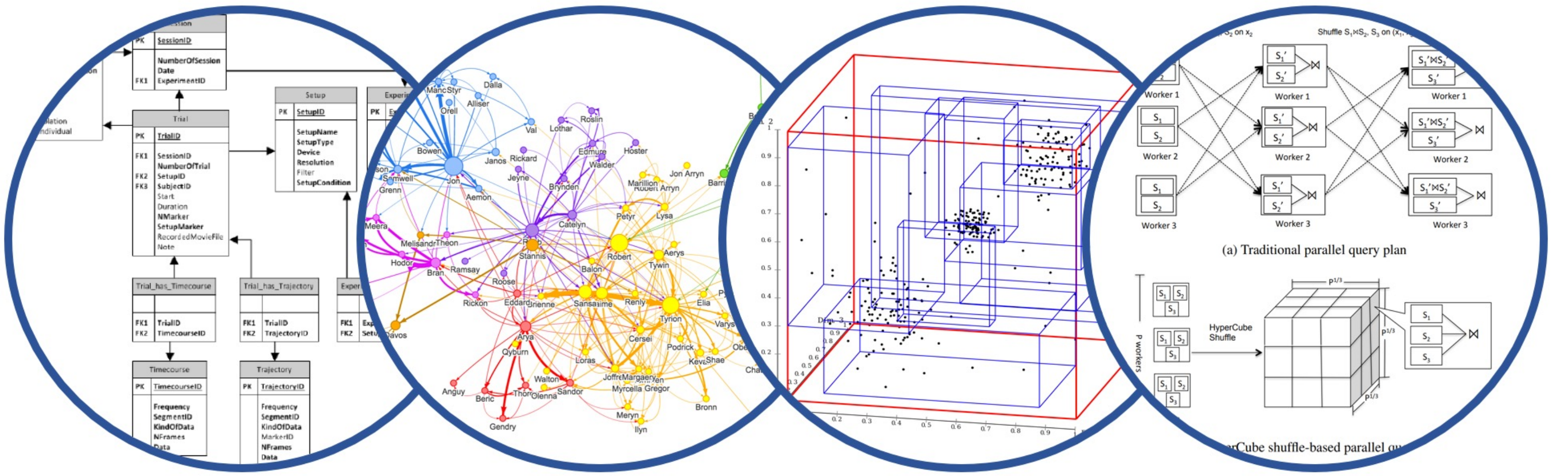

Database System Internals

Concurrency Control - Locking

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Announcement

- Lab 3 out now – Transaction Scheduler
  - Make sure to go to section for important tips!
    - Synchronized keyword is very important, but making all methods synchronized will lead to problems
  - Part 1 due Friday Feb. 14
  - Part 2 due Friday Feb. 21

About Lab 3

- In lab 3, we implement transactions
- Focus on concurrency control
  - Want to run many transactions at the same time
  - Transactions want to read and write same pages
  - Will use locks to ensure conflict serializable execution
  - Use strict 2PL
- Build your own lock manager
  - Understand how locking works in depth
  - Ensure transactions rather than threads hold locks
    - Many threads can execute different pieces of the same transaction
    - Need to detect deadlocks and resolve them by aborting a transaction
  - But use Java synchronization to protect your data structures

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

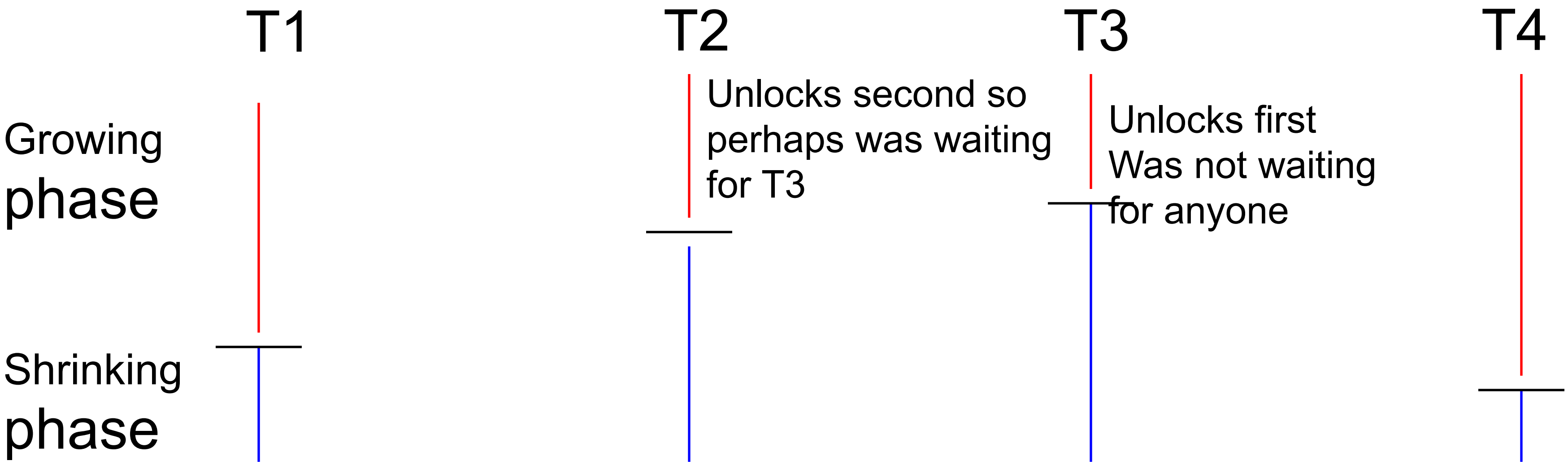
- This ensures conflict serializability ! (will prove this shortly)

