Lecture 7. Transaction, Concurrency Control (Chapter 20 and 21)

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Outline

- Transaction
- Brake 10 min
- Concurrency Control Techniques

Introduction to Transaction Processing Concepts and Theory

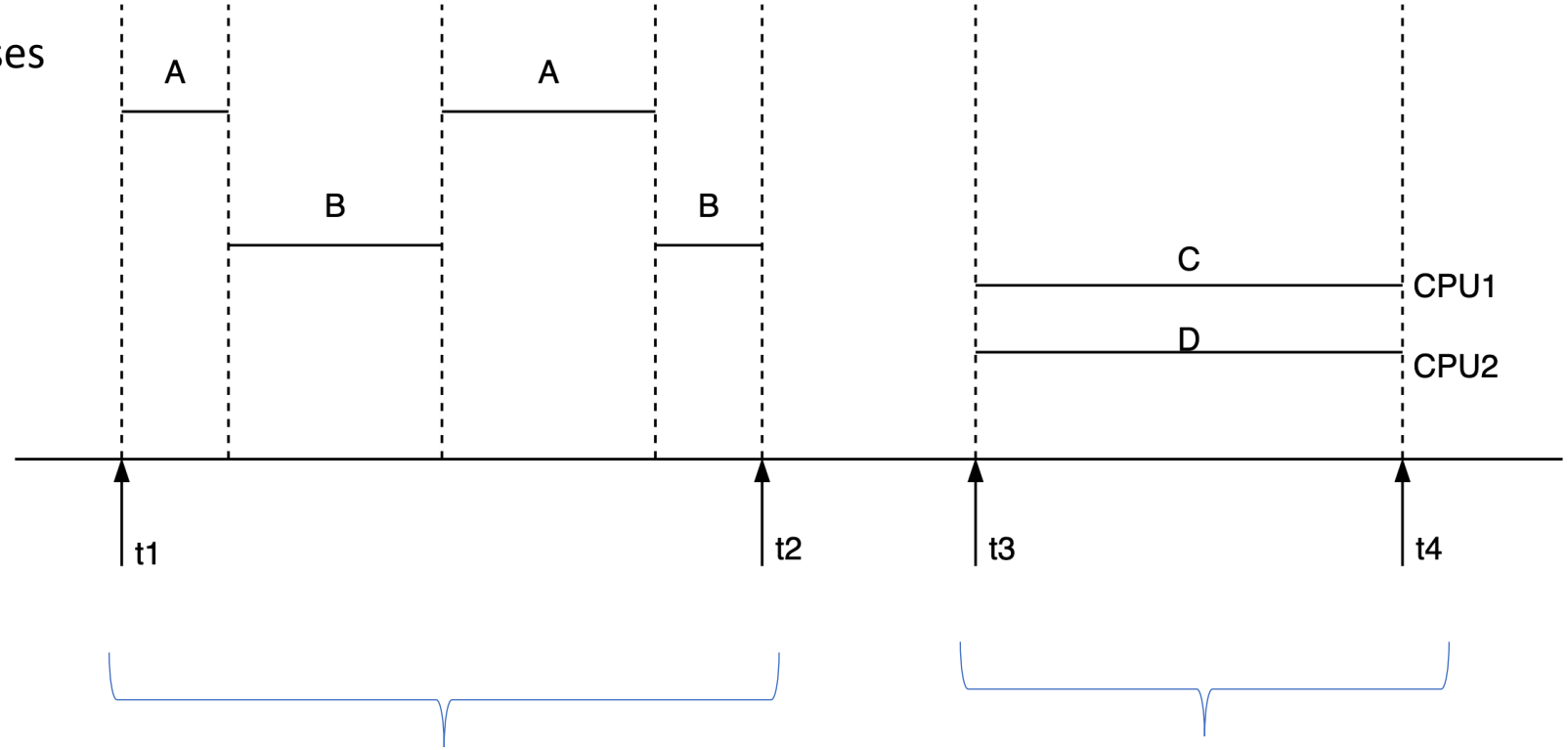
- The concept of transaction provides a mechanism for describing logical units of database processing
- Transaction processing system are systems with large databases and hundreds of concurrent users executing database transaction.
- Examples of such systems are:
  - Airline reservation companies
  - Bank organization
  - Online retail shops
  - Supermarket checkouts
  - And many other applications

Single-User versus Multiuser Systems

- A database system can be characterizes by number of users who can use the system **concurrently**.
- A DBMS is single-user is at most one user at a time can use the system, and it is multiuser if many users can use the system and access the database concurrently.
- In multiuser systems , hundreds and thousands of users submitting transactions concurrently to the system
- Multiple users can access database simultaneously because of the concept of multiprocessing which allows the operation system to execute multiple processes at the same time.
- A single central processing unit (CPU) can only execute at most one process at a time.
- If the computer has multiple CPUs, a parallel processes are executed

