Database Management Systems

Module 49: Concurrency Control/1

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Module Recap

- With proper planning, a database can be recovered back to a consistent state from inconsistent state in the face of system failures. Such a recovery is done via cascaded or cascadeless rollback
- View Serializability is a weaker serializability system for better concurrency. However, testing for view serializability is NP complete

Module Objectives

- Concurrency Control through design of serializable schedule is difficult in general. Hence we take a look into locking mechanism and Lock-Based Protocols
- We need to understand how locks may be implemented

Module Outline

- Concurrency Control
- Lock-Based Protocols
- Implementing Locking

Concurrency Control

Concurrency Control

- A database must provide a mechanism that will ensure that all possible schedules are both:
  - **Conflict serializable**
  - **Recoverable and, preferably, Cascadeless**
- A policy in which only one transaction can execute at a time generates serial schedules, but provides a poor degree of concurrency
- Concurrency-control schemes tradeoff between the amount of concurrency they allow and the amount of overhead that they incur
- Testing a schedule for serializability *after* it has executed is a little too late!
  - Tests for serializability help us understand why a concurrency control protocol is correct
- **Goal**: *To develop concurrency control protocols that will assure serializability*

Concurrency Control (2)

- One way to ensure isolation is to require that data items be *accessed in a mutually exclusive manner*; that is, while one transaction is accessing a data item, no other transaction can modify that data item
  - Should a transaction hold a lock on the whole database
    - ▷ Would lead to strictly serial schedules – very poor performance
- The most common method used to implement locking requirement is to allow a transaction to access a data item only if it is currently holding a **lock** on that item

Lock-Based Protocols

Lock-Based Protocols

- *A lock is a mechanism to control concurrent access to a data item*
- Data items can be locked in two modes:
  a) *exclusive (X)* mode:
     - Data item can be *both read as well as written*
     - **X-lock** is requested using **lock-X** instruction

  b) *shared (S)* mode:
     - Data item can *only be read*
     - **S-lock** is requested using **lock-S** instruction
- A transaction can unlock a data item Q by the **unlock**(Q) Instruction
- Lock requests are made to the concurrency-control manager by the programmer
- *Transaction can proceed only after request is granted*

Lock-Based Protocols (2): Lock Compatibility Matrix

- **Lock-Compatibility Matrix**: A lock compatibility matrix is used which states whether a data item can be locked by two transactions at the same time
- Full compatibility matrix

State of the lock \ Lock request type	Shared	Exclusive
Unlock	Yes	Yes
Shared	Yes	No
Exclusive	No	No

- Abbreviated compatibility matrix

State of the lock \ Lock request type	Shared	Exclusive
Shared	Yes	No
Exclusive	No	No

Lock-Based Protocols (3)

- *Requesting for / Granting of a Lock*
  - A transaction may be granted a lock on an item if the requested lock is compatible with locks already held on the item by other transactions
- *Sharing a Lock*
  - Any number of transactions can hold shared locks on an item
  - But if any transaction holds an exclusive lock on the item no other transaction may hold any lock on the item
- *Waiting for a Lock*
  - If a lock cannot be granted, the requesting transaction is made to wait till all incompatible locks held by other transactions have been released
- *Holding a Lock*
  - A transaction must hold a lock on a data item as long as it accesses that item
- *Unlocking / Releasing a Lock*
  - Transaction T_i may unlock a data item that it had locked at some earlier point
  - It is not necessarily desirable for a transaction to unlock a data item immediately after its final access of that data item, since serializability may not be ensured

Lock-Based Protocols: Example: Serial Schedule

- Let A and B be two accounts that are accessed by transactions T_1 and T_2.
  - Transaction T_1 transfers \$50 from account B to account A
  - Transaction T_2 displays the total amount of money in accounts A and B, that is, the sum $A + B$
- Suppose that the values of accounts A and B are \$100 and \$200, respectively
- If these transactions are executed serially, either as T_1, T_2 or the order T_2, T_1 then transaction T_2 will display the value \$300

$T1$:

```
lock-X(B);
read(B);
B := B – 50;
write(B);
unlock(B);
lock-X(A);
read(A);
A := A + 50;
write(A);
unlock(A);
```

T2:

```
lock-S(A);
read(A);
unlock(A);
lock-S(B);
read(B);
unlock(B);
display(A + B)
```

Lock-Based Protocols: Example (2): Concurrent Schedule: Bad

- If, however, these transactions are executed concurrently, then schedule 1 is possible
- In this case, transaction T_2 displays \$250, which is incorrect. The reason for this mistake is that
  - the transaction T_1 unlocked data item B too early, as a result of which T_2 saw an inconsistent state
- Suppose we delay unlocking till the end

T1:
lock-X(*B*);
read(*B*);
$B := B - 50$;
write(*B*);
unlock(*B*);
lock-X(*A*);
read(*A*);
$A := A + 50$;
write(*A*);
unlock(*A*);

