COMP9120

Week 9: Transaction Management

Semester 1, 2025

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THE UNIVERSITY OF SYDNEY

Contents co-developed with Dr Lijun Chang

Warming up

Acknowledgement of Country

I would like to acknowledge the Traditional Owners of Australia and recognise their continuing connection to land, water and culture. I am currently on the land of the Gadigal people of the Eora nation and pay my respects to their Elders, past, present and emerging.

Copyright warning

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Quiz information

- **Quiz** in Week 10 (next week)
  - Date: **Thursday, 8 May, starts at 5:30 PM Sharp.**
  - Mode: In-class
  - Each one of you will be assigned to a room for the quiz. This assignment has been announced on Ed and published on Canvas (see https://canvas.sydney.edu.au/courses/63042/groups#tab-42412). You **cannot change your room assignment**. The quiz will be held in 4 rooms (lecture theatres) across campus and 1 additional room for those on the Disability Academic Program.
  - You must arrive at **5:00pm sharp** at your **assigned quiz room** to have your id and room assignment checked before you are allowed to take the quiz. There will be no exception!
  - Duration → **90 minutes**
  - Pen-and-paper based closed book quiz. You are **not** allowed to bring anything besides your writing implements or a university approved dictionary. Everything else will be provided.
  - Covers week 1, 2, 3, 4, 5, 6, 8, 9 contents
    - **3 MCQ questions** (total of 3 marks) and
    - **6 essay questions** (total of 15 marks)

Note: **tutorials scheduled at 7pm on Thursday 8 May are cancelled**. If you are in one of these tutorials, please attend one of the alternative 8 pm sessions on Thursday or any session on Friday. **Week 10 Tutorials will be Q&A sessions.**

Outline

- Motivation for Transactions
- Required Properties of Transactions:
  - **A**tomicity, **C**onsistency, **I**solation, **D**urability (ACID)
    - Meaning of the ACID Properties (What?)
    - Importance of ACID Properties (Why?)
    - Strategies for Ensuring ACID Properties Hold (How?)

Motivation

Complex SQL statements

Not all database operations are *atomic, i.e., executed in one single operation*

Need to model *complex operations that consist of multiple steps* but should be **executed** as *one single logical operation:* **Transaction**

Example of transactions:

1. Purchasing a house
2. Bank transfer
3. Online transactions
4. etc.

No transactions?

What could happen if we *did not have* a *transaction*?

Transfer Operation

Transfer $100

from Account A

to Account B

Account A

Withdraw $100

Account B

Deposit $100

System fails

Account balance successfully updated for Account A

When the system recovers, the database state *no longer reflects the account transfer* (short of $100)!

Solution: Should *group* withdraw & deposit operations – so that they either *both succeed*, or *not happen at all*

one success
one fail

BEGIN;
Withdraw $100 from Account A;
Deposit $100 into Account B;
COMMIT;

What is a transaction?

- A database program consisting of *one* or *more* SQL statements
  - *Executed* as an *atomic* unit

    means

    - Atomicity implies that the ***effect*** of the transaction is that it executes ***fully*** or ***not at all***.

