Transaction Processing (Διαχείριση Δοσοληψιών)

- In *modern applications* databases are
  - *shared by more than one users at the same time*
  - who can *query* and *update* them
- It is *not possible* to provide each user with *their own copy of the database*
- A database management system must ensure that:
  - *concurrent access is provided*
  - *each user has a consistent view of the data*

Transaction Management

- The problems encountered in the development of large database applications led to the *development of transaction management techniques*
  - *Creation of inconsistent results (Consistency)*
    - the machine crashes in the middle of the execution process
  - *Errors in concurrent execution (Concurrency)*
    - *arbitrary concurrent execution* of processes lead to the *inconsistent views of data*
  - *Uncertainty as to when changes become permanent*:
    - can we be confident about the results residing in secondary storage even if processes have completed successfully?

The concept of a transaction was invented to solve these problems

Transaction Processing (Διαχείριση Δοσοληψιών)

- A *transaction is a series of database operations* (*reads* and *writes*) that form a *single logical entity* with respect to the application being modeled.
  - **Example**: a *transfer of funds* between accounts is considered a logical entity
- A *transaction commits* when it finishes *execution normally* otherwise it *aborts*
- *User transactions* appear to *execute in isolation*, although they may *execute concurrently*

Inconsistent view of Data (Ασυνέπεια στα Δεδομένα)

accounts

account#	lname	fname	type	balance
1234	Doe	John	Checking	900.00
5678	Doe	John	Savings	100.00
….	….	….	….	….

- ✓ Process P1 transfers $400 from account 1234 to account 5678
- ✓ Transfer is implemented by
  1. (S1) subtracting $400 from the balance of account 1234
  2. (S2) adding $400 to the balance of account 5678
- ✓ Accounts can be found in the following 3 states:

	Balance 1234	**Balance 5678**
Before P1	**$900**	**$100**
After S1	**$500**	**$100**
After S2	**$500**	**$500**

Inconsistent view of Data: Process Interleaving
(Ασυνέπεια στα Δεδομένα: Παρεμβολές μεταξύ Διαδικασιών)

- Process P2 performs a *credit check* on the account holder and requires a *minimum of $900 as the total balance* of the accounts to approve the issuance of a credit card
- P2 reads the *balance values* of the two accounts and computes their *sum*
- *P2 and P1 are running concurrently*
- *Execution is incorrect since the 'real' sum is 1000$*

Process P1	Process P2
	sum:=0
subtract 400$ from the balance of 1234 balance:=500	
	add balance of 1234 to sum sum:=sum+500 = 500
	add balance of 5678 to sum sum:=500 + 100 = 600
	reject
add $400 to the balance of 5678	

Inconsistent view of Data: Process Interleaving

- It is equivalent to *serial executions* *P1, P2*
- This execution is ***correct***
  - *both processes see the correct data*
- Transaction management must ensure that *only correct interleaving of processes takes place*

Process P1	Process P2
	sum:=0
	add balance of 1234 to sum sum:=900
subtract 400$ from the balance of 1234 balance:=500	
	add balance of 5678 to sum sum:=900+ 100 = 1000
add $400 to the balance of 5678	
	Issue approval

Transaction Management

- Transactions guarantee the following properties:
  - *Atomicity* (Ατομικότητα)
  - *Consistency* (Συνέπεια)
  - *Isolation* (Μεμονωμένη Εκτέλεση Διαδικασιών)
  - *Durability* (Διάρκεια)
- *Known as ACID Properties*

Transaction Management: ACID Properties

- *Atomicity*
  - Transactions are considered atomic when considering their *effect* on the database:
    - *all operations that make up the transaction are executed or none is:* the *set of operations* that make up the transaction is considered *indivisible*
    - result of the transaction is *preserved* even when crashes occur:
      - a *database recovery procedure* performs a *rollback* to bring the database back to its state prior to transaction execution

Transaction Management: ACID Properties

- *Consistency*
  - a transaction *should preserve a domain-specific consistency constraint* independently of whether it is *executed concurrently* with other transactions or in *isolation*.
- *Isolation (serializability)*
  - serial schedule: when *transactions are executed one after the other*
  - any *schedule of interleaved execution of transactions* is *equivalent* to some *serial schedule*
- *Durability*
  - After a *transaction commits, it is guaranteed to be recoverable*
    - transactions are *durable to crashes*

Transaction Management (ACID Properties)

