Chapter 14: Transactions

Database System Concepts, 6th Ed.

Outline

- Transaction Concept
- Transaction State
- Concurrent Executions
- Serializability
- Recoverability
- Implementation of Isolation
- Transaction Definition in SQL
- Testing for Serializability.

Transaction Concept (Θεωρία Συναλλαγών)

- A **transaction** is a *unit* of program execution that accesses and possibly updates various data items.
- E.g., transaction to transfer $50 from account A to account B:
  1. **read**(*A*)
  2. *A* := *A* – 50
  3. **write**(*A*)
  4. **read**(*B*)
  5. *B* := *B* + 50
  6. **write**(*B*)
- Two main issues to deal with:
  - Failures of various kinds, such as hardware failures and system crashes
  - Concurrent execution of multiple transactions

Required Properties of a Transaction

- Consider a transaction to transfer $50 from account A to account B:
  1. **read**(*A*)
  2. *A* := *A* – 50
  3. **write**(*A*)
  4. **read**(*B*)
  5. *B* := *B* + 50
  6. **write**(*B)*
- **Atomicity (Ατομικότητα) requirement**
  - If the transaction fails after step 3 and before step 6, money will be "lost" leading to an inconsistent database state
    - Failure could be due to software or hardware
  - The system should ensure that updates of a partially executed transaction are not reflected in the database
- **Durability (Ανθεκτικότητα) requirement** — once the user has been notified that the transaction has completed (i.e., the transfer of the $50 has taken place), the updates to the database by the transaction must persist even if there are software or hardware failures.

Required Properties of a Transaction (Cont.)

- **Consistency (Συνέπεια) requirement** in above example:
  - The sum of A and B is unchanged by the execution of the transaction
- In general, consistency requirements include
  - Explicitly specified integrity constraints such as primary keys and foreign keys
  - Implicit integrity constraints
    - e.g., sum of balances of all accounts, minus sum of loan amounts must equal value of cash-in-hand
- A transaction, when starting to execute, must see a consistent database.
- During transaction execution the database may be temporarily inconsistent.
- When the transaction completes successfully the database must be consistent
  - Erroneous transaction logic can lead to inconsistency

Required Properties of a Transaction (Cont.)

- **Isolation (Απομόνωση) requirement** — if between steps 3 and 6 (of the fund transfer transaction) , another transaction **T2** is allowed to access the partially updated database, it will see an inconsistent database (the sum *A* + *B* will be less than it should be).

T1	**T2**
1. **read**(*A*)	
2. *A* := *A* – 50	
3. **write**(*A*)	
	read(A), read(B), print(A+B)
4. **read**(*B*)	
5. *B* := *B* + 50	
6. **write**(*B*	

- Isolation can be ensured trivially by running transactions **serially**
  - That is, one after the other.
- However, executing multiple transactions concurrently has significant benefits, as we will see later.