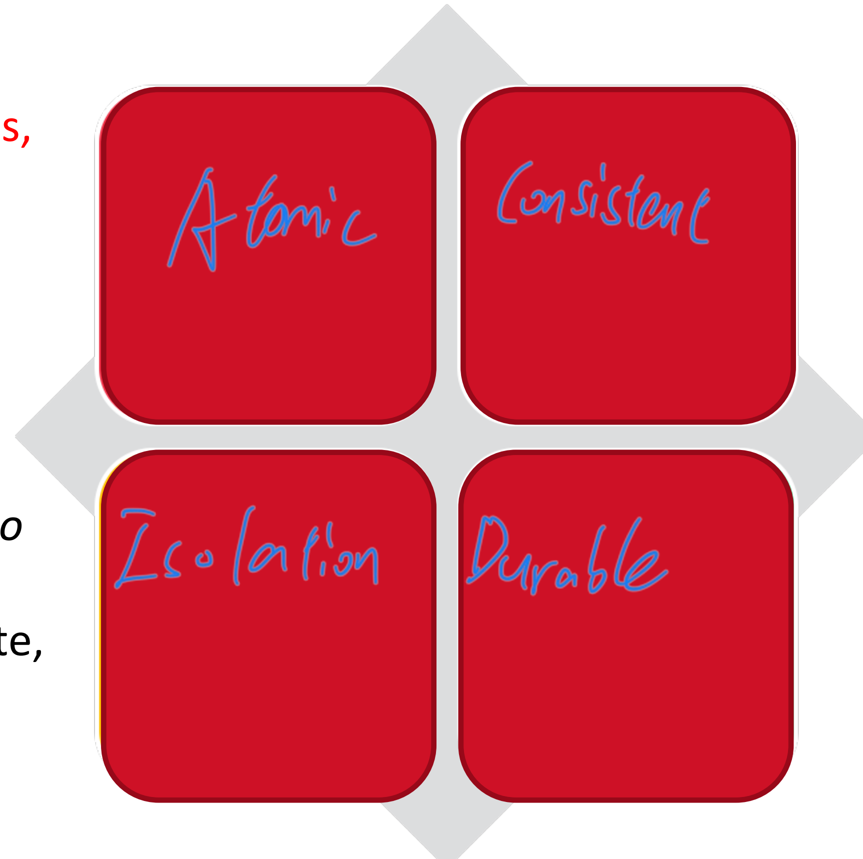
Another way to **describe** a transaction:

- *It is **a program** that is executed to change the database state in a correct way*
  - e.g., Bank balance must be *updated* on *both* accounts when a transfer is *complete*
- **Formal definition**: A ***transaction*** is a collection of *one* or *more* operations (consisting of ***reads*** and ***writes*** at the DBMS level) which reflect a *discrete* (i.e., *single*) unit of work.

Required properties of a transaction

Reliability and correctness of databases require transactions to conform to some strict expectations, called ***ACID*** *properties*.

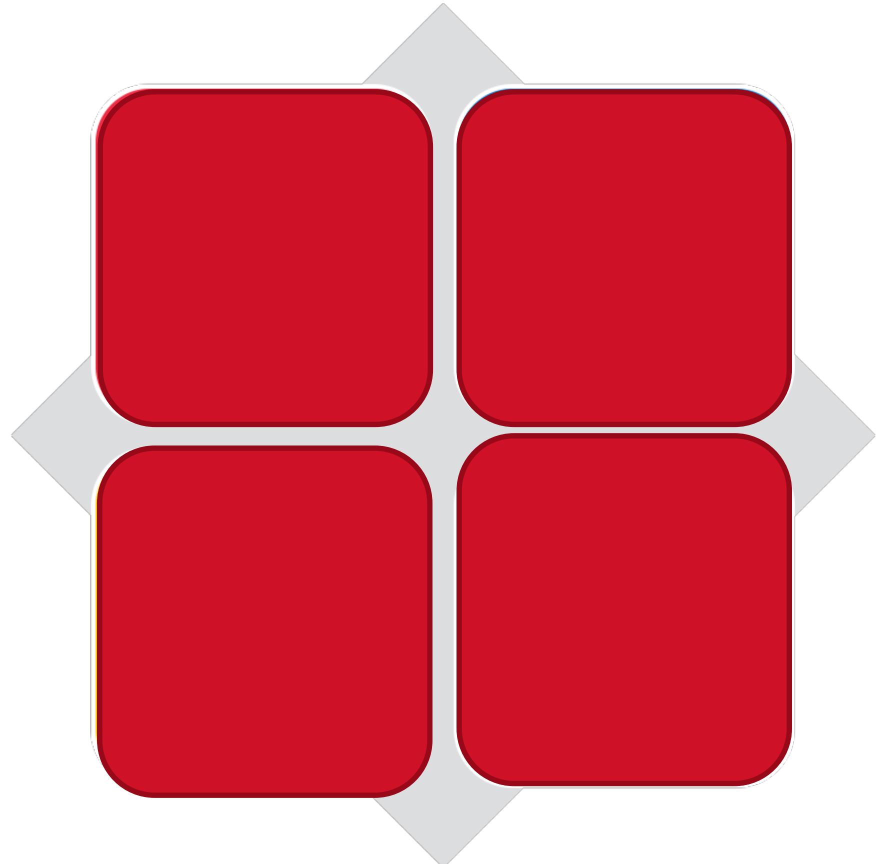
- *Atomicity*: A transaction is either performed *entirely* or *not performed at all*. The whole transaction is treated as *one atomic* operation.
- *Consistency*: A correct execution of a transaction must take a database *from one consistent state to another*: The transaction, if executed separately from others, leaves the database in a correct state, i.e., *all integrity constraints* are *satisfied*.



