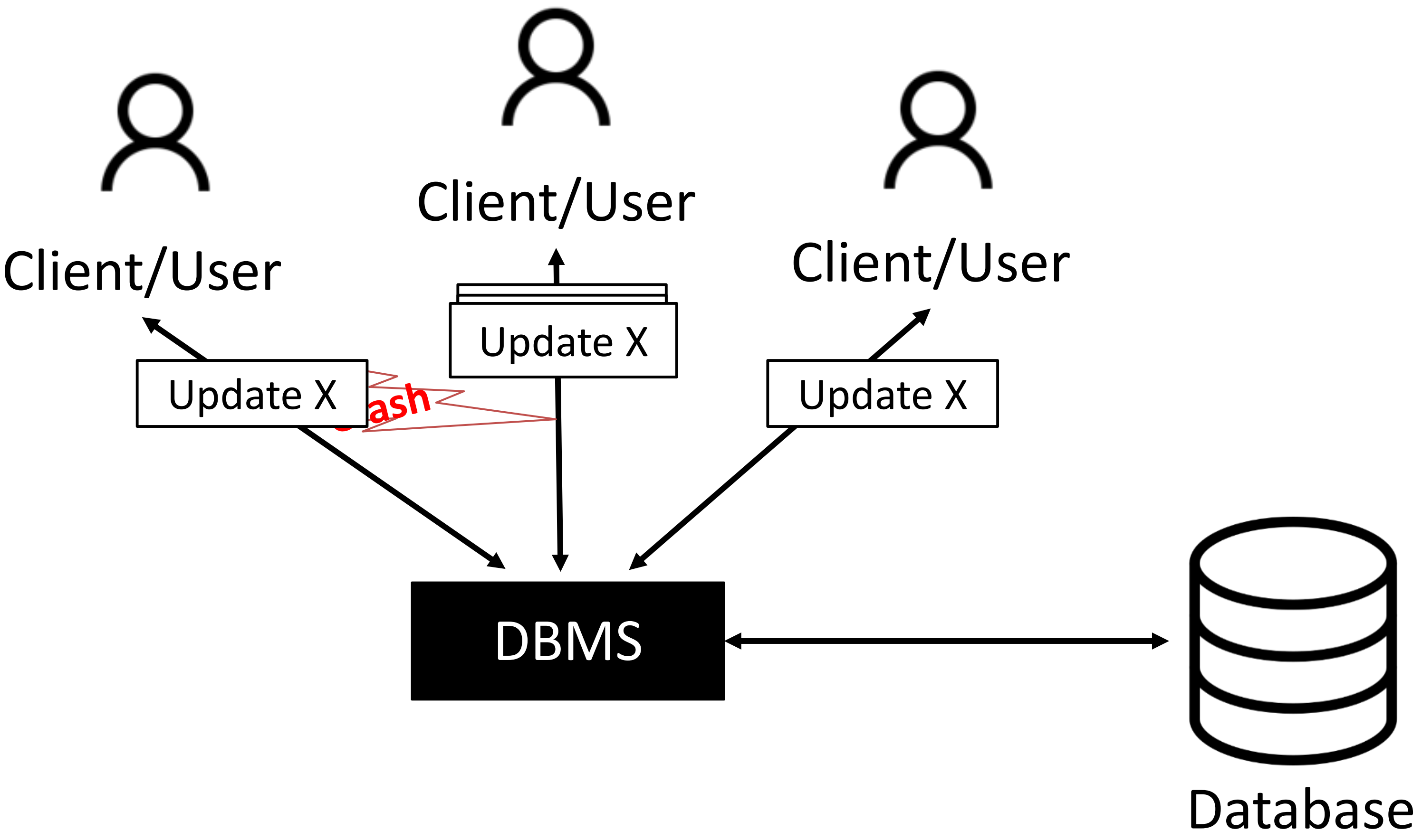
Introduction to Operating Systems and SQL for Data Science

Lecture 12 – Transactions

Previous lecture

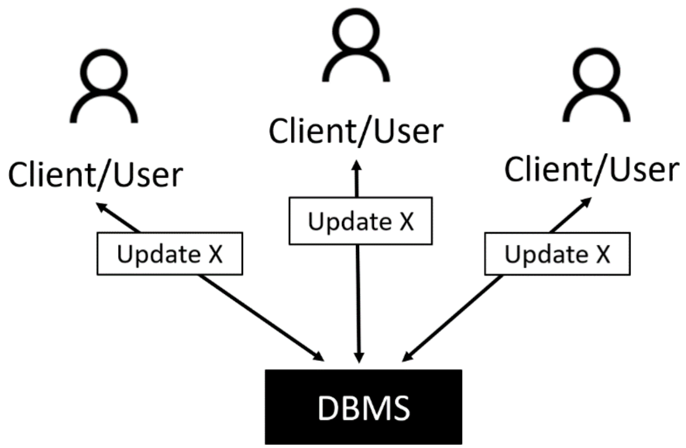
- ERD
- Entity
- attributes
- Connection between entities
- Connection types
- generalization

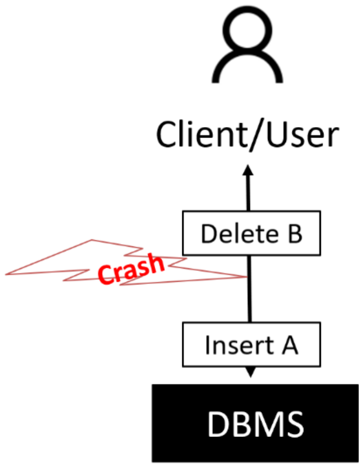
Challenges in a real database



Challenges in a real database

Challenges in a DB with **many users** that may **fail**





Transactions to save the day!

Lecture topics

- Problems in a multi-user DB that can fail
- **What is a transaction?**
  - What should a DBMS do with transactions?
- How DBMSs **implement transactions**?
- Trading data **consistency for speed**

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Transactions

Example #1: Student Cleanup

Students

ID	Name	GPA	Status
1	Avi	82.5	Active
2	Benny	62.3	Rejected
3	Danna	91.2	Active
4	Ehud	65.3	Rejected

Archive

ID	Name	GPA	Status

Is it possible for a student to be in both tables?
(In a normal condition - **no!**)

Insert into Archive

Select * from Students Where Status = 'Rejected'

Delete From Students Where Status = 'Rejected'

Example #1: Student Cleanup – normal state

Students

ID	Name	GPA	Status
1	Avi	82.5	Active
3	Danna	91.2	Active

Archive

ID	Name	GPA	Status
2	Benny	62.3	Rejected
4	Ehud	65.3	Rejected

Insert into Archive

Select * from Students Where Status = ‘Rejected’

Delete From Students Where Status = ‘Rejected’

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Example #1: Student Cleanup

Students

ID	Name	GPA	Status
1	Avi	82.5	Active
3	Danna	91.2	Active

Archive

ID	Name	GPA	Status
2	Benny	62.3	Rejected
4	Ehud	65.3	Rejected

What if the DBMS crashed after the INSERT?

