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CS 4604: Introduction to Database Management Systems

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Lecture #15: Transactions 1: Intro. to ACID

Why Transactions?

- 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.

Transactions - dfn

- = unit of work, eg.
  - move $10 from savings to checking

Statement of Problem

- Concurrent execution of independent transactions (why do we want that?)

Statement of Problem

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  – utilization/throughput ("hide" waiting for I/Os.)
  – response time

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Statement of Problem

- Concurrent execution of independent transactions
  - utilization/throughput ("hide" waiting for I/Os.)
  - response time
- would also like:
  - correctness &
  - fairness
- Example: Book an airplane seat

Definitions

- *database* - a fixed set of named data objects *(A, B, C, …)*
- *transaction* - a sequence of read and write operations *(read(A), write(B), …)*
  - DBMS' s abstract view of a user program

Example: 'Lost-update' problem

time ↓

T1	T2
Read(N)	
	Read(N)
N=N-1	
	N= N-1
Write(N)	
	Write(N)

Statement of problem (cont.)

- Arbitrary interleaving can lead to
  – Temporary inconsistency (ok, unavoidable)
  – "Permanent" inconsistency (bad!)

- Need formal correctness criteria.

Example: Bad Interaction

- You and friend each take $100 from different ATMs 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.

ACID Transactions

- *ACID transactions* are:
  - *Atomic* : Whole transaction or none is done.
  - *Consistent* : Database constraints preserved.
  - *Isolated* : It appears to the user as if only one process executes at a time.
  - *Durable* : Effects of a process survive a crash.
- Optional: weaker forms of transactions are often supported as well (like Google, Amazon system etc.): Recall NoSQL systems

COMMIT

- The SQL statement COMMIT causes a transaction to complete.
  – It's database modifications are now permanent in the database.

ROLLBACK

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

Overview

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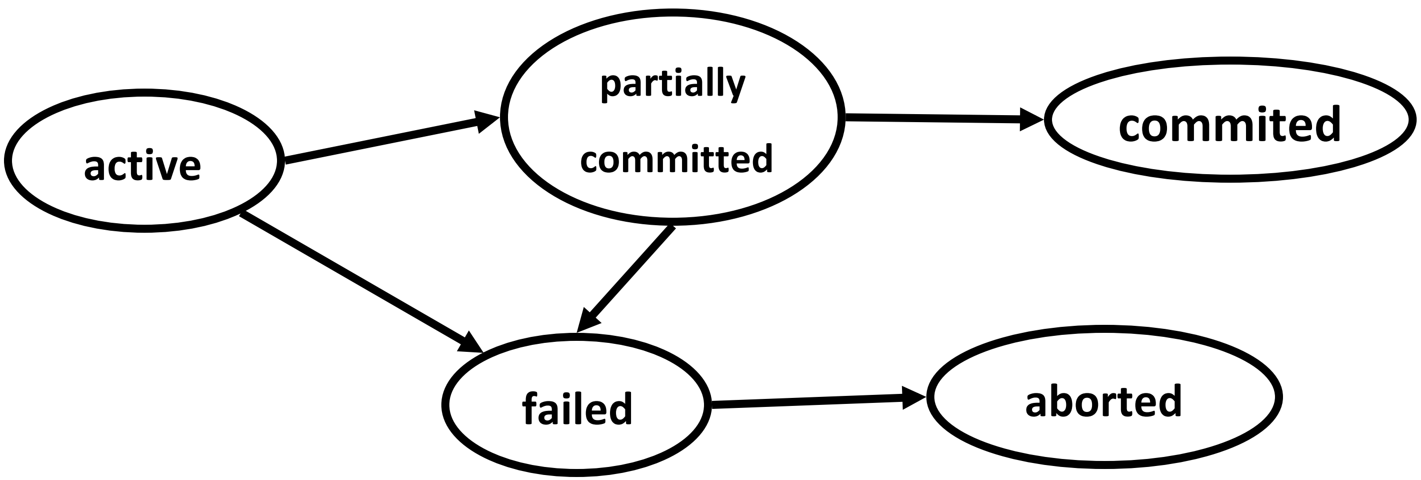
A

Atomicity of Transactions

- Two possible outcomes of executing a transaction:
  - Xact might *commit* after completing all its actions
  - or it could *abort* (or be aborted by the DBMS) after executing some actions.
- DBMS guarantees that Xacts are *atomic.*
  - From user' s point of view: Xact always either executes all its actions, or executes no actions at all.

Transaction states



A Mechanisms for Ensuring Atomicity

- What would you do?

A Mechanisms for Ensuring Atomicity

- One approach: LOGGING
  - DBMS logs all actions so that it can undo the actions of aborted transactions.
- ~ like black box in airplanes …

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A Mechanisms for Ensuring Atomicity

- Logging used by all modern systems.
- Q: why?

A Mechanisms for Ensuring Atomicity

- Logging used by all modern systems.
- Q: why?
- A:
  - – audit trail &
  - – efficiency reasons
- What other mechanism can you think of?

A Mechanisms for Ensuring Atomicity

- Another approach: SHADOW PAGES
  - – (not as popular)

Overview

- *ACID transactions* are:
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C

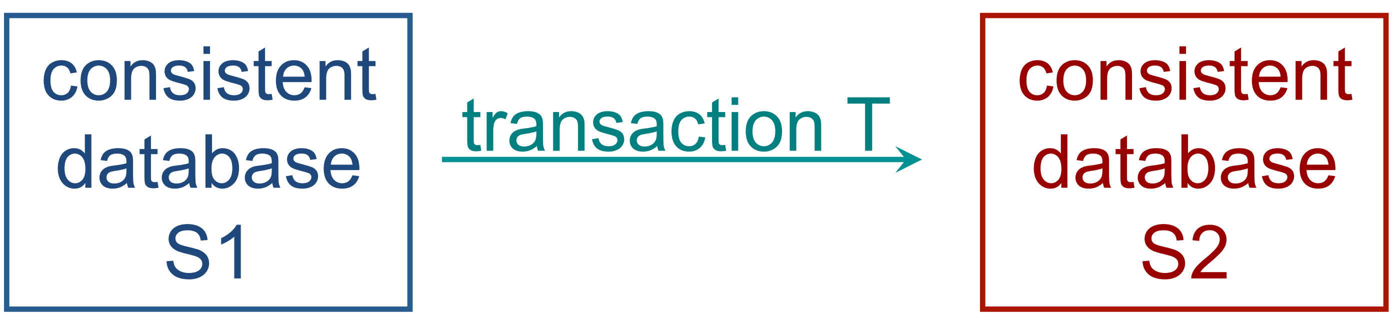
Transaction Consistency

- "Database consistency" - data in DBMS is accurate in modeling real world and follows integrity constraints

C

Transaction Consistency

- "Transaction Consistency": if DBMS consistent before Xact (running alone), it will be after also
- Transaction consistency: User's responsibility
  - DBMS just checks IC



C Transaction Consistency (cont.)

- Recall: Integrity constraints
  – must be true for DB to be considered consistent

  Examples:

  1. FOREIGN KEY R.sid REFERENCES S
  2. ACCT-BAL >= 0

C Transaction Consistency (cont.)

- System checks ICs and if they fail, the transaction rolls back (i.e., is aborted).
  - Beyond this, DBMS does not understand the semantics of the data.
  - e.g., it does not understand how interest on a bank account is computed

- Since it is the user's responsibility, we don't discuss it further

Overview

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Isolation of Transactions

- Users submit transactions, and
- Each transaction executes as if it was running by itself.
  - Concurrency is achieved by DBMS, which interleaves actions (reads/writes of DB objects) of various transactions.
- Q: How would you achieve that?
  - Tough problem!

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Isolation of Transactions

- A: Many methods - two main categories:
- Pessimistic – don’t let problems arise in the first place
- Optimistic – assume conflicts are rare, deal with them after they happen.

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Example

- Consider two transactions (Xacts):

```
T1:  BEGIN   A=A+100,   B=B-100   END
T2:  BEGIN   A=1.06*A,   B=1.06*B   END
```

- 1st xact transfers $100 from B's account to A's
- 2nd credits both accounts with 6% interest.
- Assume at first A and B each have $1000. What are the **legal outcomes** of running T1 and T2?

I

Example

```
T1:  BEGIN   A=A+100,   B=B-100   END
T2:  BEGIN   A=1.06*A,   B=1.06*B   END
```

- many - but A+B should be: $2000 *1.06 = $2120
- There is no guarantee that T1 will execute before T2 or vice-versa, if both are submitted together. But, the net effect *must* be equivalent to these two transactions running serially in some order.

Example (Contd.)

- Legal outcomes: A=1166,B=954 or A=1160,B=960
- Consider a possible interleaved *schedule*:

```
T1:   A=A+100,                B=B-100
T2:             A=1.06*A,             B=1.06*B
```

- This is OK (same as T1;T2). But what about:

```
T1:   A=A+100,                          B=B-100
T2:             A=1.06*A, B=1.06*B
```

I

Example (Contd.)

- Legal outcomes: A=1166,B=954 or A=1160,B=960
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```

- This is OK (same as T1;T2). But what about:

```
T1:   A=A+100,                      B=B-100
T2:             A=1.06*A, B=1.06*B
```

- **Result: A=1166, B=960; A+B = 2126, bank loses $6**
- **The DBMS's view of the second schedule:**

```
T1:   R(A), W(A),                          R(B), W(B)
T2:             R(A), W(A), R(B), W(B)
```

‘Correctness’ ?

- Q: How would you judge that a schedule is ‘correct’ ?

(‘schedule’ = ‘interleaved execution’)

‘Correctness’ ?

- Q: How would you judge that a schedule is ‘correct’ ?
- A: if it is equivalent to some serial execution

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Formal Properties of Schedules

- Serial schedule: Schedule that does not interleave the actions of different transactions.
- Equivalent schedules: For any database state, the effect of executing the first schedule is identical to the effect of executing the second schedule. (*)

(*) no matter what the arithmetic etc. operations are!

Formal Properties of Schedules

- Serializable schedule: A schedule that is equivalent to some serial execution of the transactions.

(Note: If each transaction preserves consistency, every serializable schedule preserves consistency.)

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Anomalies with interleaved execution:

- R-W conflicts
- W-R conflicts
- W-W conflicts

(why not R-R conflicts?)

Anomalies with Interleaved Execution

- Reading Uncommitted Data (WR Conflicts, "dirty reads"):

T1:	R(A), W(A),		R(B), W(B), Abort
T2:		R(A), W(A), C	

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Anomalies with Interleaved Execution

- Reading Uncommitted Data (WR Conflicts, “dirty reads”):

T1:	R(A), W(A),		R(B), W(B), Abort	
T2:		R(A), W(A), C		

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Anomalies with Interleaved Execution

- Unrepeatable Reads (RW Conflicts):

T1:	R(A),		R(A), W(A), C
T2:		R(A), W(A), C	

Anomalies with Interleaved Execution

- Unrepeatable Reads (RW Conflicts):

T1:	R(A),		R(A), W(A), C
T2:		R(A), W(A), C	

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Anomalies (Continued)

- Overwriting Uncommitted Data (WW Conflicts):

T1:	W(A),			W(B), C
T2:		W(A),	W(B), C	

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Anomalies (Continued)

- Overwriting Uncommitted Data (WW Conflicts):

T1:	W(A), W(B), C
T2:	W(A), W(B), C

Serializability

- Objective: find non-serial schedules, which allow transactions to execute concurrently without interfering, thereby producing a DB state that could be produced by a serial execution
- BUT
  - Trying to find schedules equivalent to serial execution is too slow!