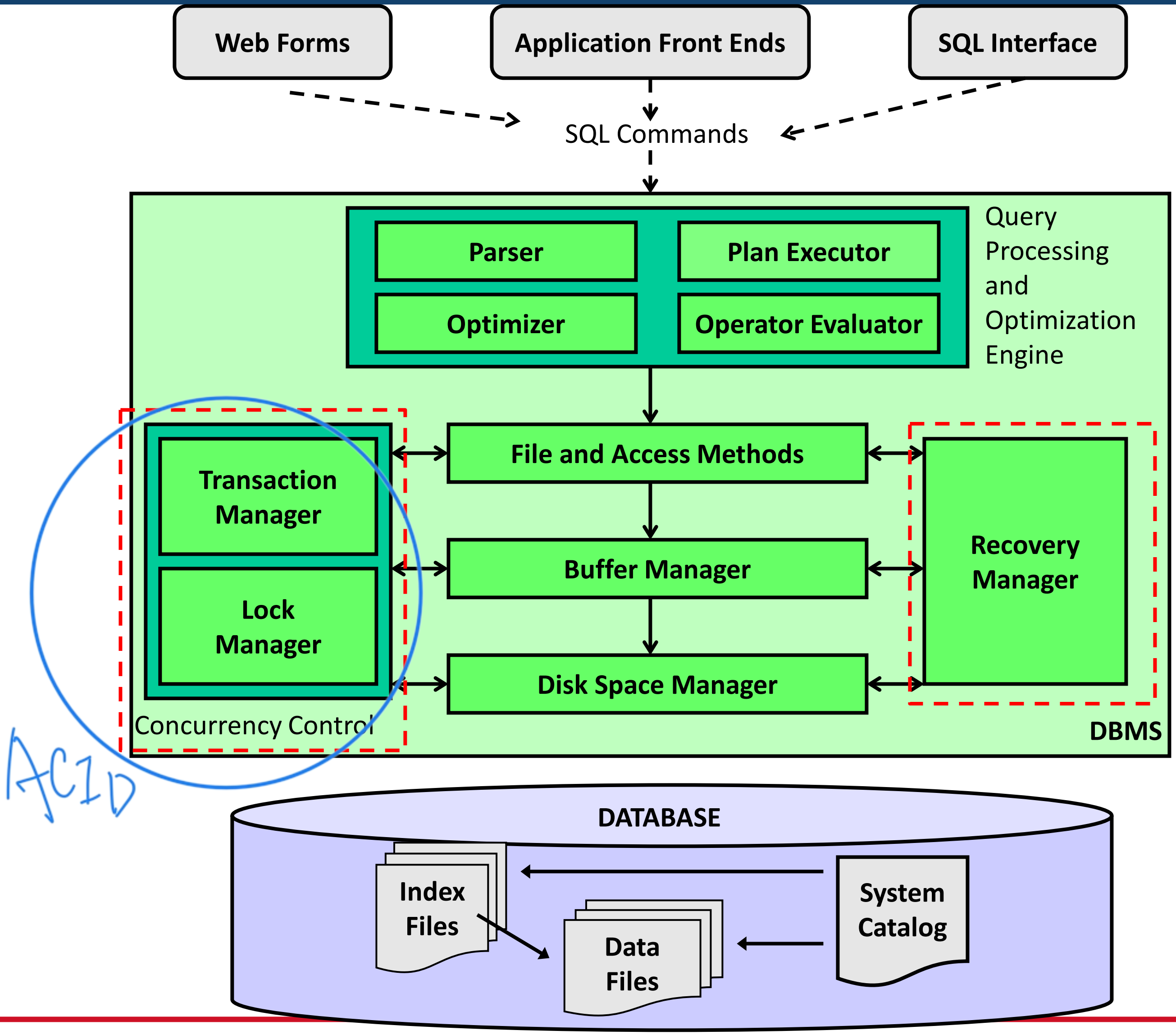
Required properties of a transaction (cont’d)

- *Isolation*: *Effect* of multiple transactions is the same as the transactions *running one after another*: For every two transactions running concurrently, the effect of the execution is as if the transactions are running sequentially, i.e., a transaction is *unaware* of other transactions that may be running *concurrently*.

