Transactions

Serializability

Isolation Levels

Atomicity

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The Setting

- Database systems are normally being accessed by many users or processes at the same time.
  - Both queries and modifications.
- Unlike Operating Systems, which *support* interaction of processes, a DMBS needs to keep processes from troublesome interactions.

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Example: Bad Interaction

- You and your spouse each take $100 from different ATM's at about the same time.
  - The DBMS better make sure one account deduction doesn't get lost.
- Compare: An OS allows two people to edit a document at the same time. If both write, one's changes get lost.

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ACID Test

- A DBMS is expected to support "ACID transactions," which are:
  - *Atomic* : Either the whole process is done or none is.
  - *Consistent* : Database constraints are preserved.
  - *Isolated* : It appears to the user as if only one process executes at a time. (aka "serializable")
  - *Durable* : Effects of a process do not get lost if the system crashes.

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Transactions in SQL

- SQL supports transactions, often behind the scenes.
  - Each statement issued at the generic query interface is a transaction by itself.
  - In programming interfaces like Embedded SQL or PSM, a transaction begins the first time an SQL statement is executed and ends with the program or an explicit end.

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COMMIT

- The SQL statement COMMIT causes a transaction to complete.
  - Its database modifications are now permanent in the database.

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ROLLBACK

- The SQL statement ROLLBACK also causes the transaction to end, but by *aborting*.
  - No effects on the database.
- Failures like division by 0 can also cause rollback, even if the programmer does not request it.

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An Example: Interacting Processes

- Assume the usual Sells(bar,beer,price) relation, and suppose that Joe's Bar sells only Bud for $2.50 and Miller for $3.00.
- Sally is querying Sells for the highest and lowest price Joe charges.
- Joe decides to stop selling Bud and Miller, but to sell only Heineken at $3.50.

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Sally’s Program

- Sally executes the following two SQL statements, which we call (min) and (max), to help remember what they do.

(max) SELECT MAX(price) FROM Sells
WHERE bar = ‘Joe’’s Bar’;

(min) SELECT MIN(price) FROM Sells
WHERE bar = ‘Joe’’s Bar’;

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Joe’s Program

- At about the same time, Joe executes the following steps, which have the mnemonic names (del) and (ins).

(del) DELETE FROM Sells
WHERE bar = ‘Joe’’s Bar’;

(ins) INSERT INTO Sells
VALUES(‘Joe’’s Bar’, ‘Heineken’,
3.50);

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Interleaving of Statements

- Although (max) must come before (min) and (del) must come before (ins), there are no other constraints on the order of these statements, unless we group Sally's and/or Joe's statements into transactions.

Example: Strange Interleaving

- Suppose the steps execute in the order (max)(del)(ins)(min).

Joe's Prices:	2.50, 3.00	2.50, 3.00		3.50
Statement:	(max)	(del)	(ins)	(min)
Result:	3.00			3.50

- Sally sees MAX < MIN!

Fixing the Problem With Transactions

- If we group Sally's statements (max)(min) into one **transaction**, then she cannot see this inconsistency.
- She see's Joe's prices at some fixed time.
  - Either before or after he changes prices, or in the middle, but the MAX and MIN are computed from the same prices.

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Another Problem: Rollback

- Suppose Joe executes (del)(ins), but after executing these statements, thinks better of it and issues a ROLLBACK statement.
- If Sally executes her transaction after (ins) but before the rollback, she sees a value, 3.50, that **never** existed in the database.

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Solution

- If Joe executes (del)(ins) as a **transaction**, its effect cannot be seen by others until the transaction executes COMMIT.
  - If the transaction executes ROLLBACK instead, then its effects can ***never*** be seen.

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Isolation Levels

- SQL defines four *isolation levels* = choices about what interactions are allowed by transactions that execute at about the same time.

- How a DBMS implements these isolation levels is highly complex, and a typical DBMS provides its own options.

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Choosing the Isolation Level

- Within a transaction, we can say:

SET TRANSACTION ISOLATION LEVEL *X*

where *X* =

1. SERIALIZABLE (strongest)
2. REPEATABLE READ
3. READ COMMITTED
4. READ UNCOMMITTED (weakest, effectively unrestricted)

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Serializable Transactions

- If Sally = (max)(min) and Joe = (del)(ins) are each transactions, and Sally runs with isolation level SERIALIZABLE, then she will see the database either before or after Joe runs, but not in the middle.
- It's up to the DBMS vendor to figure out how to do that, e.g.:
  - True isolation in time.
  - Keep Joe's old prices around to answer Sally's queries.