Interleaved Concurrency

A,B,C,D, are processes



Transactions in MySQL and Python

- A **transaction** is an executing program that forms a logical unit of database processing.
  - It may include one or more database access operations such as insertion, deletion, update, or retrieval operations.
  - We can explicitly specify the begging and end of transaction by using **begin and end transaction statement** in the application program. In this case, all database operations between begin and end statement considers as *one transaction.*
  - *Read-only transaction* is a transaction which contains only retrieval operations (SELECT statements only)
  - *Read-write transaction* is a transaction which contains both retrieval operations and modification operations (delete, insert, update).
  - Transactions submitted by the various users may execute concurrently and may access and update the same database items

```python
import mysql.connector
from mysql.connector import errors

try:

    db = mysql.connector.connect(option_files='my.conf',

    cursor = db.cursor()

    db.start_transaction()

    # these two INSERT statements are executed as a single unit

    sql1 = """
    insert into employees(name, salary) value('Tom', 19000)
    """

    sql2 = """
    insert into employees(name, salary) value('Leo', 21000)
    """

    cursor.execute(sql1)
    cursor.execute(sql2)

    db.commit()  # commit changes

    print('Transaction committed.')

except errors.Error as e:
    db.rollback()  # rollback changes
    print("Rolling back ...")
    print(e)

finally:
    cursor.close()
    db.close()
```

Possible problems with uncontrolled concurrence transaction execution (1)

- Example: Airline reservation database where each record includes the number of reserved seats on that flight
- A transaction is a particular execution of a program on a specific date, flight, and number of seats.
- T1 transfers N reservations from flight X to flight Y
- T2 reserves M seats on the flight X.

Two examples of transaction: T1, and T2

T1

read_item(X);
X:=X-N;
write_item(X);
read_item(Y);
Y:=Y + N;
write_item(Y);

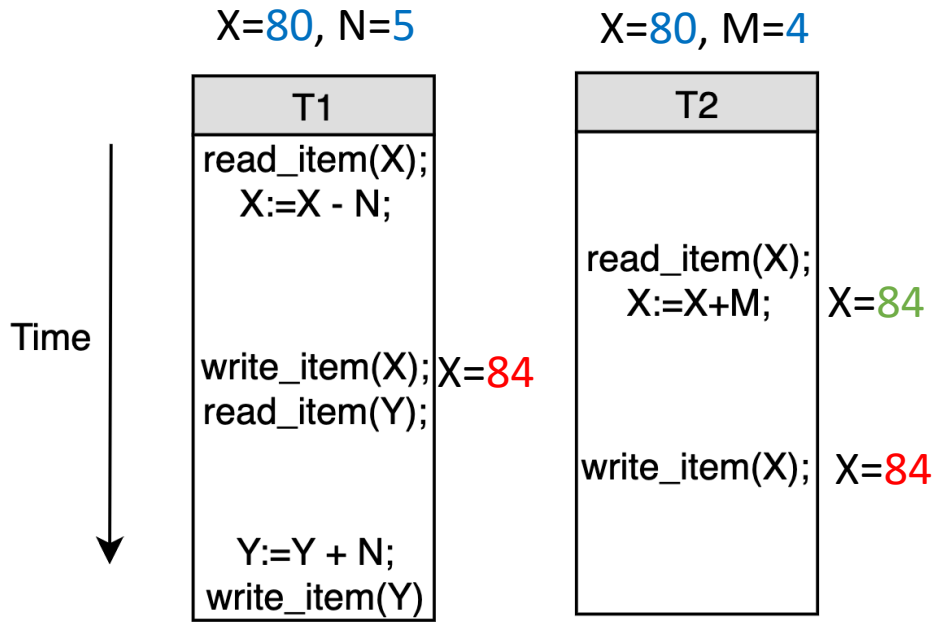
T2

read_item(X);
X:=X+M;
write_item(X);

Possible problems with uncontrolled concurrence transaction execution (2)

Problem 1: Lost Update Problem

This problem occurs when two transactions that access the same database items have their operations interleaved in a way that makes the value of some database items incorrect.



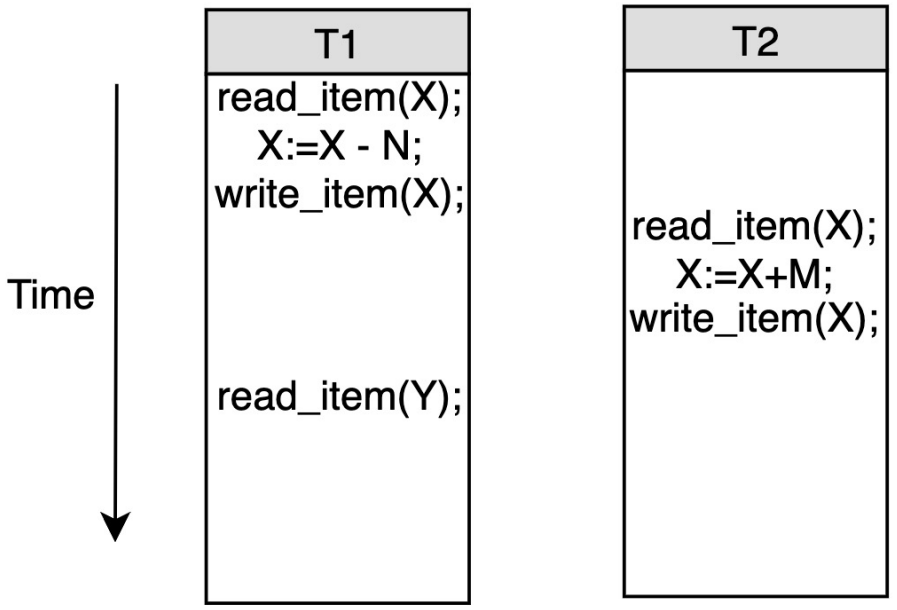
Item X has an incorrect value because its update by T2 and the original value (75) is lost (overwritten)

The final result after T1 and T2, should be X = 79 (80-5+4)

Possible problems with uncontrolled concurrence transaction execution (3)

Problem 2 the Temporary Update

It occurs when one transaction updates a database item, and then the transaction fails for some reason. Meanwhile, the updated item is accessed (read) by another transaction before it is changed back to its original value.



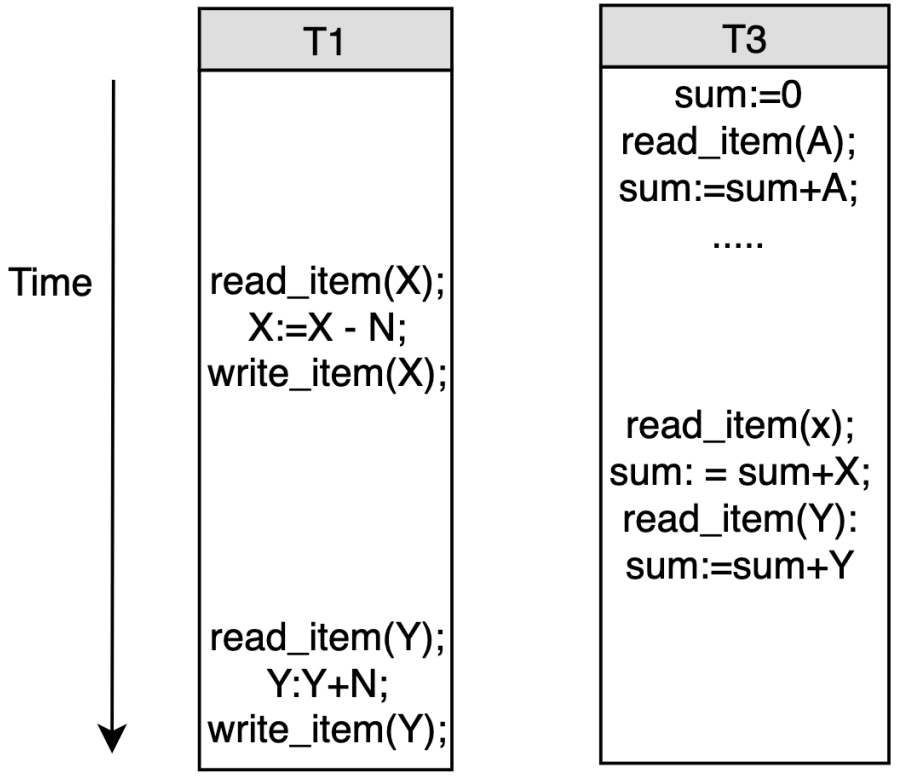
Transaction T1 fails and must
change the value of X back to its old value;
And T2 has read the temporary incorrect value of X

Possible problems with uncontrolled concurrence transaction execution (4)

Problem 3 The Incorrect Summary Problem

Occurs when one transaction is calculating an aggregated summary function (SUM, COUNT, AVG,etc.) on a number of database items while other transactions are updating some of these items, the aggregation function may calculate some values before they are updated and others after they are updated.

T3 calculates total amount of reservations on flights, meanwhile T1 is executing which is modifying number of flights in X.



T3 reads X after N is subtracted and reads Y before N is added

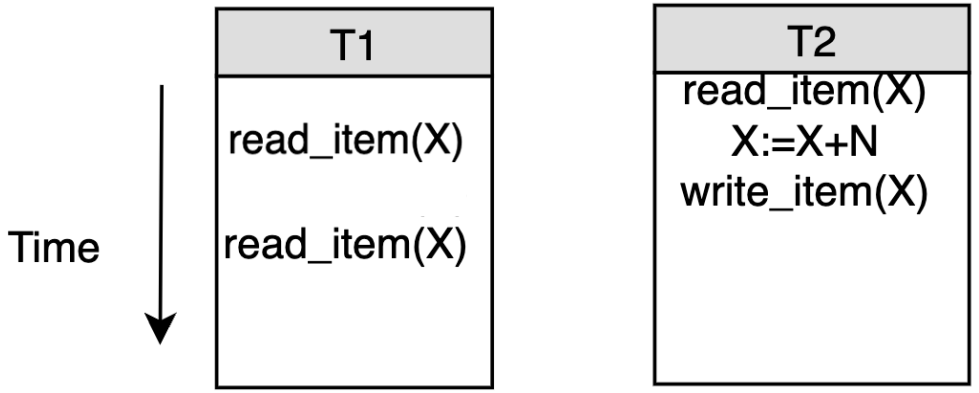
Possible problems with uncontrolled concurrence transaction execution (5)

- **Problem 4 The Unrepeatable Read Problem**

Transaction T1 reads the same item twice

Value is changed by another transaction T2 between the two reads

T receives different values for the two reads of the same item

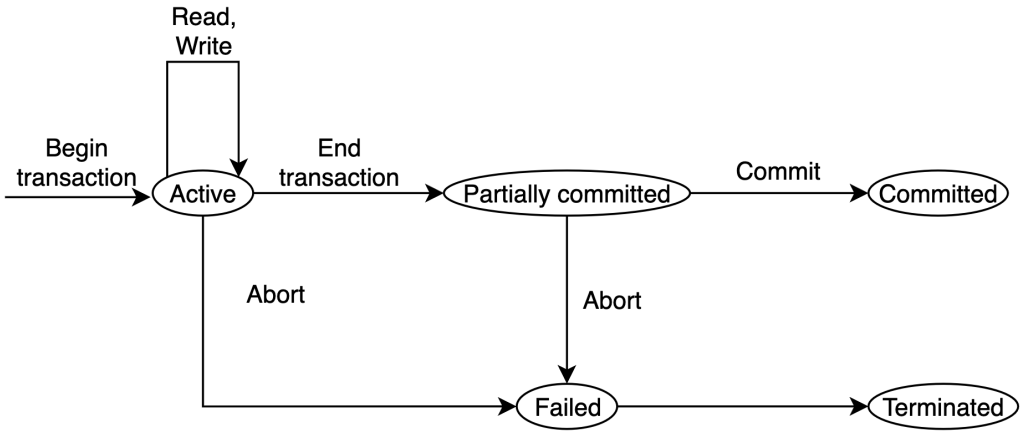


Types of Failures

- **1 A computer failure (system crash),** e.g., a hardware, software, or network error occurs in the computer system during transaction execution.
- **2 A transaction or system error.** Some transaction operation may fail such as integer overflow or division by zero, wrong parameter values (data type), or user may interrupt the transaction during its execution (e.g., pressing button Cancel)
- **3 Local errors or exception condition** detected by the transaction. For example, data for transaction may not be found.
- **4 Concurrency control enforcement**. May abort the transaction because it violates serializability or it may abort one or more transactions to resolve the state of deadlock among several transactions.
- **5 Disk failure**. A disk read/write head crash
- **6 Physical problems and catastrophes**. Endless list of problems that includes power and air conditioning failure, fire, etc.
- Most common failures are 1-4 types,
- What to do when it happens?
  - Run Database Recovery

Transaction States and Additional Operations

- Operations:
  - BEGIN_TRANSACTION
  - READ or WRITE operations
  - END_TRANSACTION. This specifies that READ and WRITE transaction operations have ended and marks the end of transaction execution. Next step, we need to check whether the changes introduced by transaction can be permanently applied to the database (committed) or whether has to be aborted because it violates serializability, etc.
  - COMMIT_TRANSACTION is a successful signal of the end of transaction and the changes can be safely committed to the database and will not be undone.
  - ROLLBACK (or ABORT) is a unsuccessful signal of the end of transaction and any changes that were introduced by the transaction must have been undone.
- States are presented in the diagram
- Failed or aborted transactions may be restarted later using some transaction maintenance strategy.
- All of the transaction operation and states are written into the System Log



The System Log

- System log keeps track of transaction operations
- Sequential, append-only file
- Not affected by failure (except disk or catastrophic failure)
- Log buffer
  - Main memory buffer
  - When buffer is full, appended to end of log file on disk
- Log file is backed up periodically
- Undo and redo operations based on log are possible

Transaction Support in SQL

- Newer SQL standards have more commands for transaction processing
- The transaction processing can be written either in DBMS or application program using DB API/library
- A sample SQL transaction might look like the following:

```
EXEC SQL WHENEVER SQLERROR GOTO UNDO;
EXEC SQL SET TRNSACTION
  READ WRITE
   DIAGNOSTIC SIZE 5
   ISOLATION LEVEL SERIALIZABLE;
EXEC SQL INSERT INTO EMPLOYEE (Fname,Lname,….) VALUES('Robert','Smith',…)
EXEC SQL UPDATE EMPLOYEE
  SET Salary = Salary *1.1 WHERE Dno = 2;
EXEC SQL COMMIT;
GOTO THE_END;
UNDO: EXEC SQL ROLLBACK;
THE_END:…;
```

When to write the Transactions in SQL or in the Application Program?

Write Transaction in SQL	Write Transactions in the Application Program
Simple Transactions containing few SQL statements	Business Logic
Database Constraints and Integrity Rules	Cross-Platform Compatibility
Atomicity Requirements	Error Handling
Concurrency Control	Performance Considerations
Combination of both approaches may be used	

Nowadays, you are rarely use begin and rollback in the application because other libraries are do it for you.
For example, Hibernate for Java. But you need to know what happens on the low level.

Desirable Properties of Transaction

- **Atomicity.** A transaction is an atomic unit of processing
- **Consistency preservation.** A transaction should be consistency executed without interference with other transactions, and it should take the database from one consistent state to another.
- **Isolation.** The execution of one transaction should not be interfere with execution of another transaction
- **Durability or permanency.** The changes applied to the database by a committed transaction must persist in the database. These changes must not be lost because of any failure.

Break 10 min

Concurrency Control Techniques (CCT)

- Protocol-based:
  - Two-Phase Locking Protocols
  - Timestamp Based Protocols
  - Validation-Based Protocols
- Multiversion CCT:
  - Optimistic protocols and
  - Snapshot isolation based CCT

Locks

- A lock is a variable associated with a data item that describes the status of the item with respect to possible operations that can be applied to it
  - There are *binary locks* (not used much) and read/write locks (or shared/Exclusive)
  - Shared lock allows to several transactions to access the same item X if they all access X for ***reading purposes only***.
  - Exclusive lock is when the transaction it about to write item into X, only one transaction can hold an exclusive lock if it is free (unlocked)
- There are three locks: read_lock(X), write_lock(X) and unlock(X).
- Three possible states*: read_locked, write_locked, unlocked*
- *Locks granularity:* objects for lock can be different size such as a cell, a collumn, a row, a set for rows, a whole table, a whole database, etc.

Two –phase locking protocols CCT

- Applying a lock to the transaction data which blocks other transactions to access the same data simultaneously
- The Two-Phase Locking protocol allows each transaction to make a lock or unlock request in two steps:
  - **Growing Phase**: In this phase transaction may obtain locks but may not release any locks.
  - **Shrinking Phase**: In this phase, a transaction may release locks but not obtain any new lock
- A transaction cannot get new locks once it releases any lock
- Two unwanted situations may occur*: starvation and deadlock*
- Other variations: Strict Two-Phase Locking Method, Centralized 2PL, primary copy 2PL, Distributed 2PL

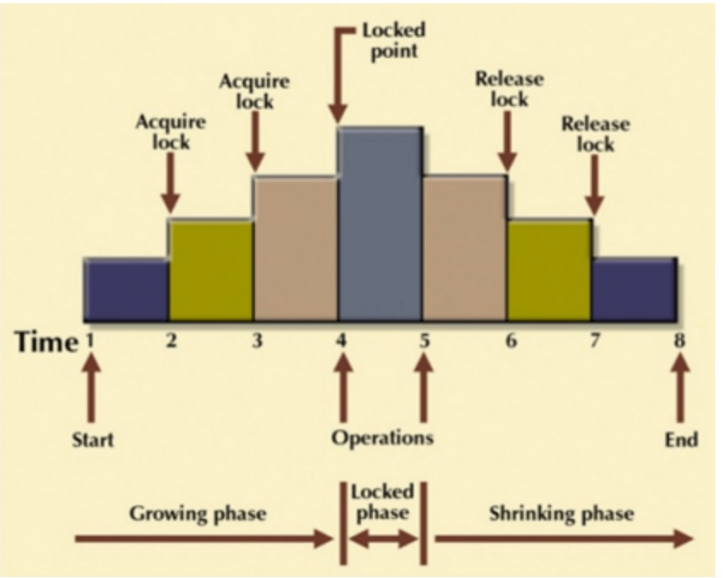


Image taken from : https://www.guru99.com/dbms-concurrency-control.html#4

Example Two phase protocol

Without Two phase protocol

T1	T2	DB state
S_lock(account)		1200
Read(account)		
Unlock(account)		
	S_lock(account)	
	Read(account)	
	unlock(account)	
Ex_lock(account)		1100
Write(account)		
Unlock(account)		
	Ex_lock(account)	
	Write(account)	1000
	Unlock(account)	

With Two Phase Protocol

T1	T2	DB state
Ex_lock(account)		
Read(account)		1200
	Ex_lock(account)	
Write(account)	T2 blocked by T1 wait for relese	1100
Unlock(account)	Ex_lock(account)	
	Read(account)	
	Write(Account)	900
	Unlock(account)	

OBS! Once a lock has been released, no new lock can be acquired

Starvation

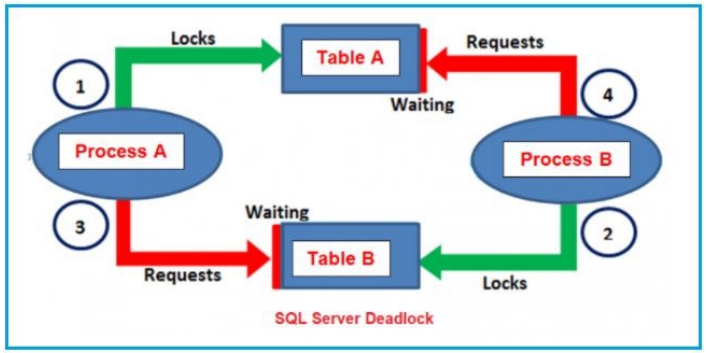
- Starvation is the situation when a transaction needs to wait for an indefinite period to acquire a lock.

Following are the reasons for Starvation:

- When waiting scheme for locked items is not properly managed
- In the case of resource leak
- The same transaction is selected as a victim repeatedly

Deadlock

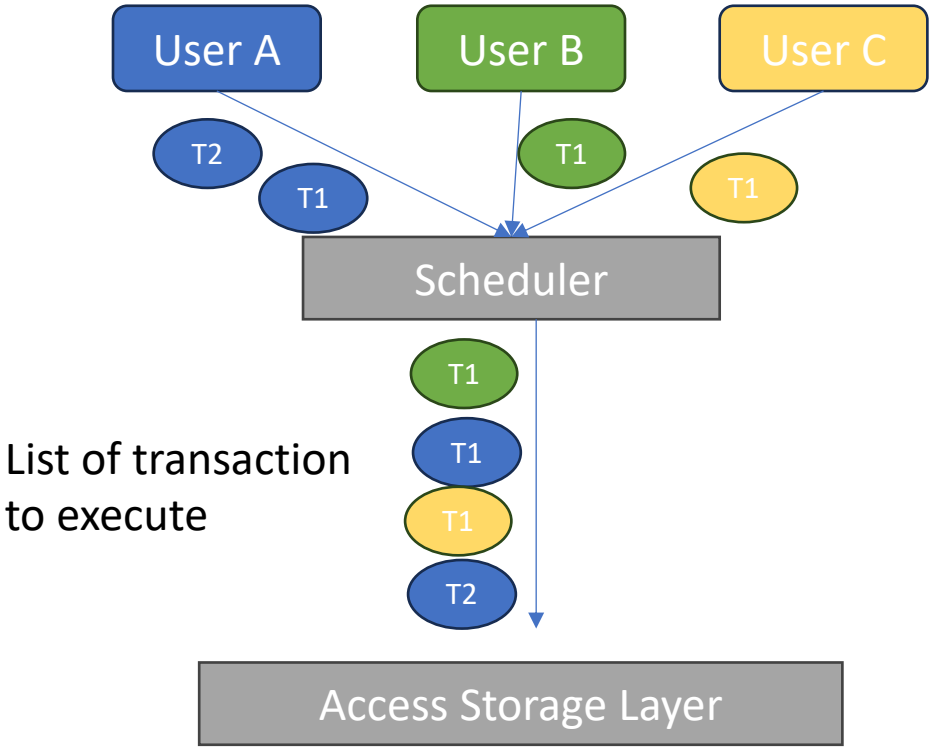
- Deadlock refers to a specific situation where two or more processes are waiting for each other to release a resource or more than two processes are waiting for the resource in a circular chain.

