Transactions

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Literature: KBL 13.1

Cursory: KBL 13.2-13.3
(complete version: Digital appendix A.1)

Mid-term evaluation

- Thanks to those who participated!

- Points (within my control):
  - Increase speech volume in lectures
  - Oral feedback on hand-ins
  - Discussion/feedback on old exercises

Today's lecture

- Transactions: Motivation
- Conflicts and serializability
- Locking
- Isolation levels in SQL
- *A surprise!*

Transaction

A transaction is a sequence of operations on a database that ***belong together***.

Examples:

- Two persons with a shared bank account try to withdraw 100 kr at the same time.
  1. read balance and store in variable B
  2. if B>=100 then B:=B-100
  3. write B to balance
- Table A refer to table B, and vice versa.
  – Consistency (referential integrity) can only be assured if two insertions happen "simultaneously".

Transactions in JDBC

- ```
  conn.setAutoCommit(false);
  // Disable automatic commit after
  each statement
  ```

- ```
  conn.commit();
  // Commit all pending updates
  ```

- ```
  conn.rollback();
  // Abort all pending updates
  ```
  ```

Another example, in SQL

Consider the following three transactions on the relation `accounts(no,balance,type)`:

Transaction A

```
UPDATE accounts SET balance=balance*1.02 WHERE type='savings';
UPDATE accounts SET balance=balance*1.07 WHERE type='salary' AND balance<0;
UPDATE accounts SET balance=balance*1.01 WHERE type='salary' AND balance>0;
```

Transaction B