- *Atomicity* and *durability* are trivially satisfied by any *transaction* that performs *only read operations*
- Notation:
  - Transactions: $T_1, T_2, \ldots T_k$
  - $R_i(X)$: transaction T_i *reads* database item X
  - $R_i(X,u)$: transaction T_i *reads* database item X, u is the *value read*
  - $W_i(X)$: transaction T_i *writes* database item X
  - $W_i(X,u)$: transaction T_i *writes* database item X, u is the *value written*
  - C_i : transaction T_i *commits*
  - A_i: transaction T_i *aborts*

Transaction Management (ACID Properties)

- A *schedule* or *history* is an *interleaved sequence of operations*.
  - Transactions: T_1, T_2
  - Schedule : $R_2(A)\ W_2(A)\ R_1(A)\ R_1(B)\ R_2(B)\ W_2(B)\ C_1\ C_2$
- A *schedule is the result of the translation of processes* - specified in some high-level language - into a *series of primitive operations*
- The *scheduler component* of the transaction processing component of a DBMS ensures that *only "correct" schedules are executed*

Transaction Management (ACID Properties)

- Given *a set of transaction specifications*, the *scheduler component* produces a *schedule that is equivalent to some serial execution of the transaction*
- If no such schedule is possible, the transaction manager *aborts* or *delays* some of the transactions
- The scheduler also detects *deadlocks*
  - Situations in which none of the transactions participating in the schedule can proceed unless one of them is aborted

Example: Scheduling

- Schedule $S = R_2(A)\ W_2(A)\ R_1(A)\ R_1(B)\ R_2(B)\ W_2(B)\ C_1\ C_2$
  - involves transactions T_1, T_2
  - is *not equivalent* to any *serial execution* of the two transactions.
- *Interpretation* of the schedule
  - $T_1 = R_1(A), R_1(B), C_1$
  - $T_2 = R_2(A), W_2(A)$, R2(B), $W_2(B), C_2$

Example: Scheduling

- Schedule $S = R_2(A)\ W_2(A)\ R_1(A)\ R_1(B)\ R_2(B)\ W_2(B)\ C_1\ C_2$
- $T_1 = R_1(A), R_1(B), C_1$
- $T_2 = R_2(A), W_2(A), R_2(B), W_2(B), C_2$

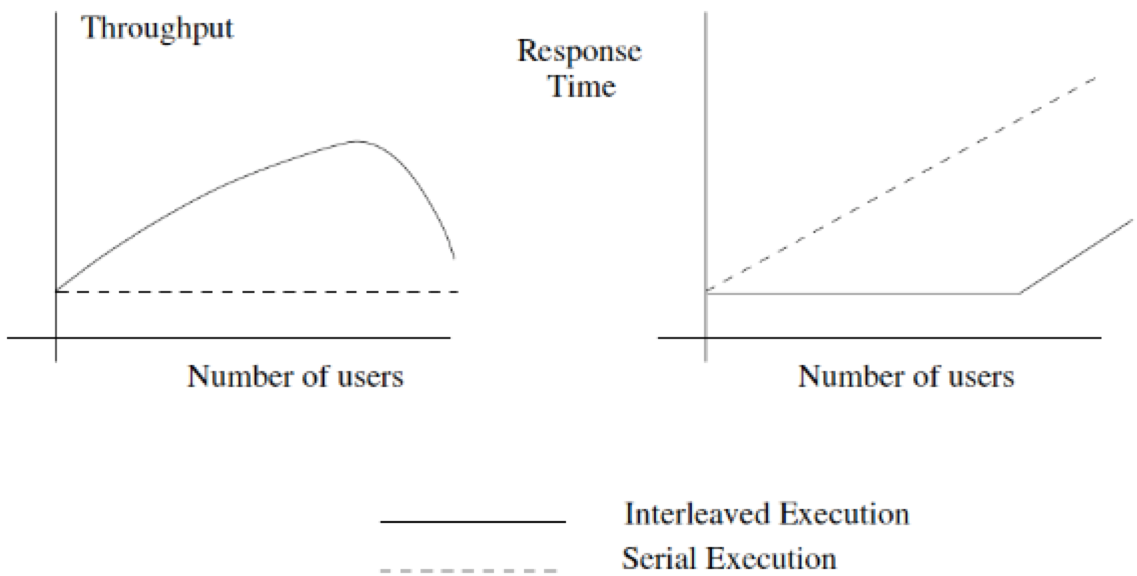
✓ S is correct *only if it is equivalent to one of the serial schedules* T_1, T_2 or T_2, T_1

- Case 1: *serial schedule S' =* T_1, T_2
  - *S*: T_1 reads *A* *after* T_2 has modified it.
  - *S' :* the values of *A* and *B* *read* by T_1 *have not been modified* by T_2
- Case 2: *serial schedule S' =* T_2, T_1
  - S: *T1* reads *B* before T_2 writes it.
  - *S':* T_2 modifies the values of *A* and *B*, then T_1 reads it.

