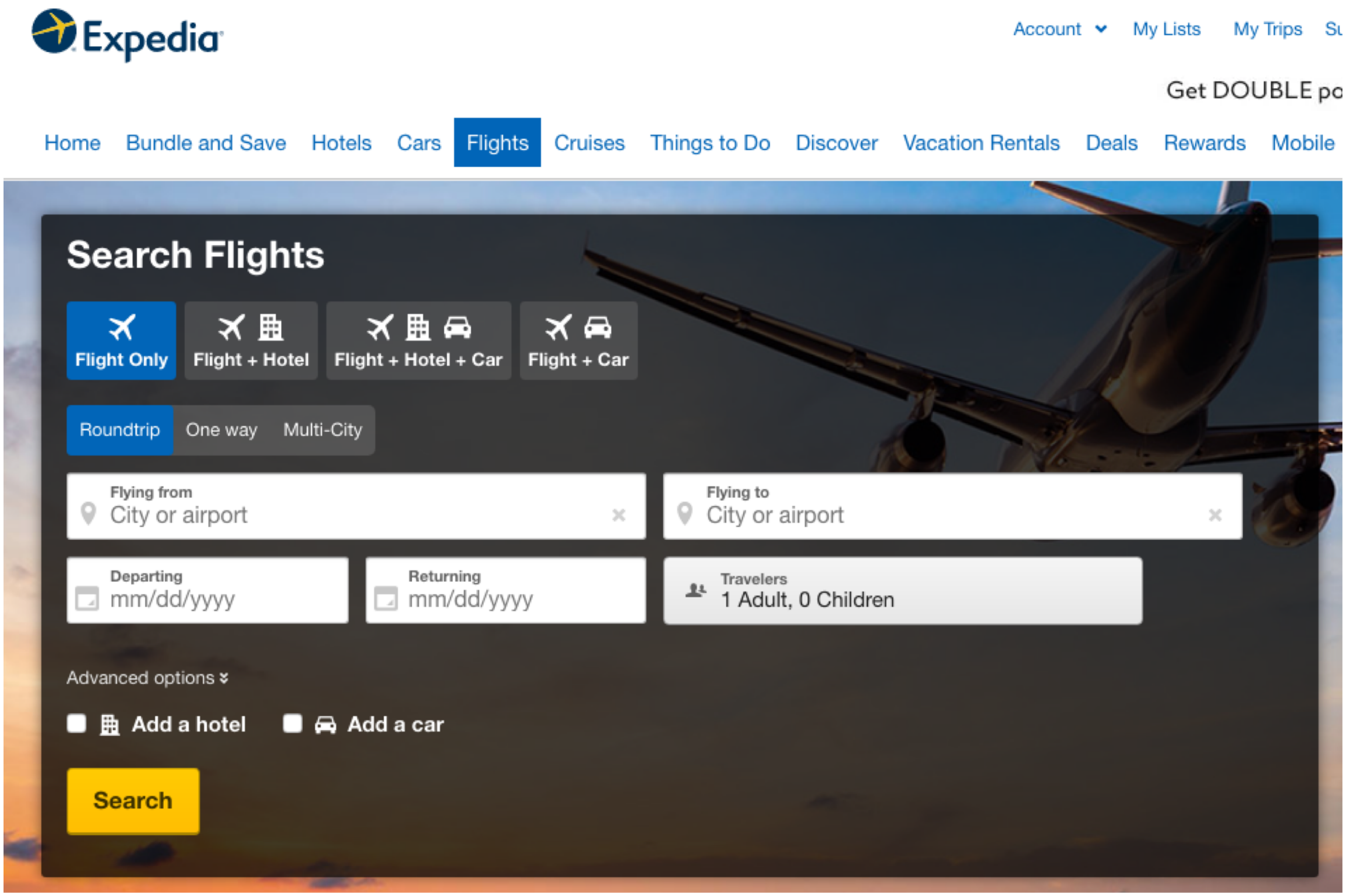
Lecture 26: More Transactions

Announcements

- Web quiz due tonight
- HW7 due tonight

- HW8 out, make sure to do setup early

HW8


Expedia
Account
My Lists
My Trips
Get DOUBLE po
Home
Bundle and Save
Hotels
Cars
Flights
Cruises
Things to Do
Discover
Vacation Rentals
Deals
Rewards
Mobile
Search Flights
Flight Only
Flight + Hotel
Flight + Hotel + Car
Flight + Car
Roundtrip
One way
Multi-City
Flying from
City or airport
Flying to
City or airport
Departing
mm/dd/yyyy
Returning
mm/dd/yyyy
Travelers
1 Adult, 0 Children
Advanced options
Add a hotel
Add a car
Search

What can go wrong?

- Manager: balance budgets among projects
  - Remove $10k from project A
  - Add $7k to project B
  - Add $3k to project C

- CEO: check company's total balance
  - `SELECT SUM(money) FROM budget;`

- This is called a dirty / inconsistent read
aka a WRITE-READ conflict

What can go wrong?

- App 1:
  ```
  SELECT inventory FROM products WHERE pid = 1
  ```
- App 2:
  ```
  UPDATE products SET inventory = 0 WHERE pid = 1
  ```
- App 1:
  ```
  SELECT inventory * price FROM products
  WHERE pid = 1
  ```
- This is known as an unrepeatable read
  aka READ-WRITE conflict

What can go wrong?

Account 1 = $100
Account 2 = $100
Total = $200

- App 1:
  - Set Account 1 = $200
  - Set Account 2 = $0
- App 2:
  - Set Account 2 = $200
  - Set Account 1 = $0
- At the end:
  - Total = $200

- App 1: Set Account 1 = $200
- App 2: Set Account 2 = $200
- App 1: Set Account 2 = $0
- App 2: Set Account 1 = $0
- At the end:
  - Total = $0

This is called the lost update aka WRITE-WRITE conflict

What can go wrong?

- Buying tickets to the next Bieber concert:
  - Fill up form with your mailing address
  - Put in debit card number
  - Click submit
  - Screen shows money deducted from your account
  - [Your browser crashes]

Lesson:

Changes to the database should be ALL or NOTHING

Transactions

- Collection of statements that are executed atomically (logically speaking)

```
BEGIN TRANSACTION
