CS422 Principles of Database Systems
Concurrency Control

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ACID Properties of DB Transaction

- Atomicity
- Consistency
- Isolation
- Durability

Need for Concurrent Execution

- Fully utilize system resources to maximize performance
- Enhance user experience by improving responsiveness

Problem of Concurrent Transactions ...

items

id	name	price
1	milk	2.99
2	beer	6.99

Transaction #1:

```
-- MIN
select min(price) from items;
-- MAX
select max(price) from items;
```

... Problem of Concurrent Transactions

Transaction #2:

```
-- DELETE
delete from items;
-- INSERT
insert into items values (3, 'water', 0.99);
```

Consider the interleaving of T1 and T2:

MIN, DELETE, INSERT, MAX

Concurrency Control

- Ensure the *correct* execution of concurrent transactions

Transaction

```
start transaction;
select balance
    from accounts
    where id=1;
update accounts
    set balance=balance-100
    where id=1;
update accounts
    set balance=balance+100
    where id=2;
commit;
```

⬇

$r_1(x),r_1(x),w_1(x),r_1(y),w_1(y)$

Schedule

- A schedule is the interleaving of the transactions as executed by the DBMS
- Example:

Two transactions

T_1: $r_1(x),w_1(x),r_1(y),w_1(y)$
T_2: $r_2(y),w_2(y),w_2(x)$

One possible schedule:

$r_1(x),w_1(x),r_2(y),w_2(y),r_1(y),w_1(y),w_2(x)$

Serial Schedule

- A serial schedule is a schedule in which the transactions are not interleaved
- Example:

$r_1(x),w_1(x),r_1(y),w_1(y),r_2(y),w_2(y),w_2(x)$

and

$r_2(y),w_2(y),w_2(x),r_1(x),w_1(x),r_1(y),w_1(y)$

Serializable Schedule

- A serializable schedule is a schedule that produces the *same result* as *some* serial schedule
- A schedule is *correct* if and only if it is serializable

Example: Serializable Schedules

- Are the following schedules serializable??

$r_1(x),w_1(x),r_2(y),w_2(y),r_1(y),w_1(y),w_2(x)$

$r_1(x),w_1(x),r_2(y),r_1(y),w_2(y),w_1(y),w_2(x)$

$r_1(x),w_1(x),r_1(y),w_1(y),r_2(y),w_2(y),w_2(x)$

How do we check if two schedules produce the same results?

Conflicting Operations

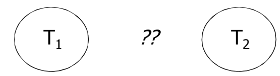
- Two operations *conflict* if the order in which they are executed can produce different results
  - Write-write conflict, e.g. $w_1(x)$ and $w_2(x)$
  - Read-write (or write-read) conflict, e.g. $r_1(y)$ and $w_2(y)$

Precedence Graph of Schedule S

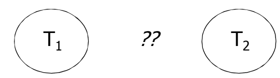
- The nodes of the graph are transactions T_i
- There is an arc from node T_i to node T_j if there are two conflicting actions a_i and a_j, and a_i proceeds a_j in S

Example: Precedence Graph

$r_1(x),w_1(x),r_2(y),r_1(y),w_2(y),w_1(y),w_2(x)$



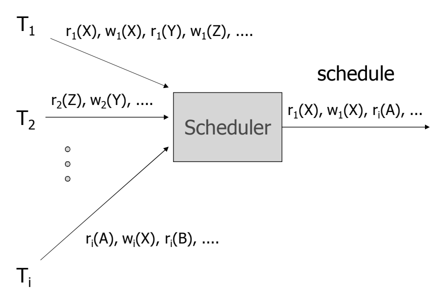
$r_1(x),w_1(x),r_1(y),w_1(y),r_2(y),w_2(y),w_2(x)$



Determine Serializablility

- A schedule is serializable if its precedence graph is acyclic

Scheduling



Locking

- Produce serializable schedules using *locks*
- Lock
  - `lock()` – returns immediately if the lock is available or is already owned by the current thread/process; otherwise wait
  - `unlock()` – release the lock, i.e. make the lock available again

Synchronization Using Locks

Lock lock;

Thread 1	Thread 2

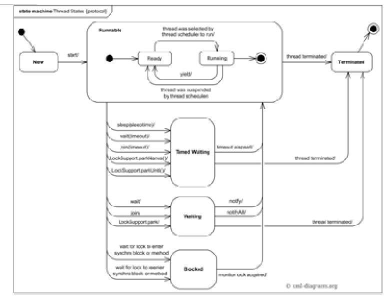
lock.lock();
// execute
// some txn
….
lock.unlock();
	lock.lock();
	// execute
	// another txn
	….
	lock.unlock();

Simple Lock Implementation in Java

```
public class Lock {

  private long value = -1;

  public void lock()
  {
      long threadId = Thread.currentThread().getId();
      if( value == threadId ) return;
      while( value != -1 ) wait(5000);
      lock = threadId;
   }

   public void unlock() { value = -1; }
}
```

Is there anything wrong with this implementation??