Hence the schedule has different effects than any serial execution

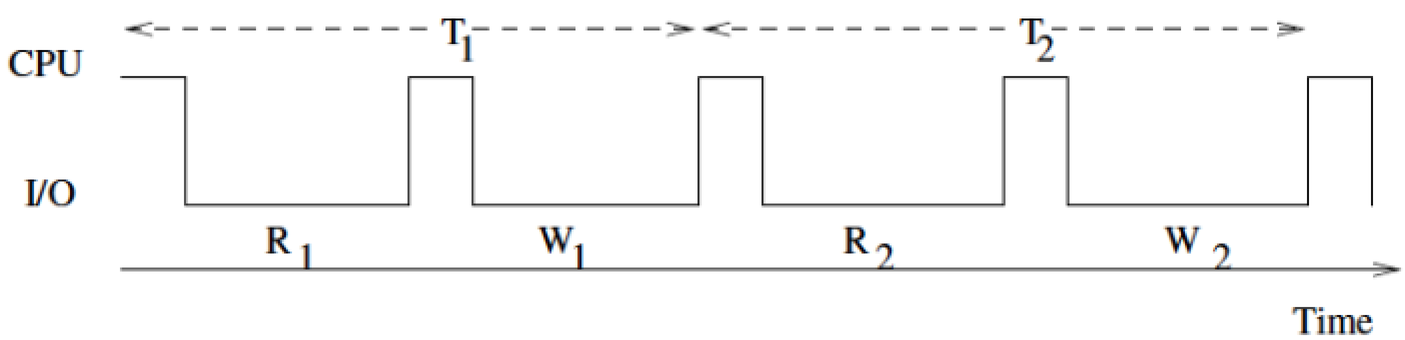
Interleaving of DB Operations

- Interleaving of database operations can yield *large performance gains*
- While some transaction is performing I/O, another transaction can use the CPU
- *System throughput*
  - the number of transactions that can finish execution in a given period of time) *increases* whereas *response time remains constant*



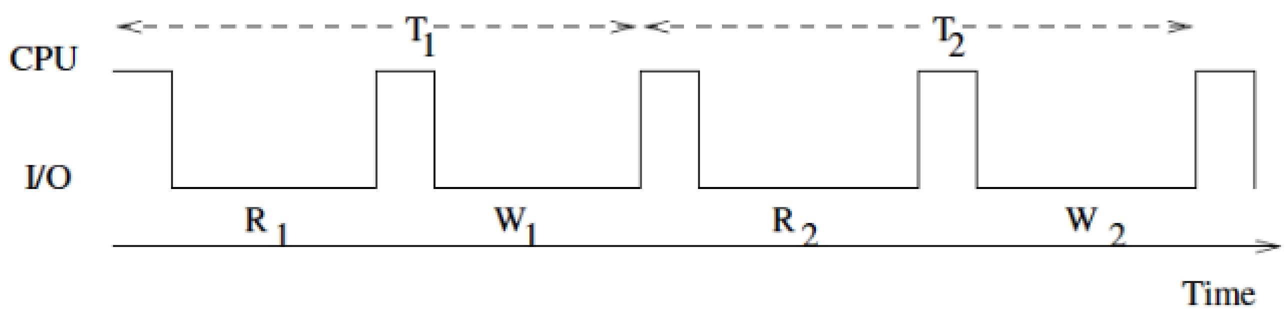
Serial vs Concurrent Execution (Example)

- *Transaction Manager* services database transactions
- Each transaction uses *both* CPU and I/O Resources
  - *T_i: (cpu operation) R_I() (cpu operation) W_I() C_I*
  - The system has a single CPU with a *5ms interval* and a *single disk*.
  - Each I/O operation requires *50ms of wait time*.
- *Serial Execution*: Resource usage



Serial vs Concurrent Execution (Example)