ACID Properties

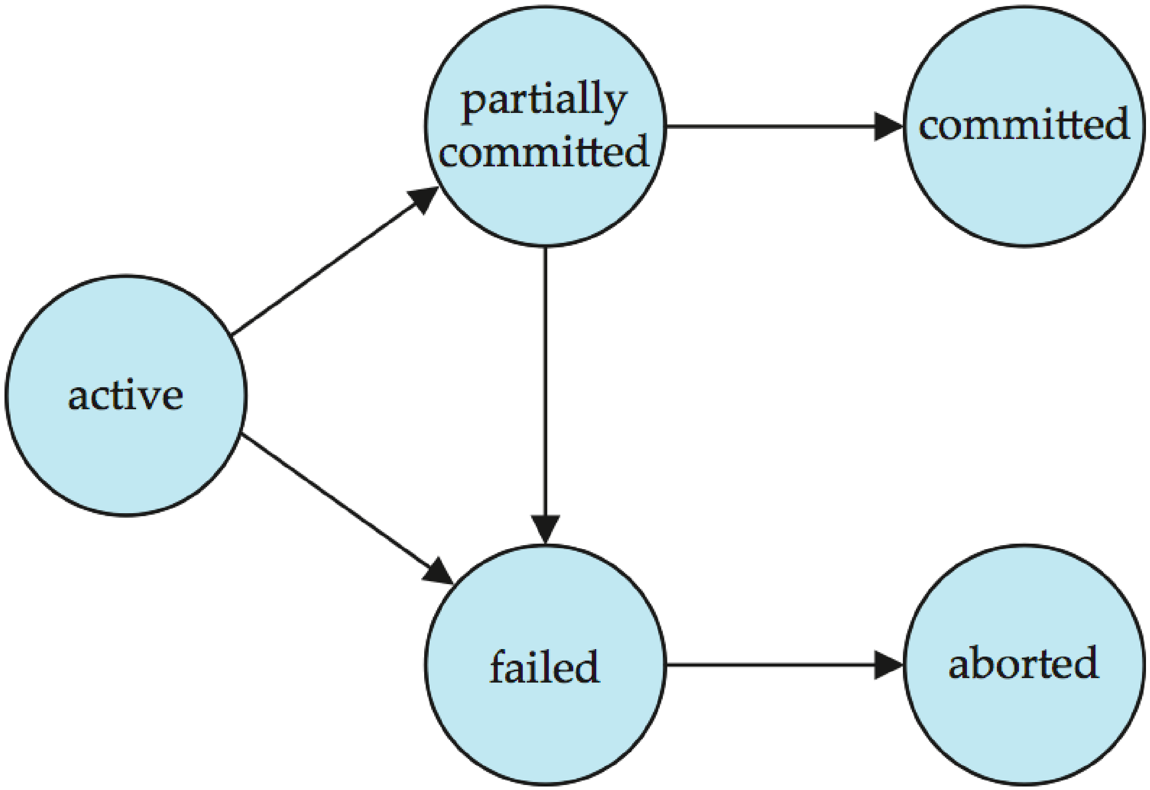
A **transaction** is a unit of program execution that accesses and possibly updates various data items. To preserve the integrity of data the database system must ensure:

- **Atomicity (Ατομικότητα).** Either all operations of the transaction are properly reflected in the database or none are.
- **Consistency (Συνέπεια).** Execution of a transaction in isolation preserves the consistency of the database.
- **Isolation (Απομόνωση).** Although multiple transactions may execute concurrently, each transaction must be unaware of other concurrently executing transactions. Intermediate transaction results must be hidden from other concurrently executed transactions.
  - That is, for every pair of transactions T_i and T_j, it appears to T_i that either T_j, finished execution before T_i started, or T_j started execution after T_i finished.
- **Durability (Ανθεκτικότητα).** After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures.

Transaction State

- **Active (Ενεργή)**– the initial state; the transaction stays in this state while it is executing
- **Partially committed (εν μέρει ολοκληρωμένη)**– after the final statement has been executed.
- **Failed (Αποτυχημένη)--** after the discovery that normal execution can no longer proceed. **May happen due to logic errors or write-to-disk failures.**
- **Aborted (Διακοπείσα)**– after the transaction has been rolled back and the database restored to its state prior to the start of the transaction. Two options after it has been aborted:
  - Restart the transaction
    - can be done only if no internal logical error
  - Kill the transaction
- **Committed(Εκτελεσμένη)** – after successful completion.

Transaction State (Cont.)



Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **Increased processor and disk utilization**, leading to better transaction *throughput*
    - E.g. one transaction can be using the CPU while another is reading from or writing to the disk
  - **Reduced average response time** for transactions: short transactions need not wait behind long ones.
- **Concurrency control schemes (Σχήματα ταυτόχρονου ελέγχου)** – mechanisms to achieve isolation
  - That is, to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database
    - Will study in Chapter 15, after studying notion of correctness of concurrent executions.

Schedules (Χρονοδιαγράμματα Εργασιών)

- **Schedule (χρονοδιάγραμμα εργασιών)**– a sequences of instructions that specify the chronological order in which instructions of concurrent transactions are executed
  - A schedule for a set of transactions must consist of all instructions of those transactions
  - Must preserve the order in which the instructions appear in each individual transaction.
- A transaction that successfully completes its execution will have a **commit** instructions as the last statement
  - By default transaction assumed to execute commit instruction as its last step
- A transaction that fails to successfully complete its execution will have an **abort** instruction as the last statement

Schedule 1

- A=1000E & B=2000E & A+B=3000E
- Let T_1 transfer \$50 from *A* to *B*, and T_2 transfer 10% of the balance from *A* to *B.*
- An example of a **serial** schedule (σειριακό χρονοδιάγραμμα) in which T_1 is followed by T_2 :

