Introduction to Database Systems CSE 444

Lecture 13

Transactions: concurrency control (part 1)

Outline

- Serial and Serializable Schedules (18.1)
- Conflict Serializability (18.2)
- Locks (18.3)

The Problem

- Multiple transactions are running concurrently T_1, T_2, …
- They read/write some common elements A_1, A_2, …
- How can we prevent unwanted interference ?
- The SCHEDULER is responsible for that

Some Famous Anomalies

- What could go wrong if we didn't have concurrency control:
  - Dirty reads (including inconsistent reads)
  - Unrepeatable reads
  - Lost updates

Many other things can go wrong too

Dirty Reads

Write-Read Conflict

T_1: WRITE(A)

T_2: READ(A)

T_1: ABORT

Inconsistent Read

Write-Read Conflict

T_1: A := 20; B := 20;
T_1: WRITE(A)

T_2: READ(A);
T_2: READ(B);

T_1: WRITE(B)

Unrepeatable Read

Read-Write Conflict

T_2: READ(A);

T_1: WRITE(A)

T_2: READ(A);

Lost Update

Write-Write Conflict

T_1: READ(A)

T_1: A := A+5

T_1: WRITE(A)

T_2: READ(A);

T_2: A := A*1.3

T_2: WRITE(A);

Schedules

- Given multiple transactions
- A *schedule* is a sequence of interleaved actions from all transactions

Example

T1	T2
READ(A, t)	READ(A, s)
t := t+100	s := s*2
WRITE(A, t)	WRITE(A,s)
READ(B, t)	READ(B,s)
t := t+100	s := s*2
WRITE(B,t)	WRITE(B,s)

A Serial Schedule

T1	T2
READ(A, t)	
t := t+100	
WRITE(A, t)	
READ(B, t)	
t := t+100	
WRITE(B,t)	
	READ(A,s)
	s := s*2
	WRITE(A,s)
	READ(B,s)
	s := s*2
	WRITE(B,s)

Serializable Schedule

- A schedule is ***serializable*** if it is equivalent to a serial schedule

A Serializable Schedule

T1	T2
READ(A, t)	
t := t+100	
WRITE(A, t)	
	READ(A,s)
	s := s*2
	WRITE(A,s)
READ(B, t)	
t := t+100	
WRITE(B,t)	
	READ(B,s)
	s := s*2
	WRITE(B,s)

Notice:
This is NOT a serial schedule

A Non-Serializable Schedule

T1	T2
READ(A, t)	
t := t+100	
WRITE(A, t)	
	READ(A,s)
	s := s*2
	WRITE(A,s)
	READ(B,s)
	s := s*2
	WRITE(B,s)
READ(B, t)	
t := t+100	
WRITE(B,t)	

Ignoring Details

- Sometimes transactions' actions can commute accidentally because of specific updates
  - Serializability is undecidable !
- Scheduler should not look at transaction details
- Assume worst case updates
  - Only care about reads r(A) and writes w(A)
  - Not the actual values involved

Notation

T_1: $r_1(A)$; $w_1(A)$; $r_1(B)$; $w_1(B)$
T_2: $r_2(A)$; $w_2(A)$; $r_2(B)$; $w_2(B)$

Conflict Serializability

Conflicts:

Two actions by same transaction T_i: $\boxed{r_i(X); w_i(Y)}$

Two writes by T_i, T_j to same element $\boxed{w_i(X); w_j(X)}$

Read/write by T_i, T_j to same element $\boxed{w_i(X); r_j(X)}$ $\boxed{r_i(X); w_j(X)}$

Conflict Serializability

- A schedule is *conflict serializable* if it can be transformed into a serial schedule by a series of swappings of adjacent non-conflicting actions

Example:

$r_1(A); w_1(A); r_2(A); w_2(A); r_1(B); w_1(B); r_2(B); w_2(B)$

$\Downarrow$

$r_1(A); w_1(A); r_1(B); w_1(B); r_2(A); w_2(A); r_2(B); w_2(B)$

The Precedence Graph Test

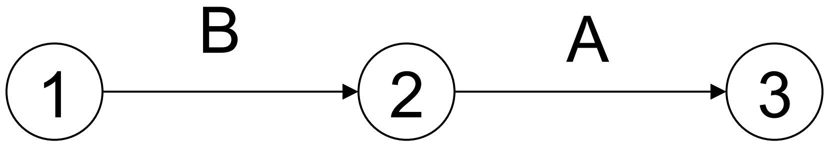
Is a schedule conflict-serializable ?

Simple test:

- Build a graph of all transactions T_i
- Edge from T_i to T_j if T_i makes an action that conflicts with one of T_j and comes first
- The test: if the graph has no cycles, then it is conflict serializable !