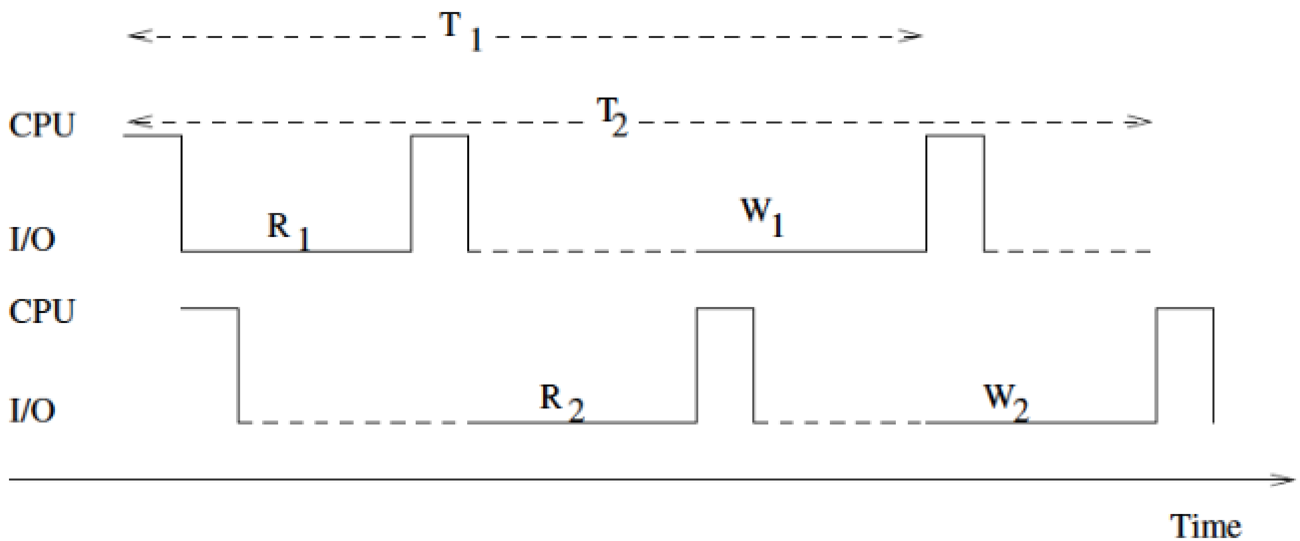
- *Serial Execution*
  - a transaction needs 110ms
  - *throughput* is *1 transaction per 110ms* (9.09 transactions per second)
  - CPU is *underutilized*: active 9.09% of the time



Interleaved execution of transactions can increase CPU utilization and thus the system throughput

Serial vs Concurrent Execution (Example)

- *Interleaved Execution*



- *throughput has increased*
- throughput will *increase* with the *number of transactions processes executed concurrently*
- *additional improvements:* more than one I/O devices are used

Testing Serializability

- Criteria to determine given a set of transactions *S* if
  - *interleaved schedules for S* are *equivalent* to some *serial execution for the transactions in S*
- *Conflicting database operations* when they
  1. belong to *different transactions*
  2. refer to the *same data item*
  3. at least *one of them* is a *write operation*

a transaction reads an attribute and another tries to write its value

Properties of Schedules

- Two schedules are called *equivalent* if *for any initial state of the database*, they result to the *same database state*.
- Two schedules *are equivalent if all pairs of conflicting operations occur in the same order*
- A schedule is called *serializable* if it can *be shown to be equivalent to some serial execution of its transactions*
- Only *serializable schedules* are *acceptable*
- **Example:**
  - $T_1 = R_1(A), R_1(B), W_1(A), C_1$
  - $T_2 = W_2(A), R_2(A), C_2$
  - $S = W_2(A)\ R_1(A)\ R_1(B)\ R_2(A)\ W_1(A)$
  - *Is S serializable?*
    - *Yes, it is equivalent to $T_2\ T_1$*

There may be more than one serial schedules equivalent to some serializable schedule

Testing Schedule Serializability

- **Notation:** $op_i(X) <<_S op_j(X)$ means that operation op_i of some transaction T_i on item X, precedes operation op_j of some transaction T_j on item X in schedule S
- **Cases:**
  - If $op_i(X) <<_{S1} op_j(X)$ then $op_i(X) <<_{S2} op_j(X)$ where *S2* is a *serial schedule equivalent* to *S1*
  - If $op_i(X) <<_{S1} op_j(X)$ and $op_j(Y) <<_{S1} op_i(Y)$, then *S1 is not serializable*.
  - If it were, then, in the *equivalent serial* schedule *S2*, transaction T_i should *both precede* and *follow* transaction T_j.

Testing Serializability: The lost update problem

- *The case in which two users want to update the same item in a database*.
  - Suppose transaction T_1 reads item A first : $R_1(A)$
  - Assume transaction T_2 reads item A: $R_2(A)$
  - T_2 writes immediately its value to A, before T_1 performs the update: $W_2(A)$
  - T_1 writes its value to A: $W_1(A)$
  - Hence any changes made by T_2, are lost.

