Transactions and Concurrency

EGCI 321: LECTURE 14 (WEEK 9)

Outline

1. Why We Need Transactions
   - Failures
   - Concurrency
2. Serializability
   - Serialization Schedules
   - Serialization Graphs
3. Transactions in SQL
   - Abort and Commit
   - Isolation Levels
4. Implementing Transactions
   - Concurrency Control
   - Recovery Management

Problems Caused by Failures

- Update all account balance at a bank branch

Accounts(Anum, Cid, BranchId, Balance)

update Accounts
set Balance = Balance * 1.05
where BranchId = 12345

Problem

If the system crashes while processing this update, some, but, not all, tuples with **BranchID = 12345** may have been updated

Another Failure-Related Problem

- Transfer money between accounts:

```
update Accounts
set     Balance = Balance – 100
where   Anum = 8888

update Accounts
set     Balance = Balance + 100
where   Anum = 9999
```

Problem

If the system fails between these updates, money may be withdrawn but not redeposited.

Problems Caused by Concurrency

Applications 1:

update Accounts
set Balance = Balance – 100
where Anum = 8888

update Accounts
set Balance = Balance + 100
where Anum = 9999

Application 2:

select Sum(Balance)
from Accounts

Problem

If the applications run concurrently, the total balance returned to application 2 may be inaccurate.

Another Concurrency Problem

Application 1:

select balance into : balance
from Accounts
where Anum = 8888

compute :newbalance using :balance

update Accounts
set Balance = :newbalance
where Anum = 8888

Application 2: same as Application 1

Problem

If the applications run concurrently, one of the updates may be “lost”

Transactions

Definition (Transaction)

An application-specified *atomic* and *durable* unit of work.

Properties of transactions ensured by the DBMS:

Atomic: a transaction occurs entirely, or not at all

Consistency: each transaction preserves the consistency of the database

Isolated: concurrent transactions do not interfere with each other

Durables: once completed, a transaction’s changes are permanent

Serializability (informal)

Concurrent transactions must appear to have been executed sequentially, i.e., one at a time, in some order. If T_i and T_j are concurrent transactions, then either:

1. T_i will appear to precede T_j , meaning that T_j , will "see" any updates made by T_i , and T_i will not see any updates made by T_j , or

2. T_i will appear to follow T_j, meaning that T_i will see T_j's updates and T_j will not see T_i's

Serializability: An Example

An interleaved execution of two transactions, T_1 and T_2:

$$H_a = w_1[x]\ r_2[x]\ w_1[y]\ r_2[y]$$

An equivalent serial execution of T_1 and T_2

$$H_b = w_1[x]\ w_1[y]\ r_2[x]\ r_2[y]$$

An interleaved execution of T_1 and T_2 with no equivalent serial execution:

$$H_c = w_1[x]\ r_2[x]\ r_2[y]\ w_1[y]$$

H_a is serializable because it is equivalent to H_b , a serial schedule H_c is not serializable

Transactions and Histories

- Two operations conflict if:
  1. They belong to different transactions,
  2. They operate on the same object, and
  3. At least one of the operations is a write
- A transaction is a sequence of read and write operations
- A *execution history* over a set of transactions $T_1 \ldots T_n$ is an interleaving of the operations of $T_1 \ldots T_n$ in which the operation ordering imposed by each transaction is preserved
- Two important assumptions:
  1. Transactions interact with each other only via reads and writes of objects
  2. A database is a fixed set of independent objects

Serializability

Definition ((Conflict) Equivalence)

Two histories are *(conflict) equivalent* if

- They are over the same set of transactions, and
- The ordering of each pair of conflicting operations is the same in each history

Definition ((Conflict) Serializability)

A history *H* is said to be *(conflict) serializable* if there exists some serial history *H'* that is (conflict) equivalent to *H*

Testing for Serializability

$r_1[x]\ r_3[x]\ w_4[y]\ r_2[u]\ w_4[z]\ r_1[y]\ r_3[u]\ r_2[z]\ w_2[z]\ r_3[z]\ r_1[z]\ w_3[y]$

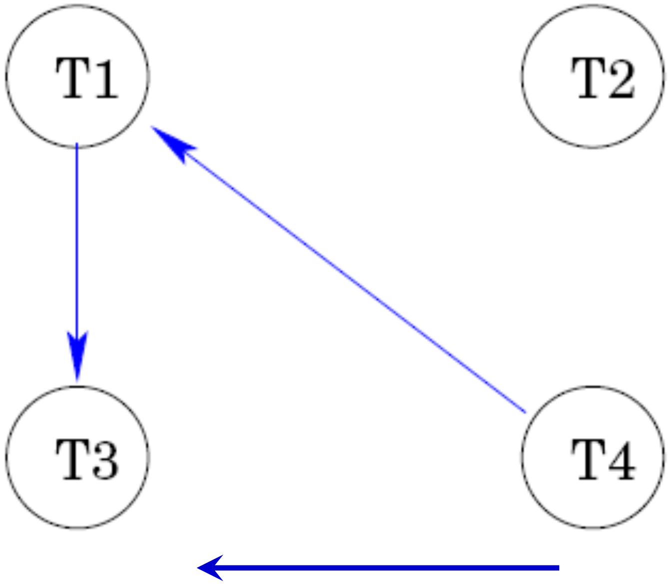
Is this history serializable?