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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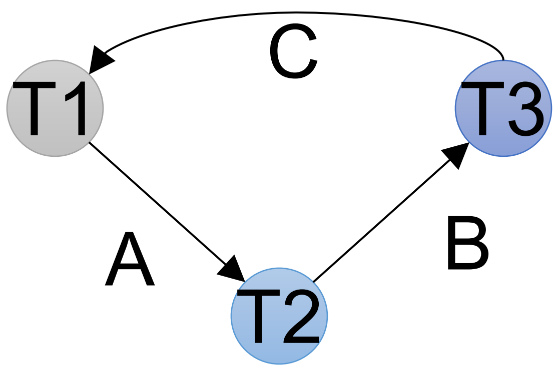
Theorem: 2PL ensures conflict serializability

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



Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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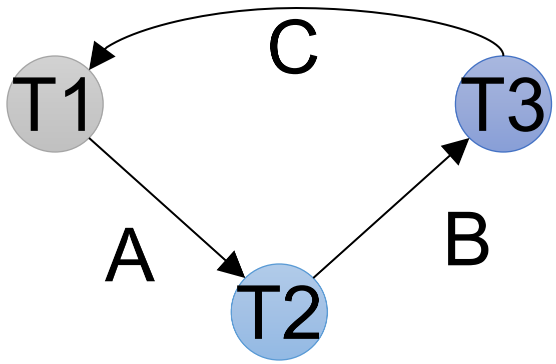

Then there is the following **temporal** cycle in the schedule:

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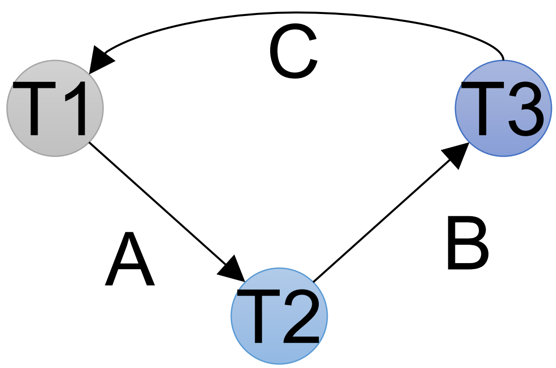

Then there is the following **temporal** cycle in the schedule:

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

Two Phase Locking (2PL)

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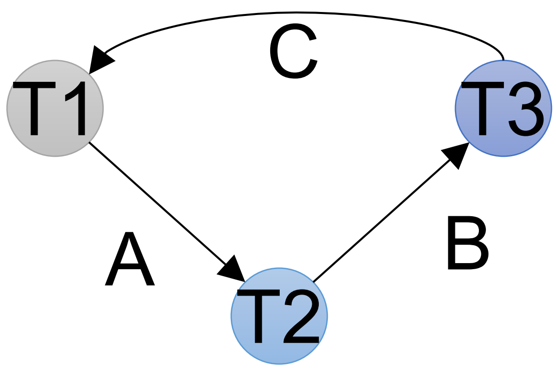


Then there is the following **temporal** cycle in the schedule:

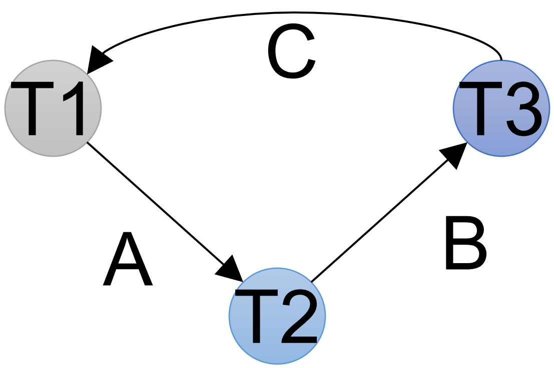
$U_1(A) \rightarrow L_2(A)$

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

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

Summary of Strict 2PL

Ensures:

