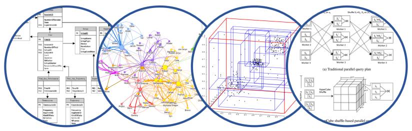

Database System Internals

Concurrency Control - Locking

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1

Announcements

- Lab 2 due tonight
  - Before final submission, clone fresh repo on attu and run “ant test-report”
- Lab 1+2 quiz on Wednesday in-class
  - Closed book. Calculator allowed but you won’t need one.
- 544M Paper 2 due next week

2

Conflicts

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

3

Conflict Serializability

Conflicts:

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 $w_i(X); r_j(X)$ $r_i(X); w_j(X)$

4

Conflict Serializability

Definition 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 in general

5

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
- No edge for actions in the same transaction

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

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Testing for Conflict-Serializability

Important:

Always draw the full graph, unless ONLY asked if (yes or no) the schedule is conflict serializable

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Example 1

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

1 2 3

8

$r_2(A)$ $r_1(B)$

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

1 2 3

9

$r_2(A)$ $r_1(B)$

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

1 2 3

10

$r_2(A)$ $r_1(B)$ No edge because no conflict (A != B)

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

1 2 3

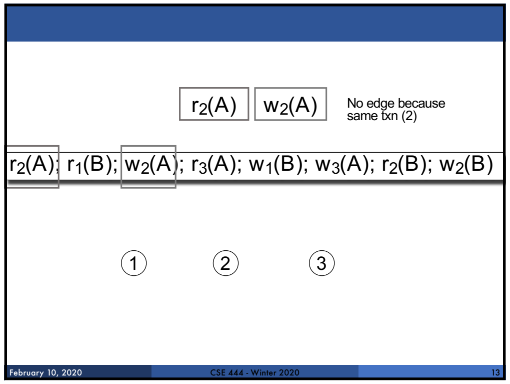
11

$r_2(A)$ $w_2(A)$

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

1 2 3

12



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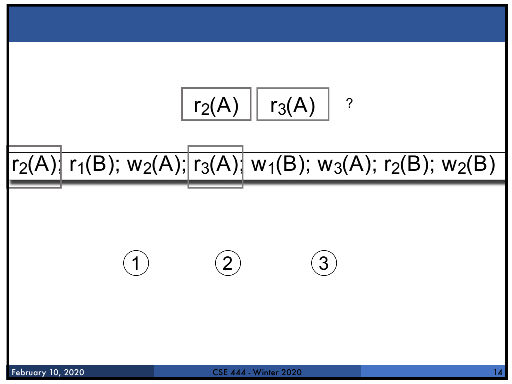

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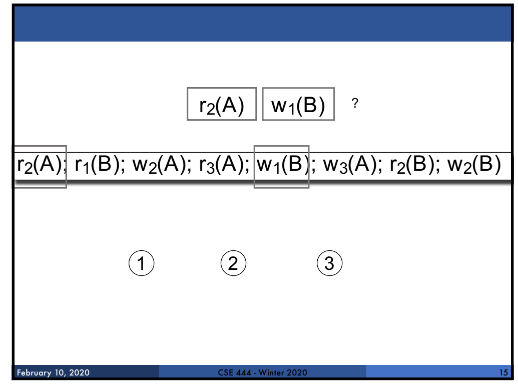

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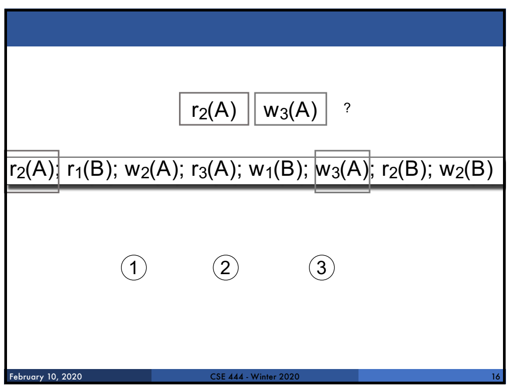

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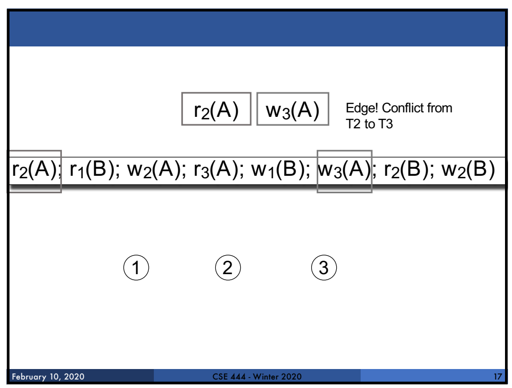

