# COURSE 2

Transaction and Concurrency Management

# Scheduling Transactions

A *schedule* is a sequential order of the instructions

(*Read* / *Write* / *Abort* / *Commit*)

of $n$ transactions such that the ordering of the instructions of each transaction is preserved

# Scheduling Transactions

```
    T1:                      T2:
read(A)
read(sum)
                         read(A)
                         A := A + 20
                         write(A)
                         commit
read(A)
sum := sum + A
write(sum)
commit
```

**Schedule**

```
read1(A)
read1(sum)
read2(A)

write2(A)
commit2
read1(A)

write1(sum)
commit1
```

# Scheduling Transactions

- ***Serial schedule:*** Schedule that does not interleave the actions of different transactions.

```
T1:                     T2:
                        read(A)
                        A := A + 20
                        write(A)
                        commit
read(A)
read(sum)
read(A)
sum := sum + A
write(sum)
commit
```

- ***Non-serial schedule***: A schedule where the ops from a set of concurrent transactions are interleaved.

# Scheduling Transactions

- *Equivalent schedules*: For any database state, the effect (on the set of objects in the database) of executing the first schedule is identical to the effect of executing the second schedule.
- *Serializable schedule*: A non-serial schedule that is equivalent to some serial execution of the transactions. (Note: If each transaction preserves consistency, every serializable schedule preserves consistency. )
- Checking serializability: which actions cannot be swapped in a schedule?:
  - Actions within the same transaction
  - Actions in different transitions transactions *on the same object* if at least one action is a **write** operation. (conflicting actions!)

# Scheduling Transactions (cont)

- Two schedules are *conflict equivalent* if:
  - Involve the same actions of the same transactions
  - Every pair of conflicting actions is ordered the same way
- Schedule S is *conflict serializable* if S is conflict equivalent to some serial schedule

| $T_1$ | $T_2$ | $T_3$ |
|---|---|---|
| $W_1(x)$ | | |
| | $R_2(x)$ | |
| $W_1(y)$ | | |
| $W_1(z)$ | | |
| | | $R_3(z)$ |
| | $W_2(y)$ | |
| | | $W_3(y)$ |
| | | $W_3(z)$ |

$S_{conf}$

| *conflict* | |
|---|---|
| $R_2(x)$ | |
| $W_2(y)$ | $W_3(y)$ |
| $R_3(z)$ | $W_3(z)$ |
| $W_3(y)$ | |

conflict-serializable

| $T_1$ | $T_2$ | $T_3$ |
|---|---|---|
| $W_1(x)$ | | |
| $W_1(y)$ | | |
| $W_1(z)$ | | |
| | $R_2(x)$ | |
| | $W_2(y)$ | |
| | | $R_3(z)$ |
| | | $W_3(y)$ |
| | | $W_3(z)$ |

$S_{ser}$

| *conflict* | |
|---|---|
| $R_2(x)$ | |
| $W_2(y)$ | $W_3(y)$ |
| $R_3(z)$ | $W_3(z)$ |
| $W_3(y)$ | |

serial schedule

# Serializability

- The objective of *serializability* is to find non-serial schedules that allow transactions to execute concurrently without interfering with one another, and thereby produce a database state that could be produced by a serial execution.
- It is important to guarantee serializability of concurrent transactions in order to prevent inconsistency from transactions interfering with one another.
- In serializability, the ordering of read and write operations is important.

