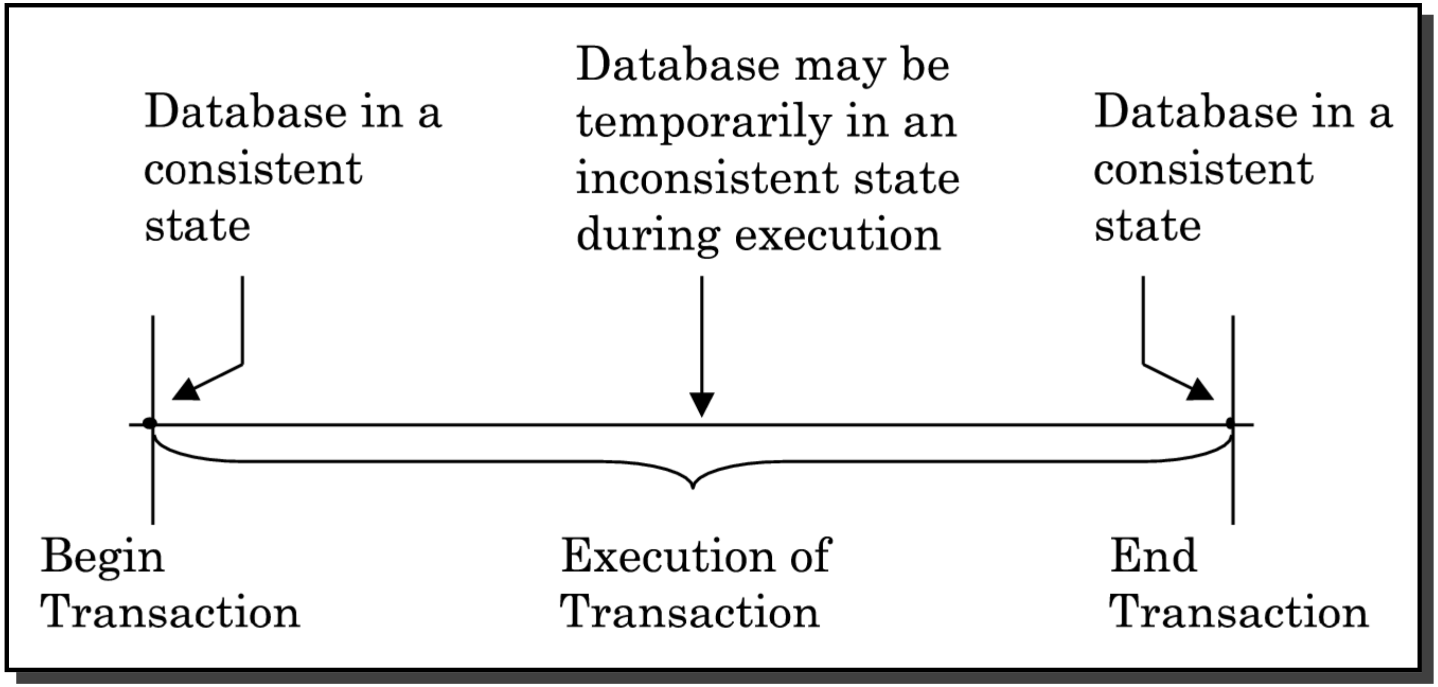
# Chapter 8: Introduction to Transaction Management

- Definition and Examples
- Properties
- Classification
- Processing Issues

**Acknowledgements:** I am indebted to Arturas Mazeika for providing me his slides of this course.

# Definition

- **Transaction:** A collection of actions that transforms the DB from one consistent state into another consistent state; during the exectuion the DB might be inconsistent.



# Definition . . .

- **States** of a transaction
  - **Active**: Initial state and during the execution
  - **Paritally committed**: After the final statement has been executed
  - **Committed:** After successful completion
  - **Failed:** After the discovery that normal execution can no longer proceed
  - **Aborted:** After the transaction has been rolled back and the DB restored to its state prior to the start of the transaction. Restart it again or kill it.