- *Durability*: Once a transaction changes the database and the changes are *committed*, these changes must *never* be *lost* because of subsequent *failures*: This means that once a transaction completes *successfully*, the results will *survive* even if there is a system *failure*.



Internal Structure of a DBMS



Outline

- **Consistency**
  - What, why, and how?

- **Atomicity**

- **Durability**

- **Isolation**

Transaction consistency

- Assuming the database is in a *consistent* state initially (*satisfying all constraints*). When the transaction *completes*, it **is consistent** if:

  1. *All database constraints* are satisfied
  2. The new database state *satisfies* the *specifications* of the transaction, i.e., *intended effects* of the transaction.

Consistency refers to the requirement that any given transaction can *only modify* data in *allowed* ways. Therefore, any data written to the database must *agree* with all *defined rules*, including *constraints* and *triggers*.

- Each transaction should preserve the consistency of the database. Note that this is *mainly the responsibility of the application developer*!
  - Database *cannot 'fix'* the correctness of a *badly coded transaction*
    - Example of a *bad transaction* for a bank transfer:
      - Withdraw $100 from account A, but only deposit $90 into account B.

Transaction: Timing of Consistency Checking

Note: We can select **when** to **enforce** the database consistency in the transaction!

Example: We may *defer* the enforcement of integrity constraints.

```
CREATE TABLE UnitOfStudy (
  uos_code        VARCHAR(8),
  title           VARCHAR(20),
  lecturer_id     INTEGER,
  credit_points   INTEGER,
  CONSTRAINT UnitOfStudy_PK PRIMARY KEY (uos_code),
  CONSTRAINT UnitOfStudy_FK FOREIGN KEY (lecturer_id)
     REFERENCES Lecturer DEFERRABLE INITIALLY IMMEDIATE
);
BEGIN;
   SET CONSTRAINTS UnitOfStudy_FK DEFERRED;
   INSERT INTO UnitOfStudy VALUES('INFO1000', 'Graphics', 3, 6);
   INSERT INTO Lecturer VALUES(3, 'Steve', CSE);
  SET CONSTRAINTS UnitOfStudy_FK IMMEDIATE ;
COMMIT;
```

does not exist yet!

UnitOfStudy

uos_code	title	lecturer_id	credit_points
COMP9120	DBMS	1	6
COMP9007	Algorithm	2	6

Lecturer

Lecturer_id	name	department
1	Adam	CSE
2	Lily	IT

Outline

- Consistency
- **<u>A</u>tomicity**
  - What, why, and how?
- Durability
- Isolation

Transactions should be Atomic

- A real-world transaction is expected to *happen* or *not happen at all* (e.g., for a bank transfer, either both withdrawal + deposit occur, or neither occurs).
  - *Partially completed* transaction can lead to an *incorrect database state*.

- Solution: DBMS ***logs** all actions* that would need to be ***undone if*** the transaction is *aborted* (i.e., it is *incomplete*).
  - E.g., in case of a *failure*, all actions of *not-committed* transactions are *undone*.
  - In some cases, we can do a **redo, i.e.,** use the logs to copy over the data

Commit and Abort

- If the transaction *successfully completes*, it is said to have **committed**
  - The DBMS is responsible for ensuring that all changes to the database have been saved
- If the transaction does *not* successfully *complete*, it is said to have been **aborted**
  - The DBMS is responsible for undoing, i.e., **rolling back**, all changes in the database that the transaction had made
  - Examples of reasons for **abort**:
    - System crash – e.g., power outage
    - Transaction aborted by system, e.g.,
      - Transaction or connection time-out,
      - Deadlocks,
      - Violation of constraints
    - Transaction explicit request to roll back

Writing a transaction in SQL

› 3 key relevant SQL commands to know:

Syntax

- **BEGIN**
- **COMMIT** *requests* to **commit** current transaction
- **ROLLBACK/ABORT** causes current transaction to **abort**.

sql statement

› Can also **SET AUTOCOMMIT OFF** or **SET AUTOCOMMIT ON** in pgadmin client
- With *auto-commit on*, each statement is *its own transaction* and 'auto-commits'
- With *auto-commit off*, statements form part of a larger transaction delimited by the keywords discussed above.