  [SQL statements]
COMMIT    or
ROLLBACK (=ABORT)
```

```
[single SQL statement]
```

If BEGIN… missing, then TXN consists of a single instruction

Know your ~~chemistry~~ transactions: ACID

- Atomic
  - State shows either all the effects of txn, or none of them
- Consistent
  - Txn moves from a DBMS state where integrity holds, to another where integrity holds
    - remember integrity constraints?
- Isolated
  - Effect of txns is the same as txns running one after another (i.e., looks like batch mode)
- Durable
  - Once a txn has committed, its effects remain in the database

Transaction Schedules

Schedules

A **schedule** is a sequence of interleaved actions from all transactions

Serial Schedule

- A *serial schedule* is one in which transactions are executed one after the other, in some sequential order
- **Fact:** nothing can go wrong if the system executes transactions serially
  - (up to what we have learned so far)
  - But DBMS don't do that because we want better overall system performance

Example

A and B are elements in the database
t and s are variables in txn source code

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

Example of a (Serial) Schedule

Time ↓

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

Another Serial Schedule

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

Time

Review: Serializable Schedule

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

A Serializable Schedule

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

Time ↓

A Serializable Schedule

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

Time

A Serializable Schedule

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

Time ↓

A Serializable Schedule

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

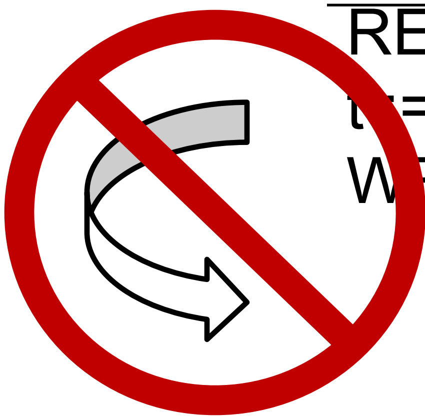
Time

This is a serializable schedule.
This is NOT a serial schedule

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)	

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)	

How do We Know if a Schedule is Serializable?

Notation:

T_1: $r_1(A); w_1(A); r_1(B); w_1(B)$
T_2: $r_2(A); w_2(A); r_2(B); w_2(B)$

Key Idea: Focus on *conflicting* operations

Conflicts

- Write-Read – WR
- Read-Write – RW
- Write-Write – WW
- Read-Read?

Conflict Serializability

Conflicts: (i.e., swapping will change program behavior)

Two actions by same transaction T_i: $r_i(X); w_i(Y)$

Two writes by T_i, T_j to same element $w_i(X); w_j(X)$

Read/write by T_i, T_j to same element $w_i(X); r_j(X)$

$r_i(X); w_j(X)$

Conflict Serializability

- A schedule is *conflict serializable* if it can be transformed into a serial schedule by a series of swappings of adjacent non-conflicting actions

- Every conflict-serializable schedule is serializable
- The converse is not true (why?)
  – Conflict serializable only looks at conflicts, not values

  - Schedules might have conflicts but would have the same output no matter the order depending on the values

Conflict Serializability

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

Conflict Serializability

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

Conflict Serializability

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

Conflict Serializability

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_2(A); r_1(B); w_2(A); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

Conflict Serializability

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_2(A); r_1(B); w_2(A); w_1(B); r_2(B); w_2(B)$

$r_1(A); w_1(A); r_1(B); r_2(A); w_2(A); w_1(B); r_2(B); w_2(B)$

....

$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

Testing for Conflict-Serializability

Precedence graph:

- A node for each transaction T_i,
- An edge from T_i to T_j whenever an action in T_i conflicts with, and comes before an action in T_j

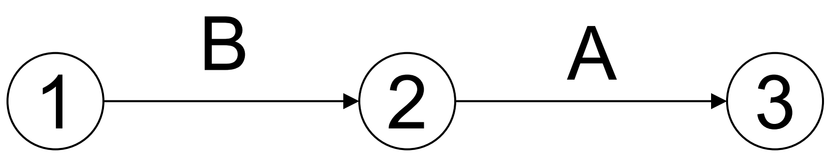
- The schedule is conflict-serializable iff the precedence graph is acyclic

Example 1

$r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B)$

Example 1

$r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B)$



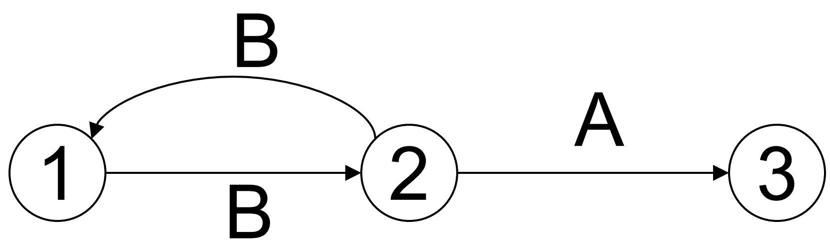
This schedule is conflict-serializable

Example 2

$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B)$

Example 2

$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B)$



This schedule is NOT conflict-serializable

Implementing Transactions

Scheduler

- Scheduler = the module that schedules the transaction's actions, ensuring serializability
- Also called Concurrency Control Manager
- We discuss next how a scheduler may be implemented

Implementing a Scheduler

Major differences between database vendors

- Locking Scheduler
  - Aka "pessimistic concurrency control"
  - SQLite, SQL Server, DB2
- Multiversion Concurrency Control (MVCC)
  - Aka "optimistic concurrency control"
  - Postgres, Oracle: Snapshot Isolation (SI)

We discuss only locking schedulers in this class

Locking 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)

By using locks scheduler ensures conflict-serializability

What Data Elements are Locked?

