Transactions and Transaction Support in SQL

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Notes

Outline

Notes

Why We Need Transactions

- 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

Notes

Problems Caused by Concurrency

`Accounts(Anum, CId, BranchId, Balance)`

- Application 1: You are depositing money to your bank account.

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

- Application 2: The branch is calculating the balance of the accounts.

```
select Sum(Balance)
from Accounts
```

Problem – Inconsistent reads

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

Notes

Another Concurrency Problem

- Application 1: You are depositing money to your bank account at an ATM.

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

- Application 2: Your partner is withdrawing money from the same account at another ATM.

```
update Accounts
set Balance = Balance - 50
where Anum = 9999
```

Problem – Lost Updates

If the applications run concurrently, one of the updates may be "lost", and the database may be inconsistent.

Notes

Yet Another Concurrency Problem

- 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 – 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.

Notes

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.

Notes

Problems Caused by Failures

- Update all account balances at a bank branch.

```
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.

Notes

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.

Notes

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.

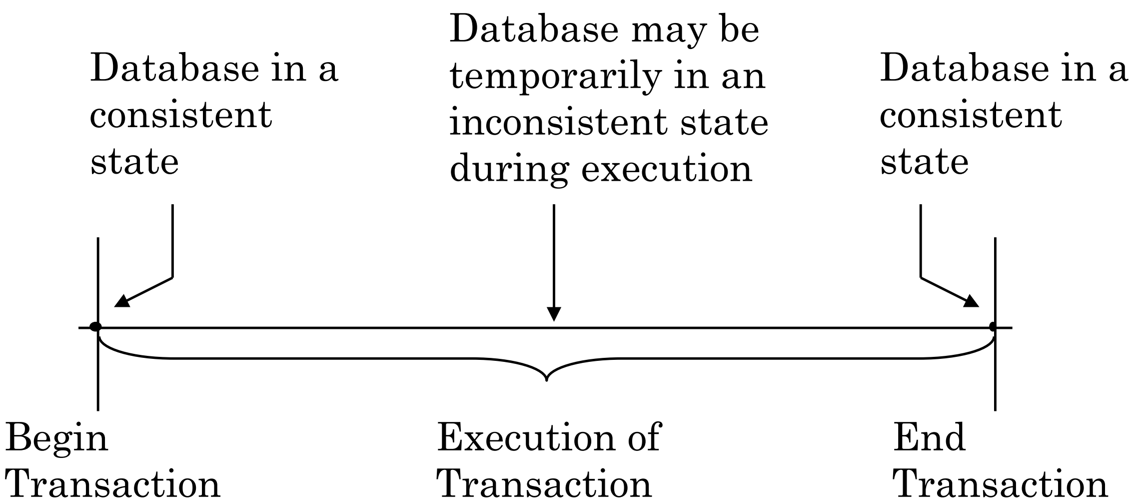
Notes

Transactions

Definition (Transaction)

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

- Concurrency transparency
- Failure transparency



Notes

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 completed, a transaction's changes are permanent

Notes

How do DBMSs Guarantee These

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

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.

Good news/Bad news...

We will not study these; they are covered in CS448.

Notes

Transaction Definition – Formal

Let

- $o_i(x)$ be some operation of transaction T operating on data item x, where $o_i \in \{\text{read}, \text{write}\}$ and o_i is atomic;
- $OS \cup o_i$;
- $N \in \{\text{abort}, \text{commit}\}$

Transaction T is a partial order $T = \{\Sigma, \prec\}$ where

1. $\Sigma = OS \cup \{N\}$,
2. For any two operations o_i, $o_j \in OS$, if $o_i = r(x)$ and $o_j = w(x)$ for any data item x, then either $o_i \prec o_j$ or $o_j \prec o_i$,
3. $\forall o_i \in OS, o_i \prec N$.

Notes

Example

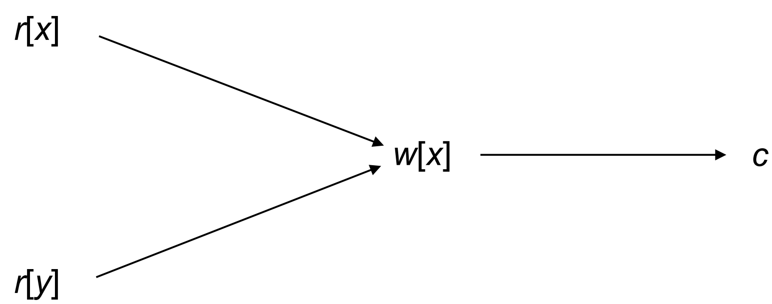
Consider a transaction T:

$$T = \{Read(x), Read(y), x \leftarrow x + y, Write(x), commit\}$$

Then

$$\Sigma = \{r[x], r[y], w[x], c\}$$
$$\prec = \{(r[x], w[x]), (r[y], w[x]), (w[x], c), (r[x], c), (r[y], c)\}$$

DAG representation



Notes

How Do Transactions Help?

- Application 1: You are depositing money to your bank account at an ATM.

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

- Application 2: Your partner is withdrawing money from the same account at another ATM.