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Isolation Level Is "Personal" Choice

- Your choice, e.g., run serializable, affects only how *you* see the database, not how others see it.
- Example: If Joe Runs serializable, but Sally doesn't, then Sally might see no prices for Joe's Bar.
  - i.e., it looks to Sally as if she ran in the middle of Joe's transaction.

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Read-Commited Transactions

- If Sally runs with isolation level READ COMMITTED, then she can **see only committed** data, but not necessarily the same data each time.
- Example: Under READ COMMITTED, the interleaving (max)(del)(ins)(min) is allowed, as long as Joe commits.
  - Sally sees MAX < MIN.

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Repeatable-Read Transactions

- Requirement is like read-committed, plus: if data is read again, then **everything seen the first time will be seen the second time**.
  - **But** the second and subsequent reads may see *more* tuples as well.

Example: Repeatable Read

- Suppose Sally runs under REPEATABLE READ, and the order of execution is (max)(del)(ins)(min).
  - (max) sees prices 2.50 and 3.00.
  - (min) can see 3.50, but must also see 2.50 and 3.00, because they were seen on the earlier read by (max).

Read Uncommitted

- A transaction running under READ UNCOMMITTED can see data in the database, even if it was written by a transaction that has not committed (and may never).
- Example: If Sally runs under READ UNCOMMITTED, she could see a price 3.50 even if Joe later aborts.

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Locking

- Locking is a system-level method for achieving serialization.
- The diagrams in slides on locking are modifications of ones due to Arthur Keller, rather than Jeff Ullman, I believe.

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Non-Serialized Transaction

T1	T2	**start with A = 5**		
Read A		A on disk	A in T1	A in T2
	Read A	5	5	5
A:= A + 1		5	6	5
	A:= 2* A	5	6	10
	Write A	10	6	10
Write A		6	6	10

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Read- vs. Write-Locks

RLOCK A
WLOCK A
UNLOCK A

		THEM		
		NO	R	W
US	NO	OK	OK	OK
	R	OK	OK	bad
	W	OK	bad	bad

RLOCK –> UNLOCK can enclose a read
WLOCK –> UNLOCK can enclose a write or read

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Transaction Serialized using Locks

T1	T2
WLOCK A	
Read A	
	WLOCK A
A:= A+1	
Write A	waits
UNLOCK A	
	granted
	Read A
	A:=2*A
	Write A
	UNLOCK A

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Problems with Unstructured Use of Locks

T1	T2	
RLOCK A		
Read A		
	RLOCK A	
	Read A	
A:= A+1		
	A:= 2*A	
	WLOCK A	request lock upgrade
WLOCK A		request lock upgrade
wait	waits	

Deadlock!

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Deadlock due to lock ordering

T1	T2
WLOCK A	
	WLOCK B
WLOCK B	
wait	WLOCK A
UNLOCK A	wait <u>deadlock</u>
	UNLOCK B
UNLOCK B	
	UNLOCK A

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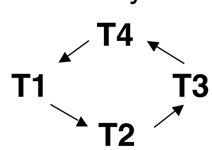
Deadlock

1. Wait and hold hold some locks while you wait for others

2. Circular chain of waiters

wait-for graph



3. No pre-emption

We can **avoid** deadlock by doing at least ONE of:

1. Get all your locks at once
2. Apply an ordering to acquiring locks
3. Allow preemption (for example, use timeout on waits)

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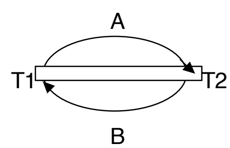
Serializability of schedules

T1	T2
Read (A)	Read (A)
A:= A-50	temp:= A * 0.1
Write (A)	A:= A + temp
Read (B)	Write (A)
B:= B+50	Read (B)
Write (B)	B:= B - temp
	Write (B)

	A	B
disk	100	200
T1		
T2		

A schedule is serializable iff its effect is the same as ***some*** serial schedule

T1 –> T2	T2 –> T1
A=	A=
B=	B=



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Ignore the exact operation semantics (too fine-grain, and generally will lead to undecidability).
What is important is the same **sequence** of operations.

