事务
Transactions

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课程概要

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- **Part 0: Overview**
  - Ch1: Introduction
- **Part 1 Relational Languages**
  - Ch2: Relational model
  - Ch3: Introduction to SQL
  - Ch4: Intermediate SQL
  - Ch5: Advanced SQL
- **Part 2 Database Design**
  - Ch6: Database design via E-R model
  - Ch7: Relational database design
- **Part 3 Application Design & Development**
  - Ch8: Complex data types
  - Ch9: Application development
- **Part 4 Big Data Analytics**
  - Ch10: Big data
  - Ch11: Data analytics
- **Part 5 Storage Management & Indexing**
  - Ch12: Physical storage systems
  - Ch13: Data storage structures
  - Ch14: Indexing
- **Part 6 Query Processing & Optimization**
  - Ch15: Query processing
  - Ch16: Query optimization
- **Part 7 Transaction Management**
  - **Ch17: Transactions**
  - Ch18: Concurrency control
  - Ch19: Recovery system
- **Part 8 Parallel & Distributed Database**
  - Ch20: Database system architecture
  - Ch21-23: Parallel & distributed storage, query processing & transaction processing
- **Advanced topics**
  - DB Platform: **OceanBase**, MongoDB, Neo4J
  - …

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事务（Transaction）

- A transaction is a unit of program execution consisting of multiple operations
  - During transaction execution, the database may be **inconsistent**
  - After the transaction is committed, the database must be **consistent**

- **Two main issues**
  - Concurrent execution of multiple transactions -> **Concurrency control** (Ch18)
  - Recover from hardware failures and system crashes -> **Recovery** (Ch19)

事务的ACID特性

- **Atomicity（原子性）**
  - Either all operations of the transaction are properly reflected in the database or none are
- **Consistency（一致性）**
  - Execution of a transaction in isolation preserves the consistency of the database
- **Isolation（隔离性）**
  - Although multiple transactions may execute concurrently, each transaction must be unaware of other transactions
- **Durability（持久性）**
  - After a transaction completes successfully, the changes it has made to the database persist, even if there are system failures

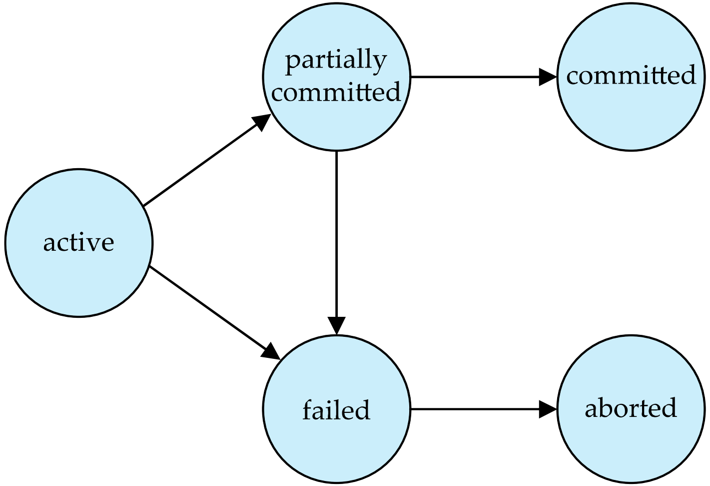
例：Fund Transfer

- 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)

- **Consistency requirement**
  - The sum of A and B is unchanged after the execution of the transaction
- **Atomicity requirement**
  - If the transaction fails after step 3 and before step 6, the system should ensure that its updates are not reflected in the database. Otherwise, an inconsistency will occur
- **Isolation requirement**
  - If between steps 3 and 6, another transaction accesses the partially updated database, it will see an inconsistent database
  - Can be ensured trivially by running transactions serially, i.e., one after the other. However, executing multiple transactions concurrently has significant benefits
- **Durability requirement**
  - Once the transaction has completed, the updates to the database by the transaction must persist despite failures