```
update Accounts
set Balance = Balance - 50
where Anum = 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.

Notes

How Do Transactions Help?

- Update all account balances at a bank branch.

```
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.

Notes

Transaction Completion

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

- Atomicity: commit is the "all" in "all-or-nothing" execution.
- Durability: updates will survive crashes.

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

- Isolation: 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*.

Notes

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

Notes

Example Transaction – Single Statement

The start of a new SQL expression (SELECT, UPDATE, INSERT, DELETE, CREATE) automatically starts a transaction – no explicit command required, but the termination needs to be specified.

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

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


Notes

Example Transaction – Embedded SQL

```
...
main()
   ...
   EXEC SQL WHENEVER SQLERROR GOTO error;
   EXEC SQL UPDATE Employee
        SET Salary = Salary + 1000
        WHERE WorkDept = 'D11';
   EXEC SQL COMMIT;
   return(0);
   ...
   error:
     printf("update failed, sqlcode = %ld\n",SQLCODE);
     EXEC SQL ROLLBACK;
     return(-1);
 ...
```


Notes

Explicitly Aborting Transaction

```
main() { ...
 EXEC SQL BEGIN DECLARE SECTION;
    int actno1, actno2;  real amount;
 EXEC SQL END DECLARE SECTION;
 gets(actno1,actno2,amount);
 EXEC SQL UPDATE Accounts
    SET Balance = Balance + :amount WHERE Anum = :actno2;
 SELECT Balance INTO tempbal FROM Accounts
   WHERE Anum = :actno1;
 if (tempbal - :amount)<0 {
     printf("insufficient funds");
     EXEC SQL ROLLBACK;
     return(-1);}
 else {
  EXEC SQL UPDATE Accounts
   SET Balance = Balance + :amount WHERE Anum = :actno1;
  EXEC SQL COMMIT;
  printf("funds transfer completed");
  return(0); }   }
```


Notes

Setting Transaction Properties

```
set transaction <transaction mode>
     [, <transaction mode>] [, <transaction mode>]

transaction mode ::= <diagnostic size>
                   | <access mode>
                   | <isolation level>
```

- Diagnostic size determines how many error conditions can be recorded.
- Access mode indicates whether the transaction is READ ONLY or READ WRITE (default).
- Isolation level determines how the interactions of transactions are to be managed (remember the concurrency problems).

Notes

SQL Isolation Levels

- Different isolation levels deal with different concurrency problems.
- Four 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)

Notes

Level 3 – Serializability

- This is the strongest form of isolation level.
- 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.

Notes

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:

$$H_b = \underbrace{w_1[x]\ w_1[y]}_{T_1}\ \underbrace{r_2[x]\ r_2[y]}_{T_2}$$

- 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.

Notes

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
- Two types of conflicts:
  1. Read-Write
  2. Write-Write
- An *execution history* over a set of transactions $T_1 \dots T_n$ is an interleaving of the operations of $T_1 \dots T_n$ 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

Notes

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

Notes

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.

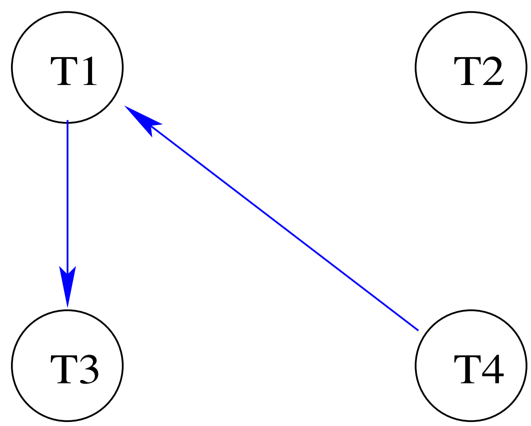
Notes

Serialization Graphs

Serialization graph $SG_H = (V, E)$ for schedule H is defined as:

1. $V = \{T | T$ is a committed transaction in $H\}$
2. $E = \{T_i \rightarrow T_j$ if $o_{ij} \in T_i \text{and} o_{kl} \in T_k$ conflict and $o_{ij} \prec_H o_{kl}\}$

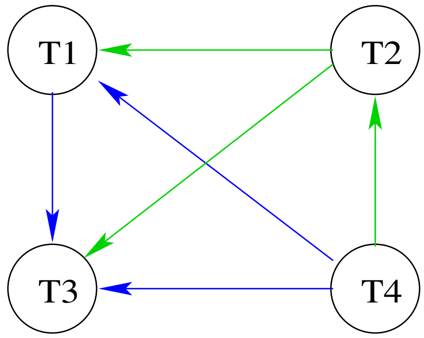
$r_1[x]\ r_3[x]\ w_4[y]\ r_2[u]\ w_4[z]\ r_1[y]\ r_3[u]\ r_2[z]\ w_2[z]\ r_3[z]\ r_1[z]\ w_3[y]$



Notes

Serialization Graphs (cont'd)

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



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.

Notes

Level 0 – Read Uncommitted

Transaction at this level may see uncommitted updates of other transactions.

- Dirty read: Transaction T_i may read the update of uncommitted transaction T_j.
- If T_j later aborts, the value that T_i read is incorrect.
- Database may be corrupted as well.

Notes

Read Uncommitted Example – Old Transaction

