Transaction Processing

CPS 116
Introduction to Database Systems

Announcements (November 28)

- Homework #4 assigned today
  - Due next Tuesday (Dec. 5)
- Project demo period starts next Thursday
- Final exam on December 15

Review

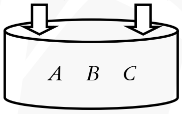
- ACID
  - Atomicity: TX's are either completely done or not done at all
  - Consistency: TX's should leave the database in a consistent state
  - Isolation: TX's must behave as if they are executed in isolation
  - Durability: Effects of committed TX's are resilient against failures
- SQL transactions

```
-- Begins implicitly
SELECT …;
UPDATE …;
ROLLBACK | COMMIT;
```

Concurrency control

- Goal: ensure the "I" (isolation) in ACID

T_1:	T_2:
read(A);	read(A);
write(A);	write(A);
read(B);	read(C);
write(B);	write(C);
commit;	commit;



Good versus bad schedules

Good!

T_1	T_2
r(A)	
w(A)	
r(B)	
w(B)	
	r(A)
	w(A)
	r(C)
	w(C)

Bad!

	T_1	T_2	
	r(A)		
Read 400		r(A)	
Write 400 – 100	w(A)		Read 400
		w(A)	Write 400 – 50
	r(B)		
		r(C)	
	w(B)		
		w(C)	

Good! (But why?)

T_1	T_2
r(A)	
w(A)	
	r(A)
	w(A)
r(B)	
	r(C)
w(B)	
	w(C)

Serial schedule

- Execute transactions in order, with no interleaving of operations
  - T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B), T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C)
  - T_2.r(A), T_2.w(A), T_2.r(C), T_2.w(C), T_1.r(A), T_1.w(A), T_1.r(B), T_1.w(B)

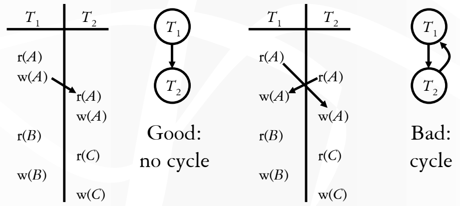
  ☞Isolation achieved by definition!
- Problem: no concurrency at all
- Question: how to reorder operations to allow more concurrency

Conflicting operations

- ❖ 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

- ❖ 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



T_1	T_2
r(A)	
w(A)	
	r(A)
	w(A)
r(B)	
	r(C)
w(B)	
	w(C)

Good: no cycle

T_1	T_2
r(A)	
	r(A)
w(A)	
	w(A)
r(B)	
	r(C)
w(B)	
	w(C)

Bad: cycle

Conflict-serializable schedule

- ❖ 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

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Locking

- ❖ 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

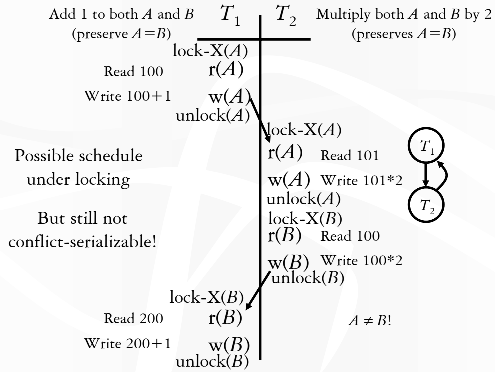
	S	X
S	Yes	No
X	No	No

Mode of lock(s) currently held by other transactions

Grant the lock?