# Example

- **Example:** Consider an SQL query for increasing by 10% the budget of the CAD/CAM project. This query can be specified as a transaction by providing a name for the transaction and inserting a begin and end tag.

```
Transaction BUDGET_UPDATE
begin
   EXEC SQL
   UPDATE PROJ
   SET    BUDGET = BUDGET * 1.1
   WHERE  PNAME = "CAD/CAM"
end.
```

# Example . . .

- **Example:** Consider an airline DB with the following relations:

```
FLIGHT(FNO, DATE, SRC, DEST, STSOLD, CAP)
CUST(CNAME, ADDR, BAL)
FC(FNO, DATE, CNAME, SPECIAL)
```

- Consider the reservation of a ticket, where a travel agent enters the flight number, the date, and a customer name, and then asks for a reservation.

```
Begin_transaction Reservation
begin
    input(flight_no, date, customer_name);
    EXEC SQL UPDATE FLIGHT
        SET   STSOLD = STSOLD + 1
        WHERE FNO = flight_no AND DATE = date;
    EXEC SQL INSERT
        INTO    FC(FNO, DATE, CNAME, SPECIAL);
        VALUES (flight_no, date, customer_name, null);
    output("reservation completed")
end .
```

# Example . . .

- **Example (contd.):** A transaction always terminates – commit or abort. Check the availability of free seats and terminate the transaction appropriately.

```
Begin_transaction Reservation
begin
   input(flight_no, date, customer_name);
   EXEC SQL SELECT STSOLD,CAP
        INTO          temp1,temp2
        FROM          FLIGHT
        WHERE         FNO = flight_no AND DATE = date;
   if temp1 = temp2 then
        output("no free seats");
        Abort
   else
      EXEC SQL UPDATE FLIGHT
        SET    STSOLD = STSOLD + 1
        WHERE FNO = flight_no AND DATE = date;
      EXEC SQL INSERT
        INTO         FC(FNO, DATE, CNAME, SPECIAL);
        VALUES (flight_no, date, customer_name, null);
     Commit
     output("reservation completed")
  endif
end.
```

# Example . . .

- Transactions are mainly characterized by its Read and Write operations
  - Read set (RS): The data items that a transaction reads
  - Write set (WS): The data items that a transaction writes
  - Base set (BS): the union of the read set and write set

- **Example (contd.):** Read and Write set of the "Reservation" transaction

RS[Reservation] = { FLIGHT.STSOLD, FLIGHT.CAP }

WS[Reservation] = { FLIGHT.STSOLD, FC.FNO, FC.DATE, FC.CNAME, FC.SPECIAL }

BS[Reservation] = { FLIGHT.STSOLD, FLIGHT.CAP, FC.FNO, FC.DATE, FC.CNAME, FC.SPECIAL }

# Formalization of a Transaction

- We use the following notation:
  - $T_i$ be a transaction and $x$ be a relation or a data item of a relation
  - $O_{ij} \in \{R(x), W(x)\}$ be an atomic $read$/$write$ operation of $T_i$ on data item $x$
  - $OS_i = \bigcup_j O_{ij}$ be the set of all operations of $T_i$
  - $N_i \in \{A, C\}$ be the termination operation, i.e., $abort/commit$
- Two operations $O_{ij}(x)$ and $O_{ik}(x)$ on the same data item are in **conflict** if at least one of them is a $write$ operation
- A **transaction** $T_i$ is a **partial order** over its operations, i.e., $T_i = \{\Sigma_i, \prec_i\}$, where
  - $\Sigma_i = OS_i \cup N_i$
  - For any $O_{ij} = \{R(x) \vee W(x)\}$ and $O_{ik} = W(x)$, either $O_{ij} \prec_i O_{ik}$ or $O_{ik} \prec_i O_{ij}$
  - $\forall O_{ij} \in OS_i (O_{ij} \prec_i N_i)$
- Remarks
  - The partial order $\prec$ is given and is actually application dependent
  - It has to specify the **execution order** between the conflicting operations and between all operations and the termination operation

# Formalization of a Transaction . . .

- **Example:** Consider the following transaction T

```
Read(x)
Read(y)
x ← x + y
Write(x)
Commit
```

