Concurrency

CPS352: Database Systems

Simon Miner
Gordon College
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Agenda

- Check-in
- Locking Protocols
- Programming Project
- Other Serializability Approaches and Issues
- Homework 5

Check-in

Motivation for Concurrent Processing

- Effective use of system resources
  - Do work on CPU while waiting for a disk access
  - Do multiple disk accesses on multiple disks in parallel
- Support multiple simultaneous database users/sessions
- Take advantage of idle time during interactive transactions
- Keep the database accessible during a long-running transaction

Requirements for Concurrency

- Need to ensure the following for concurrent transactions
  - Serializability – equivalent to a serial schedule
    - Maintains consistency
  - Recoverability – a transaction cannot commit until any transaction whose data it uses commits
- How are these requirements actually implemented?

Locking Protocols

Locks

- A *locking protocol* is a set of rules which ensure that any schedule developing over time is serializable
  - More pragmatic than testing for serializability since future transactions (usually) cannot be predicted
- New database primitives
  - *Lock* – exclude other transactions from accessing a certain data item
  - *Unlock* – releases a predefined lock on a data item
- Locks often persist until the end of a transaction
- Locks are implicit to database operations
  - No need to tell a database to lock an item; it knows when to do so
  - This lecture shows locks explicitly to help illustrate them

Granularity of Locks

- Database locking – the entire database is locked (create or drop database)
- File locking – all objects in a file become unusable by other transactions
  - Used for growing, shrinking, or reorganizing files
  - "Online" mode can cause this work to happen in the background and then be switched into place once it completes
- Database object locking – tables, indexes, etc.
  - Used when altering the object's structure (via DDL statement)
    - Adding a column to a table
    - Rebuilding an index
- Record (row) or field (column) locking – a single tuple or data item is locked during a transaction
- Block level locking – common because data is read and written in blocks
  - A transaction may lock not only the record it is using, but the other records on the block as well

Shared Locks

- Used when a transaction reads an item without changing it
- Other transactions may also obtain shared locks on the item
- Shared lock prevents the data item from being changed while the transaction(s) read it
- Example: read current account balance

  lock-s(balance)

  read(balance)

  unlock(balance)
  - If the transaction is reading balances on multiple accounts, it needs to obtain shared locks on each of them

Exclusive Locks

- Used when a transaction writes an item
  - Also allows for reading the item
- A transaction seeking an exclusive lock must wait until all other locks on the desired item are released
- No other transaction can obtain any kind of lock on an item while an exclusive lock is held on it
  - Exclusive lock remains in force until the transaction commits or rolls back
- Read-modify-write operation
  - Obtain an exclusive lock before reading the item OR
  - Obtain a shared lock for the read, and then upgrade to an exclusive lock before the write
- Example: post interest to account (without and with lock upgrading)

```
lock-x( balance )
read( balance )
write( balance )
unlock( balance )
```

```
lock-s( balance )
read( balance )
upgrade( balance )
write( balance )
unlock( balance )
```

Deadlock

- Problem that can arise with locking protocols between transactions
  - Transaction T_1 has a lock on resource R_1 and needs a lock on resource R_2 before it can unlock R_1
  - Transaction T_2 has a lock on resource R_2 and needs a lock on resource R_1 before it can unlock R_2
- Example: Transfer $50 from checking to savings while printing total of account balances

Transfer (T_1)	Balance Inquiry (T_2)
lock-x(checking balance) read(checking balance) calculate new balance = old – 50 write(checking balance)	
	lock-s(savings balance) read(savings balance) lock-s(checking balance) – *must wait*
lock-x(savings balance) – *must wait*	

Dealing with Deadlock

- Approaches
  - Deadlock Prevention – design a scheme that stops deadlock from ever occurring (not always possible)
  - Deadlock Avoidance – Delay any lock which could lead to deadlock (Requires some advance knowledge of how transactions will behave)
  - Deadlock Detection and Recovery – Allow deadlock, and when it occurs, rollback one of the transactions and restart it after the other proceeds past the point of deadlock
- Most DBMS's use deadlock detection and recovery
  - Databases usually have lots of small transactions, decreasing the probability of deadlock
    - Databases need to support rollback anyway
  - Not a good approach to deadlock at the OS level (high rollback cost)

Locking by Itself is not Enough

Transfer (T_1)	Balance Inquiry (T_2)
	lock-s(savings balance) read savings balance (S)
lock-x(checking balance) read checking balance (C) write checking balance (C-50) unlock(checking balance)	
	lock-s(checking balance) read savings balance (C-50) unlock(savings balance) unlock(checking balance)
lock-x(savings balance) read savings balance (S) write savings balance (S+50) unlock(savings balance)	

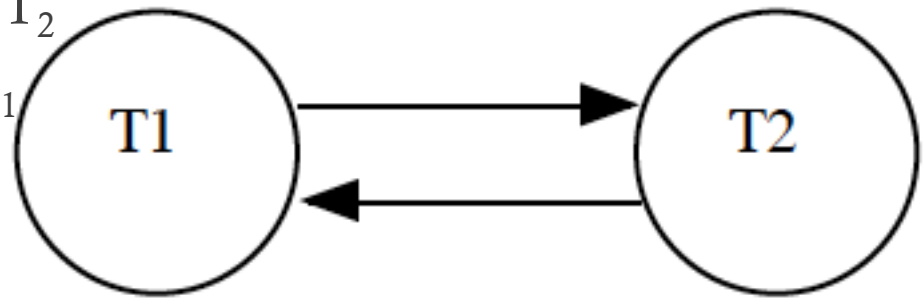
- Each transaction obtains appropriate locks
  - But there is still an error in the Inquiry transaction's balance total