Compatibility matrix

Basic locking is not enough



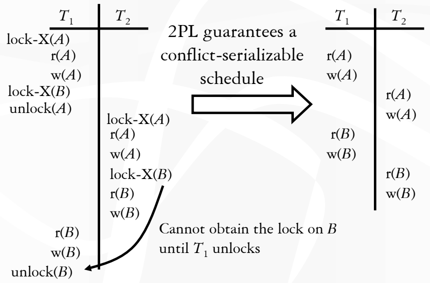
Add 1 to both A and B (preserve $A=B$)	T_1	T_2	Multiply both A and B by 2 (preserves $A=B$)
	lock-X(A)		
Read 100	r(A)		
Write 100+1	w(A)		
	unlock(A)		
		lock-X(A)	
		r(A)	Read 101
		w(A)	Write 101*2
		unlock(A)	
		lock-X(B)	
		r(B)	Read 100
		w(B)	Write 100*2
		unlock(B)	
	lock-X(B)		
Read 200	r(B)		$A \neq B$!
Write 200+1	w(B)		
	unlock(B)		

Possible schedule under locking

But still not conflict-serializable!

Two-phase locking (2PL)

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



T_1	T_2
lock-X(A)	
r(A)	
w(A)	
lock-X(B)	
unlock(A)	
	lock-X(A)
	r(A)
	w(A)
	lock-X(B)
	r(B)
	w(B)
r(B)	
w(B)	
unlock(B)	

Cannot obtain the lock on B until T_1 unlocks

2PL guarantees a conflict-serializable schedule

T_1	T_2
r(A)	
w(A)	
	r(A)
	w(A)
r(B)	
w(B)	
	r(B)
	w(B)

Problem of 2PL

T_1	T_2
r(A)	
w(A)	
	r(A)
	w(A)
r(B)	
w(B)	
	r(B)
	w(B)
Abort!	

- ❖ 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

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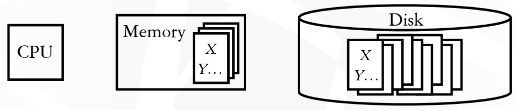
Strict 2PL

- ❖ Only release locks at commit/abort time
  - ▪ A writer will block all other readers until the writer commits or aborts

☞ Used in most commercial DBMS (except Oracle)

Recovery

- ❖ 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

- ❖ 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

- ❖ 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

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Logging

- ❖ 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

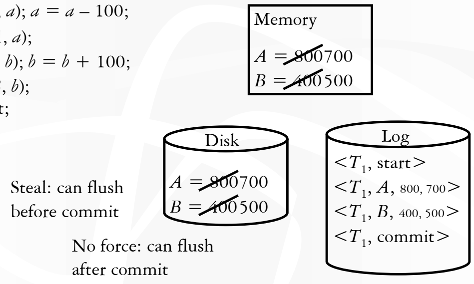
Undo/redo logging rules

- Record values before and after each modification: $\langle T_i, X, old\_value\_of\_X, new\_value\_of\_X \rangle$
- A transaction T_i is committed when its commit log record $\langle T_i$, 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 be 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

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

A = ~~800~~700
B = ~~400~~500

Disk

A = ~~800~~700
B = ~~400~~500

Log

$<T_1$, start$>$
$<T_1, A$, 800, 700$>$
$<T_1, B$, 400, 500$>$
$<T_1$, commit$>$

Steal: can flush before commit

No force: can flush after commit

No restriction on when memory blocks can/should be flushed

Checkpointing

- 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 currently active transactions, and log $\langle$ begin-checkpoint S $\rangle$
  - Flush all blocks (dirty at the time of the checkpoint) at your leisure
  - Log $\langle$ end-checkpoint *begin-checkpoint_location* $\rangle$
  - Between begin and end, continue processing old and new transactions

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Recovery: analysis and redo phase

- 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 $\langle$ start-checkpoint S $\rangle$
- Initially, let U be S
- Scan forward from that start-checkpoint to end of the log
  - For a log record $\langle T$, start $\rangle$, add T to U
  - For a log record $\langle T$, commit | abort $\rangle$, remove T from U
  - For a log record $\langle T, X, old, new \rangle$, issue write($X$, *new*)
  - ☞Basically repeats history!

Recovery: undo phase

- Scan log backward
  - Undo the effects of transactions in U
  - That is, for each log record $\langle T, X, old, new \rangle$ where T is in U, issue write(X, *old*), and log this operation too (part of the repeating-history paradigm)
  - Log $\langle T$, 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

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Summary

- 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 (backword)