Conflict Serializability

- We need a formal notion of equivalence that can be implemented efficiently…
  - Base it on the notion of "conflicting" operations

- Definition: Two operations conflict if:
  - They are by different transactions,
  - they are on the same object,
  - and at least one of them is a write.

Conflict Serializable Schedules

- Definition: Two schedules are conflict equivalent iff:
  - They involve the same actions of the same transactions, and
  - every pair of conflicting actions is ordered the same way
- Definition: Schedule S is conflict serializable if:
  - S is conflict equivalent to some serial schedule.
- Note, some “serializable” schedules are NOT conflict serializable (See Example 4 later)

CS---Intuition

- A schedule S is conflict serializable if:
  – You are able to transform S into a serial schedule by swapping consecutive non-conflicting operations of different transactions

R(A) W(A) R(B) W(B)

R(A) W(A) R(B) W(B)

====

R(A) W(A) R(B) W(B)

R(A) W(A) R(B) W(B)

CS---Intuition

- A schedule S is conflict serializable if:
  - You are able to transform S into a serial schedule by swapping consecutive non-conflicting operations of different transactions

R(A)   W(A)

R(A) W(A)

IS NOT SERIALIZABLE!

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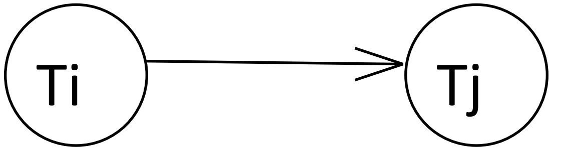
Serializability

- Q: any faster algorithm? (faster than transposing operations?)

Dependency Graph



- One node per Xact
- Edge from Ti to Tj if:
  - An operation Oi of Ti conflicts with an operation Oj of Tj and
  - Oi appears earlier in the schedule than Oj.

Dependency Graph: Theorem

- THEOREM: Schedule is conflict serializable iff the dependency graph is acyclic

- Dependency graph is also called the precedence graph
  - different than the waits-for graph we will see later

Example

- T1: R(A), W(A) R(B), W(B)
- T2: R(A) W(A) R(B) W(B)

- D. Graph:

- NOT Conflict serializable
  – Cycle is the problem---output of T1 depends on T2 and vice versa

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Example #2 (Lost update)

