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Database
Lesson 12. Transaction management

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Learning Map

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2	Relational Databases
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5	Structured Query Language – Part 2
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Outline

- Transaction
  - Definition
  - ACID properties
  - Transaction states
  - Transaction management interfaces
- Concurrency control
  - Objective
  - Scheduling
  - Serializability
  - Locks
  - Locking protocol
  - 2 Phase Locking (2PL)

Objectives

- Upon completion of this lesson, students will be able to:
  - Understanding transaction and ACID properties
  - Understanding locking and 2 phase locking algorithm

1. Transaction

- Definition
- ACID properties
- Transaction states
- Transaction management interfaces

1.1. What is transaction

- A transaction is a unit of program execution that accesses and possibly updates various data items.
- Example: transfer \$50 from account A to account B
  - 1. $R(A)$
  - 2. $A \leftarrow A - 50$
  - 3. $W(A)$
  - 4. $R(B)$
  - 5. $B \leftarrow B + 50$
  - 6. $W(B)$
- Two main issues:
  - 1. concurrent execution of multiple transactions
  - 2. failures of various kind (e.g., hardware failure, system crash)

1.2. ACID Properties

- Database system must guarantee ACID for transactions:
  - **Atomicity**: either all operations of the transaction are executed or none
  - **Consistency**: execution of a transaction in isolation preserves the consistency of the database
  - **Isolation**: although multiple transactions may execute concurrently, each transaction must be unaware of the other concurrent transactions.
  - **Durability**: After a transaction completes successfully, changes to the database persist even in case of system failure.

1.2.1. Atomicity

- Example: transfer $50 from account *A* to account *B*
  1. $R(A)$
  2. $A \leftarrow A - 50$
  3. $W(A)$
  4. $R(B)$
  5. $B \leftarrow B + 50$
  6. $W(B)$
- **What if failure (hardware or software) after step 3?**
  - money is lost
  - database is inconsistent
- **Atomicity:**
  - either all operations or none
  - updates of partially executed transactions not reflected in database

1.2.2. Consistency

- Example: transfer \$50 from account A to account B
  1. $R(A)$
  2. $A \leftarrow A - 50$
  3. $W(A)$
  4. $R(B)$
  5. $B \leftarrow B + 50$
  6. $W(B)$
- **Consistency in example**: sum $A + B$ must be unchanged
- **Consistency in general:**
  - explicit integrity constraints (e.g., foreign key)
  - implicit integrity constraints (e.g., sum of all account balances of a bank branch must be equal to branch balance)
- **Transaction:**
  - must see consistent database
  - during transaction inconsistent state allowed
  - after completion database must be consistent again

1.2.3. Isolation

- Example: transfer \$50 from account A to account B
  - 1. $R(A)$
  - 2. $A \leftarrow A - 50$
  - 3. $W(A)$
  - 4. $R(B)$
  - 5. $B \leftarrow B + 50$
  - 6. $W(B)$
- **Imagine second transaction $T2$:**
  - $T2 : R(A), R(B), print(A + B)$
  - $T2$ is executed between steps 3 and 4
  - $T2$ sees an inconsistent database and gives wrong result

