Transactions and their Properties

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Outline

1. Why We Need Transaction Management
   - Concurrency
   - Failures
2. Transactions
   - Transaction Termination
   - Transactions in SQL
3. Properties of Transactions
4. Transaction Based Concurrency Control
5. Transaction Based Recovery

Why We Need Transaction Management

- A database is a shared resource accessed by many users and processes concurrently.
  - Both queries and modifications
- Not managing this concurrent access to a shared resource will cause problems (not unlike in operating systems)
  - Problems due to concurrency
  - Problems due to failures
Problems Caused by Concurrency

Accounts(AccountNumber, CustID, BranchID, Balance)

- Application 1: You are depositing money to your bank account.
  ```sql
  update Accounts
  set Balance = Balance + 100
  where AccountNumber = 9999
  ```

- Application 2: The branch is calculating the balance of the accounts.
  ```sql
  select Sum(Balance)
  from Accounts
  ```

**Problem - Inconsistent reads**
If the applications run concurrently, the total balance returned to application 2 may be inaccurate.

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Another Concurrency Problem

- Application 1: You are depositing money to your bank account at an ATM.
  ```sql
  update Accounts
  set Balance = Balance + 100
  where AccountNumber = 9999
  ```

- Application 2: Your partner is withdrawing money from the same account at another ATM.
  ```sql
  update Accounts
  set Balance = Balance - 50
  where AccountNumber = 9999
  ```

**Problem - Lost Updates**
If the applications run concurrently, one of the updates may be "lost", and the database may be inconsistent.

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Yet Another Concurrency Problem

- Application 1:
  ```sql
  update Employee
  set Salary = Salary + 1000
  where WorkDept = 'D11'
  ```

- Application 2:
  ```sql
  select * from Employee
  where WorkDept = 'D11'
  ```

**Problem - Non-Repeatable Reads**
If there are employees in D11 with surnames that begin with "A", Application 2's queries may see them with different salaries.
High-Level Lesson

We need to worry about interaction between two applications when
- one reads from the database while the other writes to (modifies) the database;
- both write to (modify) the database.

We do not worry about interaction between two applications when both only read from the database.

Problems Caused by Failures

- Update all account balances at a bank branch.

  ```sql
  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 (i.e., some account balances) may have been updated.

  **Problem**
  If the system crashes after this update is processed but before all of the changes are made permanent (updates may be happening in the buffer), the changes may not survive.

Another Failure-Related Problem

- Transfer money between accounts:

  ```sql
  update Accounts
  set Balance = Balance - 100
  where AccountNumber = 8888

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

  **Problem**
  If the system fails between these updates, money may be withdrawn but not redeposited.
High-Level Lesson

We need to worry about partial results of applications on the database when a crash occurs.

We need to make sure that when applications are completed their changes to the database survive crashes.

Transactions

Definition (Transaction)
An application-specified atomic and durable unit of work (a process).

- Concurrency transparency
- Failure transparency

Transaction Termination

COMMIT: Any updates a transaction has made become permanent and visible to other transactions. Before COMMIT, changes are tentative.

ABORT: Any updates a transaction may have made are undone (erased), as if the transaction never ran at all.

ABORTED BY SYSTEM: Same effect as ABORT by application.
- Happens in case of problems that may only be detected by the DBMS (e.g. timeout, deadlock)

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`: commits the transaction
  - `rollback`: aborts the transaction

- A new transaction begins with the application’s next SQL command after `commit` or `rollback`.

Example Transaction – Single Statement

```sql
SELECT * FROM Employee
WHERE WorkDept = 'D11'
COMMIT

UPDATE Employee
SET Salary = Salary + 1000
WHERE WorkDept = 'D11'
COMMIT
```

Outline

- Why We Need Transaction Management
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  - Failures

- Transactions
  - Transaction Termination
  - Transactions in SQL

- Properties of Transactions

- Transaction Based Concurrency Control

- Transaction Based Recovery
Properties of Transactions

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
Durable: once committed successfully, a transaction’s changes are permanent

Consistency

Database in a consistent state
Database may be temporarily in an inconsistent state during execution
Database in a consistent state

Begin Transaction Execution of Transaction End Transaction

How Do Transactions Help?