Insert into Archive

Select * from Students Where Status = 'Rejected'

Delete From Students Where Status = 'Rejected'

Example #1: Student Cleanup

Students

ID	Name	GPA	Status
1	Avi	82.5	Active
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ID	Name	GPA	Status

Insert into Archive

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Example #1: Student Cleanup

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Archive

ID	Name	GPA	Status
2	Benny	62.3	Rejected
4	Ehud	65.3	Rejected

Crash

Insert into Archive

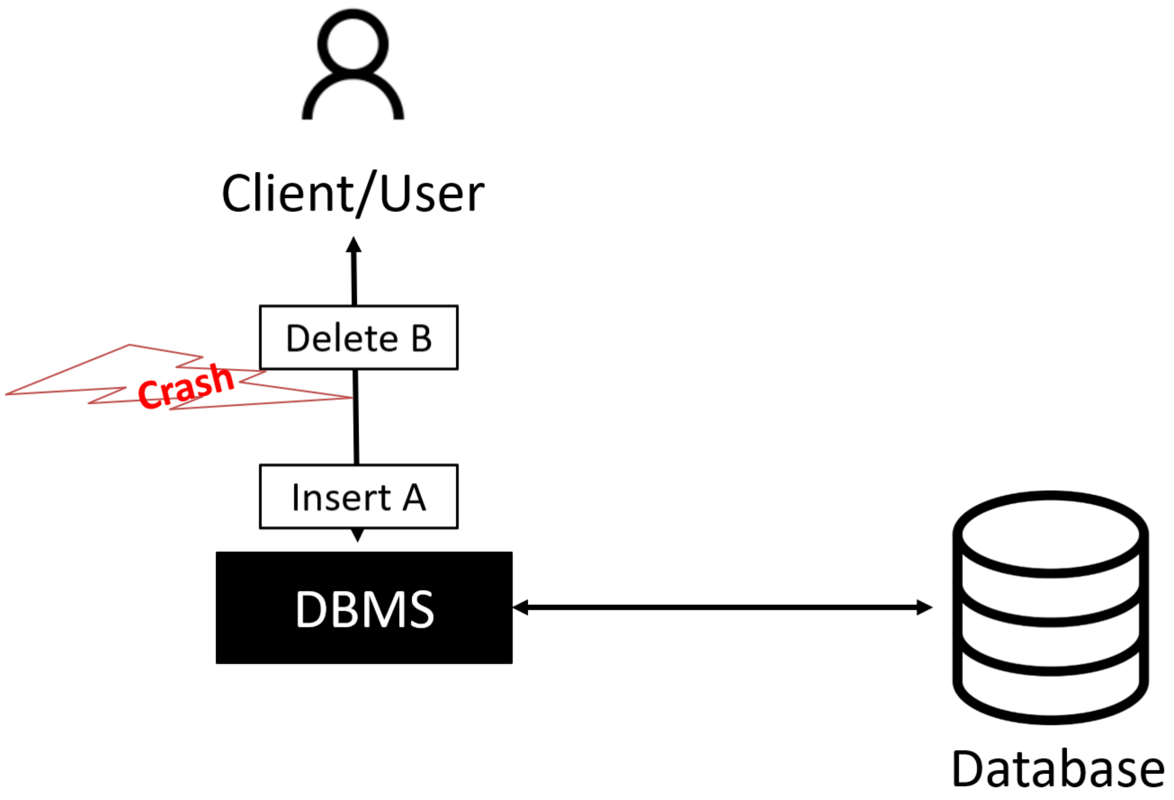
Select * from Students Where Status = ‘Rejected’

Delete From Students Where Status = ‘Rejected’

Example #1: Student Cleanup

- There will be duplicate records both in Archive and Students tables
- If, we run again the query we get failure (duplicate records with the same primary key)
- We need a way to say execute **“all or nothing”**

Example #1: DBMS crash



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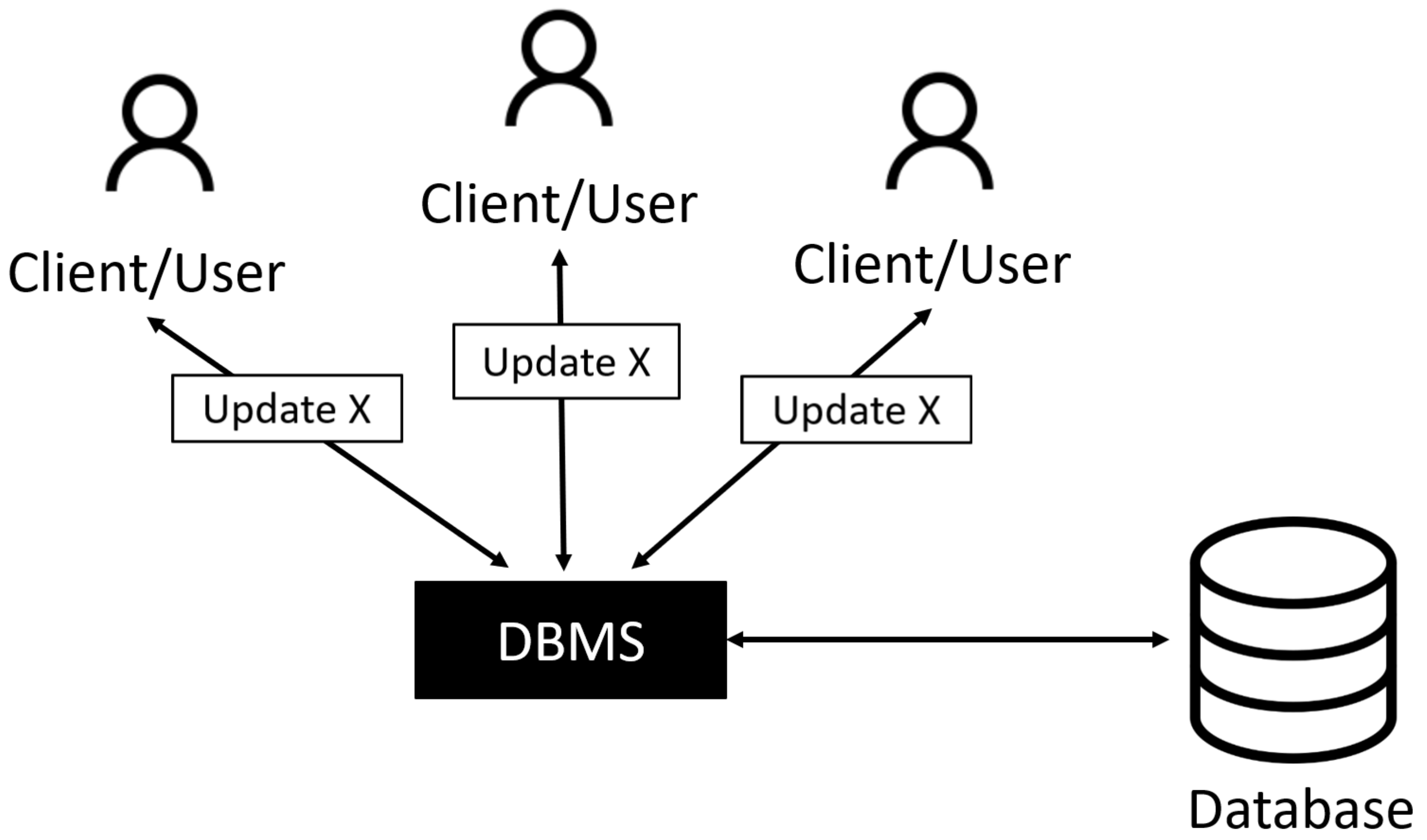
Example #2: Multiple Users



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How to preform an update

```
Update Employees
Set salary = salary + 1000
Where SSN= 7
```

Problem #1: Concurrent Updates

Update **Employees**
Set **salary = salary + 1000**
Where **SSN= 7**

Update **Employees**
Set **salary = salary + 1500**
Where **SSN= 7**

Concurrently

Is it 14,500?