Conflicts
- Read-write
- Write-write

Two schedules S1, S2 are **equivalent** if
1. Each transaction does the same operations in S1 and S2.
2. For each data item Q,
   if in S1, Ti executes Read (Q)
   and the value of Q read by Ti was written by Tj
   then the same is true in S2.
3. For each data item Q,
   if in S1, transaction Ti executes the **last** write (Q),
   then same is true in S2

A schedule is serializable iff it is **equivalent** to some serial schedule.

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Wanted:

A way to test serializabilty
by analyzing lock operations
among transactions

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Serializability Test

Algorithm: Testing serializability of a schedule

Input: Schedule S for **transactions** T1,… , Tk

Output: Determination of whether S is serializable,
and if so, an equivalent serial schedule.

Method: Create a directed graph G (called a **serialization graph**)
Create a node for each transaction and label with transaction ID
Create an edge for each Ti: UNLOCK A followed by Tj: LOCK A
(where lock modes conflict). (A is the data item being locked.)
Label edge Ti --> Tj with A.

If there is a cycle then schedule is non-serializable.

If there is no cycle, then (it is a DAG)
do a **topological sort** to get a serial schedule

DAG implies some partial order.

Any total order **consistent** with the partial order is an equivalent serial schedule.

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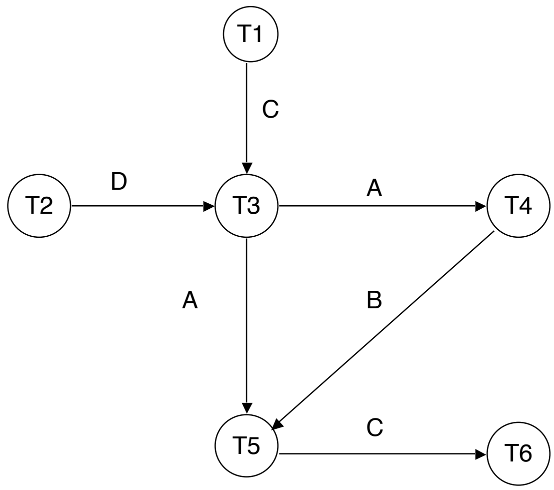
Serializability Test Example 1



T1
T2
T3
T4
T5
T6

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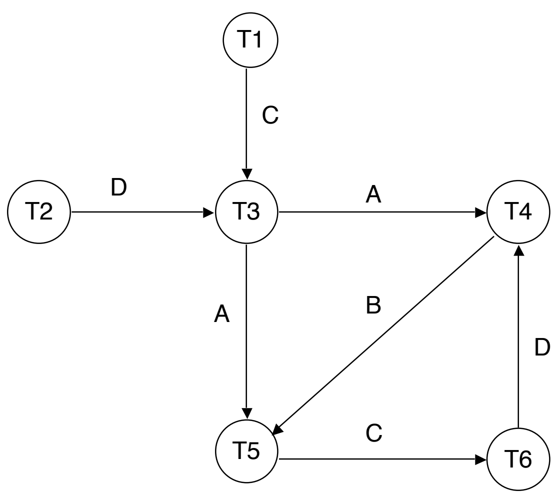
Serializability Test Example 2



T1
T2
T3
?

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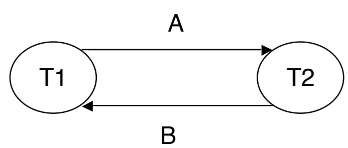
Simplest Non-Serializable Case

T1	T2
WLOCK A	
UNLOCK A	
	WLOCK A
	UNLOCK A
	WLOCK B
	UNLOCK B
WLOCK B	
UNLOCK B	



Possible Serialization Strategies

- Static transaction analysis
- Dynamic detection of non-serializability, rollback if necessary
- Devise a safe but simple policy that avoids non-serializability

Simple Strategy: 2-Phase Locking (2PL)

Every transaction has is divided into two phases that occur in sequence:

Phase I: All requesting of locks (no releasing)
Phase II: All releasing of locks (no further requesting)

Theorem: Any schedule for 2-phase locked transaction is serializable

[Similar-sounding, but distinct idea: **2-Phase Commit** used in distributed databases.]

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Rollback Hazards

T1	**T2**
LOCK A	
Read A	
change A	
Write A	
UNLOCK A	
	LOCK A
	Read A
	change A
	Write A
	UNLOCK A
LOCK B	
Read B	
Discover problem	
ABORT: ROLLBACK	
	Need to undo the change to A by T2 that was made based on data written by T1. (CASCADED ROLLBACK)

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