# CSC 742
# Database Management Systems

Topic #12: Transaction Concepts



## What is a transaction?

- Informally, a transaction is an execution of a program that satisfies certain properties.
  - Atomicity
  - Consistency
  - Isolation
  - Durability



## Database Model for Transaction Processing

- A database is modeled as a collection of named items.
- Operations to database items are simplified to:
  - Read(x)
  - Write(x)
- The read-set (write-set) of a transaction is the set of items that the transaction reads (writes).



## An Example Transaction

```
T1:
-----------------
Read(X)
X:= X – 10
Write (X)
Read(Y)
Y := Y + 10
Write (Y)
```

Read-set (T1) = ?
Write-set (T1) = ?

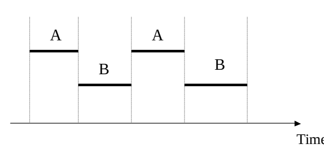


## What are transactions for?

- Concurrency control
- Recovery



## Currency Control




- Currently running processes are actually interleaved.
- They may access same database items in these interleaved operations.
- The purpose of transactions (in the context of concurrency control) is to avoid the problems that may arise from interleaving

# Problem 1: Lost Update

- The effect of a transaction on the DB is accidentally overwritten by another transaction
- T1 = r1(a); → a++; w1(a)
- T2 = r2(a); → a++; w2(a)



# Problem 2: Dirty Read

- A transaction prematurely reads a value from the DB that is later invalidated by another transaction

Time ↓

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10<br>Write (X) | |
| | Read(X)<br>X:= X + 100<br>Write (X) |
| Read(Y) | |

T1 fails and has to change X back to its old value



# Problem 3: Incorrect Summary

Also termed *inconsistent analysis*

- A transaction observes an incorrect state of the DB
  - typically with some sort of aggregation

Time ↓

| T1 | T2 |
|---|---|
| | **Sum := 0**<br>**Read (A)**<br>**Sum := Sum + A** |
| **Read(X)**<br>**X:= X – 10**<br>**Write (X)** | |
| | **Read(X)**<br>**Sum := Sum + X**<br>**Read(Y)**<br>**Sum := Sum + Y** |
| **Read (Y)**<br>**Y := Y + 100**<br>**Write (Y)** | |



# Recovery

- The DBMS needs to make sure that
  - Either all the operations of a transaction are completed and the effect is recorded *permanently* in the database,
  - Or the transaction has no effect at all.
- Recovery is necessary to make sure this is true *in case of failures*.



# Desirable Transaction Properties

- These define traditional transactions
  - Atomicity or Failure Atomicity
    - All-or-nothing
    - If failed then no changes or messages
  - Consistency
    - Don't violate DB integrity constraints
  - Isolation or Isolation Atomicity
    - As if the transaction is being executed alone.
  - Durability
    - Effects (of transactions that "happened" or committed) are forever.



# Atomicity or Failure Atomicity

- All or nothing
- If failed then
  - no changes
  - no messages

## Consistency

- Don't violate DB integrity constraints
  - These constraints include
    - both the integrity constraints defined on database schemas and
    - other constraints that should hold on the database.
      - Rarely evaluated formally
      - Mostly just enforced by the programmer



## Isolation or Isolation Atomicity

- Concurrent transactions are executed as if they are all executed alone.
- Partial results are hidden from users and other transactions



## Durability

- Effects (of transactions that "happened" or committed) are forever.
- Should not affected by failures.

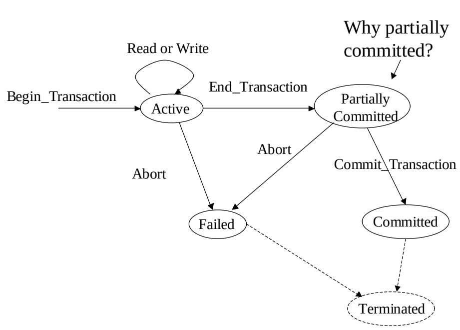


## Programming with Transactions

- Transactions simplify programming
  - the programmer guarantees correctness of individual transactions
  - the system eventually recovers
  - then the system guarantees the ACID properties for the entire set of transactions that execute concurrently



## Transaction States and Operations






## System Log

- System log:
  - To keep track of all transaction operations.
  - Kept on disk.
  - Necessary for recovery from failures.
- Log records: Entries in the system log
  - [Start_Transaction, T]
  - [Write, T, old_value, new_value]
  - [Read, T, X] (May not be required, depending on the protocol.)
  - [Commit, T]
  - [Abort, T]
  - [checkpoint]

## Commit Point of a Transaction

- A transaction T reaches its *commit point* when
  - All its operations that access the database have been executed, and
  - The effect of all transaction operations have been recorded in the log.
- A transaction is *committed* beyond its commit point.
  - [Commit, T] in the log.
- *Force write* the log:
  - Before T's commit point, all of the log must be written to the disk.
  - Why?