事务的状态

- **Active(活跃)**
  - The initial state. The transaction stays in this state while it is executing
- **Partially committed(部分提交)**
  - After the final statement has been executed
- **Failed(失败)**
  - After discovering that normal execution can no longer proceed
- **Aborted(中止)**
  - The transaction has been rolled back and the database restores to its state prior to the start of the transaction
    - Restart the transaction – only if no internal logical error happens in the transaction
    - Kill the transaction – problems arising with the transaction, input data, no desirable data found in the database
- **Committed(提交)**
  - After successful completion



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- 事务的概念
- 事务的调度
- 可串行化调度
- 可恢复调度
- 可串行性检测

并发执行

- **Concurrent execution**
  - Multiple transactions run concurrently in the system
  - Advantages
    - Increase the utilization of processors and disks
    - Reduce the average response time

- **Concurrency control**
  - Mechanisms to achieve isolation, i.e., to control the interaction among the concurrent transactions in order to prevent them from destroying the consistency of the database

调度（Schedule）

- **Schedule**
  - Sequences that indicate the **chronological order** in which instructions of concurrent transactions are executed
  - A schedule for a set of transactions must consist of all the instructions of those transactions
  - Must preserve the order in which the instructions appear in each individual transaction
- **Example**
  - Let T_1 transfer \$50 from A to B, and T_2 transfer 10% of the balance from A to B
  - Schedule 1 is a serial schedule (**串行调度**), 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

Schedule 1

调度（续）

- Another serial schedule where T_2 is followed by T_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

Schedule 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 2

调度（续）

- **Non-serial schedule**
  - Let T_1 and T_2 be the transactions defined previously
  - Schedule 3 is not a serial schedule, but equivalent to Schedule 1
    - A’=(A-50)*0.9
    - B’=B+50+(A-50)*0.1
    - A’+B’=A+B

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 3

调度（续）

- The following concurrent schedule does not preserve the value of the sum A + B.
  - A’=A-50
  - B’=B+A*0.1
  - A’+B’=A+B-50+A*0.1≠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

Schedule 4

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- 可恢复调度
- 可串行性检测

可串行化（Serializability）

- **Assumption**
  - Each transaction preserves database consistency, thus serial execution of a set of transactions preserves database consistency
- **Serializability**
  - A schedule is serializable if it is equivalent to a serial schedule
    - **Conflict serializability（冲突可串行性）**
    - **View serializability（视图可串行性）**
- **Note**
  - We ignore operations other than **read** and **write** instructions

冲突可串行化（Conflict Serializability）

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- **Conflict**
  - Given instructions I_i and I_j of transactions T_i and T_j respectively, conflict occurs iff there exists some item Q accessed by both I_i and I_j, and at least one of these instructions wrote Q
  - **Four cases**
    - I_i = read(Q), I_j = read(Q). (**no conflict**)
    - I_i = read(Q), I_j = write(Q). (**conflict**)
    - I_i = write(Q), I_j = read(Q). (**conflict**)
    - I_i = write(Q), I_j = write(Q). (**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 do not conflict, their results would remain the same even if they are interchanged in the schedule

冲突可串行化（续）

- **Conflict equivalent (冲突等价)**
  - 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**
  - A schedule S is conflict serializable (冲突可串行化) if it is conflict equivalent to a serial schedule (串行调度)
- Example of a schedule that is not conflict serializable
  - Cannot swap instructions in the following schedule to obtain either the serial schedule $<T_3, T_4>$, or the serial schedule $< T_4, T_3>$.