Theorem

A history is serializable iff its serialization graph is acyclic

Serialization Graphs

$r_1[x]\ r_3[x]\ w_4[y]\ r_2[u]\ w_4[z]\ r_1[y]\ r_3[u]\ r_2[z]\ w_2[z]\ r_3[z]\ r_1[z]\ w_3[y]$



Consider read-write, write-read, and write-write of same object but different transactions

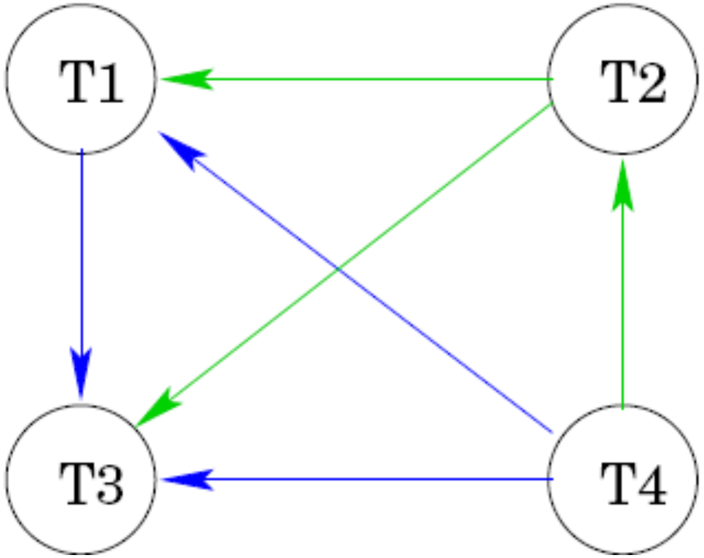
Ex. w4,r1,w3,…

Conflict pairs y: $(w_4[y]\ r_1[y])$, $(r_1[y]\ w_3[y])$, $(w_4[y]\ w_3[y])$

Serialization Graph (cont.)

$r_1[x]\ r_3[x]\ w_4[y]\ r_2[u]\ w_4[z]\ r_1[y]\ r_3[u]\ r_2[z]\ w_2[z]\ r_3[z]\ r_1[z]\ w_3[y]$

Conflict pairs
y: ($w_4[y]$ $r_1[y]$), ($r_1[y]$ $w_3[y]$), ($w_4[y]$ $w_3[y]$)
z: ($w_4[z]$ $r_2[z]$), ($w_2[z]$ $r_3[z]$), ($w_2[z]$ $r_1[z]$)



The history above is equivalent to

$$w_4[y]\ w_4[z]\ r_2[u]\ r_2[z]\ w_2[z]\ r_1[x]\ r_1[y]\ r_1[z]\ r_3[x]\ r_3[u]\ r_3[z]\ w_3[y]$$

That is, it is equivalent to executing T_4 followed by T_2 followed by T_1 followed by T_3

Abort and Commit

- A transaction may terminate in one of two ways:
  - When a transaction ***commits***, any updates it made become durable, and they become visible to other transactions. A commit it the "all" in "all-or-nothing" execution
  - When a transaction ***aborts***, any updates it may have made are undone (erased), as if the transaction never ran at all. An abort is the "nothing" in "all-or-nothing" execution

- A transaction that has started but has not yet aborted or committed is said to be ***active***

Transactions in SQL

- A new transaction is begun when an application first executes an SQL command

- Two SQL commands are available to terminate a transaction:
  - **commit work:** commits the transaction
  - **rollback work:** abort the transaction

- A new transaction begins with the application's next SQL command after **commit work** or **rollback work**

SQL Isolation Levels

- SQL allows the serializability guarantee to be relaxed, if necessary
- For each transaction, it is possible to specify an *isolation level*
- For isolation levels are supported, with the highest being serializability:

Level 0 (Read Uncommitted): transaction may see uncommitted updates

Level 1 (Read Committed): transaction sees only committed changes, but non-repeatable reads are possible