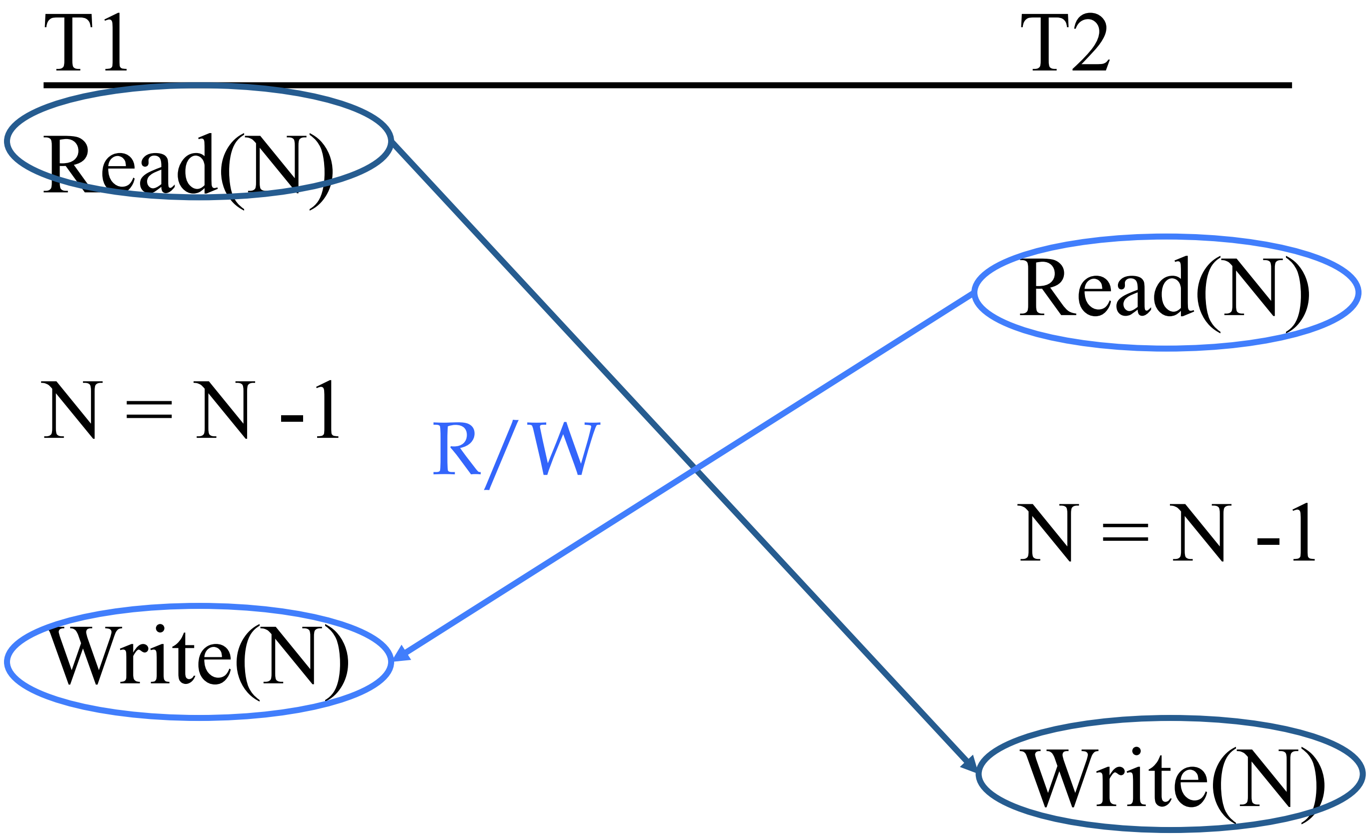
T1	T2
Read(N)	
	Read(N)
N = N -1	
	N = N -1
Write(N)	
	Write(N)

Example #2 (Lost update)