Example 1

$r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B)$


$$\begin{tikzcd} 1 \arrow[r, "B"] & 2 \arrow[r, "A"] & 3 \end{tikzcd}$$

This schedule is conflict-serializable

Example 2

$r_2(A); r_1(B); w_2(A); r_2(B); r_3(A); w_1(B); w_3(A); w_2(B)$

$$\begin{tikzcd}
1 \arrow[r, "B"'] & 2 \arrow[l, bend right, "B"'] \arrow[r, "A"] & 3
\end{tikzcd}$$

This schedule is NOT conflict-serializable

Conflict Serializability

- A serializable schedule need not be conflict serializable, even under the "worst case update" assumption

Lost write

$w_1(Y); w_2(Y); w_2(X); w_1(X); w_3(X);$

$$\not\Downarrow$$

$w_1(Y); w_1(X); w_2(Y); w_2(X); w_3(X);$

Equivalent, but can't swap

Scheduler

- The scheduler is the module that schedules the transaction's actions, ensuring serializability
- How ? We discuss three techniques in class:
  - Locks
  - Time stamps (next lecture)
  - Validation (next lecture)

Locking Scheduler

Simple idea:

- Each element has a unique lock
- Each transaction must first acquire the lock before reading/writing that element
- If the lock is taken by another transaction, then wait
- The transaction must release the lock(s)

Notation

$l_i(A)$ = transaction T_i acquires lock for element A

$u_i(A)$ = transaction T_i releases lock for element A

Example

T1	T2
L_1(A); READ(A, t)	
t := t+100	
WRITE(A, t); U_1(A); L_1(B)	
	L_2(A); READ(A,s)
	s := s*2
	WRITE(A,s); U_2(A);
	L_2(B); **DENIED…**
READ(B, t)	
t := t+100	
WRITE(B,t); U_1(B);	
	…**GRANTED;** READ(B,s)
	s := s*2
	WRITE(B,s); U_2(B);

Scheduler has ensured a conflict-serializable schedule

Example

T1	T2
L_1(A); READ(A, t)	
t := t+100	
WRITE(A, t); U_1(A);	
	L_2(A); READ(A,s)
	s := s*2
	WRITE(A,s); U_2(A);
	L_2(B); READ(B,s)
	s := s*2
	WRITE(B,s); U_2(B);
L_1(B); READ(B, t)	
t := t+100	
WRITE(B,t); U_1(B);	

Locks did not enforce conflict-serializability !!!

Two Phase Locking (2PL)

The 2PL rule:

- In every transaction, all lock requests must preceed all unlock requests

- This ensures conflict serializability ! (why?)

Example: 2PL transactions

T1	T2
L_1(A); L_1(B); READ(A, t)	
t := t+100	
WRITE(A, t); U_1(A)	
	L_2(A); READ(A,s)
	s := s*2
	WRITE(A,s);
	L_2(B); **DENIED…**
READ(B, t)	
t := t+100	
WRITE(B,t); U_1(B);	
	…**GRANTED;** READ(B,s)
	s := s*2
	WRITE(B,s); U_2(A); U_2(B);

Now it is conflict-serializable

What about Aborts?

- 2PL enforces conflict-serializable schedules
- But what if a transaction releases its locks and then aborts?

- Serializable schedule definition only considers transactions that commit
  - Relies on assumptions that aborted transactions can be undone completely

Example with Abort

T1	T2
L_1(A); L_1(B); READ(A, t)	
t := t+100	
WRITE(A, t); U_1(A)	
	L_2(A); READ(A,s)
	s := s*2
	WRITE(A,s);
	L_2(B); **DENIED…**
READ(B, t)	
t := t+100	
WRITE(B,t); U_1(B);	
	…**GRANTED;** READ(B,s)
	s := s*2
	WRITE(B,s); U_2(A); U_2(B);
Abort	Commit

Strict 2PL

- Strict 2PL: All locks held by a transaction are released when the transaction is completed

- Ensures that schedules are recoverable
  - Transactions commit only after all transactions whose changes they read also commit
- Avoids cascading rollbacks

Deadlock

- Transaction T_1 waits for a lock held by T_2;
- But T_2 waits for a lock held by T_3;
- While T_3 waits for . . . .
- . . .
- . . .and T_{73} waits for a lock held by T_1 !!

- Could be avoided, by ordering all elements (see book); or deadlock detection + rollback

Lock Modes

- S = shared lock (for READ)
- X = exclusive lock (for WRITE)
- U = update lock
  - Initially like S
  - Later may be upgraded to X
- I = increment lock (for A := A + something)
  - Increment operations commute

Recommended reading: chapter 18.4

The Locking Scheduler

Task 1:
Add lock/unlock requests to transactions

- Examine all READ(A) or WRITE(A) actions
- Add appropriate lock requests
- Ensure 2PL !

Recommended reading: chapter 18.5

The Locking Scheduler

Task 2:

Execute the locks accordingly

- Lock table: a big, critical data structure in a DBMS !
- When a lock is requested, check the lock table
  - Grant, or add the transaction to the element's wait list
- When a lock is released, re-activate a transaction from its wait list
- When a transaction aborts, release all its locks
- Check for deadlocks occasionally

Recommended reading: chapter 18.5