Transactions

Lecture 18

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Today's Session…

- Why we need user-defined transactions
- Properties of transactions
- How to use transactions
- Concurrent access to data
- Locking and deadlocking
- Database recovery

What is a (database) Transaction?

- A logical unit of work that must either be entirely completed or aborted (indivisible, atomic)
- DML statements are already atomic
- RDBMS also allows for *user-defined* transactions
- These are a sequence of DML statements, such as
  - a series of UPDATE statements to change values
  - a series of INSERT statements to add rows to tables
  - DELETE statements to remove rows
- Transactions will be treated as atomic
- A successful transaction changes the database from one consistent state to another
  - All data integrity constraints are satisfied

Why do we need Transactions?

- Transactions solve TWO problems:

1. users need the ability to define a unit of work

2. concurrent access to data by >1 user or program

Problem 1: Unit of work

- Single DML or DDL command (implicit transaction)
  - e.g. Update 700 records,
    but database crashes after 200 records processed
  - Restart server: you will find no changes to any records
  - Changes are "all or none"
- Multiple statements (user-defined transaction)
  - START TRANSACTION; (or, 'BEGIN')
    - SQL statement;
    - SQL statement;
    - SQL statement;
    - …
  - COMMIT; (commits the whole transaction)
    - Or ROLLBACK (to undo everything)
- SQL keywords: **begin, commit, rollback**

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Business transactions as units of work

- Each transaction consists of several SQL statements, embedded within a larger application program
- Transaction needs to be treated as an indivisible unit of work
- “Indivisible” means that either the whole job gets done, or none gets done: if an error occurs, we don’t leave the database with the job half done, in an inconsistent state

In the case of an error:

- Any SQL statements already completed must be reversed
- Show an error message to the user
- When ready, the user can try the transaction again
- This is briefly annoying – but inconsistent data is disastrous

Demo: Transaction as unit of work

- Demonstrate Transactions
  - CRE_ACCOUNT TXN_ACCOUNT on LMS resources

```sql
/* bank account transfer example */

/* check what is now in accounts*/
select * from Account;
select sum(balance) from Account;

start transaction;

/* transfer chosen amount from one account to another */
set @amount = 100;
update Account set balance = balance - @amount where id = 1;
update Account set balance = balance + @amount where id = 2;

commit;

/* check what is now in accounts*/
select * from Account;
select sum(balance) from Account;
```

Id	AccountType	Balance
1	savings	5000.00
2	credit	1000.00
NULL	NULL	NULL

Transaction Properties (ACID)

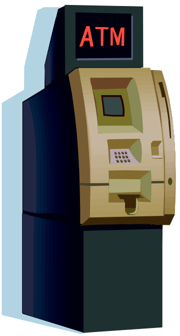
- Atomicity
  - A transaction is treated as a single, indivisible, logical unit of work. All operations in a transaction must be completed; if not, then the transaction is aborted
- Consistency
  - Constraints that hold before a transaction must also hold after it
  - (multiple users accessing the same data see the same value)
- Isolation
  - Changes made during execution of a transaction cannot be seen by other transactions until this one is completed
- Durability
  - When a transaction is complete, the changes made to the database are permanent, even if the system fails

Problem 2: Concurrent access

- What happens if we have multiple users accessing the database at the same time…
- Concurrent execution of DML against a shared database
- Note that the sharing of data among multiple users is where much of the benefit of databases derives – users communicate and collaborate via shared data
- But what could go wrong?
  – lost updates
  – uncommitted data
  – inconsistent retrievals

The Lost Update problem

Alice



Read account balance
(balance = $1000)

Withdraw $100
(balance = $900)

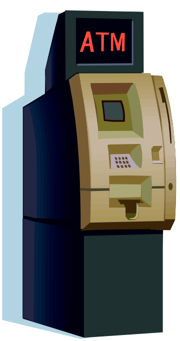
Write balance
balance = $900

t1a t2a t3a

Time

t1b t2b t3b

Bob



Read account balance
(balance = $1000)

Withdraw $800
(balance = $200)

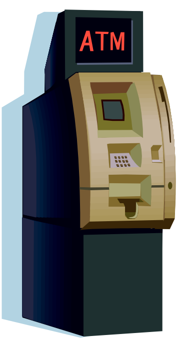
Write balance
balance = $200

Balance should be $100

The Uncommitted Data problem

- Uncommitted data occurs when two transactions execute concurrently and the first is rolled back after the second has already accessed the uncommitted data