Two-Phase Locking Protocol

- Governs the order in which transactions acquire and release locks
- Requires that a transaction must acquire all the locks it needs before releasing any of them
  - *Growth phase* – transaction acquires locks, but may not release any
    - Includes upgrading locks
  - *Shrinking phase* – transaction may release locks, but may not acquire any more
    - Includes downgrading locks (i.e. from exclusive to shared)

Two-Phase Locking and Transaction Serializability

- Two-phase locking can be used to ensure serializability
- Extension to precedence graph (used to test for conflict serializability)
- Directed edge for a *precedes relationship*
  - T_1 precedes T_2 ($T_1 \rightarrow T_2$) if in some schedule T_1 acquires a lock on some resource R before T_2 acquires an incompatible lock on R
  - If the precedence graph is acyclic, the schedule is serializable
- Example: transfer (T_1) and inquiry (T_2)
  - T_1 locks checking balance before T_2
  - T_2 locks savings balance before T_1
  - Cycle in graph, so not serializable



Two-Phase Locking and Transaction Recoverability

- Extensions to two-phase locking protocol
  - *Strict* two-phase protocol requires that all exclusive locks be held until a transaction commits
  - *Rigorous* two-phase protocol requires that all locks (shared or exclusive) be held until a transaction commits
- Both of these variants guarantee cascade-less recoverability, because no transaction can read data written by an uncommitted transaction
- Both variants are widely used along with some deadlock detection and recovery mechanism
  - Since two-phase locking can lead to deadlock

Programming Project

Other Serializability Approaches and Issues

Other Methods to Ensure Serializability

- Timestamps
- Validation
- Multiversion Schemes

Timestamps

- Each transaction is issued a unique serial number/clock reading when it starts
  - If an old transaction T_1 has time-stamp TS(T_1), a new transaction T_2 is assigned time-stamp TS(T_2) such that TS(T_1) <TS(T_2)
- Timestamps ensure that a transaction schedule is equivalent to a serial schedule
  - T_1 completes before T_2 because TS(T_1) < TS(T_2)
  - Stops reads or writes that would lead to a non-serializable schedule (like locking)
- Each data item Q maintains two timestamp values
  - W-timestamp(Q) – largest timestamp of any transaction that successfully wrote to Q
  - R-timestamp(Q) – largest timestamp of any transaction that successfully read Q
  - Conflicting read and write operations are executed in timestamp order
- Can have cascading rollbacks

Validation

- Allow transaction to read and write freely, but before it commits, ensure the outcome is serializable
  - Optimistic concurrency control – transaction fully executes "hoping" that validation goes well
- Allows higher levels of concurrency
  - Good if most transactions are read-only and do not interfere with each other

Multiversion Schemes

- Multiversion schemes keep old versions of data item to increase concurrency.
  - Multiversion Timestamp Ordering
  - Multiversion Two-Phase Locking
- Each successful **write** results in the creation of a new version of the data item written.
  - The old version(s) also retained
  - Use timestamps to label versions.
- When a **read**(*Q*) operation is issued, select an appropriate version of *Q* based on the timestamp of the transaction, and return the value of the selected version.
- **read**s never have to wait as an appropriate version is returned immediately.
- Requires extra storage for versioned tuples and versioning data

Other Issues

- Deletes, Inserts, and Phantom Rows
- Weak Levels of Consistency
- Locking and Index Structures

Deletes and Inserts

- Inserts and deletes are like write operations (with regard to an entire row)
- Consider the following query:
  select count(*) from checked_out where borrower_id = 12345
  - What happens if a concurrent transaction does an insert or delete of a row with borrower_id = 12345?
    - If the operation is "ahead" of the select, it impacts the count
    - If the operation is "behind" the select, it does not impact the count
      - This *phantom row* is a problem.
- Solution: make doing an insert or delete a lockable operations
  - Insert/delete obtains an exclusive lock on this ability before executing
  - Count operation obtains a shared lock to prevent other rows from being inserted or deleted while it runs
  - Does not lock the whole table – other transactions can continue to run

Weak Levels of Consistency

- Ensuring serializable schedules takes overhead to either
  - Require transactions to wait for lock(s) to release before proceeding
  - Roll back transactions performing operations that would lead to a non-serializable schedule (and potentially restart them)

- Serializability enforcement can be relaxed if an approximate answer is close enough
  - Different levels of weakened serializability supported by SQL
    - **Serializable**– enforces full serializability
    - **Repeatable read**: allows only committed records to be read, and repeating a read within a single transaction should return the same value (Other transactions cannot change the value between successive reads)
      - However, phantom rows are still possible
        - T1 may see some records inserted by T2, but may not see others inserted by T2
    - **Read committed**: only committed records can be read, and repeating a read within a single transaction might return different values (if some other transaction changes the data item)
    - **Read uncommitted**: allows even uncommitted data to be read (dirty read)

Locks and Index Structures

- What happens to indexes when the data they reference gets locked
  - A transaction looking up data via an index (e.g. read) needs shared locks on all index leaf nodes that it uses
  - A transaction doing inserts, updates, or deletes (e.g. write) needs exclusive locks on all leaf nodes affected by the operation
    - Also needs to update all pertinent indexes
- Indexes are accessed very often, so some index locking protocols do not require two phases
  - Accuracy is still required
  - Need for speed trumps serializability

Homework 5