Transaction Processing

CPS 196.3
Introduction to Database Systems

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

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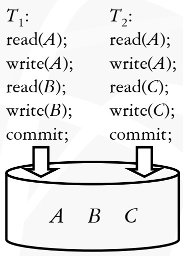
-- Begins implicitly
SELECT …;
UPDATE …;
ROLLBACK | COMMIT;
```

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

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

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

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
  - 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*)

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

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

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

Compatibility matrix

Grant the lock?

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

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

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” (isolation) 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)?
- Media fails; data on disk corrupted
    - How do we reconstruct the database (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:
- 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:

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

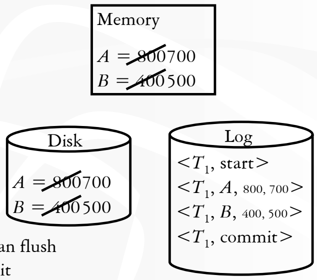
Undo/redo logging rules

- Record values before and after each modification: $\langle T_i, X, \mathit{old\_value\_of\_X}, \mathit{new\_value\_of\_X} \rangle$
- 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

- Naïve approach:
  - Stop accepting new transactions (lame!)
  - Finish all active transactions
  - Take a database dump
  - Now safe to truncate the redo log
- Fuzzy checkpointing
  - Determine S, the set of currently active transactions, and log ⟨ begin-checkpoint S ⟩
  - Flush all modified memory blocks at your leisure
  - Log ⟨ end-checkpoint *begin-checkpoint_location* ⟩
  - Between begin and end, continue processing old and new transactions

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 ⟨ start-checkpoint S ⟩
- Initially, let U be S
- Scan forward from that start-checkpoint to end of the log
  - For a log record ⟨ T, start ⟩, add T to U
  - For a log record ⟨ T, commit | abort ⟩, remove T from U
  - For a log record ⟨ T, X, *old*, *new* ⟩, 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 $\langle T, \text{abort} \rangle$ 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

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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 redo (backword)