› Different clients have different defaults for auto-commit.

What value should be returned?

uosCode	lecturerId
COMP5138	3456
COMP5338	4567

```
BEGIN;
UPDATE Course SET lecturerId=1234 WHERE uosCode='COMP5138';
COMMIT;
SELECT lecturerId FROM Course WHERE uosCode='COMP5138';
```

1. 1234 ✓
2. 3456
3. 4567

What value should be returned?

<u>uosCode</u>	lecturerId
COMP5138	3456
COMP5338	4567

```
BEGIN;
UPDATE Course SET lecturerId=1234 WHERE uosCode='COMP5138';
ROLLBACK;
SELECT lecturerId FROM Course WHERE uosCode='COMP5138';
```

1. 1234
2. 3456 ✓
3. 4567

What value should be returned?*

uosCode	lecturerId
COMP5138	3456
COMP5338	4567

fail now, because lectureId is PK and should be unique

```
BEGIN;
UPDATE Course SET lecturerId=4567 WHERE uosCode='COMP5138';
COMMIT;
SELECT lecturerId FROM Course WHERE uosCode='COMP5138';
```

1. 1234
2. 3456 ✓
3. 4567

Outline

- Consistency
- Atomicity
- **Durability**
  - What, why, and how?
- Isolation

Transactions should be Durable

- Once a transaction is *committed*, its effects should *persist* in a database, and these effects should be *permanent* even if the *system crashes*.

  - In the event of software or hardware malfunction, parts of the database may be erased or corrupted:
    - A database should *always* be *able* to *recover* to the last *consistent* state

Transaction logs

- Solution: use **stable storage** (e.g., hard disk) as a **log** to store a history of modifications made to the database.
- What part of the DBMS is responsible for this? **Recovery Manager**
- Mechanism:
  - Every transaction has a "log" associated with it.
  - Every time an **exclusive lock** on an item is granted, **any update** to that item is also **mirrored** in the log.
  - If a transaction **aborts**, depending on the **recovery protocol**, use the **log** to **undo/redo** the transaction.

- **Undo** operation: bring back an item to its initial value (i.e., *before* the transaction started execution).
- **Redo** operation: *copy* the *log value* of an item from *stable storage* to disk (making the modification now persistent/permanent).

Outline

- Consistency
- Atomicity
- Durability
- **Isolation**
  - What, why, and how?
  - Isolation through conflict serializability
  - Lock-based concurrency control

Purpose of Concurrency Control

› Note

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- Transactions can run concurrently; meaning their operations can be interleaved. The interleaving is usually *decided* by the *host operating system* based on some scheduling algorithm.
- If there is *no intervention* from the transaction manager, the database may be left in an *incorrect* and *inconsistent* state because of

  problem

  - **Concurrent access** (i.e., interleaving of operations) involving ***updates*** to the database

› Therefore, there is a need to:

- **Control concurrent** *access* to the database to ensure not only **correctness** but also **efficiency**

Concurrent access issues

- We identify three (3) types of **problems** that can **compromise** database **correctness** in the presence of **concurrent** access:
  - **Lost update** problem
  - **Temporary update** problem
  - **Incorrect summary** problem

Interference issues

- **Lost Update Problem**:
  - Occurs when two transactions are *interleaved* in such a way that makes an *item's final value incorrect*. That is, a transaction *does not* see its *own update* but rather *sees the updates* of *other* transactions. This means that the ***update** of a transaction is **lost*** because **another** transaction has **updated** this value.