Maybe 13,500 or 13,000???

Employees

SSN	Name	Salary
7	Danna	12,000

What is Danna's salary?

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Problem #2: Concurrent Updates

Update **Employees**
Set **salary = salary + 2000**
Where **SSN= 7**

Update **Employees**
Set **salary = salary/2**
Where **SSN= 7**

Concurrently

Is it 7,000 or 8,000? (even worser than the previous example – no final stage)

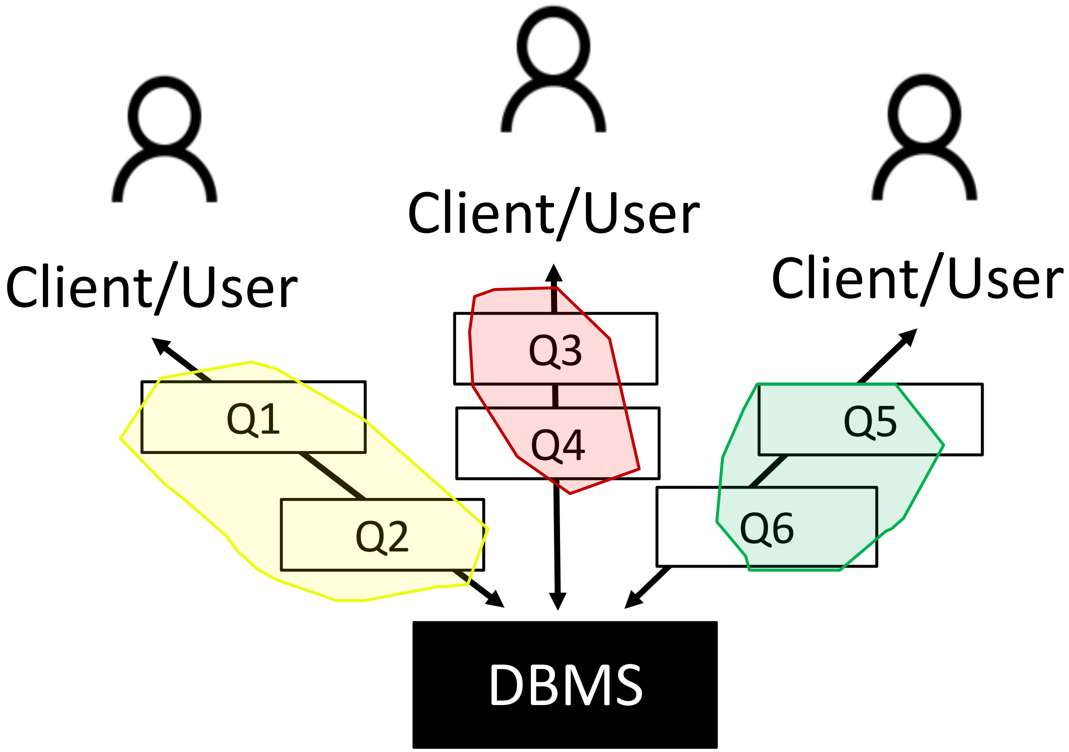
Employees

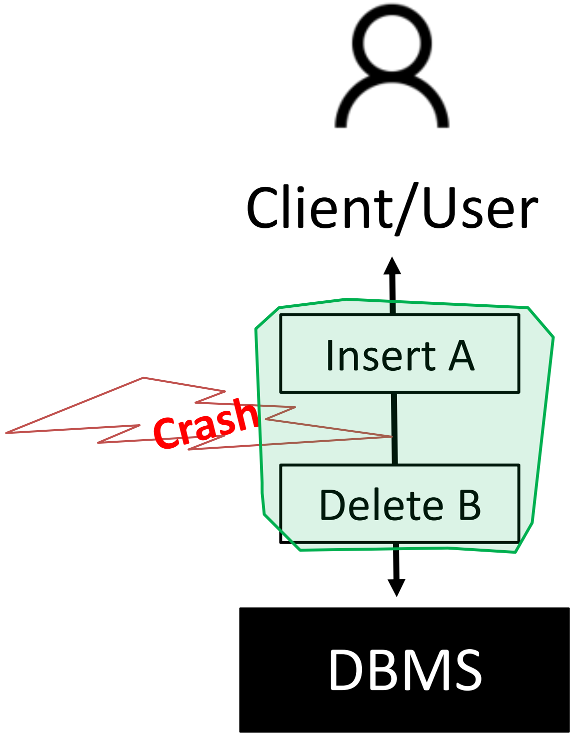
SSN	Name	Salary
7	Danna	12,000

Maybe 14,000 or 6,000???

What is Danna's salary?

Actions Need to be Grouped Together!





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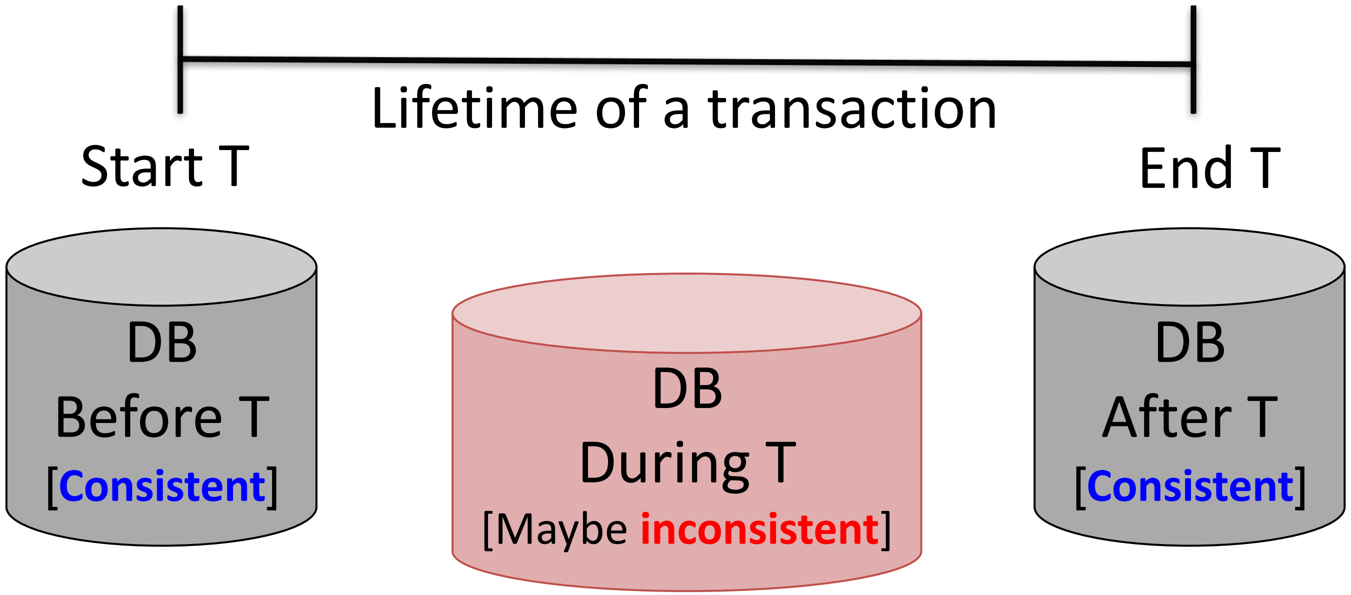
Transactions

Transactions to the Rescue!