```
main() { ...
 EXEC SQL BEGIN DECLARE SECTION;
    int actno1, actno2;  real amount;
 EXEC SQL END DECLARE SECTION;
 gets(actno1,actno2,amount);
 EXEC SQL UPDATE Accounts
    SET Balance = Balance + :amount WHERE Anum = :actno2;
 SELECT Balance INTO tempbal FROM Accounts
   WHERE Anum = :actno1;
 if (tempbal - :amount)<0 {
     printf(”insufficient funds”);
     EXEC SQL ROLLBACK;
     return(-1);}
 else {
  EXEC SQL UPDATE Accounts
   SET Balance = Balance + :amount WHERE Anum = :actno1;
  EXEC SQL COMMIT;
  printf(”funds transfer completed”);
  return(0); }   }
```


Notes

Read Uncommitted Example

Start Balance(777) = \$300, Balance(888) = \$100, Balance(999)= \$200

$T_1(888, 999, \$150)$	$T_2(999, 777, \$250)$
	Add \$250 to 777 (550)
Add \$150 to 999 (350)	
	Test Balance of 999 (\$350)
Test Balance of 888 (\$100)	
	Deduct \$250 from 999 and Commit (\$100)
Rollback: Deduct \$150 from 999 (\$-50)	

Time

Notes

Level 1 – Read Committed

Transaction at this level will not see uncommitted updates of other transactions, but non-repeatable reads are possible.

- Non-repeatable read: Transaction T_i reads a value from the database. Transaction T_j updates that value. When T_i reads the value again, it will see different value.
- T_i is reading T_j's value after T_j commits (so no dirty reads).
- However, T_j's update is in between two reads by T_i.

We have seen an example early on.

Notes

Level 2 – Repeatable Reads

Transaction at this level will not have repeatable reads problem (i.e., multiple reads will return the same value), but phantoms are possible.

- Transaction T_i reads a row from a table (perhaps based on a predicate in WHERE clause).
- Transaction T_j inserts some tuples into the table.
- T_i issues the same read again and reads the original row *and a number of new rows that it did not see the first time* (these are the phantom tuples).

Notes

Repeatable Reads Example

Application 1:

```
select *
from Employee
where WorkDept = 'D11'
```

```
select *
from Employee
where Salary > 50000
```

Application 2:

```
insert into Employee
  values('000123','Sheldon','Q','Jetstream','D11',
     '05/01/00',52000.00)
```

Problem

Application 1's second query may see Sheldon Jetstream, even though its first query does not.

Notes

Interaction Between Transactions at Different Isolation Levels

Isolation Level	Type of Violation		
	Dirty Read	Nonrepeatable Read	Phantom
Read Uncommitted	Yes	Yes	Yes
Read Committed	No	Yes	Yes
Repeatable Read	No	No	Yes
Serializable	No	No	No

Notes

Snapshot Isolation

A transaction will see a consistent snapshot of the database when it started executing.

- A transaction reads the committed values from the database when it starts.
- If it does not make any updates, no problem.
- If it makes updates that do not conflict by any updates made by any other transaction, it can commit.
- If it makes updates that do conflict by an update made by another transaction, it has to rollback.

Read-Write conflicts are avoided; only Write-Write conflicts are managed.

Notes