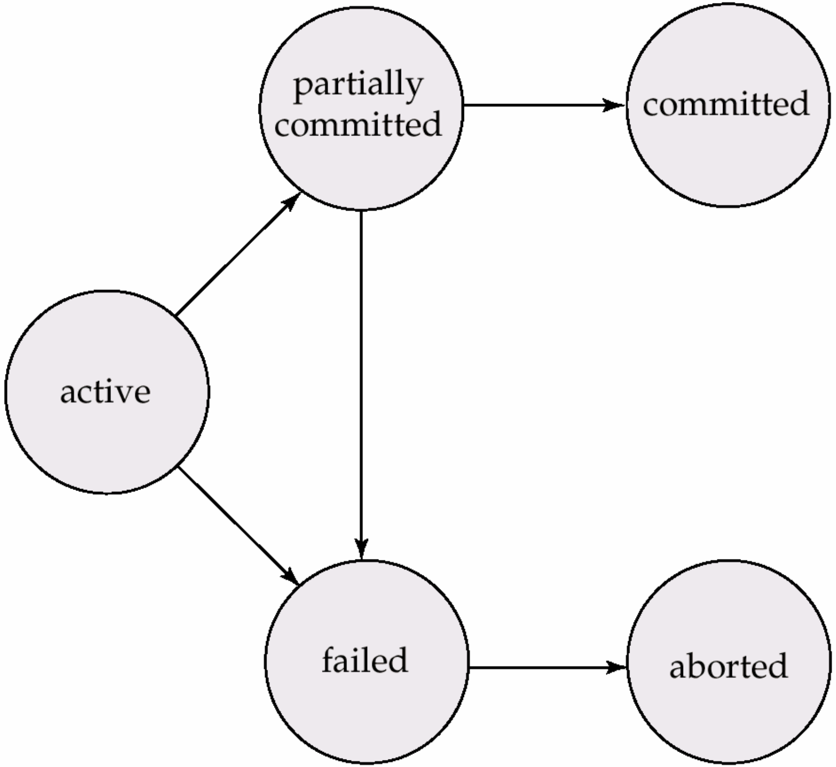
1.2.3. Isolation

- **Trivial isolation:** run transactions serially
- Isolation for concurrent transactions:
  - For every pair of transactions *Ti* and *Tj*,
  - it appears to *Ti* as if either *Tj* finished execution before *Ti* started
  - or *Tj* started execution after *Ti* finished.

1.2.4. Durability

- When a transaction is done it commits.
- **Example**: transaction commits too early
  - transaction writes *A*, then commits
  - *A* is written to the disk buffer
  - then system crashes
  - value of *A* is lost
- **Durability**: After a transaction has committed, the changes to the database persist even in case of system failure.
- Commit only after all changes are permanent:
  - either written to log file or directly to database
  - database must recover in case of a crash

1.3. Transaction states



1.4. Transaction management interfaces

- Begin Trans
- Commit ()
- Abort()
- Savepoint Save()
- Rollback (savepoint)

  (savepoint = 0 ==> Abort)

Schedule

- A list of operations conducted by concurrent transactions
- Serial schedule: transactions are executed non-interleaved, i.e., a serial schedule is one in which no transaction starts until a running transaction has ended
- Non-serial schedule: operations of multiple transactions are interleaved

Schedule

T_1	T_2
R(A)	
W(A)	
R(B)	
	W(B)
	R(A)
	R(B)

Serial schedule

T_1	T_2
R(A)	
W(A)	
	W(A)
	R(A)
commit	
	commit

Non-serial schedule

Problem 1 – Lost updated data

- A = 100 + 100 – 10 = 190
- Updated data is overwritten by other transaction

T_1	T_2	Account A
	Begin Transaction	100
Begin Transaction	**Read**(A);	100
Read(A);	A = A + 100 ;	100
A:=A-10;	**Write**(A);	200
Write(A);	Commit	90
Commit		90

Problem 2 – Uncommitted transaction

- A = 100 – 10 = 90
- A transaction allows other transactions to see temporary results before they are committed

T_3	T_4	TK A
	Begin Transaction	100
	Read(A);	100
	A = A + 100 ;	100
Begin Transaction	**Write**(A);	200
Read(A);	:	200
A:=A-10;	**Rollback**	100
Write(A);		190
Commit		190

Problem 3 – Dirty read/Unrepeatable read

- Read-only transaction reads data which is being updated by other transaction

T_5	T_6	X	Y	Z	Sum
	Begin Transaction	100	50	25	
Begin Transaction	Sum = 0	100	50	25	0
Read(X);	**Read**(X);	100	50	25	0
X = X – 10 ;	Sum = Sum + X	100	50	25	100
Write (X);	**Read**(Y);	90	50	25	100
Read (Z)	Sum = Sum + Y	90	50	25	150
Z = Z + 10		90	50	25	150
Write(Z);		90	50	35	150
Commit	**Read**(Z)	90	50	35	150
	Sum = Sum + Z	90	50	35	185
	Commit	90	50	35	185

2. Concurrency control

- Objective
- Scheduling
- Serializability
- Locks
- Locking protocol
- 2 Phase Locking (2PL)

2.1. Objective

- Objective:
  - ensures that database transactions are performed concurrently without violating the data integrity
  - guarantees that no effect of committed transactions is lost, and no effect of aborted (rolled back) transactions remains in the related database.
- Example