Major differences between vendors:

- Lock on the entire database
  - SQLite

- Lock on individual records
  - SQL Server, DB2, etc

More Notations

$L_i(A)$ = 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)	
A := A+100	
WRITE(A)	
	READ(A)
	A := A*2
	WRITE(A)
	READ(B)
	B := B*2
	WRITE(B)
READ(B)	
B := B+100	
WRITE(B)	

Example

T1	T2
$L_1(A)$; READ(A)	
A := A+100	
WRITE(A); $U_1(A)$; $L_1(B)$	
	$L_2(A)$; READ(A)
	A := A*2
	WRITE(A); $U_2(A)$;
	$L_2(B)$; BLOCKED…
READ(B)	
B := B+100	
WRITE(B); $U_1(B)$;	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); $U_2(B)$;

Scheduler has ensured a conflict-serializable schedule

But what if…

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

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

Example: 2PL transactions

T1	T2
$L_1(A)$; $L_1(B)$; READ(A)	
A := A+100	
WRITE(A); $U_1(A)$	
	$L_2(A)$; READ(A)
	A := A*2
	WRITE(A);
	$L_2(B)$; BLOCKED…
READ(B)	
B := B+100	
WRITE(B); $U_1(B)$;	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); $U_2(A)$; $U_2(B)$;

Now it is conflict-serializable

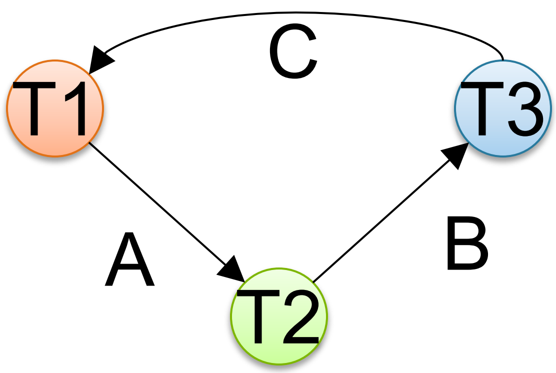
Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

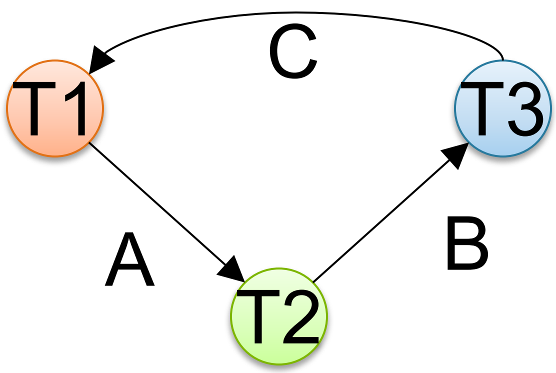
Proof. Suppose not: then there exists a cycle in the precedence graph.



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:

Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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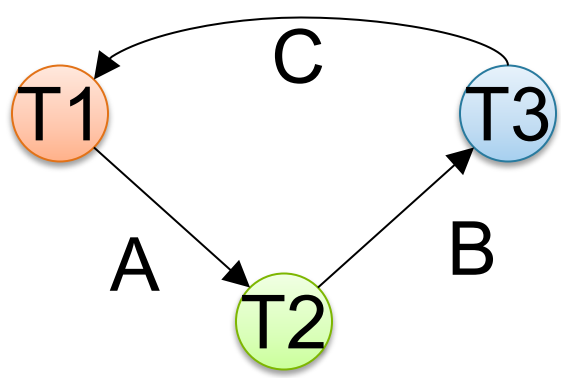


Then there is the following **temporal** cycle in the schedule:

