CSE 544
Principles of Database Management Systems

Alvin Cheung

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Lecture 11 –
Transactions: Concurrency Control

Announcements

- HW2 due tonight
- HW3 posted
  - Due in two weeks
  - Check website for OH
- Next couple of lectures we will talk about **transactions**

Where We Are

- Data models
  - Relational
  - IMS / Codasyl
  - Unstructured
- Query processing
  - Algorithms for relational operators
  - Indexing and physical design
- Dealing with the real world
  - Data warehousing
  - **Transaction processing**

References

- **Concurrency control and recovery.**

  Michael J. Franklin. The handbook of computer science and engineering. A. Tucker ed. 1997

- **Database management systems.**

  Ramakrishnan and Gehrke.

  Third Ed. **Chapters 16 and 17.**

Outline

- Transactions motivation, definition, properties
- Concurrency control and locking
- Optimistic concurrency control

Motivating Example

```
UPDATE Budget
SET money=money-100
WHERE pid = 1

UPDATE Budget
SET money=money+60
WHERE pid = 2

UPDATE Budget
SET money=money+40
WHERE pid = 3
```

```
SELECT sum(money)
FROM Budget
```

Would like to treat each group of instructions as a unit

Definition

- **A transaction** = one or more operations, single real-world transition
- Examples
  - Transfer money between accounts
  - Purchase a group of products
  - Register for a class (either waitlist or allocated)
  - What else?

Transactions

- Major component of database systems
- Critical for most applications; arguably more so than SQL

- Fact: Turing awards to database researchers:
  - Charles Bachman 1973 for CODASYL
  - Edgar Codd 1981 for inventing relational dbms
  - Jim Gray 1998 for inventing transactions
  - Michael Stonebraker 2015 for postgres

Transaction Example

```
START TRANSACTION
UPDATE Budget SET money = money - 100
WHERE pid = 1
UPDATE Budget SET money = money + 60
WHERE pid = 2
UPDATE Budget SET money = money + 40
WHERE pid = 3
COMMIT
```

ROLLBACK

- If the application gets to a place where it can't complete the transaction successfully, it can execute **ROLLBACK**
- This causes the system to "abort" the transaction
  - Database returns to a state without any of the changes made by the transaction

Reasons for Rollback

- User changes their mind (“ctl-C”/cancel)
- Explicit in program, when app program finds a problem
  - e.g., when qty on hand < qty being sold
- System-initiated abort
  - System crash
  - Housekeeping
    - e.g., due to timeouts, admission control, etc

ACID Properties

- Atomicity: Either all changes performed by transaction occur or none occurs
- Consistency: A transaction as a whole does not violate integrity constraints
- Isolation: Transactions appear to execute one after the other in sequence
- Durability: If a transaction commits, its changes will survive failures

- Q: Benefits & drawbacks of providing ACID transactions?

What Could Go Wrong?

- Why is it hard to provide ACID properties?
- Concurrent operations
  - Isolation problems
  - We saw one example earlier
- Failures can occur at any time
  - Atomicity and durability problems
  - Next lecture
- Transaction may need to abort

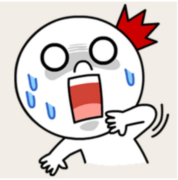
In a World Without Transactions

```
Client 1: INSERT INTO SmallProduct(name, price)
            SELECT pname, price
            FROM Product
            WHERE price <= 0.99

            DELETE Product
            WHERE price <=0.99

Client 2: SELECT count(*)
            FROM Product

            SELECT count(*)
            FROM SmallProduct
```



What could go wrong ?

Inconsistent reads

Different Types of Problems

Client 1:

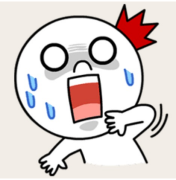
```
UPDATE Product
SET Price = Price – 1.99
WHERE pname = 'Gizmo'
```

Client 2:

```
UPDATE Product
SET Price = Price*0.5
WHERE pname='Gizmo'
```

What could go wrong ?

Lost update



Different Types of Problems

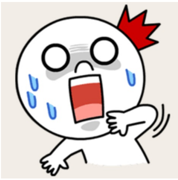
Client 1: UPDATE SET Account.amount = 1000000
WHERE Account.number = 1001

Aborted by system

Client 2: SELECT Account.amount
FROM Account
WHERE Account.number = 1001

What could go wrong ?

Dirty reads



Types of Problems: Summary

- Concurrent execution problems
  - Write-read conflict: dirty read (includes inconsistent read)
    - A transaction reads a value written by another transaction that has not yet committed
  - Read-write conflict: unrepeatable read
    - A transaction reads the value of the same object twice. Another transaction modifies that value in between the two reads
  - Write-write conflict: lost update
    - Two transactions update the value of the same object. The second one to write the value overwrite the first change
- Failure problems
  - DBMS can crash in the middle of a series of updates
  - Can leave the database in an inconsistent state

Outline

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Schedules

- Given multiple transactions

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

Example Schedule

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)

Time ↓

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)	

Notation

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

Serializable Execution

- **Serializability**: interleaved execution has same effect as some serial execution

- Schedule of two transactions (Figure 1)

  $r_0[A] \rightarrow w_0[A] \rightarrow r_1[A] \rightarrow r_1[B] \rightarrow c_1 \rightarrow$
  $\rightarrow r_0[B] \rightarrow w_0[B] \rightarrow c_0$

