THE UNIVERSITY OF MELBOURNE

INFO20003 Database Systems

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Lecture 17
Transactions

Week 9

What is a (database) transaction?

- A **logical unit of work** that must **either be entirely completed or aborted** (also called atomic unit of work)
- DML or SQL statements if nothing else stated, are commonly assumed to be atomic in most DBMSs
- They are not the common “unit” of execution though
- DBMSs allow for **user-defined** units: **transactions**
- These are a sequence of DML/SQL 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
  - …
- A successful transaction changes the database from one consistent state to another: all integrity constraints satisfied

Reading: Chapters 16, 17, 18 (Skim only)

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, and everything is then undone
- **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

Why do we need transactions?

- Transactions solve mainly TWO problems:

  1. Users' need for the ability to define a unit of work

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

Problem 1: Unit of work

– Single SQL, DML or even DDL command (implicit transaction)
  - Changes are "all or none"
  - **Example**:
    - Update 700 records, but DBMS crashes after 200 records processed
    - Restart server -- you will find no changes to *any* records

– 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)

– keywords: **begin, commit, rollback**

Business case for transactions as units of work

- Each transaction consists of several 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

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Example: Transaction as unit of work

```sql
-- Transaction;
 START TRANSACTION; -- An explicit start - but after any commit a NEW transaction begins

-- Statement 2
 SELECT * FROM ACCOUNT;

--  (declare a temporary variable amount persistent for this session)
 set @amount = 100;

-- Statement 3

 UPDATE ACCOUNT set balance = balance - @amount where id =1;

-- Statement 4 confirm deduction from savings but not yet deposited to credit
 SELECT * FROM ACCOUNT;

--  Statement 5 deposit the amount into the credit account
 UPDATE ACCOUNT set balance = balance + @amount where id = 2;

-- Statement 6 confirm all changes
 SELECT * FROM ACCOUNT;

-- Statement 7 EXPLICIT COMMIT;
 COMMIT;

-- ALL CHANGES PERMANENT CAN NOT BE UNDONE WITH ROLLBACK
```

Problem 2: Concurrent access

- What happens if we have multiple users accessing the database at the same time?
- E.g. 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 comes from – users communicate and collaborate via shared data

- But what could possibly go wrong?
  - lost updates
  - uncommitted data
  - inconsistent retrievals

The Lost Update problem

Alice

Read account balance (balance = $1000)

Withdraw $100 (balance = $900)

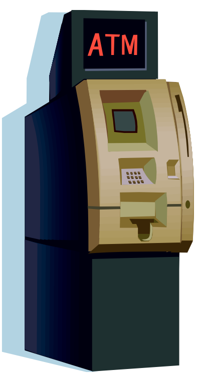
Write balance balance = $900

Time

t1a — t2a — t3a

t1b — t2b — t3b

Bob



Read account balance (balance = $1000)

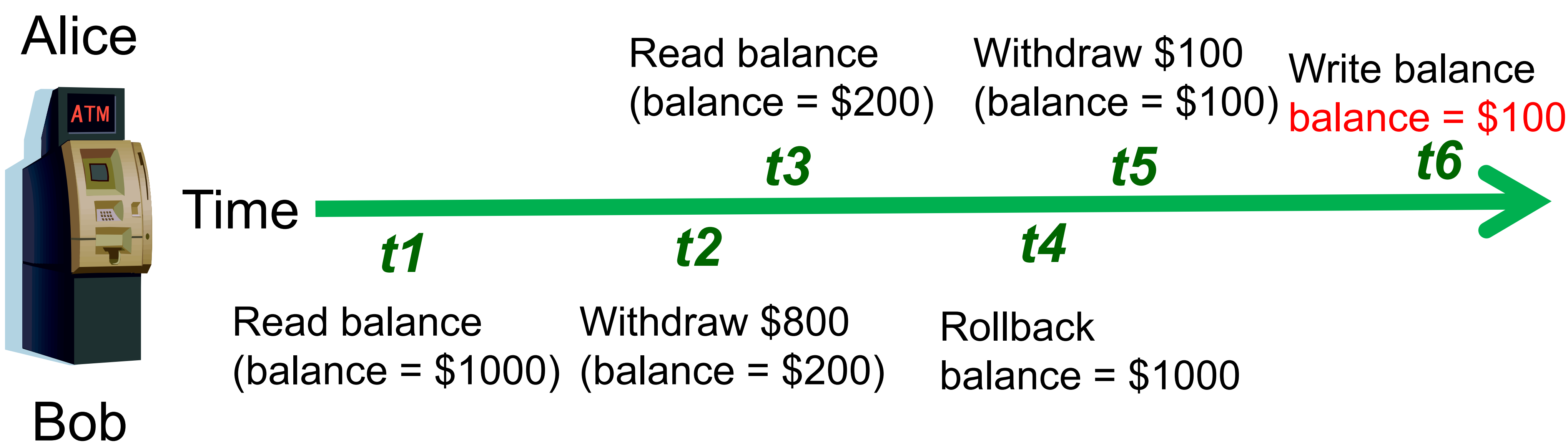
Withdraw $800 (balance = $200)