Transaction: a **sequence of SQL operations** that are considered as a single unit

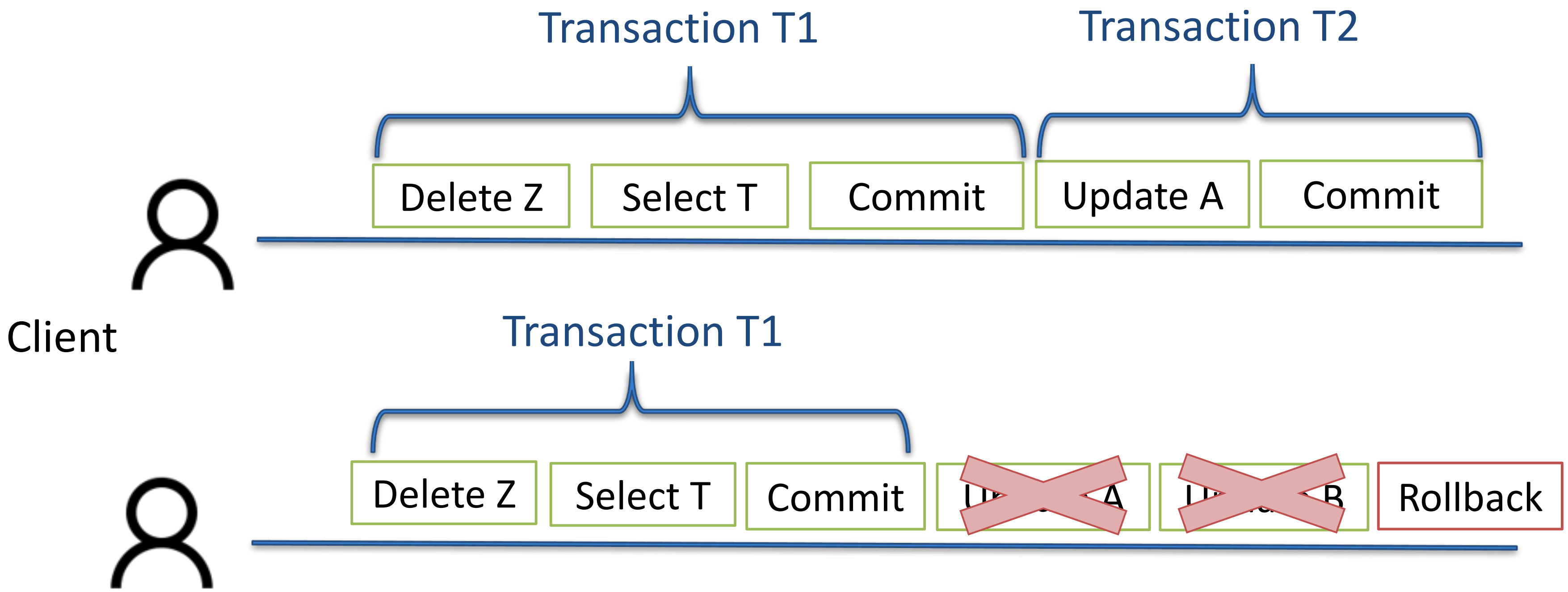
- In a transaction either **all actions are done or none**
- Transitions the DB from one consistent state to another



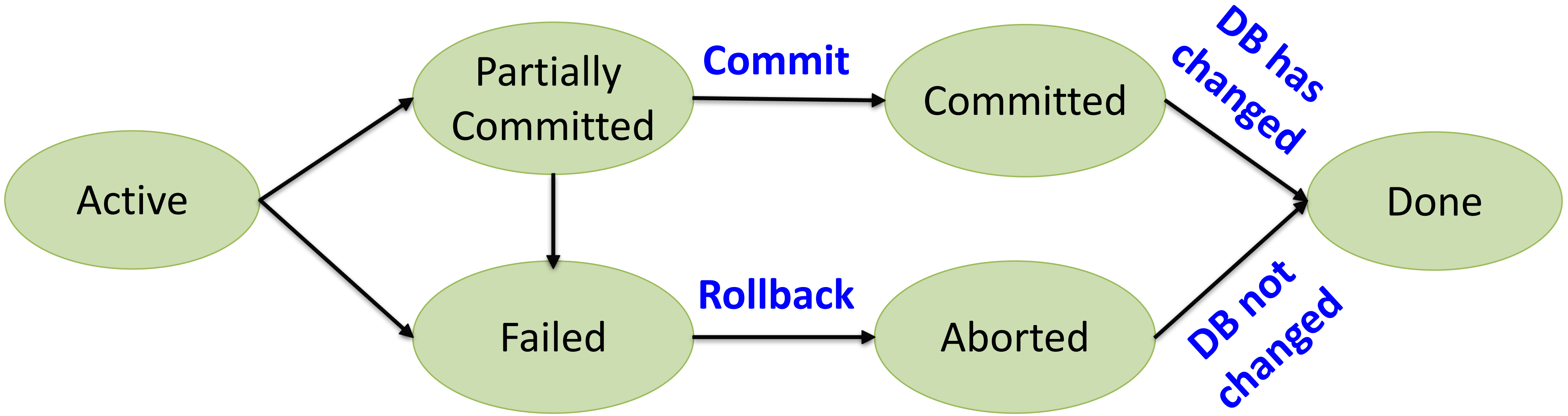
Transaction mechanism

- How we creates transactions?
  1. We apply SQL actions.
  2. When we want to “close” a Transaction we call this command **Commit**.
  3. If we want to “cancel” a started Transaction we do a **Rollback.**

- In many languages we can define auto commit



Transaction lifecycle



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ACID

ACID: Desired Properties of Transactions

- Atomicity
- Consistency
- Isolation
- Durability

ACID: Atomicity

- Each transaction is “all-or-nothing” never left half done.
- What to do if an error occurs in the middle of a Transaction?
  - We perform a rollback to the Transaction to "clear" the changes

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Atomicity

Students

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1	Avi	82.5	Active
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4	Ehud	65.3	Reject

Archive

ID	Name	GPA	Status
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Crash

We solve this problem with atomicity as we return to the commit stage.