- The transaction is formally represented as

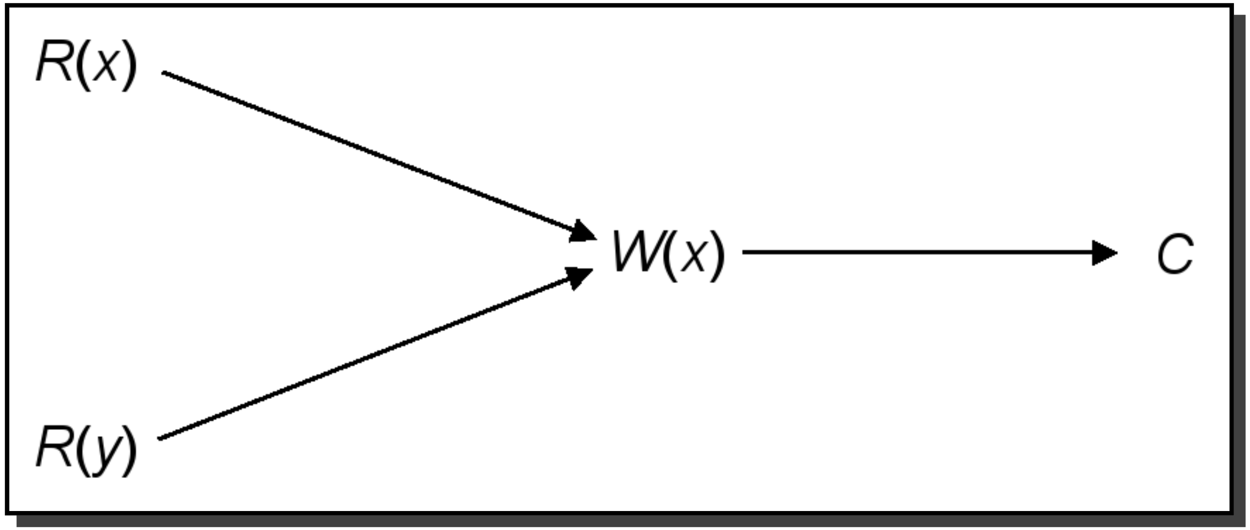
$$\Sigma = \{R(x), R(y), W(x), C\}$$

$$\prec = \{(R(x), W(x)), (R(y), W(x)), (W(x), C), (R(x), C), (R(y), C)\}$$

- **Example (contd.):** A transaction can also be specified/represented as a directed acyclic graph (DAG), where the vertices are the operations and the edges indicate the ordering.
  - Assume

$$\prec = \{(R(x), W(x)), (R(y), W(x)), (W(x), C), (R(x), C), (R(y), C)\}$$

  - The DAG is



# Formalization of a Transaction ...

- **Example:** The reservation transaction is more complex, as it has two possible termination conditions, but a transaction allows only one
  - BUT, a transaction is the **execution** of a program which has obviously only one termination
  - Thus, it can be represented as two transactions, one that aborts and one that commits

Transaction T1:

$$\Sigma = \{R(STSOLD), R(CAP), A\}$$

$$\prec = \{(R(STSOLD), A), (R(CAP), A)\}$$

Transaction T2:

$$\Sigma = \{R(STSOLD), R(CAP), W(STSOLD), W(FNO), W(DATE), W(CNAME), W(SPECIAL), C\}$$

$$\prec = \{(R(STSOLD), W(STSOLD)), \ldots\}$$

```
Begin_transaction Reservation
begin
   input(flight_no, date, customer_name);
   EXEC SQL SELECT STSOLD,CAP
       INTO        temp1,temp2
       FROM        FLIGHT
       WHERE       FNO = flight_no AND DATE = date;
   if temp1 = temp2 then
       output("no free seats");
       Abort
   else
     EXEC SQL UPDATE FLIGHT
       SET    STSOLD = STSOLD + 1
       WHERE  FNO = flight_no AND DATE = date;
     EXEC SQL INSERT
       INTO      FC(FNO, DATE, CNAME, SPECIAL);
       VALUES (flight_no, date, customer_name, null);
    Commit
    output("reservation completed")
  endif
end.
```

# Properties of Transactions

- The **ACID properties**
  - **Atomicity**
    - A transaction is treated as a single/atomic unit of operation and is either executed completely or not at all
  - **Consistency**
    - A transaction preserves DB consistency, i.e., does not violate any integrity constraints
  - **Isolation**
    - A transaction is executed as if it would be the only one.
  - **Durability**
    - The updates of a committed transaction are permanent in the DB

# Properties of Transactions . . .

- **Atomicity**
  - Either **all or none** of the transaction's operations are performed
  - Partial results of an interrupted transactions must be undone
  - **Transaction recovery** is the activity of the restoration of atomicity due to input errors, system overloads, and deadlocks
  - **Crash recovery** is the activity of ensuring atomicity in the presence of system crashes

# Properties of Transactions ...

- **Consistency**
  - The consistency of a transaction is simply its correctness and ensures that a transaction transforms a consistent DB into a consistent DB
  - Transactions are **correct** programs and do not violate database integrity constraints
  - **Dirty data** is data that is updated by a transaction that has not yet committed
  - Different **levels of DB consistency** (by Gray et al., 1976)
    - Degree 0
      - Transaction $T$ does not overwrite dirty data of other transactions
    - Degree 1
      - Degree 0 + $T$ does not commit any writes before EOT
    - Degree 2
      - Degree 1 + $T$ does not read dirty data from other transactions
    - Degree 3
      - Degree 2 + Other transactions do not dirty any data read by $T$ before $T$ completes