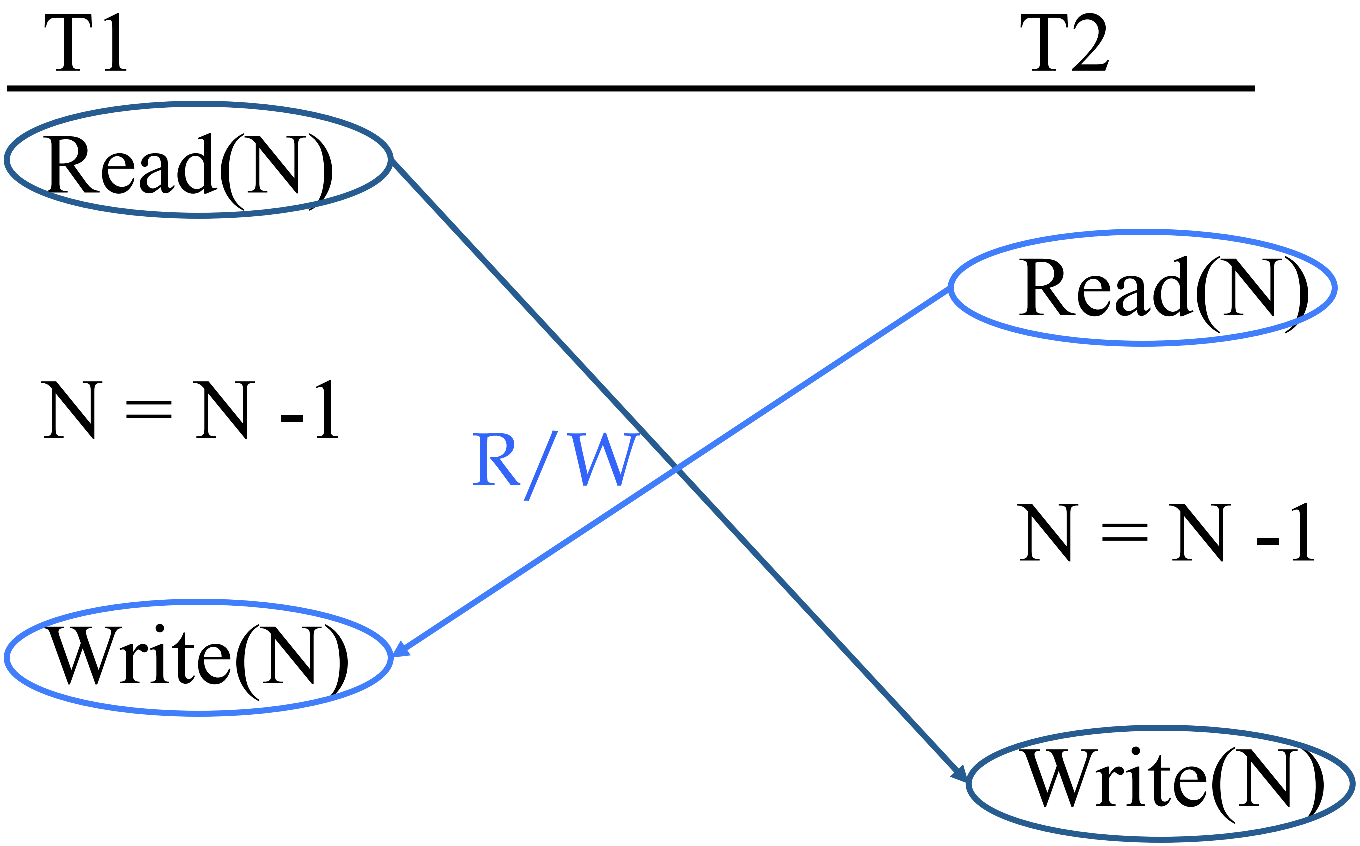
T1	T2
Read(N)	
	Read(N)
N = N -1	
	N = N -1
Write(N)	
	Write(N)

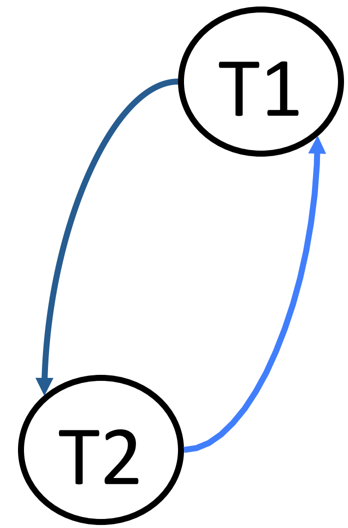
R/W

Example #2 (Lost update)



Example #2 (Lost update)



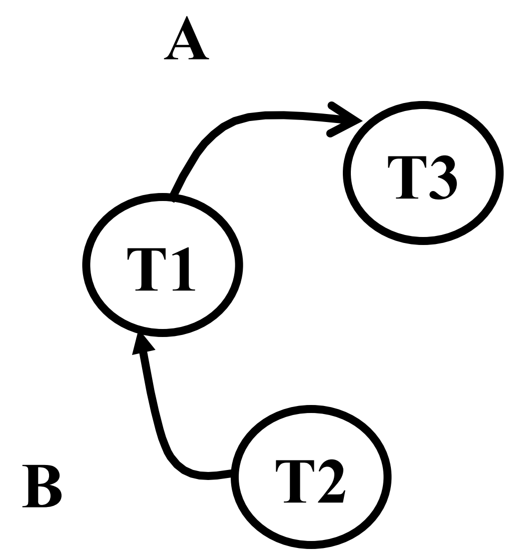


Example #3

T1	T2	T3
Read(A)		
…		
write(A)		
		Read(A)
		…
		Write(A)
	Read(B)	
	…	
	Write(B)	
Read(B)		
…		
Write(B)		

Example #3

T1	T2	T3
Read(A)		
…		
write(A)		
		Read(A)
		…
		Write(A)
	Read(B)	
	…	
	Write(B)	
Read(B)		
…		
Write(B)		



equivalent serial execution?