T_1	T_2
read (A)	
$A := A - 50$	
write (A)	
read (B)	
$B := B + 50$	
write (B)	
commit	
	read (A)
	$temp := A * 0.1$
	$A := A - temp$
	write (A)
	read (B)
	$B := B + temp$
	write (B)
	commit

Finally A=855E & B=2145E & A+B=3000E

Schedule 2

- A **serial** schedule in which T_2 is followed by T_1 :

T_1	T_2
	read (A)
	$temp$:= A * 0.1
	A := A - $temp$
	write (A)
	read (B)
	B := B + $temp$
	write (B)
	commit
read (A)	
A := A – 50	
write (A)	
read (B)	
B := B + 50	
write (B)	
commit	

Schedule 3

- Let T_1 and T_2 be the transactions defined previously. The following schedule is not a serial schedule **(concurrent transactions ταυτόχρονες συναλλαγές)**, but it is **equivalent** to Schedule 1.

T_1	T_2
read (A)	
$A := A - 50$	
write (A)	
	read (A)
	$temp := A * 0.1$
	$A := A - temp$
	write (A)
read (B)	
$B := B + 50$	
write (B)	
commit	
	read (B)
	$B := B + temp$
	write (B)
	commit

Note -- In schedules 1, 2 and 3, the sum “A + B” is preserved = 3000E.

Schedule 4

- The following concurrent schedule (ταυτόχρονο χρονοδιάγραμμα) does not preserve the sum of "*A* + *B*"

T_1	T_2	A	B	temp
read (*A*)		1000		
A := *A* – 50		950		
	read (*A*)	1000		
	temp := *A* * 0.1			100
	A := *A* - *temp*	900		
	write (*A*)	**900**		
	read (*B*)		2000	
write (*A*)		**950**		
read (*B*)			2000	
B := *B* + 50			2050	
write (*B*)			2050	
commit				
	B := *B* + *temp*		2100	
	write (*B*)		2100	
	commit			

Finally A=950E & B=2100E & A+B=3050E

Serializability (Σειριοποιησιμότητα)

- **Basic Assumption** – Each transaction preserves database consistency.
- Thus, serial execution of a set of transactions preserves database consistency.
- A (possibly concurrent) schedule is **serializable (σειριοποιήσιμο)** if it is equivalent to a serial schedule. Different forms of schedule equivalence give rise to the notions of:
  1. **conflict serializability (διένεξη σειριοποιησιμότητας)**
  2. **view serializability (σειριοποιησιμότητα προβολών)**

Simplified view of transactions

- We ignore operations other than **read** and **write** instructions
- We assume that transactions may perform arbitrary computations on data in local buffers in between reads and writes.
- Our simplified schedules consist of only **read** and **write** instructions.

Conflicting Instructions (Εντολές διένεξης)

- Let I_i **and** I_j **be two Instructions** of **transactions** T_i **and** T_j respectively. Instructions I_i and I_j **conflict** if and only if there exists some item Q accessed by both I_i and I_j, and at least one of these instructions wrote Q.

  1. I_i = **read**(Q), I_j = **read**(Q). I_i and I_j don't conflict.
  2. I_i = **read**(Q), I_j = **write**(Q). They conflict.
  3. I_i = **write**(Q), I_j = **read**(Q). They conflict
  4. I_i = **write**(Q), I_j = **write**(Q). They conflict

- Intuitively, a conflict between I_i and I_j forces a (logical) temporal order between them.
  - If I_i and I_j are consecutive in a schedule and they do not conflict **(eg they are reads)**, their results would remain the same even if they had been interchanged in the schedule.

Conflict Serializability (Διένεξη σειριοποιησιμότητας)

- If a schedule ***S*** **can be transformed into a schedule** ***S´*** by a series of swaps of non-conflicting instructions, we say that ***S*** **and** ***S´*** are **conflict equivalent (ισοδύναμα ως προς τις διενέξεις)**.
- We say that a **schedule** ***S*** is **conflict serializable (σειριοποιήσιμο ως προς τις διενέξεις)** if it is conflict equivalent to a **serial schedule**

Conflict Serializability (Cont.)