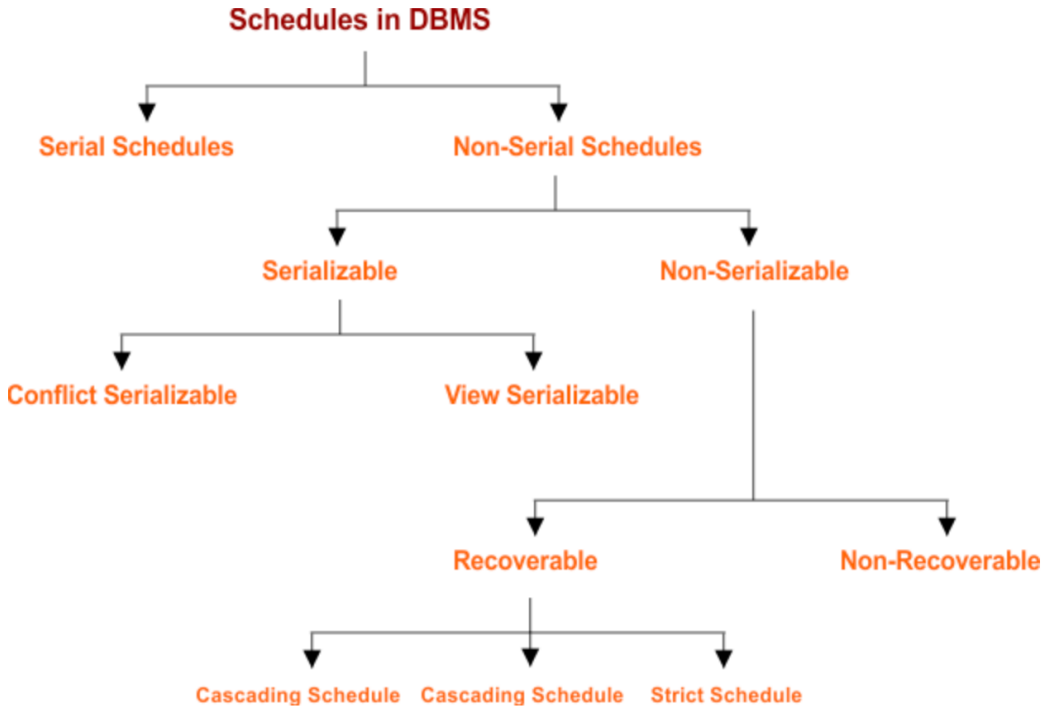


Time	User 1 Actions	User 2 Actions
1	Starts Transaction	
2		Starts Transaction
3	Updates row 2 in table A	
4		Updates row 10 in table B
5	Attempts to update row 10 in table B	
	U1 Is Blocked by U2	
6		Attempts to update row 2 in table A
	U1 Is Blocked by U2	*U2 Is Blocked by U1*
	DEADLOCK!!!	

Schedules and Its Types

- Scheduler decides the execution order of concurrent database access.





Serial Schedules

- Schedules in which no transaction can starts until a running transaction is ended are called serial schedules.
- Advantage: no concurrency problem, works good for single user application
- Disadvantage: It is very time consuming approach which is not applicable for multiuser application

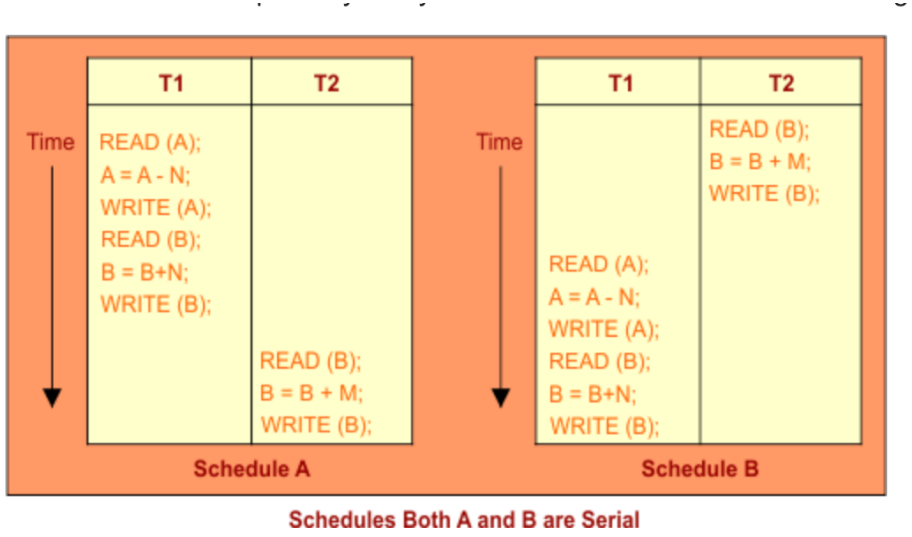
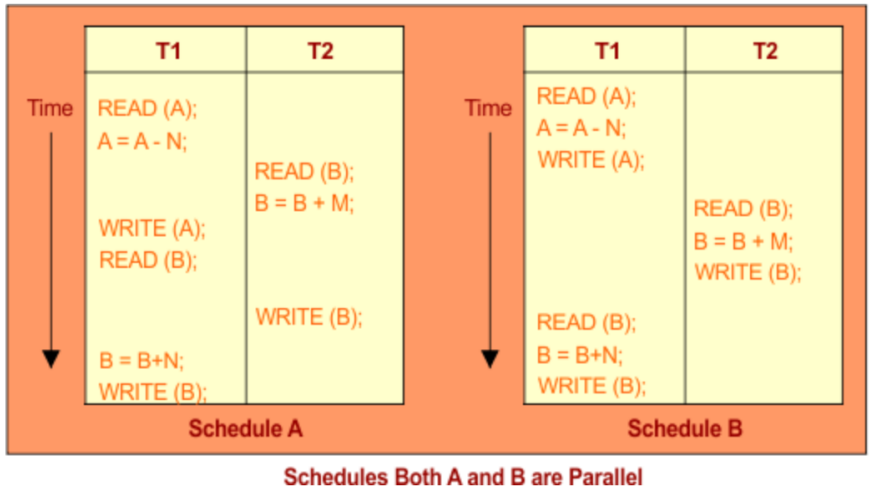


Image and Example is taken from: https://cstaleem.com/schedules-and-its-types

Non-serial (Parallel Schedule)

- In the non-serial schedule, the other transaction proceeds without waiting for the previous transaction to complete.
- Cause the concurrency problem and conflicts: write read, read write and write write conflicts