## Checkpoint

- [Checkpoint] is appended to the log when writes of all previously committed transactions are effected on the database.
- Purpose:
  - Reduce the work required for recovery.



## Schedules

- Schedules are histories of computations showing all the events of interest
  - Schedule or history of T1...Tn has operations of T1...Tn
  - Operations may be interleaved, but must be in the same order as within each Ti
  - Events of interest:
    - Read, Write, Commit, Abort in Ti
    - Abbreviations: $r_i$, $w_i$, $c_i$, $a_i$.



Time ↓

| T1 | T2 |
| --- | --- |
| Read(X)<br>X:= X – 10<br>Write (X) | |
| | Read(X)<br>X:= X + 100<br>Write (X) |
| Read(Y) | |

Schedule:



Time ↓

| T1 | T2 |
| --- | --- |
| | **Sum := 0**<br>**Read (A)**<br>**Sum := Sum + A** |
| **Read(X)**<br>**X:= X – 10**<br>**Write (X)** | |
| | **Read(X)**<br>**Sum := Sum + X**<br>**Read(Y)**<br>**Sum := Sum + Y** |
| **Read (Y)**<br>**Y := Y + 100**<br>**Write (Y)** | |

Schedule:



## Conflict

- Two operations in a schedule *conflict* if
  - They are in different transactions
  - They involve the same data item
  - At least one of them is write.

**Time** ↓

| **T1** | **T2** |
| --- | --- |
| **Read(X)**<br>**X:= X – 10**<br>**Write (X)** | |
| | **Read(X)**<br>**X:= X + 100**<br>**Write (X)** |
| **Read(Y)** | |

What are the conflict operations?

## Complete Schedule

- A schedule S of n transactions T1, …, Tn is a *complete schedule* if
  - The operations in S are exactly those in T1, …, Tn, including a commit or abort as the last operation for each Ti;
  - For any pair of operations from the same Ti, their order is the same as in Ti;
  - For any two conflicting operations, one must occur before the other.
- A *partial order* in which
  - a commit or abort event for each Ti is included
  - conflicting ops are ordered



## Examples

Transactions:

T1: r1(X); w1(X); r1(Y); w1(Y); c1;
T2: r2(Y); w2(Y); a2;
T3: r3(X); w3(X);

S1: r1(X); r2(Y); w1(X); w2(Y); r1(Y); a2; w1(Y); c1; r3(X); w3(X);

S2: r1(X); r2(Y); w1(X); w2(Y); r1(Y); a2; w1(Y); c1;

S3: r1(X); w2(Y); w1(X); r2(Y); r1(Y); a2; w1(Y); c1;

Is Si a complete schedule? For what?



## Committed Projection

- A *committed projection*: C(S) of a schedule S include the operations in S only from the committed transactions.

Transactions:

T1: r1(X); w1(X); r1(Y); w1(Y); c1;
T2: r2(Y); w2(Y); a2;
T3: r3(X); w3(X);

S1: r1(X); r2(Y); w1(X); w2(Y); r1(Y); a2; w1(Y); c1; r3(X); w3(X);

C(S1) = ?



## Recoverable Schedules

- Goal:
  - Once a transaction T is committed, it should never be necessary to roll back T.
  - Recoverable schedules: schedules that meet this criterion.

S1: r1(X); w1(X); r2(X); w2(X); c2; a1;

Is this recoverable?

In terms of the ACID properties, what is the risk in allowing a non-recoverable schedule?



## Recoverable Schedules (Cont'd)

- A schedule S is *recoverable* if each transaction commits after all transactions it *read from* have committed
  - T reads from T2 if the schedule contains a subsequence w2(x)...r(x), where w2 is the first write on x going backwards from r(x).

S1: r1(X); w1(X); r2(X); w2(X); c1; c2;



## Avoid Cascading Aborts

- A schedule S can *avoid cascading aborts* if no transaction in S read from uncommitted transactions.
- What is the risk in doing so?