Alice



Bob

Time

	t1	t2	t3	t4	t5	t6
Alice			Read balance (balance = $200)		Withdraw $100 (balance = $100)	Write balance balance = $100
Bob	Read balance (balance = $1000)	Withdraw $800 (balance = $200)		Rollback balance = $1000		

Balance should be $900

The Inconsistent Retrieval problem

- Occurs when one transaction calculates some aggregate functions over a set of data, while other transactions are updating the data
  - Some data may be read after they are changed and some before they are changed, yielding inconsistent results

Alice	Bob
SELECT SUM(Salary) FROM Employee;	UPDATE Employee SET Salary = Salary * 1.01 WHERE EmpID = 33;
	UPDATE Employee SET Salary = Salary * 1.01 WHERE EmpID = 44;
(finishes calculating sum)	COMMIT;

Example: Inconsistent Retrieval

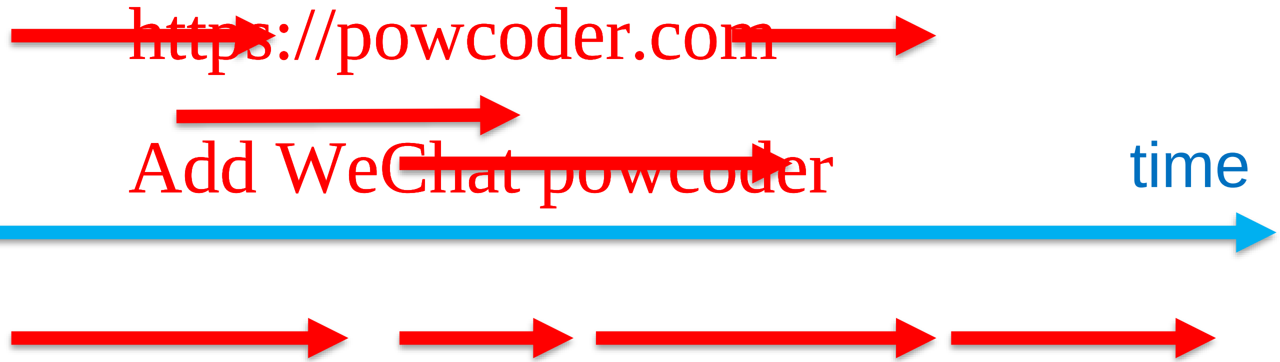
Time	Trans-action	Action	Value	T1 SUM	Comment
1	T1	Read Salary for EmpID 11	10,000	10,000	
2	T1	Read Salary for EmpID 22	20,000	30,000	
3	T2	Read Salary for EmpID 33	30,000		
4	T2	Salary = Salary * 1.01			
5	T2	Write Salary for EmpID 33	30,300		
6	T1	Read Salary for EmpID 33	30,300	60,300	*after* update
7	T1	Read Salary for EmpID 44	40,000	100,300	*before* update
8	T2	Read Salary for EmpID 44	40,000		
9	T2	Salary = Salary * 1.01			
10	T2	Write Salary for EmpID 44	40,400		
11	T2	COMMIT			
12	T1	Read Salary for EmpID 55	50,000	150,300	
13	T1	Read Salary for EmpID 66	60,000	210,300	

we want either
before \$210,000 or
after \$210,700

Serializability

- Transactions ideally are "serializable"
  - Multiple, concurrent transactions *appear as if* they were executed one after another
  - Ensures that the concurrent execution of several transactions yields consistent results

Reality: concurrent execution



Appearance: serial execution

but true serial execution (i.e. no concurrency) is very expensive!

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Concurrency control methods

- To achieve efficient execution of transactions, the DBMS creates a schedule of read and write operations for concurrent transactions
- Interleaves the execution of operations, based on concurrency control algorithms such as locking and time stamping

- Several methods of concurrency control

  – *Locking* is the main method used
  – Alternate methods

    - Time Stamping
    - Optimistic Methods

Concurrency Control with Locking

- Lock
  - Guarantees exclusive use of a data item to a current transaction
    - T1 acquires a lock prior to data access; the lock is released when the transaction is complete
    - T2 does not have access to data item currently being used by T1
    - T2 has to wait until T1 releases the lock
  - Required to prevent another transaction from reading inconsistent data
- Lock manager
  - Responsible for assigning and policing the locks used by the transactions
- Question: at what granularity should we apply locks?