Example #3

- A: T2, T1, T3

(Notice that T3 should go after T2 in the equivalent serial order, although it starts before it!)

- Q: algo for generating serial execution from (acyclic) dependency graph?

Example #3

- A: T2, T1, T3

(Notice that T3 should go after T2 in the equivalent serial order, although it starts before it!)

- Q: algo for generating serial execution from (acyclic) dependency graph?
- A: Topological sorting

Example #4 (Inconsistent Analysis)

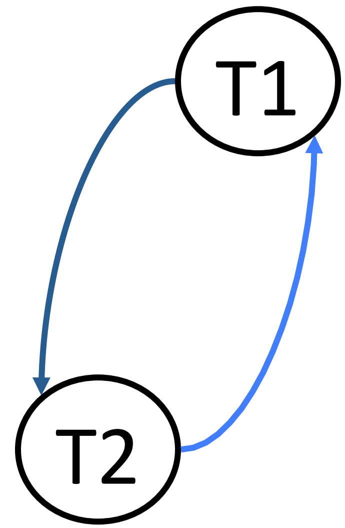
T1	T2
R (A)	
A = A-10	
W (A)	
	R(A)
	Sum = A
	R (B)
	Sum += B
R(B)	
B = B+10	
W(B)	

dependency graph?

Example #4 (Inconsistent Analysis)

T1	T2
R (A)	
A = A-10	
W (A)	
	R(A)
	Sum = A
	R (B)
	Sum += B
R(B)	
B = B+10	
W(B)	

dependency graph?



So NOT Conflict Serializable (and not serializable)

Example #4 (Inconsistent Analysis)

T1	T2
R (A)	
A = A-10	
W (A)	
	R(A)
	Sum = A
	R (B)
	Sum += B
R(B)	
B = B+10	
W(B)	

Q: create a 'correct' Schedule based on this one that is not conflict-serializable

Example #4' (Inconsistent Analysis)

T1	T2
R (A)	
A = A-10	
W (A)	
	R(A)
	if (A>0), count=1
	R (B)
	if (B>0), count++
R(B)	
B = B+10	
W(B)	

A: T2 asks for the count of my active Accounts (assuming A>10, B>0)

NOTES:

1. This schedule is still not CS
2. BUT it is serializable! It is equivalent to either of [T1 T2] or [T2 T1] (both are OK)

Serializability in Practice

- DBMS does not test for conflict serializability of a given schedule
  - Impractical as interleaving of operations from concurrent Xacts could be dictated by the OS
- Approach:
  - Use specific protocols that are known to produce conflict serializable schedules
  - But may reduce concurrency

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Solution?

- One solution for “conflict serializable” schedules is Two Phase Locking (2PL)

Answer

- (Full answer:) use locks; keep them until commit (‘strict 2 phase locking’)
- We’ll see the details later (in next class!)

(Review) Goal: ACID Properties

- *ACID transactions* are:
  - *Atomic* : Whole transaction or none is done.
  - *Consistent* : Database constraints preserved.
  - *Isolated* : It appears to the user as if only one process executes at a time.
  - *Durable* : Effects of a process survive a crash.

What happens if system crashes between *commit* and *flushing modified data to disk* ?

D

Durability

- == Recovery
- We'll see it **later** (after concurrency control)

Summary

- Concurrency control and recovery are among the most important functions provided by a DBMS.
- Concurrency control is automatic
  - System automatically inserts lock/unlock requests and schedules actions of different Xacts
  - Property ensured: resulting execution is equivalent to executing the Xacts one after the other in some order.

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ACID properties

Atomicity (all or none)

Consistency

Isolation (as if alone)

Durability