- Schedule 3 can be transformed into Schedule 6 -- a serial schedule where T_2 follows T_1, by a series of swaps of non-conflicting instructions. Therefore, Schedule 3 is conflict serializable.

T_1	T_2
read (A)	
write (A)	
	read (A)
	write (A)
read (B)	
write (B)	
	read (B)
	write (B)

Schedule 3

T_1	T_2
read (A)	
write (A)	
read (B)	
write (B)	
	read (A)
	write (A)
	read (B)
	write (B)

Schedule 6

Conflict Serializability (Cont.)

- Example of a schedule that is not conflict serializable (σειριοποιήσιμο ως προς τις διενέξεις) :

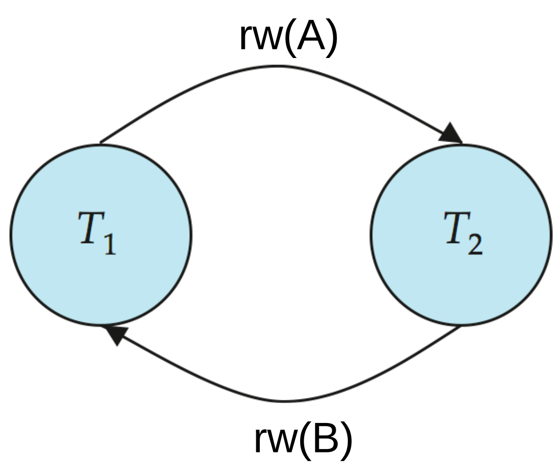
T_3	T_4
read (Q)	
	write (Q)
write (Q)	

- We are unable to swap instructions in the above schedule to obtain either the serial schedule < T_3, T_4 >, or the serial schedule < T_4, T_3 >.

Precedence Graph

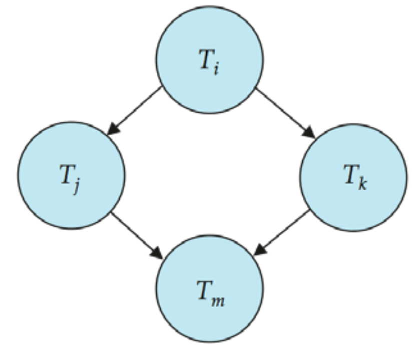
- Consider some schedule of a set of transactions $T_1, T_2, ..., T_n$
- **Precedence graph (γράφημα προτεραιότητας)**— a direct graph where the vertices are the transactions (names).
- We draw an arc from T_i to T_j if the two transaction conflict, and T_i accessed the data item on which the conflict arose earlier (eg wr,rw, ww).
- We may label the arc by the item that was accessed.
- **Example**

T_1	T_2
read (A)	
A := A – 50	
	read (A)
	temp := A * 0.1
	A := A - temp
	write (A)
	read (B)
write (A)	
read (B)	
B := B + 50	
write (B)	
commit	
	B := B + temp
	write (B)
	commit

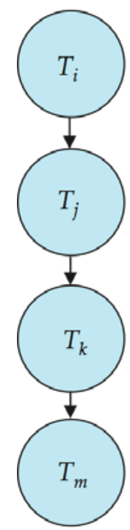


Testing for Conflict Serializability (Έλεγχος Σειριοποιήσιμου ως προς τις Διενέξεις)

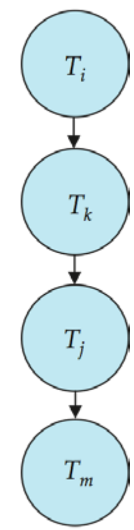
- A schedule is conflict serializable **(σειριοποιήσιμο ως προς τις διενέξεις)** if and only if its precedence graph (γράφημα προτεραιότητας) is acyclic.
- Cycle-detection algorithms exist which take order n^2 time, where n is the number of vertices in the graph.
  - (Better algorithms take order $n + e$ where e is the number of edges.)
- If precedence graph is acyclic, the serializability order can be obtained by a *topological sorting (τοπολογική ταξινόμηση)* of the graph.
  - That is, a linear order consistent with the partial order (εν μέρη σειρά) of the graph.
  - For example, a serializability order for the schedule (a) would be one of either (b) or (c)



(a)



(b)



(c)

Recoverable Schedules (Χρονοδιαγράμματα με δυνατότητα Αποκατάστασης)

- **Recoverable schedule** — if a transaction T_j reads a data item previously written by a transaction T_i , then the **commit operation of T_i must appear before the commit operation of T_j.**
- The following schedule is **not recoverable (although it is conflict serializable)** if T_9 commits immediately after the read(A) operation.