```
UPDATE accounts SET type='salary' WHERE no=12345;
```

Transaction C

```
UPDATE accounts SET balance=balance-1000 WHERE no=12345;
```

Course goals

After the course the students should be able to:

- identify possible problems in transaction handling, related to consistency, atomicity, and isolation.
- apply a simple technique for avoiding deadlocks

ACID Properties

Atomicity: Each transaction runs to completion or has no effect at all

Consistency: After a transaction completes, the integrity constraints are satisfied

Isolation: Transactions executed in parallel have the same effect as if they were executed sequentially

Durability: The effect of a committed transaction remains in the database even if the computer crashes.

Durability in a nutshell

- There exist disk systems that are highly reliable (e.g. still functions if one or two disks fail).
  - Trade-off: Redundancy vs reliability
- A database transaction is only really committed when the actions made by the transaction have *all* been written to the *log* on disk.
  - In case of crash, the log is used to reverse the state to the one implied by committed transactions.
- More info in KBL section 13.2.

Today: Atomicity and isolation

- This lecture is mainly concerned with atomicity and isolation.
- Consistency is a consequence of atomicity and isolation + maintaining any declared DB constraint (not discussed in this course).

Isolation and serializability

- Want transactions to satisfy *serializability*:
  - The state of the database should always look as if the committed transactions ran in a *serial schedule*.
- The scheduler of the DBMS is allowed to choose the order of transactions:
  - It is not necessarily the transaction that is started first, which is first in the serial schedule.
  - The order may even look different from the viewpoint of different users.
  - Demo in MySQL…

A simple scheduler

- A simple scheduler would maintain a queue of transactions, and carry them out in order.
- Problems:
  - Transactions have to *wait* for each other, even if unrelated (e.g. requesting data on different disks).
  - Possibly smaller throughput. (Why?)
  - Some transactions may take very long, e.g. when external input or remote data is needed during the transaction.

A simple scheduler

- A simple scheduler would maintain a queue of transactions, and carry them out in order.
- Some believe this is fine for *transaction processing*:

The End of an Architectural Era
(It's Time for a Complete Rewrite)

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Stavros Harizopoulos

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Interleaving schedulers

- Most DBMSs have schedulers that allow the actions of transactions to interleave.
- However, the result should be **as if** some serial schedule was used.
- Such schedules are called serializable.
- In practice schedulers do not recognize all serializable schedules, but allow just some.
  Next: Conflict serializable schedules.

Simple view on transactions

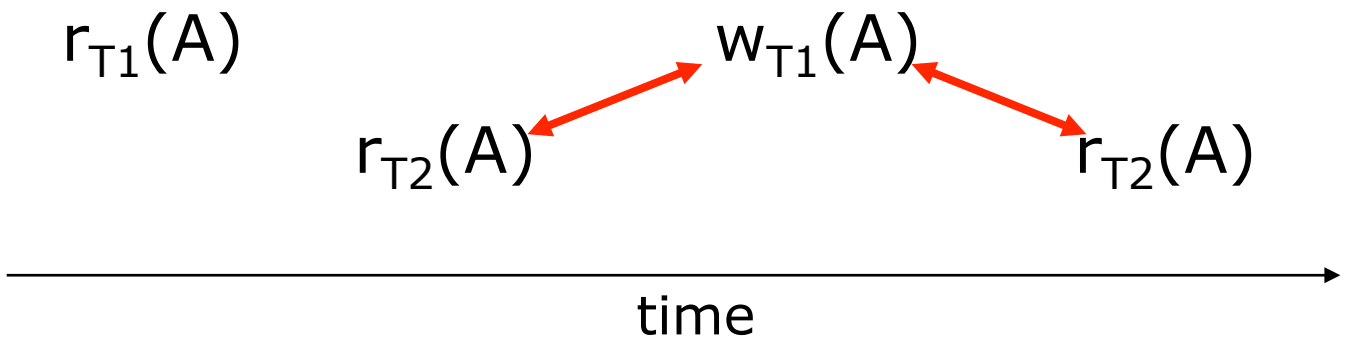
- We regard a transaction as a **sequence of reads and writes** of DB elements, that may interleave with sequences of other transactions.
- DB elements could be e.g. a value in a tuple, an entire tuple, or a disk block.
- $r_T(X)$, shorthand for ”transaction T reads database element X”.
- $w_T(X)$, shorthand for ”transaction T writes database element X”.

Conflicts

- The order of *some* operations is of no importance for the final result of executing the transactions.
- **Example**: We may interchange the order of any two read operations without changing the behaviour of the transactions doing the reads.
- In other cases, changing the order may give a different result - there is a conflict.

What operations conflict?

- It can easily be seen that two operations can conflict only if:
  - They involve the same DB element, and
  - At least one of them is a write operation.
- Note that this is a conservative, but safe, rule.



Conflict serializability

- Suppose we have a schedule for the operations of several transactions.
- We obtain *conflict-equivalent* schedules by swapping adjacent operations that do not conflict (any number of times).
- If a schedule is conflict-equivalent to a serial schedule, it is serializable.
  - The converse is not true.
- (Aside: Testing conflict serializability amounts to checking for cycles in the ”conflict graph”.)

Enforcing serializability

- Knowing how to recognize conflict-serializability is not enough.
- We will now study a mechanism that *enforces* serializability: **Locking**.

- Other methods exist: Time stamping / optimistic concurrency control.
  - Out of scope for this course.

Locks

- In its simplest form, a lock is a right to perform operations on a database element.
- Only one transaction may hold a lock on an element at any time.
- Locks must be requested by transactions and granted by the locking scheduler.

Two-phase locking

- Commercial DBMSs widely use two-phase locking, satisfying the condition:
  - In a transaction, all requests for locks precede all unlock requests.
- If two-phase locking (2PL) is used, the schedule is conflict-equivalent to a serial schedule in which transactions are ordered according to the time of their first unlock request. (Why?)

Strict two-phase locking

- In **strict** 2PL all locks are released when the transaction completes.
- This is commonly implemented in commercial systems, since:
  - it makes transaction **rollback** easier to implement, and
  - avoids so-called **cascading aborts** (this happens if another transaction reads a value by a transaction that is later rolled back)

Lock modes

- The simple locking scheme we saw is too restrictive, e.g., it does not allow different transactions to read the same DB element concurrently.
- **Idea**: Have several kinds of locks, depending on what you want to do. Several locks on the same DB element may be ok (e.g. two read locks).

Shared and exclusive locks

- Locks for reading can be shared (S).
- Locks needed for writing must be exclusive (X).
- Compatibility matrix says which locks are granted:

	Lock requested		
Lock held		S	X
	S	Yes	No
	X	No	No

Locks via B-trees

- If it is known that tuples in a relation are only accessed through a B-tree structure, an efficient way of locking many tuples (e.g. in a range) is to lock the corresponding B-tree nodes.
- This is known as **index locking**.
  - MySQL manual: *"A locking read, an UPDATE, or a DELETE generally set record locks on every index record that is scanned in the processing of the SQL statement."*

Phantom tuples

- Suppose we lock tuples where A=42 in a relation, and subsequently another tuple with A=42 is inserted.
- For some transactions this may result in unserializable behaviour, i.e., it will be clear that the tuple was inserted during the course of a transaction.
- Such tuples are called phantoms.

Avoiding phantoms

- Phantoms can be avoided by putting an exclusive lock on a relation before adding tuples.
  - However, this gives poor concurrency.
- Index locking can be used to prevent other transactions from inserting phantom tuples, but allow most non-phantom insertions.
- In SQL, the programmer may choose to either allow phantoms in a transaction or insist they should not occur.

SQL isolation levels

- A transaction in SQL may be chosen to have one of four isolation levels:
  - `READ UNCOMMITTED`: *Dirty reads* are possible.
  - `READ COMMITTED`: Dirty reads are not permitted (but nonrepeatable reads and phantoms are possible).
  - `REPEATABLE READ`: Nonrepeatable and dirty reads are not permitted (but phantoms are possible).
  - `SERIALIZABLE`: Transaction execution must be serializable (above anomalies not allowed).

SQL isolation levels

- Possible implementations:
  - `READ UNCOMMITTED`:
    ”No locks are obtained.”
  - `READ COMMITTED`:
    ”Read locks are immediately released - read values may change during the transaction.”
  - `REPEATABLE READ`:
    ”2PL but no lock when adding new tuples.”
  - `SERIALIZABLE`:
    ”2PL with lock when adding new tuples.”

Problem session

Consider the following three transactions on the relation `accounts(no,balance,type)`:

Transaction A