S1: r1(X); w1(X); r2(X); w2(X); a1; a2;

S2: r1(X); w1(X); r2(X); w2(X); r3(X); w3(X); a1; a2; a3;

S3: r1(X); w1(X); a1; r2(X); w2(X); c2; r3(X); w3(X); c3;

## Strict Schedules

- A schedule S is *strict* if no transaction can read or write an item X until the previous transaction to write that item has committed or aborted.

S1: r1(X); w1(X); w2(X); c1; c2;

S2: r1(X); w1(X); c1; w2(X); c2;

Avoid Cascading Abort?
Strict?



## Strict Schedules (Cont'd)

- Benefit:
  - Allows us to UNDO by restoring the before image

X=9

S1: w1(X, 5); w2(X, 8); a1;

X=?

Log:
…
[write, T1, X, 9, 5]
[write, T2, X, 5, 8]
[abort, T1]
…

---

X=9

S1: w1(X, 5); a1; w2(X, 8);

X=?

Log:
…
[write, T1, X, 9, 5]
[abort, T1]
[write, T2, X, 9, 8]
…



## Note

- Strict → Avoid Cascading Abort → Recoverable.
- All of them are about recovery.



## Serial Schedules

Transactions are wholly before or after others.

- Serial schedules are correct (assuming each transaction is correct)
- Clearly, we must allow for service requests to come in slowly, one-by-one.

Time ↓

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10<br>Write (X) | |
| | Read(X)<br>X:= X + 100<br>Write (X) |



## Non-serial Schedules

X = 10, Y = 20

Time ↓

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10 | |
| | Read(X)<br>X:= X + 100 |
| Write (X)<br>Read (Y) | |
| | Write (X) |
| Y := Y + 20<br>Write (Y) | |

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10<br>Write (X) | |
| | Read(X)<br>X:= X + 100<br>Write (X) |
| Read (Y)<br>Y := Y + 20<br>Write (Y) | |

Are they correct?



## Serializable Schedules: 1

- *Serializable schedules* are those *equivalent* to some serial schedule.
- Here equivalent can mean
  - *conflict* equivalent
    - The order of any two conflicting operations is the same in both schedules.
    - Alternatively, to be equivalent to a serial schedule, a non-serial schedule must have all pairs of conflicting operations ordered the same way.
  - *view* equivalent—each read of a transaction gets the same view in both schedules.

X = 10, Y = 20

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10 | |
| | Read(X)<br>X:= X + 100 |
| Write (X)<br>Read (Y) | |
| | Write (X) |
| Y := Y + 20<br>Write (Y) | |

Time →

| T1 | T2 |
|---|---|
| Read(X)<br>X:= X – 10<br>Write (X) | |
| | Read(X)<br>X:= X + 100<br>Write (X) |
| Read (Y)<br>Y := Y + 20<br>Write (Y) | |

Order of conflicting operations?
Are they conflict equivalent to any serial schedule?
Are they serializable w.r.t. conflict?



# Serializable Schedules: 2

- Most approaches use conflict equivalence, because conflict equivalence
  - entails view equivalence
  - is relatively easy to ensure



# Checking Serializability

- Build a *serialization graph* for the given concurrent mix of transactions:
  - a node for each transaction
  - a directed edge for each conflict
  - serializability ←→the graph is acyclic



S1: r2(Z); r2(Y); w2(Y); r3(Y); r3(Z); r1(X); w1(X); w3(Y); w3(Z); r2(X); r1(Y); w1(Y); w2(X);

S2: r3(Y); r3(Z); r1(X); w1(X); w3(Y); w3(Z); r2(Z); r1(Y); w1(Y); r2(Y); w2(Y); r2(X); w2(X);

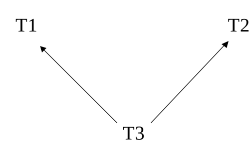


# Serializable Schedules: 3

Can we find an equivalent serial schedule for a serializable schedule?

- Such a serial schedule exists by definition
- Can easily derive from serialization graph.






Equivalent serial schedules: ?

## Achieving Serializability

- Optimistically: Let each transaction run, but check for serializability before committing.
- Pessimistically: Use a protocol, e.g., locking, to ensure that only serializable schedules are realized

Generally, the pessimistic approach is more common