Insert into Archive

Select * from Students Where Status = ‘Rejected’

Delete From Students Where Status = ‘Rejected’

ACID: Consistency

Each client, each transaction:

- If all **constraints hold when transaction begins**
- Guarantee all **constraints hold when transaction ends**

- What kind of database constraints are there?

Referential integrity(e.g., cascade delete)

- What is an inconsistent state?

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Atomicity vs. Consistency: are they the same?

- **Atomicity** - In an atomic transaction, a series of database operations either all occur, or nothing occurs. A guarantee of atomicity prevents updates to the database occurring only partially, which can cause greater problems than rejecting the whole series outright.

- **Consistency** - In database systems, a consistent transaction is one that does not violate any integrity constraints during its execution. If a transaction leaves the database in an illegal state, it is aborted, and an error is reported.

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Atomicity vs. Consistency: are they the same? (Simple words)

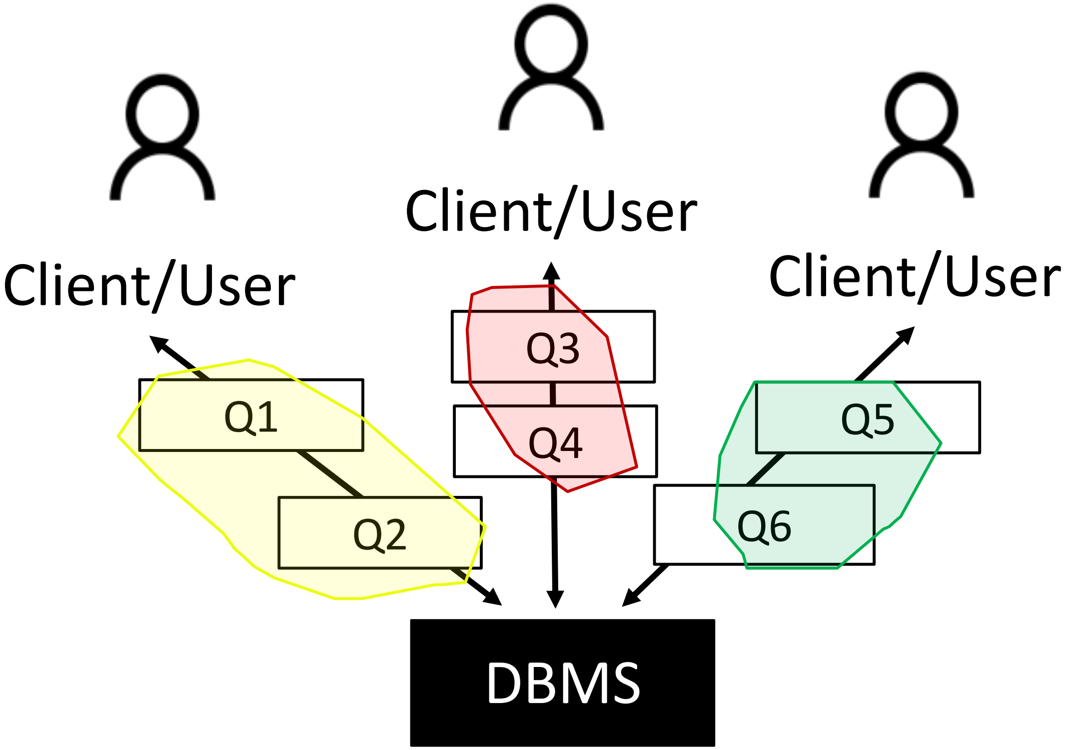
- Atomicity – all the transaction or nothing.

- Consistency – guarantee all constrains in the database. Such as, Referential integrity (e.g., cascade delete)

ACID: Isolation

Isolation

The transaction will behave as if it is the only operation being performed upon the database



Problem #1: Concurrent Updates

Update **Employees** Set **salary = salary + 1000** Where **SSN= 7**

Update **Employees** Set **salary = salary + 1500** Where **SSN= 7**

Concurrently

Is it 14,500?

Maybe 13,500 or 13,000???

Employees

SSN	Name	Salary
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What is Danna's salary?

Problem #2: Concurrent Updates

Update **Employees**
Set **salary = salary + 2000**
Where **SSN= 7**

Update **Employees**
Set **salary = salary/2**
Where **SSN= 7**

Concurrently

Is it 7,000 or 8,000? (even worser than the previous example – no final stage)

Employees

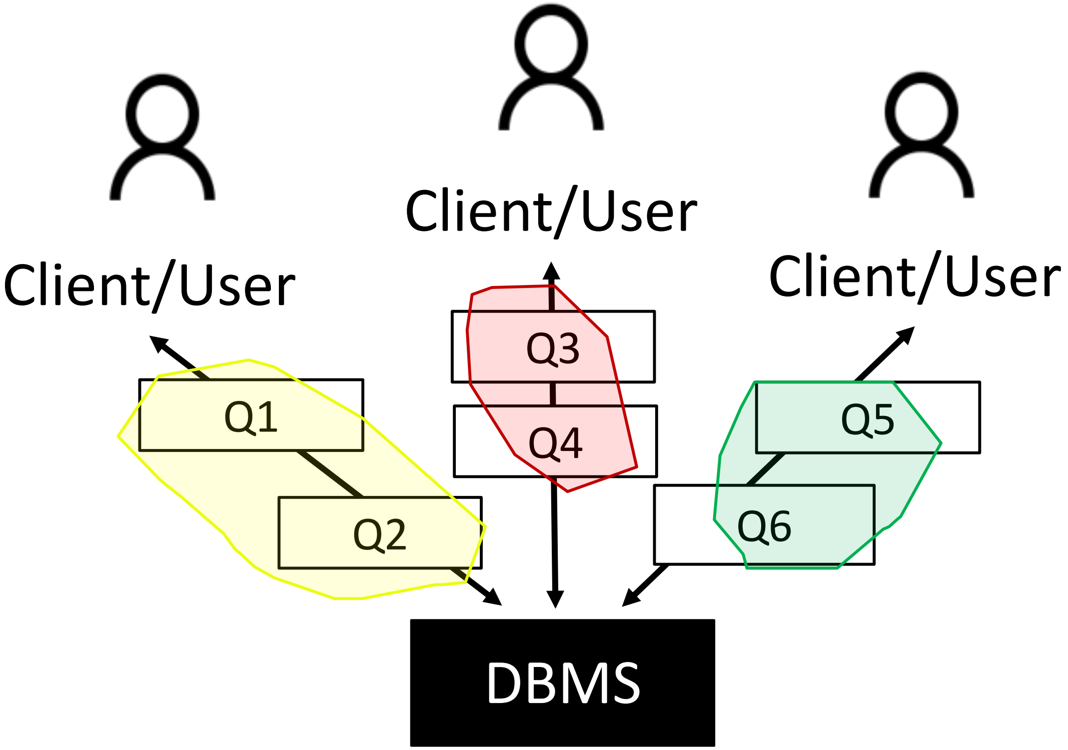
SSN	Name	Salary
7	Danna	12,000

Maybe 14,000 or 6,000???

What is Danna's salary?