- **Temporary Update Problem**:
  - Occurs when a transaction *updates* an item and then *fails*. Another transaction that read the item is *unaware* it has been *changed back* to its *original* value.

    due to failure

- **Incorrect Summary Problem**:
  - Happens when a transaction is *updating* an *aggregate of items*. If another concurrent transaction is allowed, the *aggregating transaction* may potentially access a *mixture of old and new values*.

Lost Update Problem

› Example of the **Lost Update Problem**:

› Consider 2 concurrent transactions T1 and T2. T1 is a bank account **transfer**. T2 is a bank account **deposit**. X and Y are two different accounts.

› First case: Let us assume that the transferred amount in T1 is N=$50, and the amount deposited in T2 is M=$100. Assume that before we execute the schedule below, the accounts values for X=$60, Y=$30.

T_1	T_2
READ (X)	READ(X)
X= X-N	X=X+M
WRITE(X)	WRITE(X)
READ(Y)	
Y=Y+N	
WRITE(Y)	

update here

read old (because before WRITE(x) in left)

TIME

	T_1	T_2	
X=60	READ (X)		
X=10	X= X-N		
		READ(X)	X=60
		X=X+M	X=160
X=10	WRITE(X)		
Y=30	READ(Y)		
		WRITE(X)	X=160
Y=80	Y=Y+N		
Y=80	WRITE(Y)		

item X has an **incorrect** value because its update by T1 is **lost**! X is now $160 (60+100) but should be $110 (60-50+100) at the end of this schedule!

Temporary update problem

› Example of the **temporary update problem**:

› Consider two transactions T1 and T2 with the same initial values as in the previous example. A possible execution schedule is:

TIME

	T_1	T_2	
X=60	*READ (X)*		
X=10	*X= X-N*		
X=10	*WRITE(X)*		
		READ(X)	X=10
		X=X+M	X=110
		WRITE(X)	X=110
Y=30	*READ(Y)*		
	Y=Y+N		
	WRITE(Y)		

T1 fails here

. Read the new X
. but fail later so
new X rollback

› T1 **fails**: should change X back to its *original* value, i.e., X=\$60, but meanwhile T2 has read the *temporary incorrect value* of X=\$10!

Because T1 *failed*, all of T1 operations are *undone*. The issue is that T2 had *already* read the *updated value of X* from T1 *producing the value \$110* which *is no longer correct!*

Incorrect summary problem

› Example of the **incorrect summary problem**:

› Consider two transactions T1 and T2 and the following execution schedule. Assume that A=$80 and N=$50 and that initially X=$60, Y=$30

	T_1	T_2	
		SUM=0	
		READ(A)	A=80
		SUM=SUM+A	A=80
X=60	*READ(X)*		
X=10	*X=X-N*		
X=10	*WRITE(X)*		
		READ(X)	X=10
		SUM=SUM+X	SUM=90
		READ(Y)	Y=30
		SUM=SUM+Y	SUM=120
Y=30	*READ(Y)*		
Y=80	*Y=Y+N*		
Y=80	*WRITE(Y)*		

TIME

› T2 reads X after N is subtracted and reads Y *before* N is added: an **incorrect summary** is obtained. It consists of *new* and *old* values. In this case, SUM=$120 while it should be SUM=$170 after the completion of the two transactions!

Transactions in SQL standard

› There are four ***isolation levels*** in the SQL standard:

- ***read uncommitted***: A transaction can *read data* written by a concurrent *uncommitted* transaction. This is a called **dirty read**.
- ***read committed***: the database *will not read* any of the *uncommitted* values, i.e., **no dirty reads.**
- ***repeatable read***: A transaction *only sees data committed* **before** the transaction **began**; it *never sees* either *uncommitted* data or *changes committed* by concurrent transactions while it is executing.
- ***serializable***: *highest level* of isolation - *serializable execution* is defined to be an execution of concurrently executing transactions which produce the *same effect* as some *serial execution* of these same transactions.