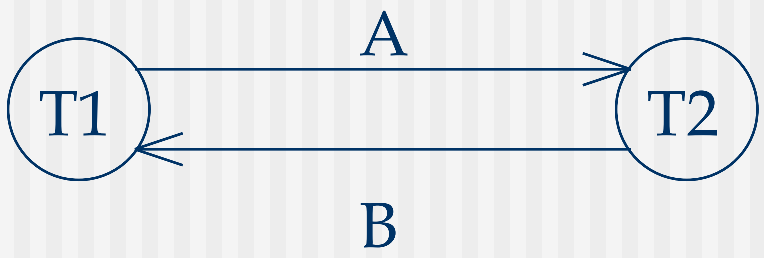
# Dependency Graph

- *Dependency graph*:
  - One node per transaction
  - Edge from $T_i$ to $T_j$ if $T_j$ reads/writes an object last written by $T_i$.
- Theorem: Schedule is conflict serializable if and only if its dependency graph is acyclic

# Example

- A schedule that is not conflict serializable:

T1: R(A), W(A), R(B), W(B)
T2: R(A), W(A), R(B), W(B)



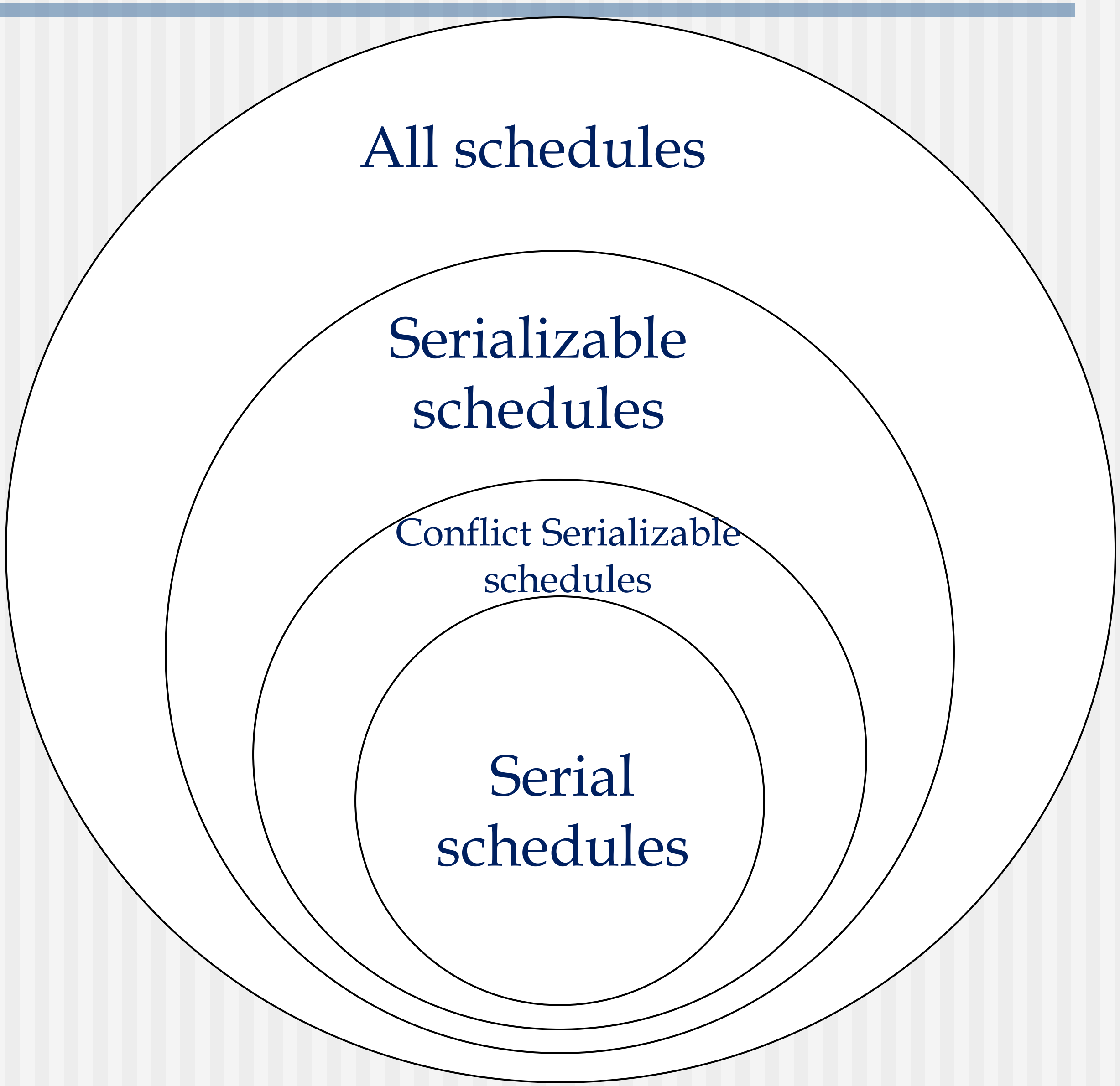

*Dependency graph*

- The cycle in the graph reveals the problem. The output of T1 depends on T2, and vice-versa.

# Algorithm for Testing Serializability of **S**

1. For each transaction $T_i$ in **S** create a node labeled $T_i$ in the precedence graph.
2. For each case in **S** where $T_j$ executes a Read(x) after a Write(x) executed by $T_i$ create an edge $(T_i, T_j)$ in the precedence graph
3. For each case in **S** where $T_j$ executes a Write(x) after a Read(x) executed by $T_i$ create an edge $(T_i, T_j)$ in the precedence graph
4. For each case in **S** where $T_j$ executes a Write(x) after a Write(x) executed by $T_i$ create an edge $(T_i, T_j)$ in the precedence graph
5. **S** is serializable iff the precedence graph has no cycles