ACID: Isolation

- Serializability - Execution must be equivalent to some sequential (serial) order of all transactions
- Often implemented by a locking mechanism



Problem #2: Concurrent Updates

- What is the right answer?

```
Update Employees
Set salary = salary + 2000
Where SSN= 7
```

```
Update Employees
Set salary = salary/2
Where SSN= 7
```

Concurrently

Employees

SSN	Name	Salary
7	Danna	12,000

What is Danna's salary?

- The thing is there is no one answer…
- With Isolation we will get both 7,000 and 8,000 as valid answers but not 14,000 and 6,000.
- As we make sure that transaction preformed in a serialize manner.

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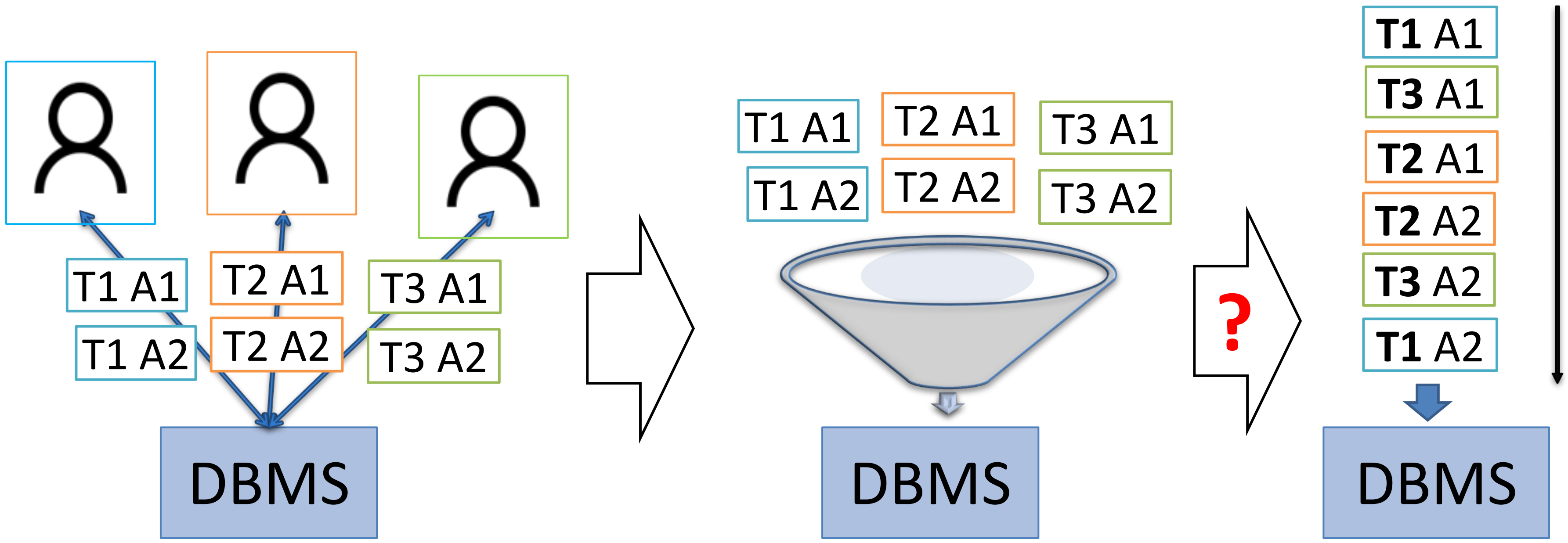
Implementing Transactions on DMBS

Goal: maintaining Isolation

How to preserve Isolation? (while executing concurrently)



Scheduling

- Scheduling is the execution of several Transactions in parallel.
- Only one action is performed at each point in time.
- A reading / writing operation is performed in an atomic form.
- The timing represents the order on the timeline (the vertical axis) in which the actions are performed.

	Read(A)
Read(C)	
	Write(A)
	Read(B)
Write(C)	
Read(B)	
Write(B)	
	Write(B)

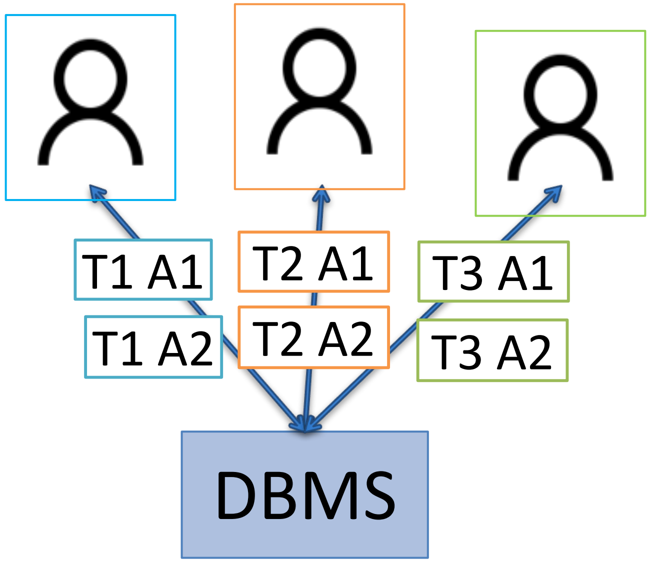
Serializable scheduling

- Scheduling where transactions are performed one after the other.
- Serial timing is correct. (serializable)

Read(A)	
Write(A)	
Read(B)	
Write(B)	
	Read(C)
	Write(C)
	Read(B)
	Write(B)

What is Isolation?

- What is a ***correct*** schedule?



Sequential schedules (s1, s2, s3) **?** (s4, s5)

s1	s2	s3	s4	s5
T1 A1	**T3** A1	**T2** A1	**T2** A2	**T1** A1
T1 A2	**T3** A2	**T2** A2	**T2** A1	**T2** A1
T2 A1	**T1** A1	**T3** A1	**T1** A2	**T2** A2
T2 A2	**T1** A2	**T3** A2	**T3** A1	**T3** A1
T3 A1	**T2** A1	**T1** A1	**T1** A1	**T1** A2
T3 A2	**T2** A2	**T1** A2	**T3** A2	**T3** A2

Serializable schedule

- A schedule is a serializable schedule if it is equivalent to any serial scheduling.
- Serializable schedule is a correct schedule.
- Need a way to determine that a schedule is serializable without knowing what calculations are being performed.
- That is, for every possible calculation, the timing should be equivalent to a serial scheduling.

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Equivalent schedules

Two schedules are equivalent if:

- They are composed of the same actions.
- Both schedules have the same effect on the database, meaning that the database has the same values at the end of each of the schedules.
- Both schedules produce the same output to the user, i.e., present the user with the same values for each item they read.

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How the DBMS Achieves Isolation?

Serializability

Operations may be interleaved, but execution must be equivalent to *some* sequential (serial) order of all transactions

How?