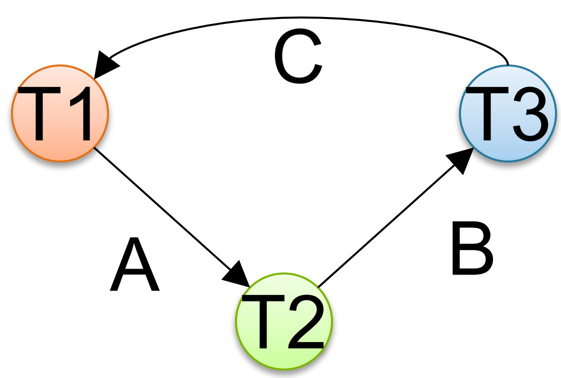
$U_1(A) \rightarrow L_2(A)$ why?

$U_1(A)$ happened strictly *before* $L_2(A)$

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:

$U_1(A) \rightarrow L_2(A)$

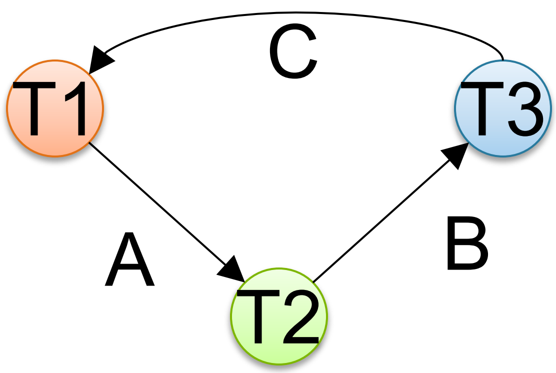
$L_2(A) \rightarrow U_2(B)$ why?

$L_2(A)$ happened strictly *before* $U_1(A)$

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:

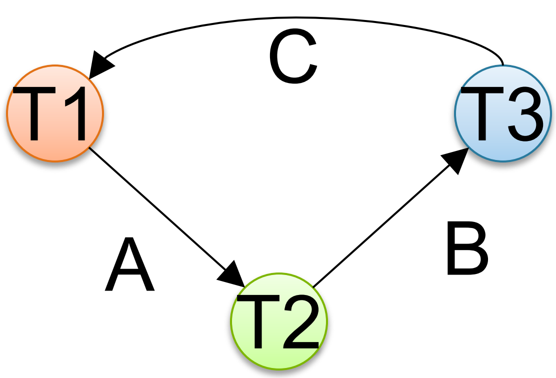
$U_1(A) \rightarrow L_2(A)$

$L_2(A) \rightarrow U_2(B)$ 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:

$U_1(A) \rightarrow L_2(A)$

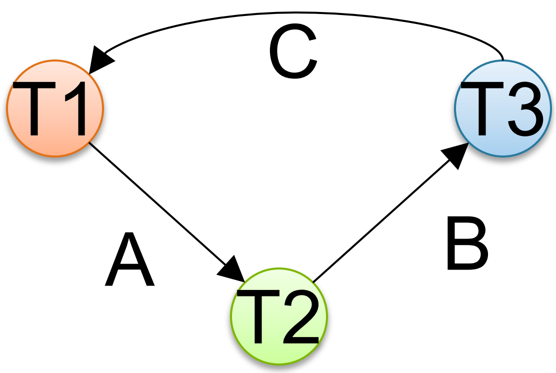
$L_2(A) \rightarrow U_2(B)$

$U_2(B) \rightarrow L_3(B)$ 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:

$U_1(A) \rightarrow L_2(A)$

$L_2(A) \rightarrow U_2(B)$

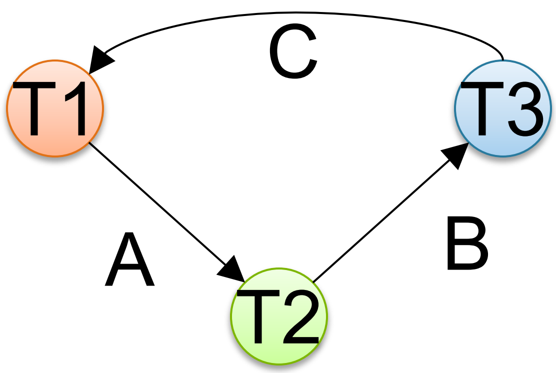
$U_2(B) \rightarrow L_3(B)$

......etc.....