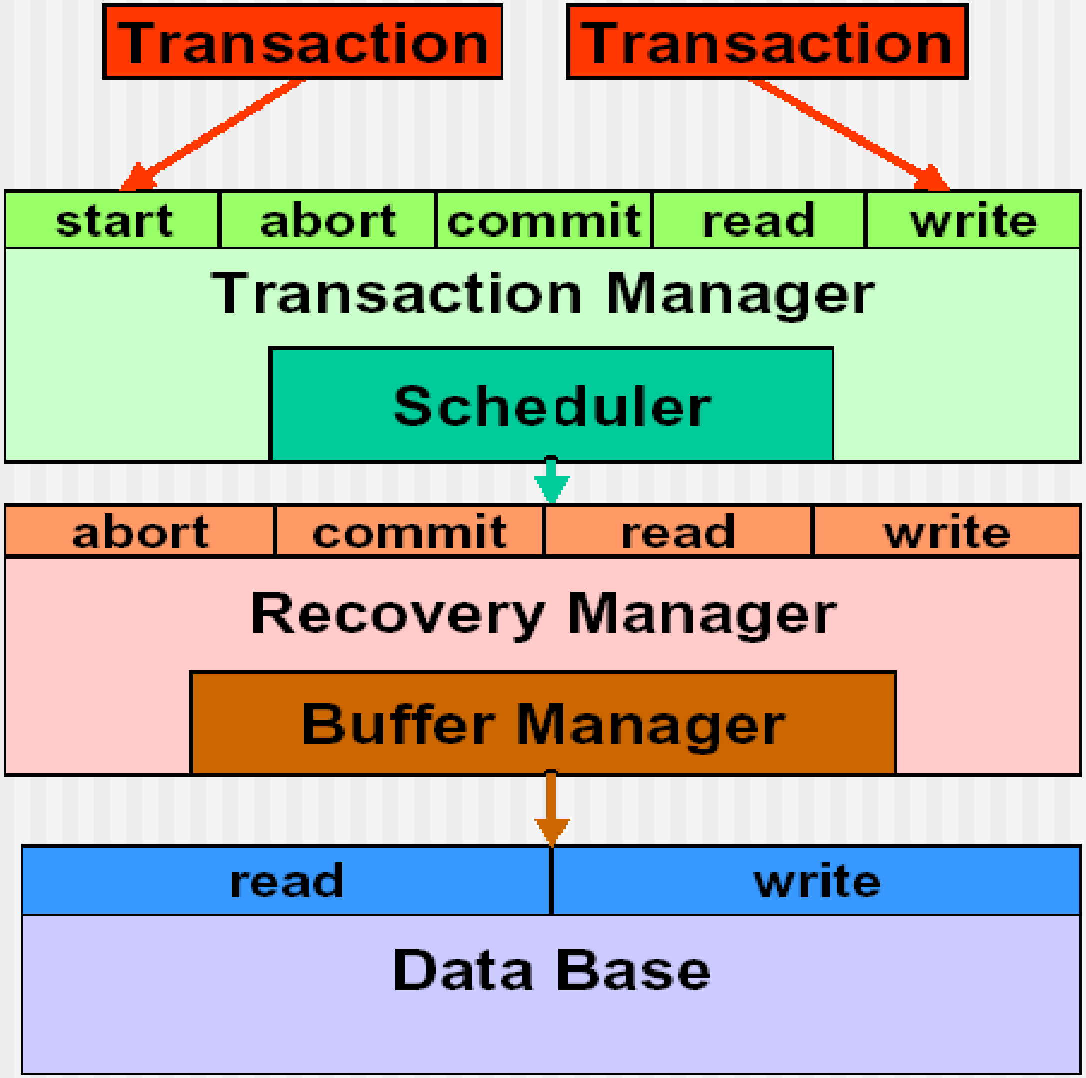
# Transactions schedules



# Serializability in Practice

- In practice, a DBMS does not test for serializability of a given schedule. This would be impractical since the interleaving of operations from concurrent transactions could be dictated by the OS and thus could be difficult to impose.
- The approach taken by the DBMS is to use specific protocols that are known to produce serializable schedules.
- These protocols could reduce the concurrency but eliminate conflicting cases.

# Transaction Execution



# Recoverable Schedules

- In a *recoverable schedule* transactions **can only read** data that has been **already committed**
- There is still the situation of a **blind write**

| $T_1$ | $T_2$ |
|---|---|
| R(A) | |
| W(A) | |
| | W(A) |
| | Commit |
| Abort | |

- What should the value of A be after the abort?

# Phantom Reads

- A transaction re-executes a query and finds that another committed transaction has inserted additional rows that satisfy the condition
  - If the rows have been modified or deleted, it is called an unrepeatable read

Example:

- $T_1$ executes `select * from Students where age < 25`
- $T_2$ executes `insert into Students values(12,'Jim', 23, 7)`
- $T_2$ commits
- $T_1$ executes `select * from Students where age < 25`

# Lock-Based Concurrency Control

- We use locks to guarantee recoverable /serializable schedules