T_8	T_9
read (A)	
write (A)	
	read (A)
	commit
read (B)	

- If T_8 should abort, T_9 would have read (and possibly shown to the user) an inconsistent database state. **Hence, database must ensure that schedules are recoverable.**

Cascading Rollbacks (Διαδοχικές αναιρέσεις)

- **Cascading rollback** – a single transaction failure leads to a series of transaction rollbacks. Consider the following schedule where none of the transactions has yet committed (so the **schedule is recoverable**)

T_{10}	T_{11}	T_{12}
read (A)		
read (B)		
write (A)		
	read (A)	
	write (A)	
		read (A)
abort		

If T_{10} fails, T_{11} and T_{12} must also be rolled back.

- Can lead to the undoing of a significant amount of work

Cascadeless Schedules (Χρονοδιαγράμματα χωρίς διαδοχικές αναιρέσεις)

- **Cascadeless schedules** — for each pair of transactions T_i and T_j such that T_j **reads a data item previously written by** T_i, the **commit operation of** T_i **appears before the read operation of** T_j.
- Every **cascadeless** schedule is also **recoverable**
- It is desirable to restrict the schedules to those that are **cascadeless**
- Example of a schedule that is NOT cascadeless

T_{10}	T_{11}	T_{12}
read (A)		
read (B)		
write (A)		
	read (A)	
	write (A)	
		read (A)
abort		

Concurrency Control (Σχήματα Ταυτόχρονου ελέγχου)

- A database must provide a mechanism that will ensure that all possible schedules are both:
  - Conflict serializable (σειριοποιήσιμα ως προς τις διενέξεις).
  - Recoverable and preferably cascadeless (με δυνατότητα Αποκατάστασης και προτιμώνται χωρίς διαδοχικές αναιρέσεις)
- A policy in which only one transaction can execute at a time generates serial schedules, but provides a poor degree of concurrency
- Concurrency-control schemes tradeoff between the amount of concurrency they allow and the amount of overhead that they incur
- Testing a schedule for serializability *after* it has executed is a little too late!
  - **Tests for serializability help us understand why a concurrency control protocol is correct**
- **Goal – to develop concurrency control protocols that will assure serializability.**

Weak Levels of Consistency

- Some applications are willing to live with weak levels of consistency, allowing schedules that are not serializable
  - E.g., a read-only transaction that wants to get an approximate total balance of all accounts
  - E.g., database statistics computed for query optimization can be approximate (why?)
  - Such transactions **need not be serializable** with respect to other transactions
- Tradeoff **accuracy** for **performance**

Levels of Consistency in SQL-92
Επίπεδα συνέπειας στην SQL

- **Serializable** Σειριοποιήση— default (εξασφάλιση σειριοποιήσιμης εκτέλεσης)
- **Repeatable read Επαναλαμβανόμενο διάβασμα**— only committed records to be read**, repeated reads of same record must return same value (eg other transactions are not allowed to update the record between the repeated reads)**. However, a transaction may not be serializable – it may find some records inserted by a transaction but not find **others (eg when it searches for a conditional statement)**.
- **Read committed Διάβασμα Ολοκληρωμένων** — only committed records can be read, **but successive reads of record may return different (but committed) values**.
- **Read uncommitted Διάβασμα μη Ολοκληρωμένων** — even uncommitted records may be read.

- Lower degrees of consistency useful for gathering approximate information about the database
- Warning: some database systems do not ensure serializable schedules by default
  - E.g., Oracle and PostgreSQL by default support a level of consistency called snapshot isolation (not part of the SQL standard)

Transaction Definition in SQL

- Data manipulation language must include a construct for specifying the set of actions that comprise a transaction.
- In SQL, a transaction begins implicitly.
- A transaction in SQL ends by:
  - **Commit work** commits current transaction and begins a new one.
  - **Rollback work** causes current transaction to abort.
- In almost all database systems, by default, every SQL statement also commits implicitly if it executes successfully
  - Implicit commit can be turned off by a database directive
    - E.g. in JDBC, connection.setAutoCommit(false);

End of Chapter 14