T0: read(A);
A := A -50;
write(A);
read(B);
B := B + 50;
write(B);
	T1: read(A);
	temp := A *0.1;
	A := A -temp;
	write(A);
	read(B);
	B := B + temp;
	write(B);

2.1. Scheduling

T_0	T_1
read(A)	
A := A - 50	
write(A)	
read(B)	
B := B + 50	
write(B)	
	read(A)
	temp := A * 0.1
	A := A -temp
	write(A)
	read(B)
	B := B + temp
	write(B)

(1)

T_0	T_1
	read(A)
	temp := A * 0.1
	A := A -temp
	write(A)
	read(B)
	B := B + temp
	write(B)
read(A)	
A := A - 50	
write(A)	
read(B)	
B := B + 50	
write(B)	

(2)

T_0	T_1
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)	
	B := B + temp
	write(B)

(3)

2.2. Serializability

- A schedule of a set of transactions is a linear ordering of their actions
  - e.g. for the simultaneous deposits example:

    R1(X) R2(X) W1(X) W2(X)
- A serial schedule is one in which all the steps of each transaction occur consecutively
- A serializable schedule is one which is equivalent to some serial schedule

2.3. Locks

- A lock is a mechanism to control concurrency on a data item.
  - one way of enforcing concurrency control policies
- Two types of locks on a data item A:
  - exclusive – $xL(A)$: prevents other transactions from accessing the data.
  - shared – $sL(A)$: data can only be read.
- Lock request are made to concurrency control manager.
- Transaction is blocked until lock is granted.
- Unlock A – $uL(A)$: release the lock on a data item A

2.3.1. Lock Compatibility

- Lock compatibility matrix:

$T_1 \downarrow \quad T_2 \rightarrow$	shared	exclusive
shared	true	false
exclusive	false	false

- *T*1 holds shared lock on *A*:
  - shared lock is granted to *T*2
  - exclusive lock is not granted to *T*2
- *T*2 holds exclusive lock on *A*:
  - shared lock is not granted to *T*2
  - exclusive lock is not granted to *T*2
- Shared locks can be shared by any number of transactions.

2.4. Locking protocol

- Example transaction $T2$ with locking:
  1. $sL(A)$, $R(A)$, $uL(A)$
  2. $sL(B)$, $R(B)$, $uL(B)$
  3. $print(A + B)$
- $T2$ uses locking, but is not serializable
  - A and/or B could be updated between steps 1 and 2
  - printed sum may be wrong
- Locking protocol:
  - set of rules followed by all transactions while requesting/releasing locks
  - locking protocol restricts the set of possible schedules

Pitfalls of Locking Protocols – Deadlock

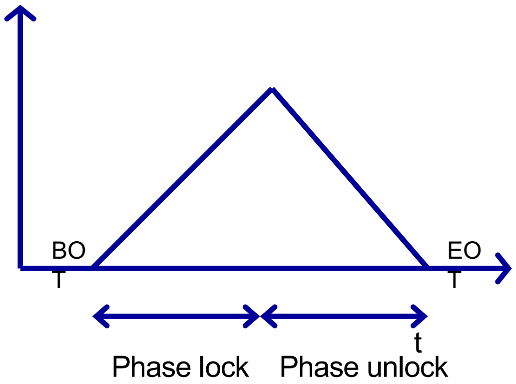
- **Example**: two concurrent money transfers
  - $T1$: $R(A)$, $A \leftarrow A + 10$, $R(B)$, $B \leftarrow B - 10$, $W(A)$, $W(B)$
  - $T2$: $R(B)$, $B \leftarrow B + 50$, $R(A)$, $A \leftarrow A - 50$, $W(A)$, $W(B)$
  - possible concurrent scenario with locks:
  - $T1.xL(A)$, $T1.R(A)$, $T2.xL(B)$, $T2.R(B)$, $T2.xL(A)$, $T1.xL(B)$, . . .
  - $T1$ and $T2$ block each other – no progress possible

2.4.2. Pitfalls of locking protocols – Starvation

- **Starvation**: transaction continues to wait for lock
- **Examples**:
  - the same transaction is repeatedly rolled back due to deadlocks
  - a transaction continues to wait for an exclusive lock on an item while a sequence of other transactions are granted shared locks
- Well-designed concurrency manager avoids starvation.