```
UPDATE accounts SET balance=balance*1.02 WHERE type='savings';
UPDATE accounts SET balance=balance*1.07 WHERE type='salary' AND balance<0;
UPDATE accounts SET balance=balance*1.01 WHERE type='salary' AND balance>0;
```

Transaction B

```
UPDATE accounts SET type='salary' WHERE no=12345;
```

Transaction C

```
UPDATE accounts SET balance=balance-1000 WHERE no=12345;
```

The purpose of Transaction A is to add interest to the balance of accounts, depending on the type and balance. Transaction B changes the type of a particular account. Transaction C makes a withdrawal from a particular account.

a) Suppose that the transactions are run more or less simultaneously at isolation level `READ COMMITTED`. What results of running the transactions are possible in this case, but not if the transactions had been run at isolation level `SERIALIZABLE`?

Isolation level syntax

- Begin transaction with:

```
SET TRANSACTION ISOLATION LEVEL
{ READ UNCOMMITTED |
  READ COMMITTED |
  REPEATABLE READ |
  SERIALIZABLE }
```

ACID testing MySQL

- Most storage engines are made with only very simple concurrency control in mind.
- InnoDB (default engine) supports the standard SQL isolation concurrency control features, and more.
- Beware: Using SQL isolation levels with another storage engine may have no effect (except perhaps a warning).

Be careful with SERIALIZABLE

- Some common implementations of ”SERIALIZABLE” allows, e.g., the following:
  - Suppose we have a relation R with a tuple for each reserved seat in a plane.
  - Transactions A and B simultaneously read R and find that seat 13A is free.
  - Transaction A and B both insert a tuple indicating that seat 13A has been booked.
- Such conflicts can be stopped by a lock or by a database constraint.

Explicit row locking

- Many DBMSs allow transactions to explicitly lock a set of tuples.
- Example:

