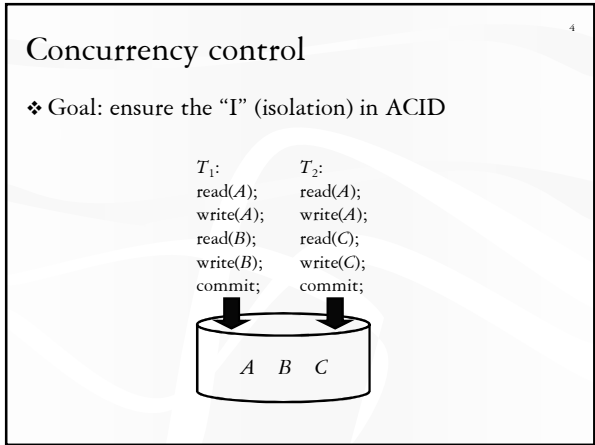


# Transaction Processing

CompSci 316  
Introduction to Database Systems

- ## Announcements (Tue. Nov. 26)
- ❖ Homework #4 due in a week
  - ❖ Project demo period: Dec. 9-11; you will be contacted by email regarding the sign-up process
    - Public demo slots: Dec. 5; email me if you are interested
  - ❖ Final exam 9am-12pm Wednesday Dec. 11
    - Open book, open notes
    - Focus on the second half of the course
    - Sample final available soon

- ## Review
- ❖ ACID
    - Atomicity: TX's are either completely done or not done at all
    - Consistency: TX's should leave the database in a consistent state
    - Isolation: TX's must behave as if they are executed in isolation
    - Durability: Effects of committed TX's are resilient against failures
  - ❖ SQL transactions
    - Begins implicitly
    - SELECT ...;
    - UPDATE ...;
    - ROLLBACK | COMMIT;



## Good versus bad schedules

Good!		Bad!		Good! (But why?)	
T <sub>1</sub>	T <sub>2</sub>	T <sub>1</sub>	T <sub>2</sub>	T <sub>1</sub>	T <sub>2</sub>
r(A)		r(A)		r(A)	
w(A)		Read 400	r(A)	w(A)	
r(B)		Write w(A)	Read 400		r(A)
w(B)		400 - 100	w(A) Write		w(A)
	r(A)	r(B)	400 - 50	r(B)	
	w(A)		r(C)		r(C)
	r(C)	w(B)		w(B)	
	w(C)	w(C)		w(C)	

- ## Serial schedule
- ❖ Execute transactions in order, with no interleaving of operations
    - T<sub>1</sub>.r(A), T<sub>1</sub>.w(A), T<sub>1</sub>.r(B), T<sub>1</sub>.w(B), T<sub>2</sub>.r(A), T<sub>2</sub>.w(A), T<sub>2</sub>.r(C), T<sub>2</sub>.w(C)
    - T<sub>2</sub>.r(A), T<sub>2</sub>.w(A), T<sub>2</sub>.r(C), T<sub>2</sub>.w(C), T<sub>1</sub>.r(A), T<sub>1</sub>.w(A), T<sub>1</sub>.r(B), T<sub>1</sub>.w(B)
  - ☞ Isolation achieved by definition!
  - ❖ Problem: no concurrency at all
  - ❖ Question: how to reorder operations to allow more concurrency

## Conflicting operations

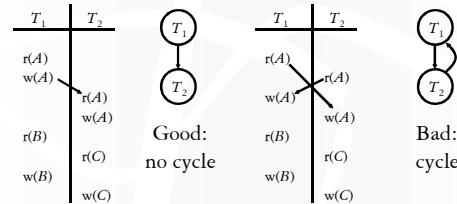
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- ❖ Two operations on the same data item conflict if at least one of the operations is a write
  - $r(X)$  and  $w(X)$  conflict
  - $w(X)$  and  $r(X)$  conflict
  - $w(X)$  and  $w(X)$  conflict
  - $r(X)$  and  $r(X)$  do not
  - $r/w(X)$  and  $r/w(Y)$  do not
- ❖ Order of conflicting operations matters
  - E.g., if  $T_1.r(A)$  precedes  $T_2.w(A)$ , then conceptually,  $T_1$  should precede  $T_2$