Level 2 (Repeatable Read): reads are repeatable, but "phantoms" are possible

Level 3 (Serializability)

Non-Repeatable Reads

Application 1:

```
update Employee
set    Salary = Salary +1000
where  WorkDept = 'D11'
```

Application 2:

```
select * from Employee
where  WorkDept = 'D11'
select * from Employee
where  Lastname Like 'A%'
```

Problem

If there are employees in D11 with surnames that begin with "A", Application 2's queries may see them with different salaries

Phantoms

Application 1:

insert into Employee

values (‘000123’, ’Sheldon’, ‘Q’, ‘Jetstream’, ‘D11’, ‘’05/01/00, 520000.00)

Application 2

select *

from Employee

where WorkDept = ‘D11’

select *

from Employee

where Salary > 5000

Problem

Application 2’s second query may see Sheldon Jetstream, even though its first query does not

Implementing Transactions

The implementation of transactions in a DBMS has two parts:

Concurrency Control: guarantees that the execution history has the desired properties (such as serializability)

Recovery Management: guarantee that committed transactions are durable (despite failures), and that aborted transactions have no effect on the database

Concurrency Control

- Serializability can be guaranteed by executing transactions serially, but, in many environments, this leads to poor performance
- Typically, many transactions are in progress concurrently, and a concurrency control protocol is used to ensure that the resulting history is serializable
- Many concurrency control protocols have been proposed, based on:
  - Locking, or
  - Timestamps, or
  - Serialization graph analysis
- By far the most commonly implemented protocol is *strict two-phase locking*
- The strict two-phase locking protocol can be relaxed, as necessary, to accommodate isolation levels below serializability

Strict Two-Phase Locking

The rules:

1. Before a transaction may read or write an object, it must have a lock on the object
   - A shared lock is required to read an object
   - An exclusive lock is required to write an object
2. Two or more transactions may not hold locks on the same object unless all hold shared locks
3. A transaction may not release any locks until it commits (or aborts)

If all transactions use strict two-phase locking, the execution history is guaranteed to be serializable

Transaction Blocking

- Consider the following sequence of events:
  - T_1 acquires a shared lock on x and reads x
  - T_2 attempts to acquire an exclusive lock on x (so that it can write x)

- The two-phrase locking rules prevent T_2 from acquiring its exclusive lock—this is called a *lock conflict*

- Lock conflicts can be resolved in one of two ways:
  1. T_2 can be *blocked* – forced to wait until T_1 release its lock
  2. T_1 can be *pre-empted* – forced to abort and give up its locks

Deadlocks

- Transaction blocking can result in deadlocks
- For example:
  - T_1 reads object x
  - T_2 reads object y
  - T_2 attempts to write object x (it is blocked)
  - T_1 attempts to write object y (it is blocked)

A deadlock can be resolved only by forcing one of the transactions involved in the deadlock to abort

Recovery Management

Recovery management means:

1. Implementing voluntary or involuntary rollback of individual transactions
2. Implementing recovery from *system failures*

System failure mean:

1. The database server is halted abruptly
2. Processing of in-progress SQL command(s) is halted abruptly
3. Connections to Applications programs (clients) are broken.
4. Contents of memory buffers are lost
5. Database files are damaged

Failures and Transactions

- To ensure that transactions are atomic, every transaction that is active when a system failure occurs must either be
  - Restarted after the failure from the point it which it left off, or
  - Rolled back after the failure

- It is difficult to restart applications after a system failure, so the recovery manager does the following:
  - Abort transactions that were active at the time of the failure
  - Ensure that changes made by transactions that committed before the failure are not lost

Logging

- Recovery management is usually accomplished using a *log*
- A log is a read/append data structure located in persistent storage (it must survive the failure)
- When transactions are running*, log records* are appended to the log. Log records contain:

UNDO information: old version of objects that have been modified by a transaction. Used to undo database changes made by a transaction that aborts.

REDO information: new versions of objects that have been modified by a transaction. Used to redo the work done by a transaction that commits.

BEGIN/COMMIT/ABORT: records are recorded whenever a transaction begins, commits, or aborts.

Requires Write-Ahead-Logging

Log records must be written ***before*** updating the database

Recovery

Recovering from a system failure:

1. Scan the log from tail (newest) to head (oldest):
   - Create a list of committed transactions
   - Undo updates of active and aborted transactions
2. Scan the log from head (oldest) to tail (newest):
   - Redo updates of committed transactions

Rolling back a single transaction:

1. Scan the log from the tail to the transaction's BEGIIN record.
   - Undo the transaction's updates

Reference

1. Ramakrishnan R, Gehrke J., Database management systems, 3rd ed., New York (NY): McGraw-Hill, 2003.