Lock Granularity: options

- Database-level lock
  - Entire database is locked
  - Good for batch processing but unsuitable for multi-user DBMSs
  - T1 and T2 can not access the same database concurrently even if they use different tables
  - (SQLite, Access)
- Table-level lock
  - Entire table is locked - as above but not quite as bad
  - T1 and T2 can access the same database concurrently as long as they use different tables
  - Can cause bottlenecks, even if transactions want to access different parts of the table and would not interfere with each other
  - Not suitable for highly multi-user DBMSs

Lock Granularity: options

- Page-level lock
  - An entire disk page is locked (a table can span several pages and each page can contain several rows of one or more tables)
  - Not commonly used now
- Row-level lock
  - Allows concurrent transactions to access different rows of the same table, even if the rows are located on the same page
  - Improves data availability but with high overhead (each row has a lock that must be read and written to)
  - Currently the most popular approach (MySQL, Oracle)
- Field-level lock
  - Allows concurrent transactions to access the same row, as long as they access different attributes within that row
  - Most flexible lock but requires an extremely high level of overhead
  - Not commonly used

Types of Locks

- Binary Locks
  - has only two states: locked (1) or unlocked (0)
  - eliminates "Lost Update" problem
    - the lock is not released until the statement is completed
  - considered too restrictive to yield optimal concurrency, as it locks even for two READs (when no update is being done)
- The alternative is to allow both Exclusive and Shared locks
  - often called Read and Write locks

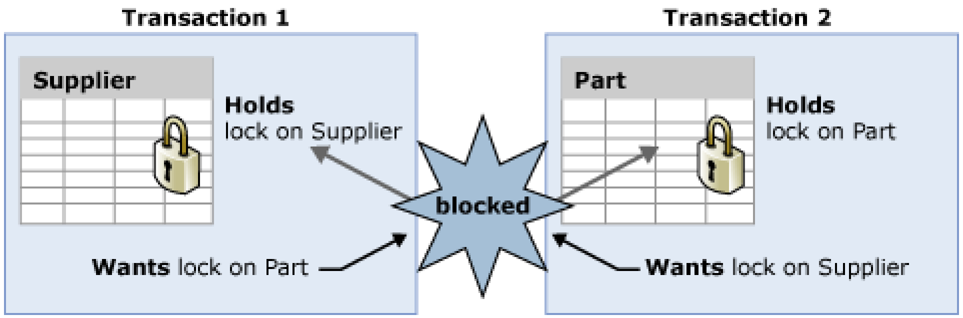
Shared and Exclusive Locks

- Exclusive lock
  - access is reserved for the transaction that locked the object
  - must be used when transaction intends to WRITE
  - granted if and only if no other locks are held on the data item
  - in MySQL: "select … for update"

- Shared lock
  - other transactions are also granted Read access
  - issued when a transaction wants to READ data, and no Exclusive lock is held on that data item
    - multiple transactions can each have a shared lock on the same data item if they are all just reading it
  - in MySQL: "select … lock in share mode"

Deadlock

- Condition that occurs when two transactions wait for each other to unlock data
  - T1 locks data item X, then wants Y
  - T2 locks data item Y, then wants X
  - each waits to get a data item which the other transaction is already holding
  - could wait forever if not dealt with
- Only happens with exclusive locks
- Deadlocks are dealt with by:
  - prevention
  - detection
  - (we won't go into the details of how in this course)