DBMS achieve isolation by

enforcing **all schedules to be serializable**

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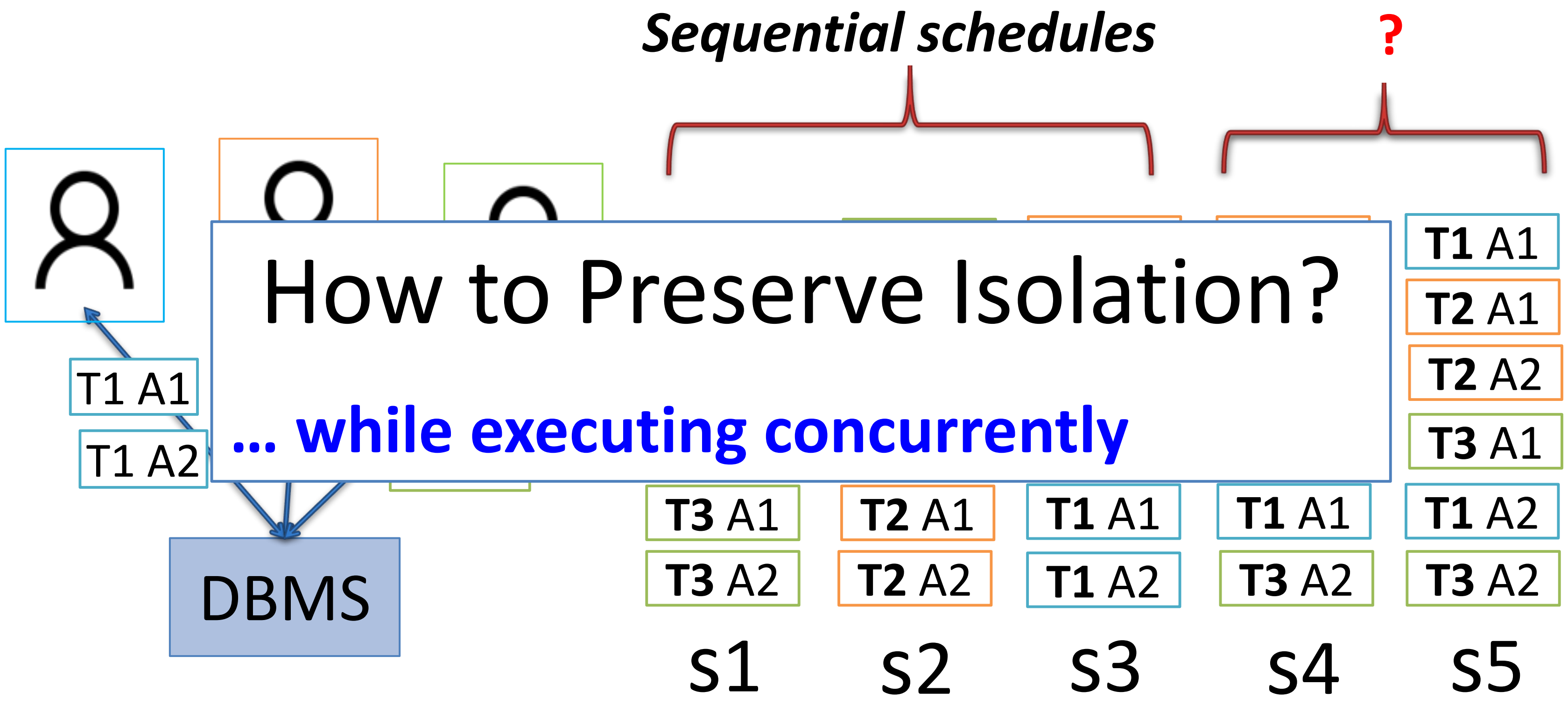
Implementing Isolation: Solution A

- Only allow sequential schedules



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Implementing Isolation: Solution B

1. Generate a schedule
2. Check if it is serializable

How to check if a schedule is serializable?

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Abstraction for computing Isolation

- How do we check if a parallel execution is correct?
  - It depends on the exact calculation of each program execution.
  - Too complicated* to analyze the exact calculation that each calculation performs.

- Thus, we refer only to the abstraction of the programs:
  - Reading operations from the database.
  - Writing actions into the database.
  - The sequence, on the timeline, in which the actions are performed.

Programs	
Read(A)	
A:=A-100	
	Read(C)
Write(A)	
	C:=C-100
Read(B)	
	Write(C)
B:=B+100	
	Read(B)
	B:=B+100
	Write(B)
Write(B)	

*In fact, it is not possible

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Program abstraction

Actual program		Abstraction	
Read(A)		Read(A)	
A:=A-100			
			ad(C)
Write(A)			
Read(B)		Read(B)	
	Write(C)		Write(C)
B:=B+100			
	Read(B)		Read(B)
	B:=B+100		
	Write(B)		Write(B)
Write(B)		Write(B)	

We focus only on the read and write operations

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How to Check if a Schedule is Serializable?

Approach: check ordering constraints

Schedule #1

T1	T2
Read(A)	
	Read(C)
Write(A)	
	Write(C)
	Read(B)
	Write(B)
Read(B)	
Write(B)	

Schedule #2

T1	T2
Read(A)	
	Read(C)
Write(A)	
Read(B)	
	Write(C)
	Read(B)
	Write(B)
Write(B)	

How to Check if a Schedule is Serializable?

Is it serializable?

Schedule #3

T1	T2
Read(A)	
	Read(C)
Write(A)	
Read(B)	
	Write(C)
	Read(B)
Write(B)	

Schedule #2

T1	T2
Read(A)	
	Read(C)
Write(A)	
Read(B)	
	Write(C)
	Read(B)
	Write(B)
Write(B)	

How to check if schedule is serializable?

- Definition: Precedence graph
  - Every transaction is a vertex.
  - There is an edge from T_i to T_j if and only if one of the following conditions is met:
    - T_i performs Read(x) before T_j performs Write (x)
    - T_i performs Write(x) before T_j performs Read(x)
    - T_i performs Write (x) before T_j performs Write(x)