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:

$U_1(A) \rightarrow L_2(A)$
$L_2(A) \rightarrow U_2(B)$
$U_2(B) \rightarrow L_3(B)$
$L_3(B) \rightarrow U_3(C)$
$U_3(C) \rightarrow L_1(C)$
$L_1(C) \rightarrow U_1(A)$

Cycle in time: Contradiction

A New Problem: Non-recoverable Schedule

T1	T2
L_1(A); L_1(B); READ(A)	
A :=A+100	
WRITE(A); U_1(A)	
	L_2(A); READ(A)
	A := A*2
	WRITE(A);
	L_2(B); BLOCKED…
READ(B)	
B :=B+100	
WRITE(B); U_1(B);	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); U_2(A); U_2(B);
	Commit
Rollback	

A New Problem: Non-recoverable Schedule

T1	T2
$L_1(A)$; $L_1(B)$; READ(A)	
A :=A+100	
WRITE(A); $U_1(A)$	
	$L_2(A)$; READ(A)
	A := A*2
	WRITE(A);
	$L_2(B)$; BLOCKED…
READ(B)	
B :=B+100	
WRITE(B); $U_1(B)$;	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); $U_2(A)$; $U_2(B)$;
	Commit
Rollback	

Elements A, B written by T1 are restored to their original value.

A New Problem: Non-recoverable Schedule

T1	T2
L_1(A); L_1(B); READ(A)	
A :=A+100	
WRITE(A); U_1(A)	
	L_2(A); READ(A)
	A := A*2
	WRITE(A);
	L_2(B); BLOCKED…
READ(B)	
B :=B+100	
WRITE(B); U_1(B);	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); U_2(A); U_2(B);
	Commit
Rollback	

Dirty reads of A, B lead to incorrect writes.

Elements A, B written by T1 are restored to their original value.

A New Problem: Non-recoverable Schedule

T1	T2
L_1(A); L_1(B); READ(A)	
A :=A+100	
WRITE(A); U_1(A)	
	L_2(A); READ(A)
	A := A*2
	WRITE(A);
	L_2(B); BLOCKED…
READ(B)	
B :=B+100	
WRITE(B); U_1(B);	
	…GRANTED; READ(B)
	B := B*2
	WRITE(B); U_2(A); U_2(B);
	Commit
Rollback	

Dirty reads of A, B lead to incorrect writes.

Elements A, B written by T1 are restored to their original value.

Can no longer undo!

Strict 2PL

The Strict 2PL rule:

All locks are held until commit/abort:
All unlocks are done together with commit/abort.

With strict 2PL, we will get schedules that are both conflict-serializable and recoverable

Strict 2PL

T1	T2
$L_1(A)$; READ(A)	
A :=A+100	
WRITE(A);	
	$L_2(A)$; BLOCKED…
$L_1(B)$; READ(B)	
B :=B+100	
WRITE(B);	
Rollback & $U_1(A)$;$U_1(B)$;	
	…GRANTED; READ(A)
	A := A*2
	WRITE(A);
	$L_2(B)$; READ(B)
	B := B*2
	WRITE(B);
	Commit & $U_2(A)$; $U_2(B)$;

Strict 2PL

- Lock-based systems always use strict 2PL
- Easy to implement:
  – Before a transaction reads or writes an element A, insert an L(A)
  – When the transaction commits/aborts, then release all locks
- Ensures both conflict serializability and recoverability