Alternative concurrency control methods

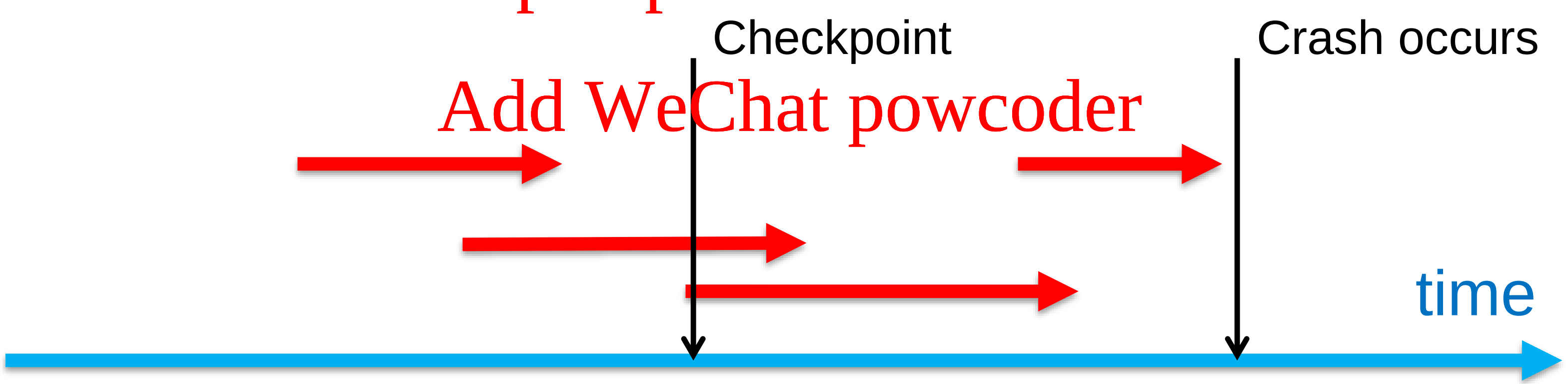
- Timestamp
  - Assigns a global unique timestamp to each transaction
  - Each data item accessed by the transaction gets the timestamp
  - Thus for every data item, the DBMS knows which transaction performed the last read or write on it
  - When a transaction wants to read or write, the DBMS compares its timestamp with the timestamps already attached to the item and decides whether to allow access
- Optimistic
  - Based on the assumption that the majority of database operations *do not* conflict
  - Transaction is executed without restrictions or checking
  - Then when it is ready to commit, the DBMS checks whether it any of the data it read has been altered – if so, rollback

Logging transactions

- Want to restore database to a previous consistent state
- If transaction cannot be completed, it must be aborted and any changes rolled back
- To enable this, DBMS tracks all updates to data
- This *transaction log* contains:
  - a record for the beginning of the transaction
  - for each SQL statement
    - operation being performed (update, delete, insert)
    - objects affected by the transaction
    - “before” and “after” values for updated fields
    - pointers to previous and next transaction log entries
  - the ending (COMMIT) of the transaction

Transaction log

- Also provides the ability to restore a corrupted database
- If a system failure occurs, the DBMS will examine the log for all uncommitted or incomplete transactions and it will restore the database to a previous state



Example transaction log

TRL ID	TRX NUM	PREV PTR	NEXT PTR	OPERATION	TABLE	ROW ID	ATTRIBUTE	BEFORE VALUE	AFTER VALUE
341	101	Null	352	START	****Start Transaction				
352	101	341	363	UPDATE	PRODUCT	54778-2T	PROD_QOH	45	43
363	101	352	365	UPDATE	CUSTOMER	10011	CUST_BALANCE	615.73	675.62
365	101	363	Null	COMMIT	**** End of Transaction				
397	106	Null	405	START	****Start Transaction				
405	106	397	415	INSERT	INVOICE	1009			1009,10016, ...
415	106	405	419	INSERT	LINE	1009,1			1009,1, 89-WRE-Q,1, ...
419	106	415	427	UPDATE	PRODUCT	89-WRE-Q	PROD_QOH	12	11
423				CHECKPOINT					
427	106	419	431	UPDATE	CUSTOMER	10016	CUST_BALANCE	0.00	277.55
431	106	427	457	INSERT	ACCT_TRANSACTION	10007			1007,18-JAN-2004, ...
457	106	431	Null	COMMIT	**** End of Transaction				
521	155	Null	525	START	****Start Transaction				
525	155	521	528	UPDATE	PRODUCT	2232/QWE	PROD_QOH	6	26
528	155	525	Null	COMMIT	**** End of Transaction				
					* * * * * C *R*A* S* H * * * *				

What is examinable

- Why do we need transactions?
- What is a transaction?
- ACID
- Locking levels & types including Deadlock scenario
- Concurrency
- Concurrency Issues
  - (Lost update, uncommitted changes, inconsistent retrieval)
- Deadlocks