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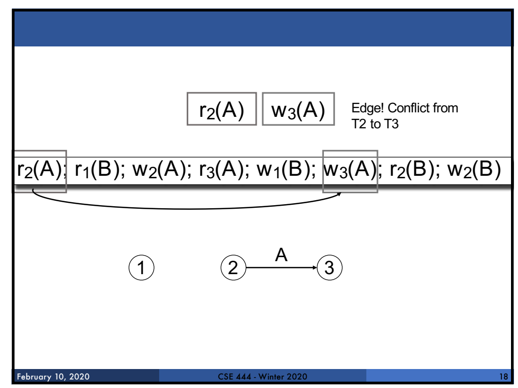

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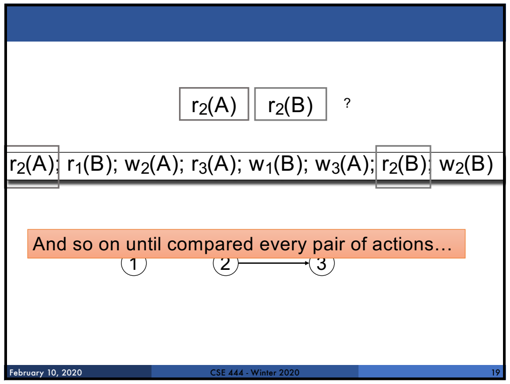

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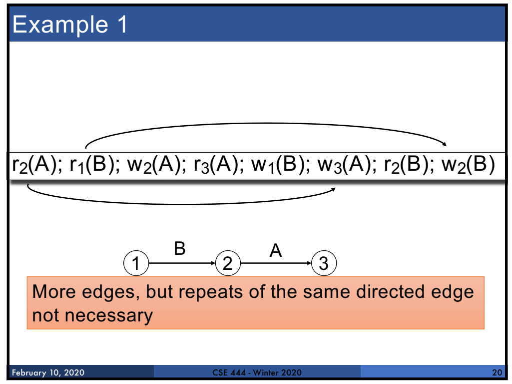

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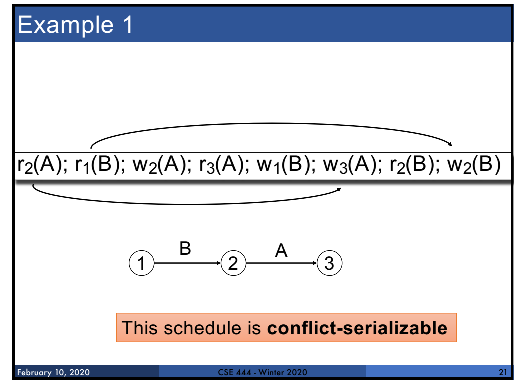

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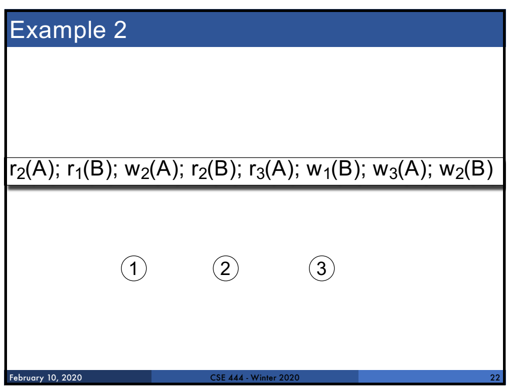

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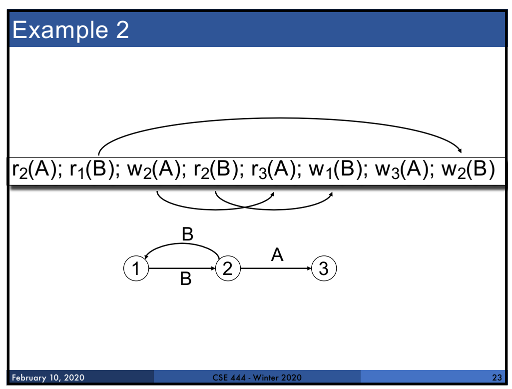

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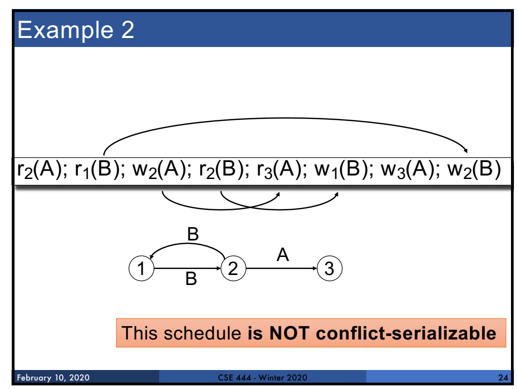

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View Equivalence

- A serializable schedule need not be conflict serializable, even under the “worst case update” assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Is this schedule conflict-serializable ?