Life Cycle of a Java Thread



http://www.uml-diagrams.org/examples/java-6-thread-state-machine-diagram-example.html

Wait() and Notify()

- Methods of the Object class
- `wait()` and `wait(long timeout)`
  - Thread becomes *not runnable*
  - Thread is placed in the *wait set* of the object
- `notify()` and `notifyAll()`
  - Awake one or all threads in the wait set, i.e. make them *runnable* again

Basic Locking Scheme

- A transaction must acquire a lock on some data before performing any operation on it
  - E.g. $l_1(x),r_1(x),ul_1(x),l_2(x),w_2(x),ul_2(x)$
- Problem: concurrent reads are not allowed

Shared Locks and Exclusive Locks

- Multiple transactions can each hold a *shared lock* on the same data
- If a transaction holds an *exclusive lock* on some data, no other transaction can hold any kind of lock on the same data
- Example:

$sl_1(x),r_1(x),xl_1(y),w_1(y),sl_2(x),r_2(x),ul_1(y),sl_2(y),r_2(y)$

About Locking and Schedule

- T_1: $r_1(x),w_1(x)$
- T_2: $r_1(x),w_1(x)$

Invalid Schedule:

$sl_1(x),r_1(x),sl_2(x),r_2(x),xl_1(x),w_1(x),\ldots$

Lock upgrade:

$sl_1(x),r_1(x),sl_2(x),r_2(x),ul_2(x),xl_1(x),w_1(x),\ldots$

Example: Releasing Locks Too Early

- Is the following schedule serializable??

$sl_1(x),r_1(x),ul_1(x),xl_2(x),w_2(x),xl_2(y),w_2(y),ul_2(x),ul_2(y),xl_1(y),w_1(y),ul_1(y)$

Two-Phase Locking Protocol (2PL)

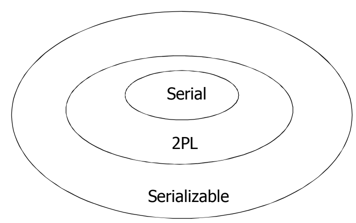
- A shared lock must be acquired before reading
- A exclusive lock must be acquired before writing
- In each transaction, *all lock requests proceed all unlock requests*

Example: 2PL

- Why the following schedule is not possible under 2PL??

$sl_1(x),r_1(x),ul_1(x),xl_2(x),w_2(x),xl_2(y),w_2(y),ul_2(x),ul_2(y),xl_1(y),w_1(y),ul_1(y)$

2PL Schedules



- Show a schedule that is 2PL but not serial
- Show a schedule that is serializable but not 2PL

The Recoverability Problem

- Serializability problem
  - Ensure correct execution of $T_1,\ldots,T_k$ when *all transactions successfully commit*
- Recoverability problem
  - Ensure correct execution of $T_1,\ldots,T_k$ when *some of the transactions abort*

Example: Unrecoverable Schedule …

- Is the following schedule serializable??
- Is the following schedule 2PL??

$w_1(x),r_2(x),w_2(x)$

… Example: Unrecoverable Schedule

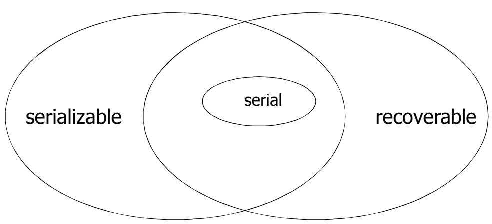
- But what if T2 commits but T1 aborts?