- Serializability
- Recoverability
- Avoids cascading aborts

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 lock is released reactivate 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)

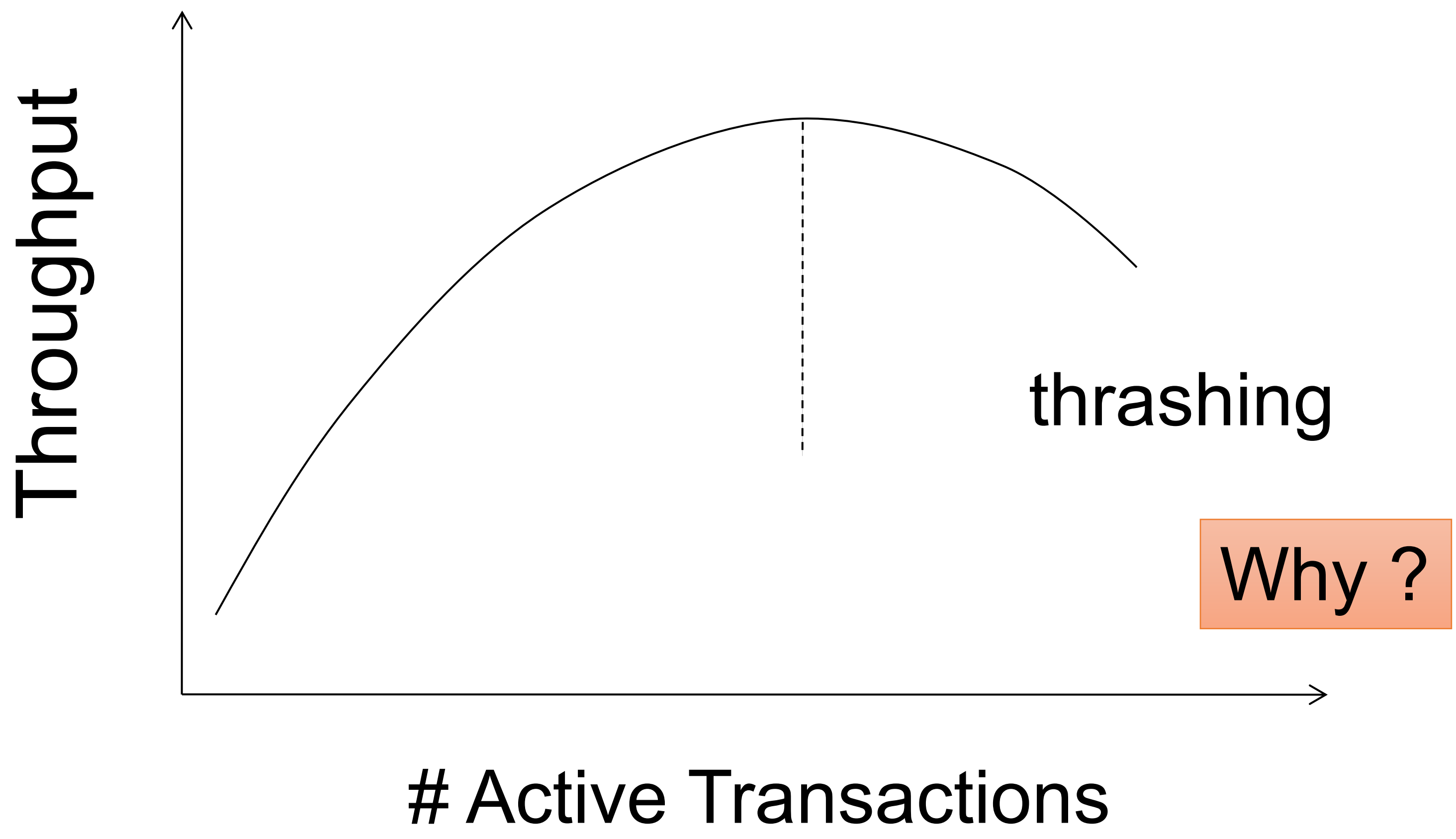
Lock compatibility matrix:

	None	S	X
None	OK	OK	OK
S	OK	OK	Conflict
X	OK	Conflict	Conflict

Lock Granularity

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

Lock Performance



2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked...			
	L(C) blocked...		
		L(D) blocked...	
			L(A) blocked...
...	...	...	...