## Precedence graph

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- ❖ A node for each transaction
- ❖ A directed edge from  $T_i$  to  $T_j$  if an operation of  $T_i$  precedes and conflicts with an operation of  $T_j$  in the schedule



## Conflict-serializable schedule

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- ❖ A schedule is conflict-serializable iff its precedence graph has no cycles
- ❖ A conflict-serializable schedule is equivalent to some serial schedule (and therefore is “good”)
  - In that serial schedule, transactions are executed in the topological order of the precedence graph
  - You can get to that serial schedule by repeatedly swapping adjacent, non-conflicting operations from different transactions

## Locking

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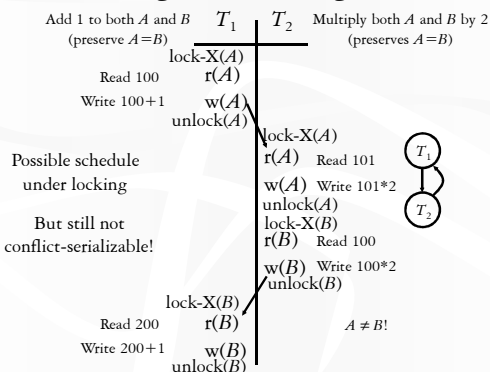
- ❖ Rules
  - If a transaction wants to read an object, it must first request a shared lock (S mode) on that object
  - If a transaction wants to modify an object, it must first request an exclusive lock (X mode) on that object
  - Allow one exclusive lock, or multiple shared locks

		Mode of the lock requested		Grant the lock?
		S	X	
Mode of lock(s) currently held by other transactions	S	Yes	No	
	X	No	No	

Compatibility matrix

## Basic locking is not enough

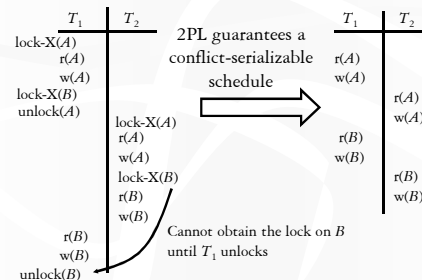
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## Two-phase locking (2PL)

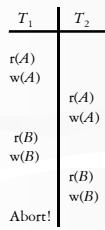
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- ❖ All lock requests precede all unlock requests
  - Phase 1: obtain locks, phase 2: release locks



## Problem of 2PL

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- ❖  $T_2$  has read uncommitted data written by  $T_1$
- ❖ If  $T_1$  aborts, then  $T_2$  must abort as well
- ❖ Cascading aborts possible if other transactions have read data written by  $T_2$
- ❖ Even worse, what if  $T_2$  commits before  $T_1$ ?
  - Schedule is not recoverable if the system crashes right after  $T_2$  commits

## Strict 2PL

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- ❖ Only release locks at commit/abort time
  - A writer will block all other readers until the writer commits or aborts
- ❖ Used in many commercial DBMS
  - Oracle is a notable exception

## Recovery

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- ❖ Goal: ensure "A" (atomicity) and "D" (durability) in ACID
- ❖ Execution model: to read/write  $X$ 
  - The disk block containing  $X$  must be first brought into memory
  - $X$  is read/written in memory
  - The memory block containing  $X$ , if modified, must be written back (flushed) to disk eventually



## Failures

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- ❖ System crashes in the middle of a transaction  $T$ ; partial effects of  $T$  were written to disk
  - How do we undo  $T$  (atomicity)?
- ❖ System crashes right after a transaction  $T$  commits; not all effects of  $T$  were written to disk
  - How do we complete  $T$  (durability)?