- Serializable schedule: equiv. to serial schedule

  $r_0[A] \rightarrow w_0[A] \rightarrow r_1[A] \rightarrow r_0[B] \rightarrow$
  $\rightarrow w_0[B] \rightarrow c_0 \rightarrow r_1[B] \rightarrow c_1$

Ignoring Details

- Sometimes transactions' actions can commute accidentally because of specific updates
  - Fact: 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

Conflict Serializability

Conflicts: (aka bad things happen if swapped)

Two actions by same transaction T_i: $r_i(X); w_i(Y)$

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

Read/write by T_i, T_j to same element $w_i(X); r_j(X)$

$r_i(X); w_j(X)$

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:

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

⇓

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

The Precedence Graph Test

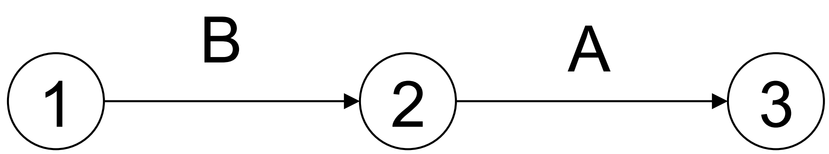
Is a schedule conflict-serializable ?

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
- Fact: if the graph has no cycles, then it is conflict serializable !

Example 1

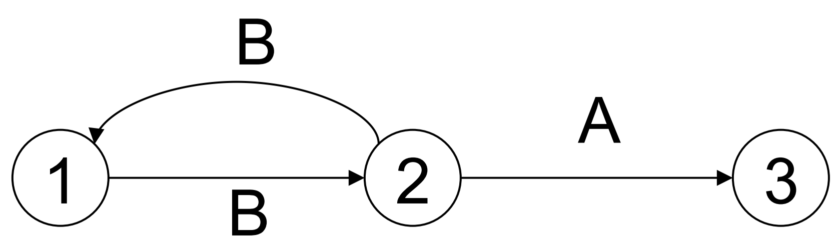
$r_2(A); r_1(B); w_2(A); r_3(A); w_1(B); w_3(A); r_2(B); w_2(B)$



This schedule is conflict-serializable

Example 2

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



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

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

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

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
  - Timestamps
  - Validation

Outline

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Locking Scheduler

Simple idea:

- Each element has a unique lock
- Each transaction must first acquire the lock before reading/writing that element
- If 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

Is this enough?

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

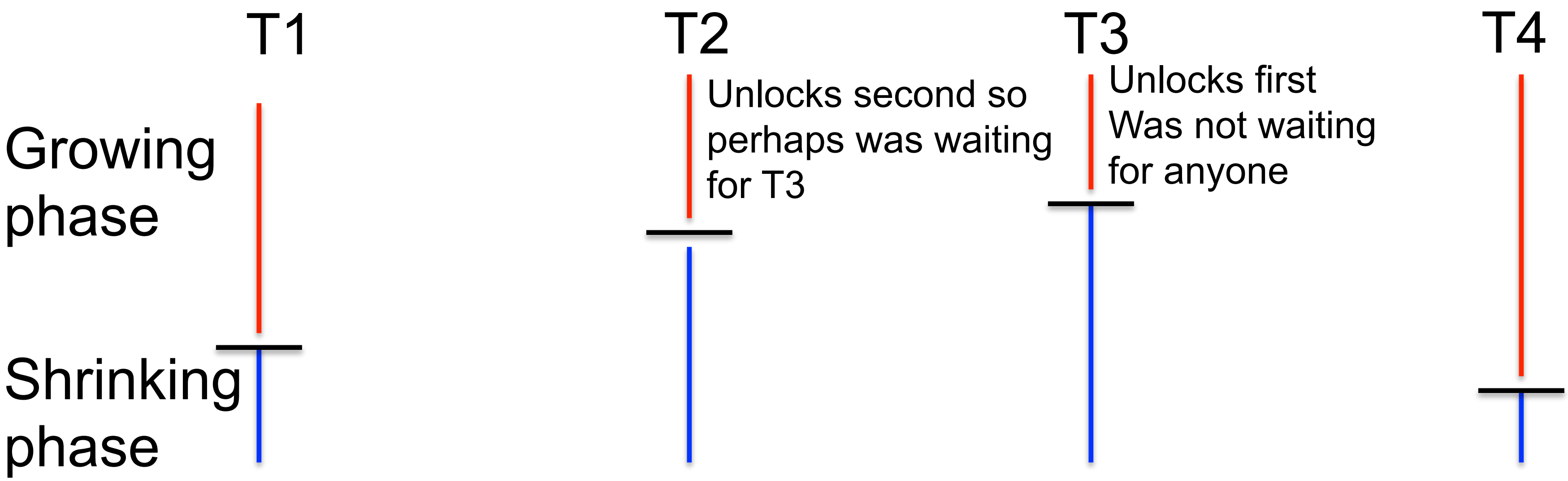
- This ensures conflict serializability ! (why?)

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

Example with Multiple Transactions



Equivalent to each transaction executing entirely the moment it enters shrinking phase

What about Aborts?

- 2PL enforces conflict-serializable schedules

- But what if a transaction releases its locks and then aborts?

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
  - Also called "long-duration locks"
- Ensures that schedules are recoverable
  - Transactions commit only after all transactions whose changes they read also commit
- Avoids cascading rollbacks