T2:
lock-S(A);
read(A);
unlock(A);
lock-S(B);
read(B);
unlock(B);
display(A + B)

T_1	T_2	concurrency contr
lock-X(B)		
		grant-X(B, T_1)
read(B) $B := B - 50$ write(B) unlock(B)		
	lock-S(A)	
		grant-S(A, T_2)
	read(A) unlock(A) lock-S(B)	
		grant-S(B, T_2)
	read(B) unlock(B) display($A + B$)	
lock-X(A)		
		grant-X(A, T_1)
read(A) $A := A + 50$ write(A) unlock(A)		

Schedule 1

Lock-Based Protocols: Example (3): Concurrent Schedule: Good

- Delaying unlocking till the end, T_1 becomes T_3 & T_2 becomes T_4

T3:	T4:

lock-X(B);
read(B);
$B := B - 50$;
write(B);
lock-X(A);
read(A);
$A := A + 50$;
write(A);
unlock(B);
unlock(A)
	lock-S(A);
	read(A);
	lock-S(B);
	read(B);
	display($A + B$);
	unlock(A);
	unlock(B)

- Hence, sequence of reads and writes as in Schedule 1 is no longer possible
- T_4 will correctly display \$300

T_3	T_4	concurrency control manager
lock-X(B)		
		grant-X(B, T_1)
read(B) $B := B - 50$ write(B) unlock(B)		
	lock-S(A)	
		grant-S(A, T_2)
	read(A) unlock(A) lock-S(B)	
		grant-S(B, T_2)
	read(B) unlock(B) display($A + B$)	
lock-X(A)		
		grant-X(A, T_1)
read(A) $A := A + 50$ write(A) unlock(A)		

Schedule 1

Lock-Based Protocols: Example (4): Concurrent Schedule: Deadlock

- Given, T_3 and T_4, consider Schedule 2 (partial)
- Since T_3 is holding an exclusive mode lock on B and T_4 is requesting a shared-mode lock on B, T_4 is waiting for T_3 to unlock B
- Similarly, since T_4 is holding a shared-mode lock on A and T_3 is requesting an exclusive-mode lock on A, T_3 is waiting for T_4 to unlock A
- Thus, we have arrived at a state where neither of these transactions can ever proceed with its normal execution
- This situation is called **deadlock**
- When deadlock occurs, the system must roll back one of the two transactions.
- Once a transaction has been rolled back, the data items that were locked by that transaction are unlocked.
- These data items are then available to the other transaction, which can continue with its execution.

$T3$:

lock-X(B);
read(B);
$B := B - 50$;
write(B);
lock-X(A);
read(A);
$A := A + 50$;
write(A);
unlock(B);
unlock(A)

$T4$:

lock-S(A);
read(A);
lock-S(B);
read(B);
display($A + B$);
unlock(A);
unlock(B)

T_3	T_4
lock-X(B)	
read(B)	
$B := B - 50$	
write(B)	
	lock-S(A)
	read(A)
	lock-S(B)
lock-X(A)	

Schedule 2

Lock-Based Protocols

- If we do not use locking, or if we unlock data items too soon after reading or writing them, we may get inconsistent states
- On the other hand, if we do not unlock a data item before requesting a lock on another data item, deadlocks may occur
- Deadlocks are a necessary evil associated with locking, if we want to avoid inconsistent states
- Deadlocks are definitely preferable to inconsistent states, since they can be handled by rolling back transactions, whereas inconsistent states may lead to real-world problems that cannot be handled by the database system
- A **locking protocol** is a set of rules followed by all transactions while requesting and releasing locks
- Locking protocols restrict the set of possible schedules
- The set of all such schedules is a proper subset of all possible serializable schedules
- We present locking protocols that allow only conflict-serializable schedules, and thereby ensure isolation

Two-Phase Locking Protocol

- This protocol ensures conflict-serializable schedules
- Phase 1: Growing Phase
  - Transaction may obtain locks
  - Transaction may not release locks
- Phase 2: Shrinking Phase
  - Transaction may release locks
  - Transaction may not obtain locks
- The protocol assures serializability. It can be proved that the transactions can be serialized in the order of their **lock points**
  - That is, the point where a transaction acquired its final lock

Two-Phase Locking Protocol (2)

- There can be conflict serializable schedules that cannot be obtained if two-phase locking is used
- However, in the absence of extra information (that is, ordering of access to data), two-phase locking is needed for conflict serializability in the following sense:
  - Given a transaction T_i that does not follow two-phase locking, we can find a transaction T_j that uses two-phase locking, and a schedule for T_i and T_j that is not conflict serializable