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



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

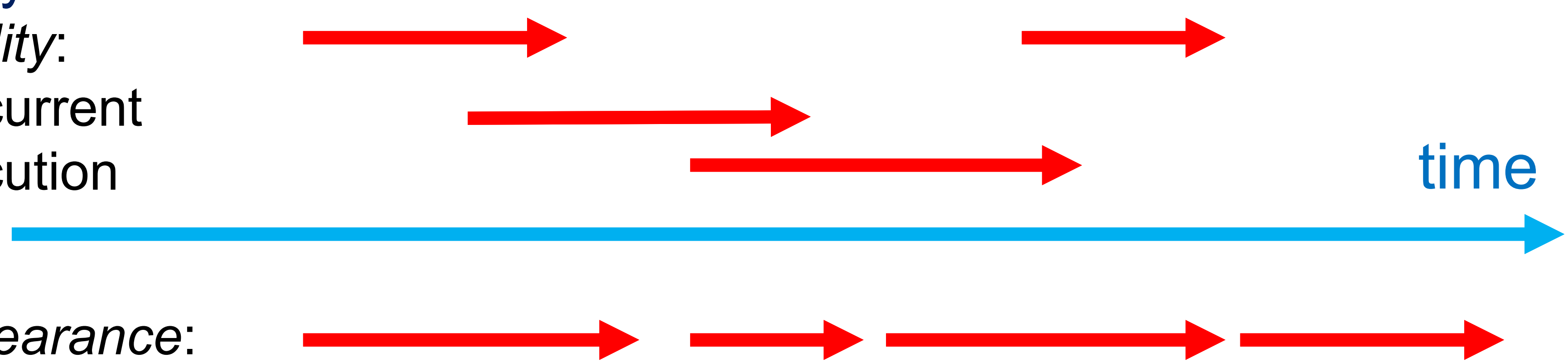
Time	Trans-action	Action	Value	T1 SUM	Comment
1	T1	Read Salary for EmpID 11	10,000	10,000	
2	T1	Read Salary for EmpID 22	20,000	30,000	
3	T2	Read Salary for EmpID 33	30,000		
4	T2	Salary = Salary * 1.01			
5	T2	Write Salary for EmpID 33	30,300		
6	T1	Read Salary for EmpID 33	30,300	60,300	*after* update
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	[illegible]	
13	T1	Read Salary for EmpID 66	60,000	210,300	

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

Serializability

- Transactions ideally should run in a schedule that is "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!

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* or *time stamping*
- Several methods of achieving concurrency control
  - Locking ← Main method used
  - Time stamping
  - Optimistic Concurrency Control

  Alternatives

Concurrency Control with Locking

- Locks:
  - Guarantees exclusive use of a data item to a 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 1/2

- Database-level lock
  - Entire *database* is locked
  - Good for batch processing but unsuitable for multi-user DBMSs
  - T1 and T2 cannot access the same database concurrently even if they use different tables
- 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 2/2

- Page-level lock
  - An entire *disk page* is locked
  - 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 Shared and Exclusive locks
  - Often called Read and Write locks

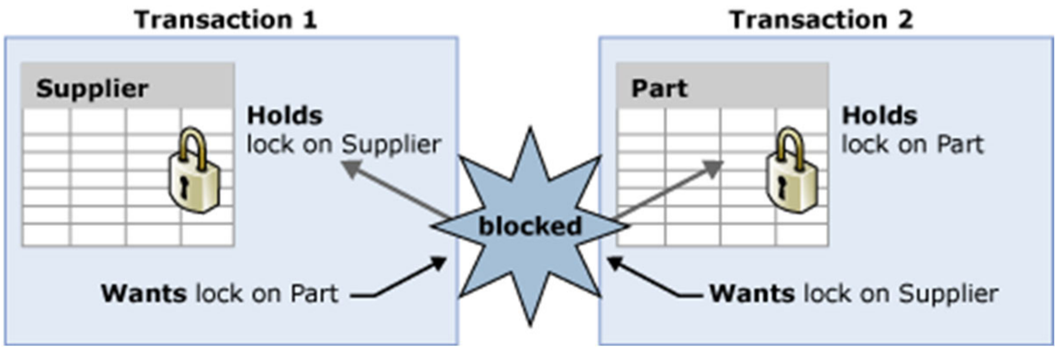
Shared and Exclusive Locks

- 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

- 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

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 details)