$w_1(x),r_2(x),w_2(x),c_2,a_1$

Recoverable Schedule

- In a recoverable schedule, each transaction commits only after each transaction from which it has read committed

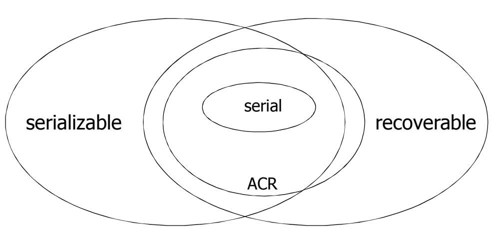
Serializable and Recoverable (I)



ACR Schedules

- Cascading rollback
  - $w_1(x),w_1(y),w_2(x),r_2(y),a_1$
- A schedule *avoids cascading rollback* (ACR) if transactions only read values written by committed transactions

Serializable and Recoverable (II)



Strict 2PL

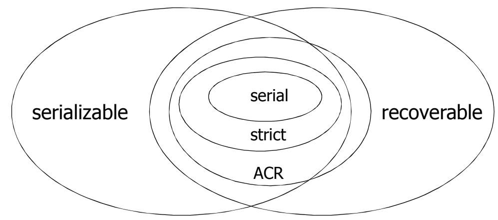
- 2PL
- A transaction releases all write-related locks (i.e. exclusive locks) after the transaction is *completed*
  - After <COMMIT,T> or <ABORT,T> is flushed to disk
  - After <COMMIT,T> or <ABORT,T> is created in memory (*would this work??*)

Example: Strict 2PL

- Why the following schedule is not possible under Strict 2PL??

$w_1(x), r_2(x), w_2(x), c_2, c_1$

Serializable and Recoverable (III)



Other Lock Related Issues

- Phantoms
- Lock granularity
- Lock and SQL Isolations Levels

Problem of Phantoms

- We can regulate the access of existing resources with locks, but how about new resources (e.g. created by appending new file blocks or inserting new records)??

Handle Phantoms

- Lock “end of file/table”

Lock Granularity

fewer locks but less concurrency →

record | block | table

← more locks but better concurrency

SQL Isolation Levels

Isolation Level	Lock Usage
Serializable	slocks held to completion; slock on eof
Repeatable read	slocks held to completion; no slock on eof
Read committed	slocks released early; no slock on eof
Read uncommitted	No slock

xlocks are always held to completion

Alternative Locking Scheme – Multiversion Locking

- Each version of a block is time-stamped with the commit time of the transaction that wrote it
- When a read-only transaction requests a value from a block, it reads from the block that was *most recently committed at the time when this transaction began*

How Multiversion Locking Works

T_1: $w_1(b_1)$, $w_1(b_2)$
T_2: $w_2(b_1)$, $w_2(b_2)$
T_3: $r_3(b_1)$, $r_3(b_2)$
T_4: $w_4(b_2)$

$w_1(b_1),w_1(b_2),c_1,w_2(b_1),r_3(b_1),w_4(b_2),c_4,r_3(b_2),c_3,w_2(b_2),c_2$

- Which version of b_1 and b_2 does T_3 read??

About Multiversion Locking

- Read-only transactions do not need to obtain any lock, i.e. never wait
- Implementation: use log to revert the current version of a block to a previous version

Deadlock

- T_1: $w_1(x),w_1(y)$
- T_2: $w_2(y),w_2(x)$

$xl_1(x),w_1(x),xl_2(y),w_2(y),\ldots$

Necessary Conditions for Deadlock

- Mutual exclusion
- Hold and wait
- No preemption
- Circular wait

Handling Deadlocks

- Deadlock prevention
- Deadlock avoidance
- Deadlock detection

Resource Numbering

- Impose a total ordering of all shared resources
- A process can only request locks in increasing order
- *Why the deadlock example shown before can no longer happen??*

About Resource Numbering

- A deadlock prevention strategy
- Not suitable for databases

Wait-Die

- Suppose T_1 requests a lock that conflicts with a lock held by T_2
  - If T_1 is older than T_2, then T_1 waits for the lock
  - If T_1 is newer than T_2, T_1 aborts (i.e. "dies")
- *Why does this strategy work??*

About Wait-Die

- A deadlock avoidance strategy (not deadlock detection as the textbook says)
- Transactions may be aborted to avoid deadlocks

Wait-For Graph

- Each transaction is a node in the graph
- An edge from T_1 to T_2 if T_1 is waiting for a lock that T_2 holds
- A cycle in the graph indicates a deadlock situation

About Wait-for Graph

- A deadlock detection strategy
- Transactions can be aborted to break a cycle in the graph
- Difficult to implement in databases because transaction also wait for buffers
  - For example, assume there are only two buffer pages
    - T_1: $xl_1(x)$, pin(b_1)
    - T_2: pin(b_2), pin(b_3), $xl_2(x)$

Readings

- Textbook Chapter 14.4-14.6
- SimpleDB source code
  - simpledb.tx
  - simpledb.tx.concurrency