- Application 1: You are depositing money to your bank account at an ATM.
  update Accounts
  set Balance = Balance + 100
  where AccountNumber = 9999
- Application 2: Your partner is withdrawing money from the same account at another ATM.
  update Accounts
  set Balance = Balance - 50
  where AccountNumber = 9999

Isolation

If each of these applications run as a transaction, their effects would be isolated from each other — Application 2 can’t see Application 1’s update until Application 1 completes.
How Do Transactions Help?

- Update all account balances at a bank branch.

```sql
update Accounts
set Balance = Balance * 1.05
where BranchID = 12345
```

Atomicity

If the application runs as a transaction, either all the accounts will get updated or none of them will.

How do DBMSs Guarantee the ACID Properties?

**Isolation:** Concurrency control algorithms and techniques guarantee concurrent transactions do not interfere with each other and don’t see each other’s changes until they complete.
- Some sort of mutual exclusion is typically implemented (i.e., locking) but alternatives exist
  ⇒ Focus of our discussion next week (Gray et al., 1976)

**Atomicity & Durability:** Recovery management guarantees that committed transactions are durable (despite failures), and that aborted transactions have no effect on the database.
- DBMS logs every action securely so that it can consult the log later to determine what to do.
  ⇒ Focus of our discussion in two weeks (Haerder and Reuter, 1983)

Scheduling Transactions for Concurrency Control

**Schedule:** a sequence of actions from multiple TAs such that the sequence of each TA is preserved

**Serial schedule:** schedule that does not interleave the actions of different TAs (i.e. the TAs are scheduled one after another)

**Equivalence of schedules:** Schedules S₁ and S₂ are equivalent if, for any database state, executing S₁ has the same effect as executing S₂ (i.e. the resulting database state is the same).

**Serializable schedule:** A schedule S is serializable if there exists a serial schedule that is equivalent to S.
Strict Two-Phase Locking Protocol (Strict 2PL)

Rules:
1. Any TA must obtain a shared lock on an object before reading.
2. Any TA must obtain an exclusive lock on an object before writing.
3. All locks held by a TA are released at the end of the TA.
4. If a TA holds an exclusive lock on an object, no other TA can get a lock (shared or exclusive) on that object.

Theorem
Strict 2PL generates only serializable schedules.

More on Concurrency Control

... in our discussion next week

Read:
- J. Gray, R. A. Lorie, G. R. Putzolu, and I. L. Traiger:
  "Granularity of Locks and Degrees of Consistency in a Shared Data Base. IFIP Working Conference on Modelling in Data Base Management Systems 1976."

Logging for Recovery

Idea
For all update operations, record REDO / UNDO information in a log.

Log: an ordered list of log records
Log record: represents a single REDO/UNDO action; contains:
- transaction ID
- page ID
- offset
- length
- old data
- new data
- additional control information
Write-Ahead Logging (WAL) Protocol

Rules:
- Persist the log record for an update operation before the corresponding data page is written to disk
  - Guarantees atomicity
- Persist all log records for (all update operations of) a transaction before reporting a successful commit
  - Guarantees durability

Recovering from a Crash

3 Phases (of the Aries recovery algorithm):
1. Analysis phase: Scan the log forward to identify:
   - all TAs that were active at the time of the crash; and
   - all “dirty” pages in the main memory page buffer (i.e. changed but not written) at the time of the crash.
2. Redo phase: Redo all updates to dirty pages in the buffer (to ensure that all logged updates are in fact carried out and written to disk).
3. Undo phase: Undo the writes of all TAs that were active at the crash (by restoring the old value of any update, as stored in the corresponding log record), working backwards in the log.
   - Some care must be taken to handle the case of another crash that may occur during the recovery.

More on Recovery

... in our discussion in two weeks

Read: