Database Management Systems

Module 46: Transactions/1

Partha Pratim Das

Department of Computer Science and Engineering
Indian Institute of Technology, Kharagpur

ppd@cse.iitkgp.ac.in

Week Recap

- Need for indexing database tables
- Understood the ordered indexes
- Recap of Balanced BST for optimal in-memory search data structures
- Issues of external search data structures for persistent data
- Explored 2-3-4 Tree as a precursor to B/B+-Tree
- Understood the B^+ Tree and B Tree for Index files and data files
- Explored Static and Dynamic Hashing
- Compared Ordered Indexing and Hashing
- Studied the use of Bitmap Indices
- Learnt to create indexes in SQL
- Learnt a set of Ground Rules for Indexing

Module Objectives

- To understand the concept of transaction – 'doing a task in a database' and its state
- To explore issues in concurrent execution of transactions

Module Outline

- Transaction Concept
- Transaction State
- Concurrent Executions

Transaction Concept

Transaction Concept

- A **transaction** is a *unit* of program execution that accesses and, possibly updates, various data items
- For example, 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: ACID: Atomicity

- **Atomicity 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

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)

Required Properties of a Transaction: ACID: Consistency

- **Consistency Requirement**
  - A + B must be unchanged by the execution of the transaction
  - In general, consistency requirements include
    - ▷ Explicitly specified integrity constraints
      - primary keys and foreign keys
    - ▷ Implicit integrity constraints
      - 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

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)

Required Properties of a Transaction: ACID: Isolation

- **Isolation 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

Required Properties of a Transaction: ACID: Durability

- **Durability Requirement**
  - Once the user has been notified that the transaction has completed (that is, 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

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)

ACID Properties

A **transaction** is a unit of program execution that accesses and possibly updates various data items:

- **Atomicity:** Atomicity guarantees that each transaction is treated as a single *unit*, which either succeeds completely, or fails completely
  - If any of the statements constituting a transaction fails to complete, the entire transaction fails and the database is left unchanged
  - Atomicity must be guaranteed in every situation, including power failures, errors and crashes
- **Consistency:** Consistency ensures that a transaction can only bring the database from one valid state to another, maintaining database invariants
  - Any data written to the database must be valid according to all defined rules, including constraints, cascades, triggers, and any combination thereof
- **Isolation:** Transactions are often executed concurrently (multiple transactions reading and writing to a table at the same time)
  - Isolation ensures that concurrent execution of transactions leaves the database in the same state that would have been obtained if the transactions were executed sequentially
- **Durability:** Durability guarantees that once a transaction has been committed, it will remain committed even in the case of a system failure (like power outage or crash)
  - This usually means that completed transactions (or their effects) are recorded in non-volatile memory

ACID Properties: Quick Reckoner

A - Atomicity

All or Nothing Transactions

C - Consistency

Guarantees Committed Transaction State

I - Isolation

Transactions are Independent

D – Durability

Committed Data is Never Lost

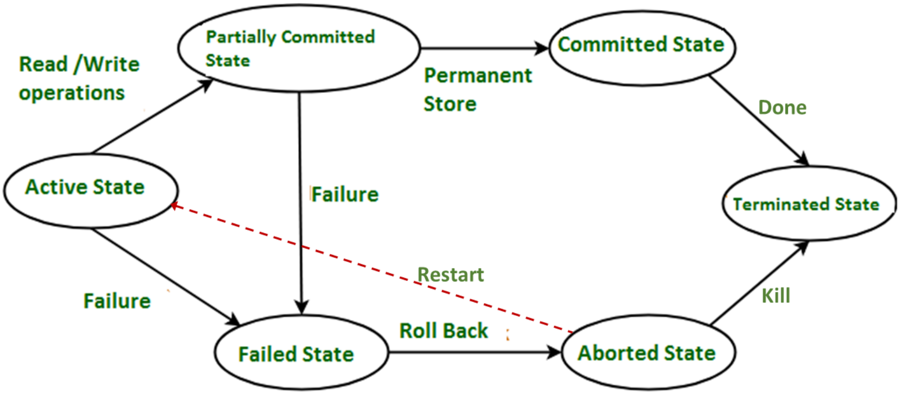
(c) http://blog.sqlauthority.com

Transaction States

Transaction States

- Every transaction can be in one of the following states (like Process States in OS)
  - **Active**
    - ▷ The initial state; the transaction stays in this state while it is executing
  - **Partially committed**
    - ▷ After the final statement has been executed
  - **Failed**
    - ▷ After the discovery that normal execution can no longer proceed
  - **Aborted**
    - ▷ 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**
    - ▷ After successful completion
  - **Terminated**
    - ▷ After it has been committed or aborted (killed)

Transitions for Transaction States



Concurrent Executions

Concurrent Executions

- Multiple transactions are allowed to run concurrently in the system. Advantages are:
  - **Increased processor and disk utilization**, leading to better transaction *throughput*
    - For example, 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**: Mechanisms to achieve isolation
  - To control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database

Schedules

- **Schedule**: A sequence 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

- 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 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

A	B	A+B	Transaction	Remarks
100	200	300	@ Start	
50	200	250	T1, write A	
50	250	300	T1, write B	@ Commit
45	250	295	T2, write A	
45	255	300	T2, write B	@Commit

Consistent @ Commit
Inconsistent @ Transit
Inconsistent @ Commit

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	

A	B	A+B	Transaction	Remarks
100	200	300	@ Start	
90	200	290	T2, write A	
90	210	300	T2, write B	@ Commit
40	210	250	T1, write A	
40	260	300	T1, write B	@Commit

Consistent @ Commit
Inconsistent @ Transit
Inconsistent @ Commit

Values of A & B are different from Schedule 1 – yet consistent

Schedule 3

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

Schedule 3

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

Schedule 1

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

A	B	A+B	Transaction	Remarks
100	200	300	@ Start	
50	200	250	T1, write A	
45	200	245	T2, write A	
45	250	295	T1, write B	@ Commit
45	255	300	T2, write B	@Commit

Consistent @ Commit
Inconsistent @ Transit
Inconsistent @ Commit

Note – In schedules 1, 2 and 3, the sum "$A + B$" is preserved

Schedule 4

- The following concurrent schedule does not preserve the sum of "$A + B$"

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

A	B	A+B	Transaction	Remarks
100	200	300	@ Start	
90	200	290	T2, write A	
50	200	250	T1, write A	
50	250	300	T1, write B	@ Commit
50	210	260	T2, write B	@ Commit

Consistent @ Commit
Inconsistent @ Transit
Inconsistent @ Commit

Module Summary

- A task in a database is done as a transaction that passes through several states
- Transactions are executed in concurrent fashion for better throughput
- Concurrent execution of transactions raise serializability issues that need to be addressed
- All schedules may not satisfy ACID properties

Slides used in this presentation are borrowed from http://db-book.com/ with kind permission of the authors.
Edited and new slides are marked with "PPD".