Lock Conversions

- Two-phase locking with lock conversions:
  - First Phase:
    - ▷ can acquire a lock-S on item
    - ▷ can acquire a lock-X on item
    - ▷ can convert a lock-S to a lock-X (upgrade)
  - Second Phase:
    - ▷ can release a lock-S
    - ▷ can release a lock-X
    - ▷ can convert a lock-X to a lock-S (downgrade)
- This protocol assures serializability. But still relies on the programmer to insert the various locking instructions

Automatic Acquisition of Locks: Read

- A transaction T_i issues the standard read/write instruction, without explicit locking calls
- The operation **read**(D) is processed as:

  if T_i has a lock on D
    then
      read(D)
    else begin
      if necessary, wait until no other transaction has a **lock-X** on D
      grant T_i a **lock-S** on D;
      read(D)
    end

Automatic Acquisition of Locks: Write

- **write**(D) is processed as:

  if T_i has a **lock-X** on D
    then
      write(D)
    else begin
      if necessary, wait until no other transaction has any lock on D,
      if T_i has a **lock-S** on D
        then
          upgrade lock on D to **lock-X**
        else
          grant T_i a **lock-X** on D
        write(D)
  end;

- All locks are released after commit or abort

Deadlocks

- Two-phase locking *does not* ensure freedom from deadlocks

T3:
lock-X(*B*);
read(*B*);
B := *B* − 50;
write(*B*);
lock-X(*A*);
read(*A*);
A := *A* + 50;
write(*A*);
unlock(*B*);
unlock(*A*)

T4:
lock-S(*A*);
read(*A*);
lock-S(*B*);
read(*B*);
display(*A* + *B*);
unlock(*A*);
unlock(*B*)

T_3	T_4
lock-x (B)	
read (B)	
$B := B - 50$	
write (B)	
	lock-s (A)
	read (A)
	lock-s (B)
lock-x (A)	

- Observe that transactions T_3 and T_4 are two phase, but, in deadlock

Starvation

- In addition to deadlocks, there is a possibility of **Starvation**
- **Starvation** occurs if the concurrency control manager is badly designed. For example:
  - A transaction may be waiting for an X-lock on an item, while a sequence of other transactions request and are granted an S-lock on the same item
  - The same transaction is repeatedly rolled back due to deadlocks
- Concurrency control manager can be designed to prevent starvation
- Starvation is also loosely referred to as **Livelock**

Cascading Rollback

- The potential for deadlock exists in most locking protocols. Deadlocks are a necessary evil
- When a deadlock occurs there is a possibility of cascading roll-backs
- Cascading roll-back is possible under two-phase locking
- In the schedule here, each transaction observes the two-phase locking protocol, but the failure of T5 after the read(A) step of T7 leads to cascading rollback of T6 and T7.

T_5	T_6	T_7
lock-X(A) read(A) lock-S(B) read(B) write(A) unlock(A)		
	lock-X(A) read(A) write(A) unlock(A)	
		lock-S(A) read(A)

More Two Phase Locking Protocols

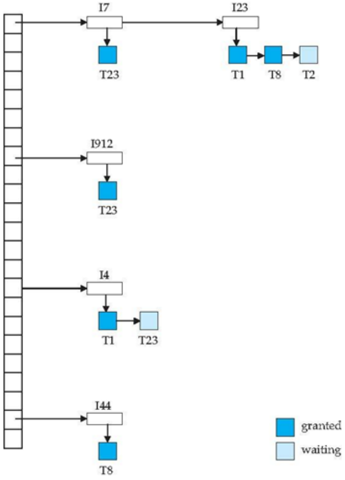
- To avoid Cascading roll-back, follow a modified protocol called **strict two-phase locking**
    - a transaction must hold all its exclusive locks till it commits/aborts
- **Rigorous two-phase locking** is even stricter
    - *All* locks are held till commit/abort. In this protocol transactions can be serialized in the order in which they commit
- Note that concurrency goes down as we move to more and more strict locking protocol

Implementation of Locking

Implementation of Locking

- A **lock manager** can be implemented as a separate process to which transactions send lock and unlock requests
- The lock manager replies to a lock request by sending a lock grant messages (or a message asking the transaction to roll back, in case of a deadlock)
- The requesting transaction waits until its request is answered
- The lock manager maintains a data-structure called a **lock table** to record granted locks and pending requests
- The lock table is usually implemented as an in-memory hash table indexed on the name of the data item being locked

Lock Table



- Dark blue rectangles indicate granted locks; light blue indicate waiting requests
- Lock table also records the type of lock granted or requested
- New request is added to the end of the queue of requests for the data item, and granted if it is compatible with all earlier locks
- Unlock requests result in the request being deleted, and later requests are checked to see if they can now be granted
- If transaction aborts, all waiting or granted requests of the transaction are deleted
    - lock manager may keep a list of locks held by each transaction, to implement this efficiently

Module Summary

- Understood the locking mechanism and protocols
- Realized that deadlock is a peril of locking and needs to be handled through rollback

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