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

冲突可串行化（续）

- Schedule 1 can be transformed into Schedule 2, a serial schedule where T_2 follows T_1, by a series of swaps of non-conflicting instructions
- Therefore, Schedule 1 is conflict serializable

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

Schedule 1

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

Schedule 2

冲突可串行化（续）

- 例

Sc1=r1(A)w1(A)r2(A)w2(A)r1(B)w1(B)r2(B)w2(B)

- Swap w2(A) and r1(B)w1(B), then we have

  r1(A)w1(A)r2(A)r1(B)w1(B)w2(A)r2(B)w2(B)

- Swap r2(A) and r1(B)w1(B), then：

  Sc2＝r1(A)w1(A)r1(B)w1(B)r2(A)w2(A)r2(B)w2(B)

- Sc2 is equivalent to a serializable schedule T_1,T_2
- Then Sc1 is conflict serializable

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- A conflict serializable schedule is a serializable schedule, but a serializable schedule is not always conflict serializable.
- E.g., three transactions: **T1=W1(Y)W1(X)**，**T2=W2(Y)W2(X)**，**T3=W3(X)**
  - **S1=W1(Y)W1(X)W2(Y)W2(X)W3(X)** is serializable
  - **S2=W1(Y)W2(Y)W2(X)W1(X)W3(X)** is not conflict equivalent to S1, and not conflict serializable
  - S2 is serializable, and its result is equivalent to S1

视图可串行化（View Serializability）

- **S and S' are view equivalent if the following three conditions are met:**
  - For each data item Q, if transaction T_i reads the initial value of Q in schedule S, then transaction T_i in schedule S' should also read the initial value of Q
  - For each data item Q, if transaction T_i executes read(Q) in schedule S, and that value was produced by transaction T_j (if any), then transaction T_i in schedule S' should also read the value of Q that was produced by transaction T_j
  - For each data item Q, the transaction (if any) that performs the final write(Q) operation in schedule S must perform the final write(Q) operation in schedule S'
- View equivalence is also based purely on reads and writes

视图可串行化（续）

- If a schedule S is view serializable, it is view equivalent to a serial schedule
- Every conflict serializable schedule is also view serializable
- E.g., the following schedule, equivalent to T_3, T_4, T_6, is view-serializable but not conflict serializable

T_3	T_4	T_6
read(Q)		
	write(Q)	
write(Q)		
		write(Q)

⇔

T_3	T_4	T_6
read(Q)		
Write(Q)		
	Write(Q)	
		write(Q)

其他可串行性情形

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- The following schedule produces the same outcome as the serial schedule <T_1, T_5>, yet it is not conflict equivalent or view equivalent

T_1	T_5
read (A) $A := A - 50$ write (A)	
	read (B) $B := B - 10$ write (B)
read (B) $B := B + 50$ write (B)	
	read (A) $A := A + 10$ write (A)

- Determining such equivalence requires analysis of operations other than read and write

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可恢复性（Recoverability）

- **Recoverable schedule（可恢复调度）**
  - If a transaction T_j reads a data item previously written by a transaction T_i, the commit operation of T_i should appear before the commit operation of T_j
  - The following schedule is not recoverable if T_9 commits immediately after the read

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

可恢复性（续）

- **Cascading rollback(级联回滚)**
  - A single transaction failure leads to a series of transaction rollbacks
  - Consider the following schedule where none of the transactions has yet committed

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
- **Could lead to the undoing of a significant amount of work**

可恢复性（续）

- **Cascadeless schedules (无级联回滚调度)**
  - 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 should appear before the read operation of T_j
  - Cascading rollbacks cannot occur and every cascadeless schedule is also recoverable
  - It is desirable to restrict the schedules to those that are cascadeless

SQL中的事务定义

- DML 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 starts a new one
  - Rollback work: causes current transaction to abort
- Levels of isolation specified by SQL-92
  - Serializable – default：保证可串行化调度
  - Repeatable read：只允许读取已提交数据，两次读取之间数据不能更新
  - Read committed：只允许读取已提交数据，不要求可重复读
  - Read uncommitted：允许读取未提交数据