    - Note: read(X) read(X) do not add an edge

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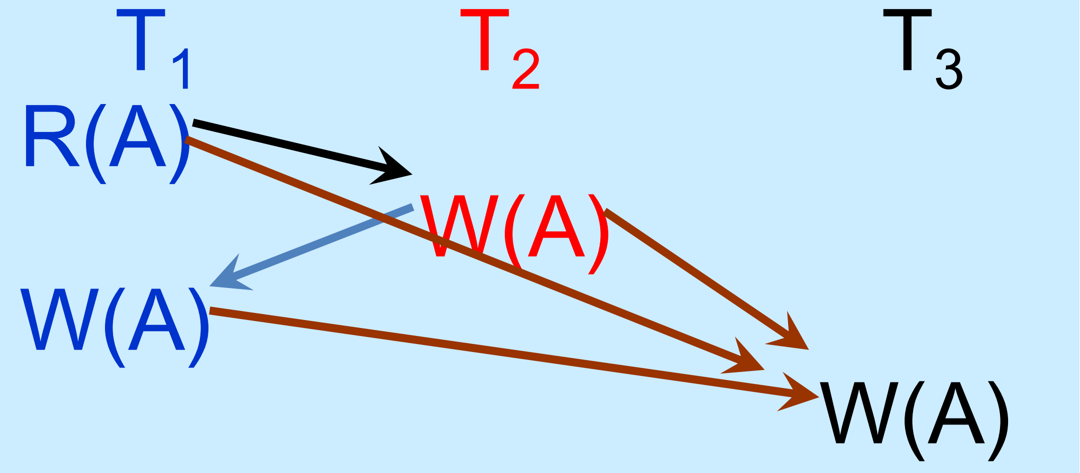
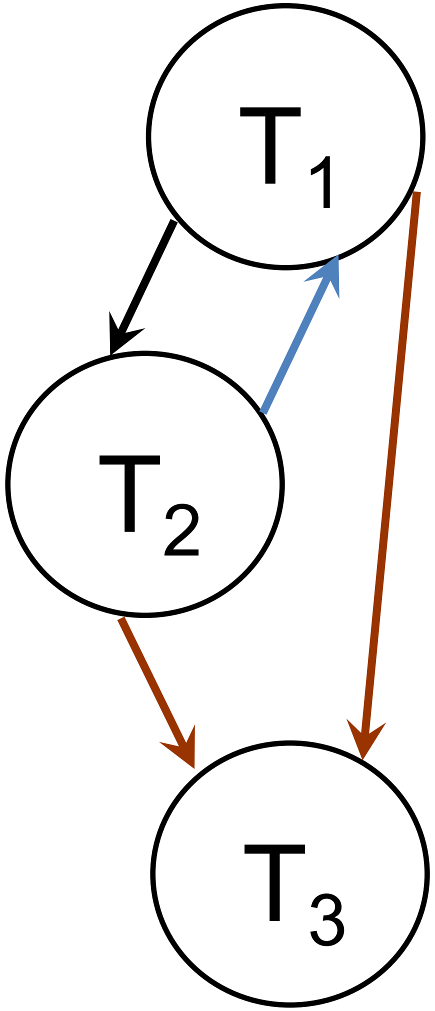
How to check if schedule is serializable?

- Scheduling is serializable if there are no circles in the precedence graph.
  - How to check if there are circuits (algorithm course)?
  - Is it possible to have a serializable schedule in a situation where there are circuits?

Precedence graph - illustration





Equivalent serial scheduling:

T_1	T_2	T_3
R(A)		
W(A)		
	W(A)	
		W(A)

https://www.youtube.com/watch?v=U3SHusK80q0

Implementing Isolation: Solution C

- Goal: create serializable schedules

Approach #1: using **locks**

- What are we locking and why?
- What types of locks do we need?
- When to use which lock?

Exclusive and Shared Locks

- **Exclusive** lock
  - Only one transaction can hold it at time
  - When to use?

- **Shared** lock
  - Many transaction can hold this lock
  - When to use?

When we lock a key?

- To read item A you must first lock it in a shared lock.
  - It is possible to release the lock after reading.
- To write item A you must first lock it with an exclusive lock.
  - It is possible to release the lock after writing.
- If after reading need to write, then transaction can upgrade a shared lock to an exclusive lock.
- Requests for locks are directed to the lock manager.

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When is it allowed to lock a key?

- Multiple transactions can simultaneously hold a shared lock on item A.
  - Provided there is no transactions holding an exclusive lock on A.
- Only one transaction can hold an exclusive lock on item A.
  - Then no other transaction has a shared or exclusive lock on A.
- The lock manager makes sure the rules are followed.

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Lock manager

- The lock manager handles lock requests and lock releases.
- Holds a table that has an entry for each item A with:
  - List of transactions currently holding a lock on A.
  - Type of the lock.
  - Pointer to queue of lock requests on A.
- Receiving a lock and releasing a lock should be done as atomic operations.
- A common lock can be upgraded to an exclusive lock.

How and When to Lock?

Schedule #2	
T1	**T2**
Read(A)	
	Read(C)
Write(A)	
Read(B)	
	Write(C)
	Read(B)
	Write(B)
Write(B)	

Lock Type	Owner	Data item
Shared / Exclusive	T1	A
Shared / Exclusive	T2	C
Shared	T1	B
Shared / Exclusive	T2	B
Exclusive	T1	B

T1 must release its shared key on B before T2

T2 must release its exclusive key on B before T1

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Concurrency Control with Locking

- Goal: **create serializable schedules**
- Approach: using locks

2 Phase Locking (2PL)!

Two-Phase Locking (2PL)

Two-Phase Locking (2PL)

- Transaction must get:
  - Shared lock before reading an item.
  - Exclusive lock before writing an item.

- Once a transaction releases a lock it cannot request additional locks.
- That is why the protocol is called "two-phase locking“
  - First a phase of making locks.
  - Followed by a phase of release of locks.

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2PL Example

Is 2PL?	
T1	**T2**
S(A) Read(A)	
	S(C) Read(C)
X(A) Write(A)	
S(B) Read(B)	
	X(C) Write(C)
	S(B) Read(B)
	X(B) Write(B)
X(B) Write(B)	

Not a 2PL!

Is 2PL?	
T1	**T2**
S(A) Read(A)	
	S(C) Read(C)
X(A) Write(A)	
S(B) Read(B)	
X(B) Write(B)	
T1 release all its keys	X(C) Write(C)
	S(B) Read(B)
	X(B) Write(B)

2PL

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The Downside of Using Locks Is …

Deadlocks

How handle deadlocks?

Detect & handle

Avoid

Deadlock

- A state of deadlock occurs when there is a circle of transactions, so that every transaction in the circle waits for a lock that is currently held by the next transaction in the circle.

- Two ways to deal with deadlock:
  - Prevention of deadlock.
  - Detection of deadlock and cancellation.

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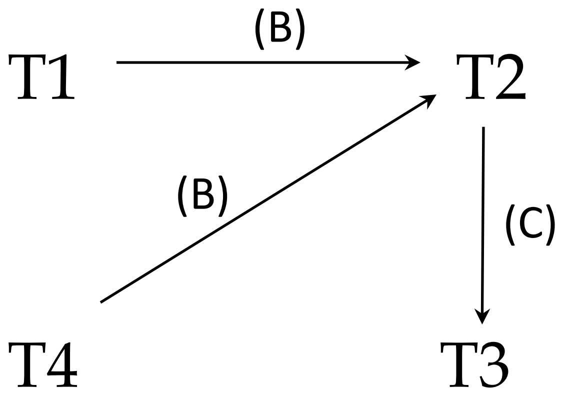
Is there a Deadlock here?

T1:	S(A), R(A),		S(B)					
T2:		X(B),W(B)				X(C)		
T3:				S(C), R(C)				X(A)
T4:					X(B)			

How to find a Deadlock?

T1:	S(A), R(A),		S(B)				
T2:		X(B),W(B)				X(C)	
T3:				S(C), R(C)			X(A)
T4:					X(B)		



Detection of deadlock – option 1

- Build a "wait for" graph
  - Node for every transaction.
  - from T_1 to T_2 if T_1 is waiting for a lock that T_2 currently holds.
- From time-to-time check if there is a circle in the graph (which means a state of deadlock)
- If there is a circle, cancel one of the transaction that is on the circle, and start it again.

Detection of deadlock – option 2

- Timeout method - after a certain amount of time without progress in making the transactions, it can be assumed that there is a Deadlock.

- Release from Deadlock is done by performing ABORT on at least one of the transactions.

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