

Transactions and Concurrency

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CS 348
Introduction to Database Management
Winter 2017

① Why We Need Transactions

Failures

Concurrency

② Serializability

Serializable 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 balances at a bank branch.

Accounts (Anum, CId, BranchId, Balance)

update Accounts

set Balance = Balance * 1.05

where BranchId = 12345

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

If the system fails between these updates, money may be withdrawn but not redeposited.

Problems Caused by Concurrency

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from Accounts
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- Application 2:

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select Sum(Balance)
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from Accounts
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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
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- Application 2: same as Application 1

Problem

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

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
- Durable:** 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 :

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

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

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

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 - 1 they belong to different transactions,
 - 2 they operate on the same object, and
 - 3 at least one of the operations is a write

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- 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

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Two histories are (*conflict*) *equivalent* if

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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?

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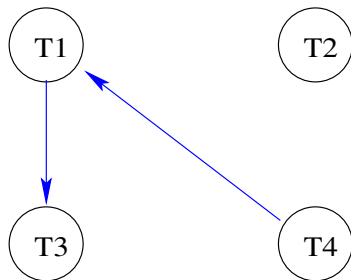
Is this history serializable?

Theorem

A history is serializable iff its serialization graph is acyclic.

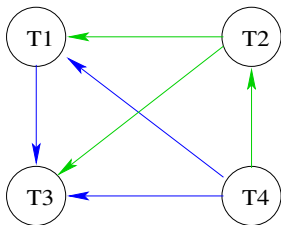
Serialization Graphs

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



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 .

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 - When a transaction *commits*, any updates it made become durable, and they become visible to other transactions. A commit is 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

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- 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

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- For each transaction, it is possible to specify an *isolation level*.
- 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)

Non-Repeatable Reads

- Application 1:

```
update Employee
```

```
set Salary = Salary + 1000
```

```
where WorkDept = 'D11'
```

Non-Repeatable Reads

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

- Application 2:

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

```
select * from Employee  
where Lastname like 'A%'
```


Non-Repeatable Reads

- Application 1:

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update Employee  
set Salary = Salary + 1000  
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```

- 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.

- Application 1:

```
insert into Employee  
values ('000123', 'Sheldon', 'Q', 'Jetstream', 'D11',  
        '05/01/00', 52000.00)
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- Application 2:

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

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

Phantoms

- Application 1:

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

- Application 2:

```
select *  
from Employee  
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```

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

Problem

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

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

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

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 - locking, or
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- Many concurrency control protocols have been proposed, based on:
 - locking, or
 - timestamps, or
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- 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.

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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
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- The two-phase 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 releases its lock
 - ② T_1 can be *pre-empted* - forced to abort and give up its locks

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

Recovery Management

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 - ② implementing recovery from *system failures*
- *System failure* means:
 - ① the database server is halted abruptly
 - ② processing of in-progress SQL command(s) is halted abruptly
 - ③ connections to application programs (clients) are broken.
 - ④ contents of memory buffers are lost
 - ⑤ database files are not damaged.

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- 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

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Requires Write-Ahead-Logging

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

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- Rolling back a single transaction:
 - ① Scan the log from the tail to the transaction's BEGIN record.
 - Undo the transaction's updates.