```
SELECT * FROM seats
WHERE seat = '13A'
FOR UPDATE;
```

- Can be used to control a resource, e.g. the right to insert a reservation tuple for seat 13A in another table.

Snapshot isolation

- Some DBMSs implement **snapshot isolation**, an isolation level that gives a stronger guarantee than `READ COMMITTED`.
- MySQL/InnoDB:
  `START TRANSACTION WITH CONSISTENT SNAPSHOT;`
- Each transaction T executes against the version of the data items that was committed "when the T started".
- Possible implementation:
  - No locks for read, locks for writes.
  - Store old versions of data (costs space).

Granularity of locks

- So far we did not discuss what DB elements to lock: Atomic values, tuples, blocks, relations?
- What are the advantages and disadvantages of fine-grained locks (such as locks on tuples) and coarse-grained locks (such as locks on relations)?
- The following advice can be found in the book by Shasha and Bonnet:
  "Long transactions should use table locks, short transactions should use record locks".

Granularity of locks

- Fine-grained locks allow a lot of concurrency, but may cause problems with *deadlocks*.
- Coarse-grained locks require fewer resources by the locking scheduler.
- We want to allow fine-grained locks, but use (or switch to) coarser locks when needed.
- Some DBMSs switch automatically - this is called lock escalation. The downside is that this easily leads to **deadlocks**.

Granularity in MySQL

- InnoDB uses row-level locking by default.
  - No lock escalation.
- Table locking can be done manually:
  - LOCK TABLES T1 READ, T2 WRITE,…
  - UNLOCK TABLES

Locks and deadlocks

- The DBMS sometimes must make a transaction wait for another transaction to release a lock.
- This can lead to deadlock if e.g. A waits for B, and B waits for A.
- In general, we have a deadlock exactly when there is a cycle in the waits-for graph.
- Deadlocks are resolved by aborting some transaction involved in the cycle.

Simple deadlock prevention

- 2001 MySQL manual:

  All locking in MySQL is deadlock-free.

  This is managed by always requesting all needed locks at once at the beginning of a query and always locking the tables in the same order.

- 2008 MySQL manual:

  All locking in MySQL is deadlock-free, except for *InnoDB* and *BDB* type tables.

  – Explanation? Why use InnoDB and BDB?

- **Problem session**: Why does ”always locking tables in the same order” never lead to deadlock?

Summary

- Concurrency control mechanisms give various trade-offs between isolation and performance.
  - Safe choice is SERIALIZABLE (well…)
  - Sometimes lower SQL isolation levels suffice – difficult to analyze in general
  - Manual efforts may sometimes be better: Table locking, explicit row locking,…
  - Deadlocks happen. A simple (but brutal) cure is lock acquisition in fixed order.

Next

- At 10.00 Michael will share some insights on simpler SQL for hand-in 2.

Next week:

- Claus Samuelsen, IBM is guest lecturer.
- Topic: BigInsights, and more!
- No regular exercises. But a TA will be available 10-12 for questions about hand-in 3 (remember: individual).

Aside: How to represent time?

From Wikipedia:

The standard Unix time_t is a signed integer data type, traditionally of 32 bits, directly encoding the Unix [...] The minimum representable time is 1901-12-13… At 03:14:07 UTC 2038-01-19 this representation overflows […] year 2038 problem.

In some newer operating systems, time_t has been widened to 64 bits. In the negative direction, this goes back more than twenty times the age of the universe […] whether the approximately 293 billion representable years is truly sufficient depends on the ultimate fate of the universe, but it is certainly adequate for most practical purposes.