2.5. 2 Phase Locking (2PL)

- Protocol that guarantees serializability.
  - Phase 1
    - locks are acquired and no locks are released
  - Phase 2
    - locks are released and no locks are acquired



Two-Phase Locking – Example

- Example: two concurrent money transfers
  - $T1$: $R(A)$, $A \leftarrow A + 10$, $R(B)$, $B \leftarrow B - 10$, $W(A)$, $W(B)$
  - $T2$: $R(A)$, $A \leftarrow A - 50$, $R(B)$, $B \leftarrow B + 50$, $W(A)$, $W(B)$
- Possible two-phase locking schedule:
  - 1. $T1$: $xL(A)$, $xL(B)$, $R(A)$, $R(B)$, $W(A \leftarrow A + 10)$, $uL(A)$
  - 2. $T2$: $xL(A)$, $R(A)$, $xL(B)$ *(wait)*
  - 3. $T1$: $W(B \leftarrow B - 10)$, $uL(B)$
  - 4. $T2$: $R(B)$, $W(A \leftarrow A - 50)$, $W(B \leftarrow B + 50)$, $uL(A)$, $uL(B)$
- Equivalent serial schedule: $T1$, $T2$

Solve Problem 1 - Lost updated data

Time	T_1	T_2	TK A
t_1		Begin Transaction	100
t_2	Begin Transaction	Write_lock(A)	100
t_3	Write_lock(A)	Read(A);	100
t_4	**WAIT**	A = A + 100 ;	100
t_5	**WAIT**	Write(A);	200
t_6	**WAIT**	Commit/ unlock(A)	200
t_7	Read(A);		200
t_8	A:=A-10;		190
t_9	Write(A);		190
t_{10}	Commit/ Unlock(A)		190

write lock: the relevant transaction can read and write data
read lock: the relevant transaction can read but can not write data

Solve Problem 2 – Uncommitted transaction

Time	T_3	T_4	TK A
t_1		Begin Transaction	100
t_2		Write_lock (A)	100
t_3	Begin Transaction	Read(A);	100
t_4	Write_lock (A)	A = A + 100 ;	100
t_5	**WAIT**	Write(A);	200
t_6	**WAIT**	Rollback/ unlock(A)	100
t_7	Read(A);		100
t_8	A:=A-10;		90
t_9	Write(A);		90
t_{10}	Commit/ Unlock(A)		90

write lock: the relevant transaction can read and write data

read lock: the relevant transaction can read but can not write data

Solve Problem 3 – Dirty read

t	T_5	T_6	X	Y	Z	Sum
t_1		Begin Transaction	100	50	25	
t_2	Begin Transaction	Sum = 0	100	50	25	0
t_3	Write_lock (X)	Read_lock (X)	100	50	25	0
t_4	Read(X);	**WAIT**	100	50	25	0
t_5	X = X – 10 ;	**WAIT**	100	50	25	0
t_6	Write (X);	**WAIT**	90	50	25	0
t_7	Write_lock (Z)	**WAIT**	90	50	25	0
t_8	Read (Z)	**WAIT**	90	50	25	0
t_9	Z = Z + 10	**WAIT**	90	50	25	0
t_{10}	Write(Z);	**WAIT**	90	50	35	0
t_{11}	Commit/ Unlock(X,Z)	**WAIT**	90	50	35	0
t_{12}		Read(X);	90	50	35	0
t_{13}		Sum = Sum + X	90	50	35	90
t_{14}		Read_lock(Y)	90	50	35	90
t_{15}		Read(Y);	90	50	35	90
t_{16}		Sum = Sum + Y	90	50	35	140
t_{17}		Read_lock(Z)	90	50	35	140
t_{18}		Read(Z)	90	50	35	140
t_{19}		Sum = Sum + Z	90	50	35	175
t_{20}		Commit/ Unlock(X,Y,Z)	90	50	35	175

Summary

- Transaction and ACID properties
- Concurrency control based on locking mechanisms
- 2 phase locking (2PL)

Next lesson: Transaction management

- Hector Garcia-Molina, Jeffrey D. Ullman, Jennifer Widom. Database Systems: The Complete Book. Pearson Prentice Hall. the 2nd edition. 2008: Chapter 7
- Nguyen Kim Anh, Nguyên lý các hệ cơ sở dữ liệu, NXB Giáo dục. 2004: Chương 7