Non Serial but Serializable Schedule

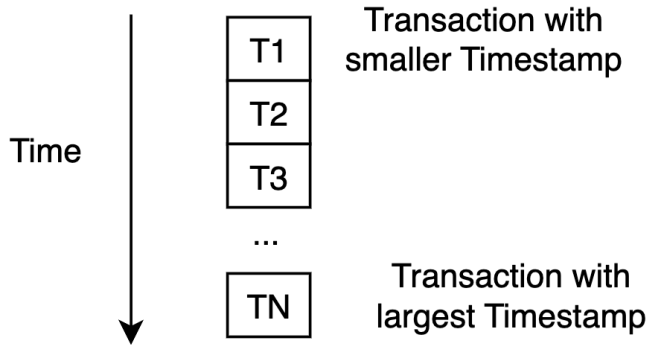
- A non-serial schedule that is still considered serializable is one where transactions are executed concurrently but the end result is equivalent to a serial execution of those transactions.
- Hence, concurrency control techniques must be used to support serializable schedule.

CCT based on Timestamps ordering (TO)

- A timestamp is unique identifies created by DBMS to identify a transaction. Also known as transaction start time (and they are ordered by time). Can be generated in several ways:
  - Using a counter that increments automatically the transaction number like 1,2,3,….to fin9ite maximum value (and reset to 0 in some certain condition)
  - Or use current system date/time value and ensure that no two timestamps values are generated during the same tick of the clock.

- The TO algorithm ensure that for each pair of conflicting operations in the schedule, the order in which item is accessed must follow the timestamp order.
  - It uses two timestamp values : Read_TS(X) and Write_TS(X)
  - Rule-based comparison algorithm of timestamps performed in order to check if the order is not violated. If the violation is occurred the transaction is aborted and resubmitted to the system as a new transaction with a new timestamp.
  - Deadlocks are not occurred with this approach in comparison to previous CCT method
  - Hence, Starvation is possible if the same transaction is restarted and continually aborted

- Examples : https://cstaleem.com/timestamp-ordering-with-examples



Multiversion Concurrency Control Technique

- Several versions (copies) are kept by the system when the data is updated
- A drawback is more storage is needed to maintain multiple version of the database.
- Support different CCT techniques:
  - Validation based technique
  - Snapshot Isolation

Validation based technique

- Uses three phases:
  - 1 Read Phase. A transaction can read values of committed data items from the database. Hence, updates are applied only to local copies (versions_ of the data items kept in the transaction workspace).
  - 2 Validation Phase. Checking is performed to ensure that serializability will not be violated if the transaction updates are applied to the database
  - 3 Write Phase. If the validation phase is successful, the transaction updates are applied to the database, otherwise the updates are discarded and the transaction is restarted.
- This approach is also called optimistic because it assume not much interference between transactions which is not in a real life case.

Snapshot Isolation

- Snapshot isolation is that a transaction begins in a certain snapshot isolated state (copy) of the database at the time when the transaction is started.
- Some anomalies that violates serializability can occur, hence they are very rare and difficult to detect.
- Uses pointers to the list of items in the tempstore, the temstore items will be removed when they not needed longer.
- Variations of this technique have been used by Oracle and PostGres DBMS.

MySQL

- MySQL Server uses InnoDB which is a transactional storage engine which uses multiversion concurrency control (MVCC)
- Locks in MySQL Server:
  - https://www.sqlshack.com/locking-sql-server/
- Optimistic Locking in MySQL:
  https://stackoverflow.com/questions/17431338/optimistic-locking-in-mysql
- Working out with deadlocks in MySQL:
  https://stackoverflow.com/questions/62846528/default-concurrency-control-implementation-in-mysql
- Uses Internal and External Locking methods which can be read in more detail at the MySQL documentation:
  - https://dev.mysql.com/doc/refman/8.0/en/internal-locking.html
  - https://dev.mysql.com/doc/refman/8.0/en/external-locking.html

Summary

- **Transaction** is a sequence of operations that belong together as a logical unit. Most database management systems offer support for grouping operations into transactions.
- ACID properties of transaction: Atomicity, Consistency, Isolation, and Durability
- **Log file** for tracking all transactions and in case of failure be able to recover to consistent state of the database
- **Locks** are used to control access to database objects and ensure that only one transaction can work with it, and others must wait. These locks are acquired and released automatically by the database engine based on the type of operation being performed and the isolation level set for the transaction
- **Concurrency control** is the procedure in DBMS for managing simultaneous operations without conflicting with each another. There are many techniques exists which are Lock-Based, Two-Phase, Timestamp-Based, Validation-Based, Snapshot Isolation are types of Concurrency handling protocols
- **Serializable schedule** for transactions refers to a schedule in which transactions appear to have been executed one after the other in a serial (or sequential) manner, even though they may have been executed concurrently.

References

- Database Locking: What it is, Why it Matters and What to do About it? https://www.methodsandtools.com/archive/archive.php?id=83
- Video tutorials on Youtube: https://www.youtube.com/watch?v=WtlbLA0pfCI
- https://www.youtube.com/watch?v=lplfcgQDsRU