## Naïve approach

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- ❖ Force: When a transaction commits, all writes of this transaction must be reflected on disk
  - Without force, if system crashes right after  $T$  commits, effects of  $T$  will be lost
  - ☞ Problem: Lots of random writes hurt performance
- ❖ No steal: Writes of a transaction can only be flushed to disk at commit time
  - With steal, if system crashes before  $T$  commits but after some writes of  $T$  have been flushed to disk, there is no way to undo these writes
  - ☞ Problem: Holding on to all dirty blocks requires lots of memory

## Logging

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- ❖ Log
  - Sequence of log records, recording all changes made to the database
  - Written to stable storage (e.g., disk) during normal operation
  - Used in recovery
- ❖ Hey, one change turns into two—bad for performance?
  - But writes are sequential (append to the end of log)
  - Can use dedicated disk(s) to improve performance

## Undo/redo logging rules

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- ❖ Record values before and after each modification:  $\langle T_i, X, \text{old\_value\_of\_}X, \text{new\_value\_of\_}X \rangle$ 
  - $T_i$  is transaction id and  $X$  identifies the data item
- ❖ A transaction  $T_i$  is committed when its commit log record  $\langle T_i, \text{commit} \rangle$  is written to disk
- ❖ Write-ahead logging (WAL): Before  $X$  is modified on disk, the log record pertaining to  $X$  must be flushed
  - Without WAL, system might crash after  $X$  is modified on disk but before its log record is written to disk—no way to undo
- ❖ No force: A transaction can commit even if its modified memory blocks have not been written to disk (since redo information is logged)
- ❖ Steal: Modified memory blocks can be flushed to disk anytime (since undo information is logged)

## Undo/redo logging example

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$T_1$  (balance transfer of \$100 from  $A$  to  $B$ )

```
read(A, a); a = a - 100;
write(A, a);
read(B, b); b = b + 100;
write(B, b);
commit;
```

Memory buffer  
 ~~$A = 800700$~~   
 ~~$B = 400500$~~

Steal: can flush  
before commit

Disk  
 ~~$A = 800700$~~   
 ~~$B = 400500$~~

No force: can flush  
after commit

Log  
 $\langle T_1, \text{start} \rangle$   
 $\langle T_1, A, 800, 700 \rangle$   
 $\langle T_1, B, 400, 500 \rangle$   
 $\langle T_1, \text{commit} \rangle$

No restriction (except WAL) on when memory blocks can/should be flushed

## Checkpointing

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- ❖ Where does recovery start?
- ❖ Naïve approach:
  - Stop accepting new transactions (lame!)
  - Finish all active transactions
  - Take a database dump
- ❖ Fuzzy checkpointing
  - Determine  $S$ , the set of (ids of) currently active transactions, and log  $\langle \text{begin-checkpoint } S \rangle$
  - Flush all blocks (dirty at the time of the checkpoint) at your leisure
  - Log  $\langle \text{end-checkpoint } \text{begin-checkpoint\_location} \rangle$
  - Between begin and end, continue processing old and new transactions

## Recovery: analysis and redo phase

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- ❖ Need to determine  $U$ , the set of active transactions at time of crash
  - ❖ Scan log backward to find the last end-checkpoint record and follow the pointer to find the corresponding  $\langle \text{start-checkpoint } S \rangle$
  - ❖ Initially, let  $U$  be  $S$
  - ❖ Scan forward from that start-checkpoint to end of the log
    - For a log record  $\langle T, \text{start} \rangle$ , add  $T$  to  $U$
    - For a log record  $\langle T, \text{commit} \mid \text{abort} \rangle$ , remove  $T$  from  $U$
    - For a log record  $\langle T, X, \text{old}, \text{new} \rangle$ , issue  $\text{write}(X, \text{new})$
- ☞ Basically repeats history!

## Recovery: undo phase

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- ❖ Scan log backward
  - Undo the effects of transactions in  $U$
  - That is, for each log record  $\langle T, X, \text{old}, \text{new} \rangle$  where  $T$  is in  $U$ , issue  $\text{write}(X, \text{old})$ , and log this operation too (part of the repeating-history paradigm)
  - Log  $\langle T, \text{abort} \rangle$  when all effects of  $T$  have been undone
- ☞ An optimization
  - Each log record stores a pointer to the previous log record for the same transaction; follow the pointer chain during undo

## Summary

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- ❖ Concurrency control
  - Serial schedule: no interleaving
  - Conflict-serializable schedule: no cycles in the precedence graph; equivalent to a serial schedule
  - 2PL: guarantees a conflict-serializable schedule
  - Strict 2PL: also guarantees recoverability
- ❖ Recovery: undo/redo logging with fuzzy checkpointing
  - Normal operation: write-ahead logging, no force, steal
  - Recovery: first redo (forward), and then undo (backward)