- A *locking protocol* is a set of rules to be followed by each transaction (enforced by the DBMS) to ensure that, even though actions of several transactions might be **interleaved**, the net effect is executing those transactions in **some** serial order.
- We will use *shared* and *exclusive* locks

# Definitions

- **Locking**: A procedure used to control concurrent access to data. When one transaction is accessing the database, a lock may deny access to other transactions to prevent incorrect results.
- **Shared Lock** (or *read lock*): If a transaction has a shared lock on a data object, it can read the object but not update it.
- **Exclusive Lock** (or *write lock*): if a transaction has an exclusive lock on a data object, it can both read and update the object.

# Locking-Based Algorithms

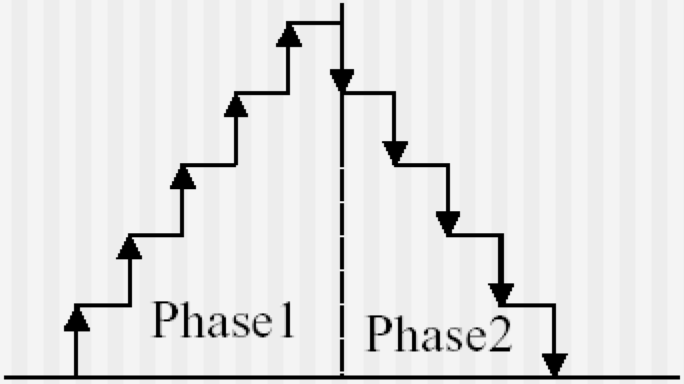
- Transactions indicate their intentions by requesting locks from the scheduler (lock manager).
- Every transaction that needs to access a data object for reading or writing must first lock the object.
- A transaction holds a lock until it explicitly releases it.
- Locks are either shared or exclusive.
- Shared and exclusive locks conflict

| | Shared | Exclusive |
|---|---|---|
| Shared | Yes | No |
| Exclusive | No | No |

- Locks allow concurrent processing of transactions.