Deadlock demo

deccles2 — mysql -u root -p — 80×24

```
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
[mysql> SELECT * FROM DEPT;                                              ]
+--------+------------+----------+
| deptno | name       | location |
+--------+------------+----------+
|     10 | ACCOUNTING | NEW YORK |
|     20 | RESEARCH   | DALLAS   |
|     30 | SALES      | CHICAGO  |
|     40 | OPERATIONS | BOSTON   |
+--------+------------+----------+
4 rows in set (0.00 sec)

1  [mysql> UPDATE DEPT set location = 'SYDNEY' where deptno = 30;        ]
Query OK, 1 row affected (0.08 sec)
Rows matched: 1  Changed: 1  Warnings: 0

3  [mysql> UPDATE DEPT set location = 'MELBOURNE' where deptno = 20;     ]
Query OK, 1 row affected (13.07 sec)
Rows matched: 1  Changed: 1  Warnings: 0

mysql>
```

deccles2 — mysql -u root -p — 71×24

```
mysql> USE SCOTT;
Reading table information for completion of table and column names
You can turn off this feature to get a quicker startup with -A

Database changed
mysql> SELECT * FROM DEPT;
+--------+------------+----------+
| deptno | name       | location |
+--------+------------+----------+
|     10 | ACCOUNTING | NEW YORK |
|     20 | RESEARCH   | DALLAS   |
|     30 | SALES      | CHICAGO  |
|     40 | OPERATIONS | BOSTON   |
+--------+------------+----------+
4 rows in set (0.00 sec)

2  mysql> UPDATE DEPT set location = 'AUCKLAND' WHERE deptno = 20;
Query OK, 1 row affected (0.00 sec)
Rows matched: 1  Changed: 1  Warnings: 0

4  mysql> Update dept set location = 'WELLINGTON' where deptno = 30;
ERROR 1213 (40001): Deadlock found when trying to get lock; try restart
ing transaction
mysql>
```

- Two separate sessions
- In order:

1. Tx1 Update row 3 (Green)
2. Tx2 Update row 2 (White)
3. Tx3 Update row 2 (Green)
4. Tx4 Update row 3 (White)

- Note: Only the session which detects the deadlock rolls back the transaction. The Green session still holds locks on row 2 and 3

Alternative concurrency control methods

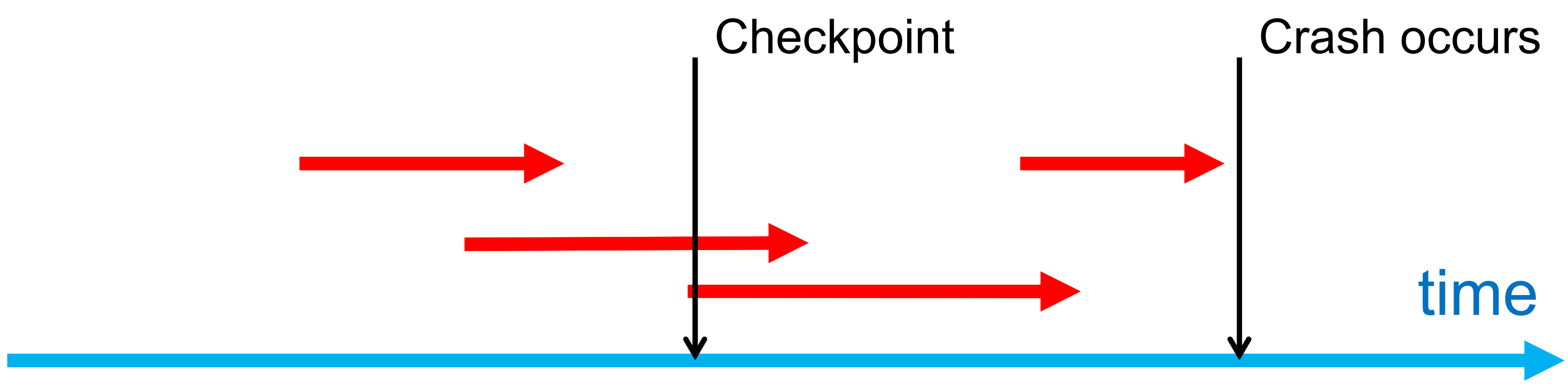
- Timestamp
  - Assigns a global unique timestamp to each transaction
  - Each data item accessed by a transaction gets the timestamp
  - Thus for every data item, the DBMS knows which transaction performed the last read or write on it
  - When a transaction wants to read or write, the DBMS compares 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 any of the data it read has been altered – if so, rollback

Logging transactions

- Allow us to restore the database to a previous consistent state
- If a 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:
  1. A record for the beginning of the transaction
  2. 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
  3. The ending (COMMIT) of the transaction

Transaction log

- Also provides the ability to restore a crashed 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 * * * *									