25

View Equivalence

- A serializable schedule need not be conflict serializable, even under the “worst case update” assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Is this schedule conflict-serializable ? No…

26

View Equivalence

- A serializable schedule need not be conflict serializable, even under the “worst case update” assumption

$w_1(X); w_2(X); w_2(Y); w_1(Y); w_3(Y);$

Lost write

$w_1(X); w_1(Y); w_2(X); w_2(Y); w_3(Y);$

Equivalent, but not conflict-equivalent

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View Equivalence

T1	T2	T3
W1(X)		
	W2(X)	
	W2(Y)	
	CO2	
W1(Y)		
CO1 (Lost)		
		W3(Y)
		CO3

→

T1	T2	T3
W1(X)		
W1(Y)		
CO1		
	W2(X)	
	W2(Y)	
	CO2	
		W3(Y)
		CO3

Serializable, but not conflict serializable

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View Equivalence

Two schedules S, S’ are *view equivalent* if:

- If T reads an initial value of A in S, then T reads the initial value of A in S’
- If T reads a value of A written by T’ in S, then T reads a value of A written by T’ in S’
- If T writes the final value of A in S, then T writes the final value of A in S’

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View-Serializability

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

Remark:

- If a schedule is *conflict serializable*, then it is also *view serializable*
- But not vice versa

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Schedules with Aborted Transactions

- When a transaction aborts, the recovery manager undoes its updates
- But some of its updates may have affected other transactions !

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Schedules with Aborted Transactions

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
Abort	

What's wrong?

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Schedules with Aborted Transactions

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
Abort	

What's wrong?

Cannot abort T1 because cannot undo T2

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Recoverable Schedules

A schedule is *recoverable* if:

- It is conflict-serializable, and
- Whenever a transaction T commits, all transactions that have written elements read by T have already committed

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Recoverable Schedules

A schedule is *recoverable* if:

- It is conflict-serializable, and
- Whenever a transaction T commits, all transactions that have written elements read by T have already committed

35

Recoverable Schedules

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
	Commit
?	

Nonrecoverable

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
Commit	
	Commit

Recoverable

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Recoverable Schedules

T1	T2	T3	T4
R(A)			
W(A)			
	R(A)		
	W(A)		
	R(B)		
	W(B)		
		R(B)	
		W(B)	
		R(C)	
		W(C)	
			R(C)
			W(C)
			R(D)
			W(D)
Abort			

How do we recover ?

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Cascading Aborts

- If a transaction T aborts, then we need to abort any other transaction T' that has read an element written by T
- A schedule *avoids cascading aborts* if whenever a transaction reads an element, the transaction that has last written it has already committed.

We base our locking scheme on this rule!

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Avoiding Cascading Aborts

T1	T2
R(A)	
W(A)	
	R(A)
	W(A)
	R(B)
	W(B)
. . .	
	. . .

With cascading aborts

T1	T2
R(A)	
W(A)	
Commit	
	R(A)
	W(A)
	R(B)
	W(B)
	. . .

Without cascading aborts

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Serializability

- Serial
- Serializable
- Conflict serializable
- View serializable

Recoverability

- Recoverable
- Avoids cascading deletes

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Scheduler

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

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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)

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Notation

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

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

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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)	

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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

45

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 ?

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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)

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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

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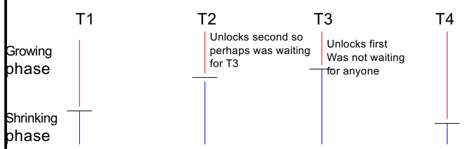
Example with Multiple Transactions



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

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Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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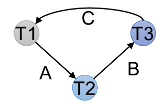
Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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

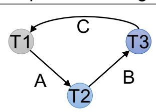


51

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:

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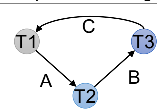
Two Phase Locking (2PL)

Theorem: 2PL ensures conflict serializability

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



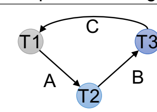
Then there is the following **temporal** cycle in the schedule:
$U_1(A) \rightarrow L_2(A)$ why?

53

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?

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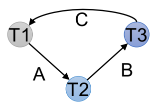
Two Phase Locking (2PL)

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

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A New Problem:

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	

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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

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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

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Summary of Strict 2PL

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

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Summary of Strict 2PL

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

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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 !

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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

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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

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Lock Granularity

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

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Lock Granularity

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

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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

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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

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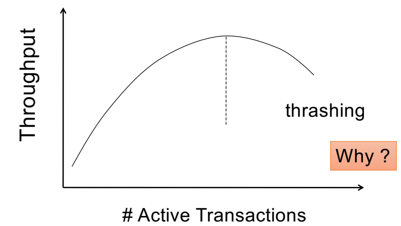
Lock Performance



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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

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Phantom Problem

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

Is this schedule serializable ?

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Phantom Problem

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

Suppose there are two blue products, X1, X2:

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

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Phantom Problem

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

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 ??

78

Phantom Problem

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

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***

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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 !

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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

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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 !

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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

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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

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- "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

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

This is not serializable yet !!!

Why ?

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4. Isolation Level Serializable

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

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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

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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

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