# Properties of Transactions . . .

- **Isolation**
  - Isolation is the property of transactions which requires each transaction to see a consistent DB at all times.
  - If two concurrent transactions access a data item that is being updated by one of them (i.e., performs a **write** operation), it is not possible to guarantee that the second will read the correct value
  - Interconsistency of transactions is obviously achieved if transactions are executed serially
  - Therefore, if several transactions are executed concurrently, the result must be the same as if they were executed serially in some order ($\longrightarrow$ serializability)

# Properties of Transactions . . .

- **Example:** Consider the following two transactions, where initially $x = 50$:

```
T1: Read(x)
    x ← x+1
    Write(x)
    Commit
```

```
T2: Read(x)
    x ← x+1
    Write(x)
    Commit
```

- Possible execution sequences:

```
T1: Read(x)
T1: x ← x+1
T1: Write(x)
T1: Commit
T2: Read(x)
T2: x ← x+1
T2: Write(x)
T2: Commit
```

```
T1: Read(x)
T1: x ← x+1
T2: Read(x)
T1: Write(x)
T2: x ← x+1
T2: Write(x)
T1: Commit
T2: Commit
```

  - Serial execution: we get the correct result $x = 52$ (the same for $\{T_2, T_1\}$)
  - Concurrent execution: $T_2$ reads the value of $x$ while it is being changed; the result is $x = 51$ and is incorrect!

# Properties of Transactions . . .

- SQL-92 specifies 3 phenomena/situations that occur if proper isolation is not maintained
  - **Dirty read**
    - $T_1$ modifies $x$ which is then read by $T_2$ before $T_1$ terminates; if $T_1$ aborts, $T_2$ has read value which never exists in the DB:
  - **Non-repeatable (fuzzy) read**
    - $T_1$ reads $x$; $T_2$ then modifies or deletes $x$ and commits; $T_1$ tries to read $x$ again but reads a different value or can't find it
  - **Phantom**
    - $T_1$ searches the database according to a predicate $P$ while $T_2$ inserts new tuples that satisfy $P$

- Based on the 3 phenomena, SQL-92 specifies different isolation levels:
  - **Read uncommitted**
    - For transactions operating at this level, all three phenomena are possible
  - **Read committed**
    - Fuzzy reads and phantoms are possible, but dirty reads are not
  - **Repeatable read**
    - Only phantoms possible
  - **Anomaly serializable**
    - None of the phenomena are possible

# Properties of Transactions . . .

- **Durability**
  - Once a transaction commits, the system must guarantee that the results of its operations will never be lost, in spite of subsequent failures
  - Database recovery is used to achieve the task

# Classification of Transactions

- **Classification** of transactions according to various criteria
  - **Duration** of transaction
    - ∗ On-line (short-life)
    - ∗ Batch (long-life)
  - **Organization** of **read** and **write** instructions in transaction
    - ∗ General model

$$T_1 : \{R(x), R(y), W(y), R(z), W(x), W(z), W(w), C\}$$

    - ∗ Two-step (all reads before writes)

$$T_2 : \{R(x), R(y), R(z), W(x), W(z), W(y), W(w), C\}$$

    - ∗ Restricted (a data item has to be read before an update)

$$T_3 : \{R(x), R(y), W(y), R(z), W(x), W(z), \mathbf{R}(\mathbf{w}), W(w), C\}$$

    - ∗ Action model: each (read,write) pair is executed atomically

$$T_2 : \{[R(x), W(x)], [R(y), W(y)], [R(z), W(z)], [R(w), W(w)], C\}$$

# Classification of Transactions ...

- **Classification** of transactions according to various criteria ...
  - **Structure** of transaction
    - **Flat** transaction
      - Consists of a sequence of primitive operations between a begin and end marker

```
Begin_transaction Reservation
  ...
end.
```

    - **Nested** transaction
      - The operations of a transaction may themselves be transactions.

```
Begin_transaction Reservation
  ...
  Begin_transaction Airline
    ...
  end.
  Begin_transaction Hotel
    ...
  end.
end.
```