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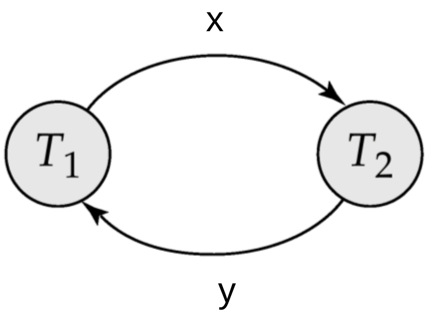
可串行性检测

- Given a set of transactions T_1, T_2, ..., T_n
- **Precedence graph（优先图）**
  – A direct graph where the vertices are the transactions
  – Draw an arc from T_i to T_j if the two transactions conflict, and T_i accessed the data item on which the conflict arose earlier
  – We label the arc by the data item that was accessed
- **Example**

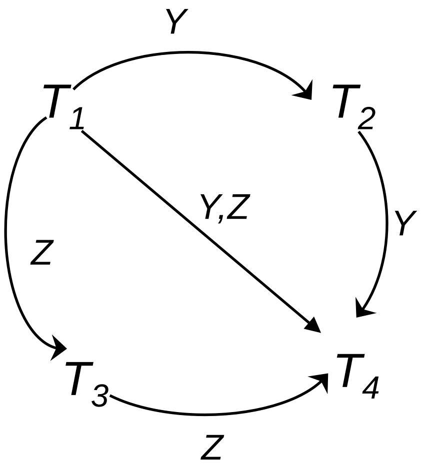


T1 write(x) before T2 read(x)
T1 write(x) before T2 write(x)
T1 read(x) before T2 write(x)

T2 write(y) before T1 read(y)
T2 write(y) before T1 write(y)
T2 read(y) before T1 write(y)

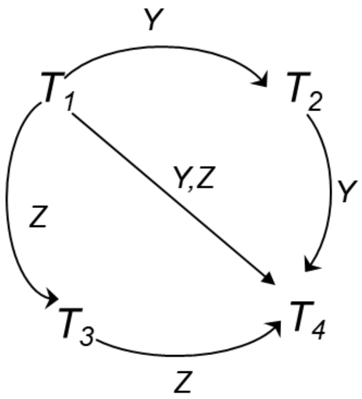
调度与优先图

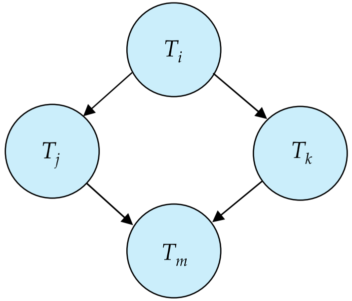
T_1	T_2	T_3	T_4	T_5
	read(X)			
read(Y)				
read(Z)				
				read(V)
				read(W)
				read(W)
	read(Y)			
	write(Y)			
		write(Z)		
read(U)				
			read(Y)	
			write(Y)	
			read(Z)	
			write(Z)	
read(U)				
write(U)				



▶ 可串行性检测（续）

- A schedule is conflict serializable if and only if its precedence graph is acyclic（无环）
- If precedence graph is acyclic, the serializability order can be obtained by a topological sorting of the graph
  - For example, a serializability order for the Schedule on the previous page would be $T_5 \rightarrow T_1 \rightarrow T_3 \rightarrow T_2 \rightarrow T_4$
    - Any others?





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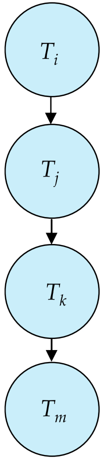

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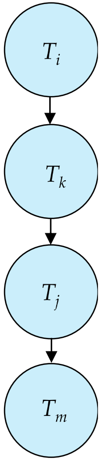

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并发执行与可串行性检测

- **Concurrency control**
  - Develop concurrency control protocols to assure serializability
  - Not examine the precedence graph as it is being created
- Testing for serializability helps understand why a concurrency control protocol is correct