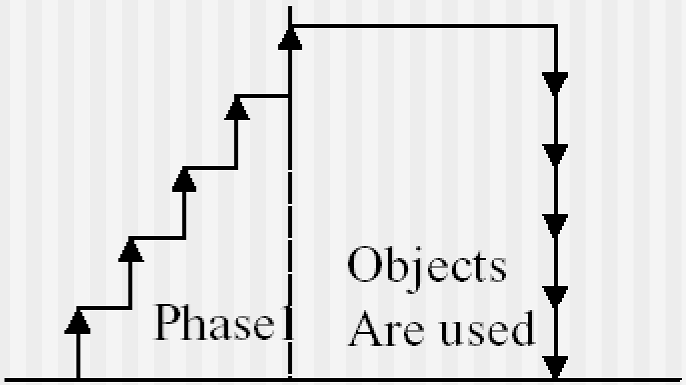
# Two-Phase Locking Protocol

- *2PL*:
  - A transaction follows the 2PL protocol if all locking operations precede the first unlock operation in the transaction.
  - Phase 1 is the "*growing phase*" during which all the locks are requested
  - Phase 2 is the "*shrinking phase*" during which all locks are released



# Strict Two-Phase Locking Protocol

- *Strict 2PL*:
  - All locks held by a transaction are released when the transaction completes (just before committing)
  - Strict 2PL allows only serializable schedules



# View Serializability

- Schedules $S_1$ and $S_2$ are view equivalent if:
  - If $T_i$ reads initial value of A in $S_1$, then $T_i$ also reads initial value of A in $S_2$
  - If $T_i$ reads value of A written by $T_j$ in $S_1$, then $T_i$ also reads value of A written by $T_j$ in $S_2$
  - If $T_i$ writes final value of A in $S_1$, then $T_i$ also writes final value of A in $S_2$

| | | | | |
|---|---|---|---|---|
| T1: | R(A) | | W(A) | |
| T2: | | W(A) | | |
| T3: | | | | W(A) |

| | | | |
|---|---|---|---|
| T1: | R(A),W(A) | | |
| T2: | | W(A) | |
| T3: | | | W(A) |

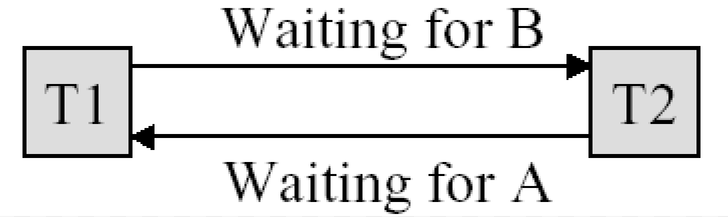
# Lock Management

- Lock and unlock requests are handled by the lock manager
- Lock table entry:
  - Number of transactions currently holding a lock
  - Type of lock held (shared or exclusive)
  - Pointer to queue of lock requests
- Locking and unlocking have to be atomic operations
- Lock upgrade: transaction that holds a shared lock can be upgraded to hold an exclusive lock (also downgrade)

# Deadlocks

- Deadlock: Cycle of transactions waiting for locks to be released by each other.
- A transaction is deadlocked if it is blocked and will remain blocked until intervention.
- Locking-based Concurrency Control algorithms may cause deadlocks.
- Two ways of dealing with deadlocks:
  - Deadlock prevention (guaranteeing no deadlocks or detecting deadlocks in advance before they occur)
  - Deadlock detection (allowing deadlocks to form and breaking them when they occur)