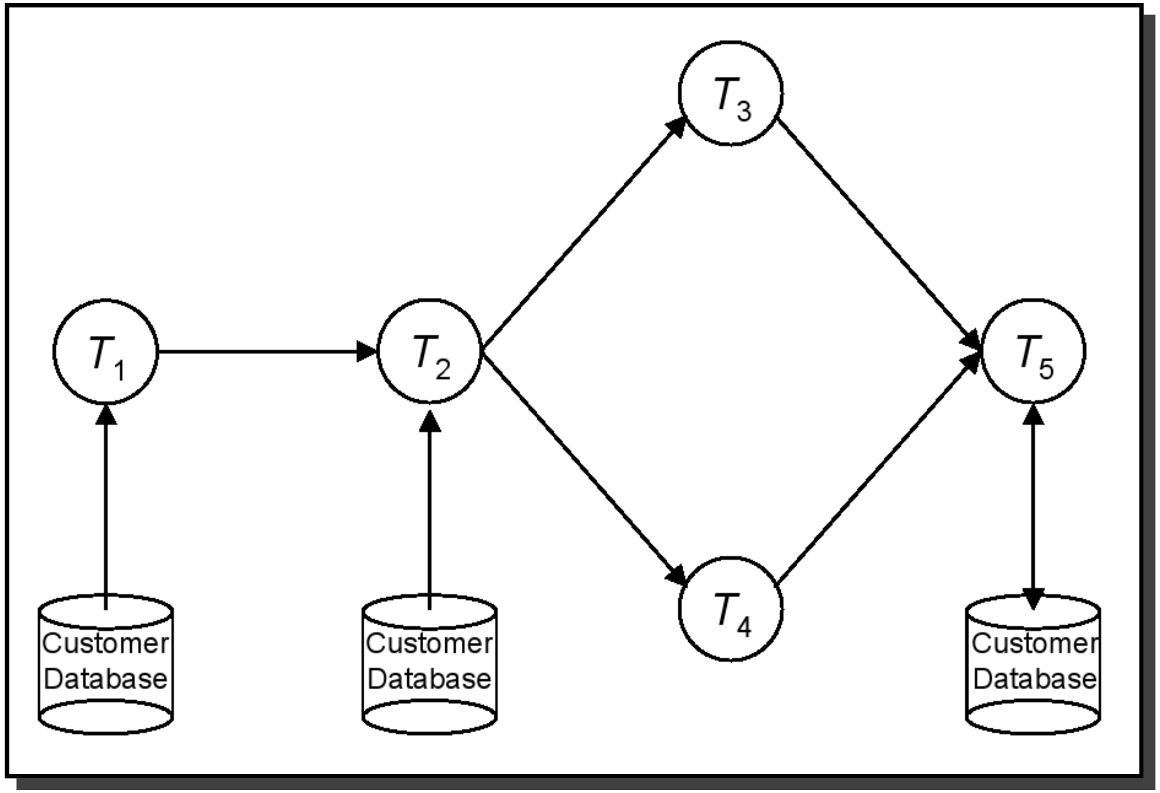
    - **Workflows** (next slide)

# Classification of Transactions . . .

- **Workflows:** A collection of tasks organized to accomplish a given business process
  - Workflows generalize transactions and are more expressive to model complex business processes
  - Types of workflows:
    - Human-oriented workflows
      - Involve humans in performing the tasks.
      - System support for collaboration and coordination; but no system-wide consistency definition
    - System-oriented workflows
      - Computation-intensive and specialized tasks that can be executed by a computer
      - System support for concurrency control and recovery, automatic task execution, notification, etc.
    - Transactional workflows
      - In between the previous two; may involve humans, require access to heterogeneous, autonomous and/or distributed systems, and support selective use of ACID properties

- **Example:** We extend the reservation example and show a typical workflow

- $T1$: Customer request
- $T2$: Airline reservation
- $T3$: Hotel reservation
- $T4$: Auto reservation
- $T5$: Bill



# Transaction Processing Issues

- Transaction structure (usually called transaction model)
  - Flat (simple), nested
- Internal database consistency
  - Semantic data control (integrity enforcement) algorithms
- Reliability protocols
  - Atomicity and Durability
  - Local recovery protocols
  - Global commit protocols
- Concurrency control algorithms
  - How to synchronize concurrent transaction executions (correctness criterion)
  - Intra-transaction consistency, isolation
- Replica control protocols
  - How to control the mutual consistency of replicated data

# Conclusion

- A transaction is a collection of actions that transforms the system from one consistent state into another consistent state
- Transaction $T$ can be viewed as a partial order: $T = \{\Sigma, \prec\}$, where $\Sigma$ is the set of all operations, and $\prec$ denotes the order of operations. $T$ can be also represented as a directed acyclic graph (DAG)
- Transaction manager aims to achieve four properties of transactions: atomicity, consistency, isolation, and durability
- Transactions can be classified according to (i) time, (ii) organization of reads and writes, and (iii) structure
- Transaction processing involves reliability, concurrency, and replication protocols to ensure the four properties of the transactions