Testing Serializability: The lost update problem

- **Schedule:** S1 = $R_1(A)\ R_2(A)\ W_2(A)\ W_1(A)\ C_1\ C_2$
- **Conflicting Operations:**
  - $R_1(A)$, $W_2(A)$
  - $R_2(A)$, $W_1(A)$
- *Assume* there is a *serial schedule S2 equivalent to S1.*
- S1: $R_1(A) <<_{S1} W_2(A)$ ➔ S2: $R_1(A) <<_{S2} W_2(A)$
  - T1 must precede T2
- S1: $R_2(A) <<_{S1} W_1(A)$ ➔ S2: $R_2(A) <<_{S2} W_1(A)$
  - T2 must precede T1
- The schedule is non-serializable

Testing Serializability: The blind write problem

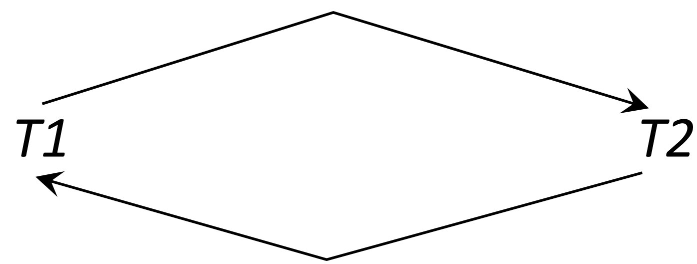
- Occurs when a *transaction writes a value before reading it*
- **Schedule:** S1 = $W_1(A)\ W_2(A)\ W_2(B)\ W_1(B)\ C_1\ C_2$
- **Conflicting Operations:**
  - $W_1(A)\ W_2(A)$
  - $W_2(B)\ W_1(B)$
- *Assume* there is a *serial schedule S2 equivalent to S1.*
- *S1:* $W_1(A) <<_{S1} W_2(A)$ → S2: $W_1(A) <<_{S2} W_2(A)$
  - T1 must precede T2
- *S1:* $W_2(B) <<_{S1} W_1(B)$ → S2: $W_2(B) <<_{S2} W_1(B)$
  - T2 must precede T1
- The schedule is non-serializable

Testing Serializability: Precedence Graphs

- Given a *schedule S*, a *precedence graph graph PG(S)* for *S* is a *directed graph* whose
  - *vertices* correspond to the *transactions T* in the schedule and
  - *set of edges* consists of *an edge Ti → Tj* whenever there exist two *conflicting operations* op_i, op_j in S and $op_i <<_S op_j$
- **Example**:
  - S1 = $R_1(A)$ $R_2(A)$ $W_1(A)$ $W_2(A)$ C_1 C_2

PG(S1)

PG(S2)



  - Schedule S2 = $W_1(A)$ $W_2(A)$ $W_2(B)$ $W_1(B)$ C_1 C_2

Serializability

- **Theorem:** A schedule *S is serializable if and only if the precedence graph PG(S) contains no cycle*
- **Lemma 1:** In any finite directed acyclic graph G, there is always a vertex u with no incoming edges
- **Proof:**
  - **Case 1:** If *PG(S) has no cycles*, *S is serializable*
    - Assume that there are *m* transactions $T_1, T_2, \ldots T_m$ in *S*. We need to find a reordering $T_{i1}, T_{i2}, \ldots T_{im}$ of the transactions in order to construct an *equivalent serial schedule*
    - By Lemma 1, in the precedence graph *PG(S)* there will be some vertex T_k with *no incoming edges*. Let T_{i1} be T_k.

Serializability

- Since T_k has no incoming edges in PG(S), *there is no pair of conflicting operations of* T_k and *some other tran*saction T_j such that the operation of T_j should precede that of T_k. Hence in the *equivalent serial schedule*, T_k should be the first to be executed.
- Remove T_k from *PG(S)* along with *all its incident edges*. The resulting graph is still acyclic. Hence we can find a vertex T_l that has no incoming edges. Let T_{i2} be T_l .Then T_l should follow T_k in the serial schedule.
- Continue this process until the precedence graph contains one vertex. The corresponding transaction is the last one in the serial schedule.

Case (2): *If S is serializable, then PG(S) is acyclic.*

- Let PG(S) contain a cycle: $T1 \ll_S T2 \ll_S T3 \ldots \ll Tk \ll_S T1$ (contradiction)