# Deadlock Example




| T1 | T2 |
|---|---|
| begin-transaction | |
| **Write-lock(A)** | begin-transaction |
| Read(A) | **Write-lock(B)** |
| A=A-100 | Read(B) |
| Write(A) | B=B*1.06 |
| **Write-lock(B)** | Write(B) |
| Wait | **write-lock(A)** |
| Wait | Wait |
| … | Wait |
| | … |

# Deadlock Prevention

- Assign priorities based on timestamps. (i.e. the oldest transaction has higher priority)
- Assume $T_i$ wants a lock that $T_j$ holds. Two policies are possible:
  - *Wait-Die*: If $T_i$ has higher priority, $T_i$ waits for $T_j$; otherwise $T_i$ aborts
  - *Wound-wait*: If $T_i$ has higher priority, $T_j$ aborts; otherwise $T_i$ waits
- If a transaction re-starts, make sure it has its original timestamp

# Deadlock and Timeouts

- A simple approach to deadlock prevention (and *pseudo* detection) is based on lock timeouts
- After requesting a lock on a locked data object, a transaction waits, but if the lock is not granted within a period (timeout), a deadlock is assumed and the waiting transaction is aborted and re-started.
- Very simple practical solution adopted by many DBMSs.

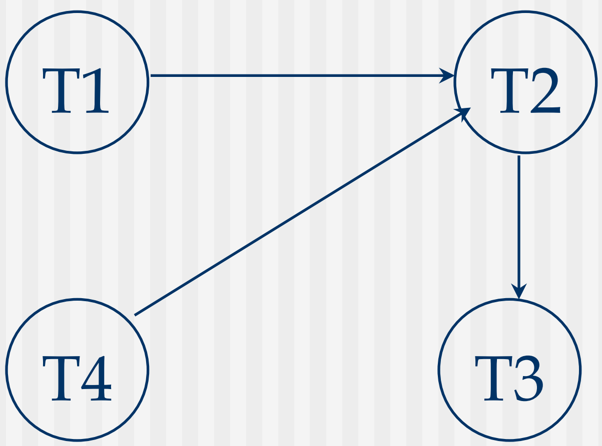
# Deadlock Detection

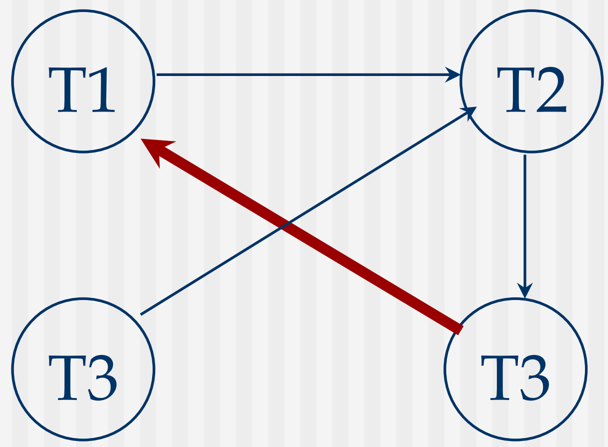
- Create a waits-for graph:
  - Nodes are transactions
  - There is an edge from $T_i$ to $T_j$ if $T_i$ is waiting for $T_j$ to release a lock
- Deadlock exists if there is a cycle in the graph.
- Periodically check for cycles in the waits-for graph

# Deadlock Detection (cont.)

Example:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| T1: | S(A), R(A), | | S(B) | | | | |
| T2: | | X(B),W(B) | | | X(C) | | |
| T3: | | | | S(C), R(C) | | | X(A) |
| T4: | | | | | | X(B) | |



# Recovery from Deadlock

- How to choose a a deadlock victim to abort?
  - How long the transaction has been running?
  - How many data objects have been updated?
  - How many data objects the transaction is still to update?
- Do we need to rollback the whole aborted transaction?
- Avoid starvation (when the same transaction is always the victim)