2PL Deadlocks

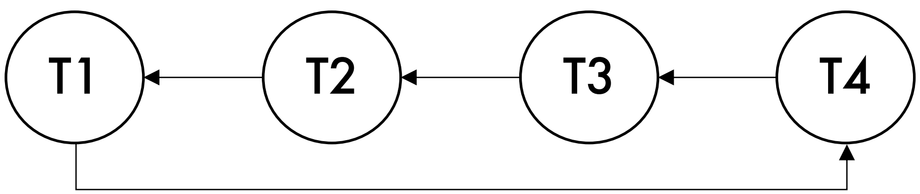
T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked…			
	L(C) blocked…		
		L(D) blocked…	
			L(A) blocked…
…		…	…

Can’t make progress since locking phase is not complete for any txn!

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked...			
	L(C) blocked...		
		L(D) blocked...	
			L(A) blocked...
...	...	...	...

- Lock requests create a precedence/waits-for graph where deadlock → cycle (2PL is doing its job!).
- Cycle detection over a graph is somewhat expensive, so we check the graph only periodically



2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked…			
	L(C) blocked…		
		L(D) blocked…	
			L(A) blocked…
…	…	…	…

If the DBMS finds a cycle:
- We rollback txns
- (Hopefully) make progress
- Eventually retry the rolledback txns

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked...			
	L(C) blocked...		
		L(D) blocked...	
			L(A) blocked...

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked...			
	L(C) blocked...		
		L(D) blocked...	
			L(A) blocked...
			Abort, U(D)

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked…			
	L(C) blocked…		
		L(D) blocked…	
			L(A) blocked…
			Abort, U(D)
		L(D)	

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked…			
	L(C) blocked…		
		L(D) blocked…	
			L(A) blocked…
			Abort, U(D)
		L(D)	
		(do operations)	

2PL Deadlocks

T1 (A, B)	T2 (B, C)	T3 (C, D)	T4 (D, A)
L(A)	L(B)	L(C)	L(D)
L(B) blocked…			
	L(C) blocked…		
		L(D) blocked…	
			L(A) blocked…
			Abort, U(D)
		L(D)	
		(do operations)	
		Commit, U(C), U(D)	
	L(C)		

Deadlocks

- Cycle in the wait-for graph:
  - T1 waits for T2
  - T2 waits for T3
  - T3 waits for T4
  - T4 waits for T1
- Deadlock detection
  - Timeouts
  - Wait-for graph
- Deadlock avoidance
  - Acquire locks in pre-defined order
  - Acquire all locks at once before starting

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

Suppose there are two blue products, A1, A2:

T1	T2
SELECT * FROM Product WHERE color=‘blue’	
	INSERT INTO Product(name, color) VALUES (‘A3’,’blue’)
SELECT * FROM Product WHERE color=‘blue’	

Is this schedule serializable ?

Phantom Problem

Suppose there are two blue products, A1, A2:

T1	T2
SELECT * FROM Product WHERE color='blue'	
	INSERT INTO Product(name, color) VALUES ('A3','blue')
SELECT * FROM Product WHERE color='blue'	

Is this schedule serializable ?

No: T1 sees a "phantom" product A3

Phantom Problem

Suppose there are two blue products, A1, A2:

T1	T2
SELECT * FROM Product WHERE color='blue'	
	INSERT INTO Product(name, color) VALUES ('A3','blue')
SELECT * FROM Product WHERE color='blue'	

$$R_1(A1);R_1(A2);W_2(A3);R_1(A1);R_1(A2);R_1(A3)$$

Phantom Problem

Suppose there are two blue products, A1, A2:

T1	T2
SELECT * FROM Product WHERE color='blue'	
	INSERT INTO Product(name, color) VALUES ('A3','blue')
SELECT * FROM Product WHERE color='blue'	

$R_1(A1);R_1(A2);W_2(A3);R_1(A1);R_1(A2);R_1(A3)$

$W_2(A3);R_1(A1);R_1(A2);R_1(A1);R_1(A2);R_1(A3)$

Phantom Problem

Suppose there are two blue products, A1, A2:

T1	T2
SELECT * FROM Product WHERE color='blue'	
	INSERT INTO Product(name, color) VALUES ('A3','blue')
SELECT * FROM Product WHERE color='blue'	

But this is conflict-serializabel

$R_1(A1);R_1(A2);W_2(A3);R_1(A1);R_1(A2);R_1(A3)$

$W_2(A3);R_1(A1);R_1(A2);R_1(A1);R_1(A2);R_1(A3)$

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 !

Dealing With Phantoms

- Lock the entire table
- 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 !

Discussion

We *always* want a serializable schedule

Strict 2PL guarantees conflict serializability

- In a ***static*** database:
  - Conflict serializability implies serializability

- In a ***dynamic*** database:
  - Need both conflict serializability *and* handling of phantoms to ensure serializability