- **PostgreSQL** does **not** implement **read uncommitted** and requests for this type of isolation is defaulted to **read committed.**

Transactions SQL standard mapping to update problems*

Mapping of *isolation levels* to *update problems*:

- **read uncommitted** ➡ allows dirty reads
- **read committed** ➡ addresses temporary update problem
- **repeatable read** ➡ addresses incorrect summary problems
- **serializable** ➡ addresses the lost update problem

fit each problem respectively

How to set the transaction isolation level for the current transaction block

- SET TRANSACTION ISOLATION LEVEL

  { SERIALIZABLE | REPEATABLE READ | READ COMMITTED | READ UNCOMMITTED };

Syntax

Short break

please stand up and stretch

Let us also menti….

Outline

- Consistency
- Atomicity
- Durability
- **Isolation**
  - What, why, and how?
  - Isolation through conflict serializability
  - Lock-based concurrency control

Transactions should be Isolated

- Transactions should be *isolated* from the effects of *other* concurrent transactions.
- Let us consider two transactions that are run *concurrently*
  - Transaction T1 is transferring $100 from account A to account B.
  - T2 credits both accounts with a 5% interest payment.

T1:	BEGIN	A=A-100,	B=B+100	COMMIT
T2:	BEGIN	A=1.05*A,	B=1.05*B	COMMIT

We assume that all transactions commit, there is no aborted transaction!

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Example Executions of Two Transactions

- **Serial execution**: we can look at the transactions in a timeline view

```
T1: A=A-100, B=B+100
T2:                           A=1.05*A, B=1.05*B
```

Time

T1 transfers $100 from account A to account B

T2 credits both accounts with a 5% interest payment

Change order would affect meaning

- The transactions can execute in another order…Remember that DBMS **allows it**!

```
T1:                           A=A-100, B=B+100
T2: A=1.05*A, B=1.05*B
```

Time

T2 credits both accounts with a 5% interest payment

T1 transfers $100 from account A to account B

- DBMS can also **interleave** the transactions execution.

```
T1: A=A-100,                B=B+100
T2:            A=1.05*A,                B=1.05*B
```

Isolation through Serializability

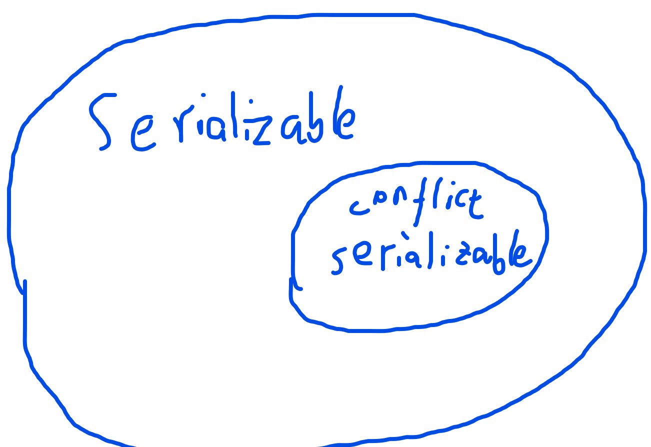
- **Serial Schedule:** A schedule in which all transactions are executed from start to finish, *without any interleaving*, i.e., *one after the other*.
  - In *serial execution*, each transaction is **isolated** from all others

- However, **Interleaving** (concurrent execution) **improves performance** and **response time**:
  - Some transactions may be *slow* and long-running – don't want to block other transactions!
  - Disk access may be *slow* – let some transactions use CPUs while others access disk!

Isolation through Serializability

- Though individual transactions **running separately** from others yield **correct** database states, their **concurrent execution** may yield **incorrect** states!

- Thus, to ensure *database correctness*, we need to ensure *transaction Isolation*: ***Serializability***.
  - A **schedule** is **serializable** if and only if it is **equivalent** to *some* **serial** schedule
  - Two schedules S1 and S2 are **equivalent** if, ***for any initial database state***, the ***effect*** on the database of executing S1 **is identical to** the *effect* of executing S2



Example of a Serializable Schedule

› Consider the following **interleaved** execution (called a **schedule**)

```
T1: A=A-100,                    B=B+100
T2:           A=1.05*A,                   B=1.05*B
```

$A_F = 1.05*(A_i-100)$, $B_F = 1.05*(B_i+100)$

serializable

› It is serializable, as the *result* of the above interleaved execution is the *same* as that of the following *serial execution* of T1 followed by T2

```
T1: A=A-100, B=B+100
T2:                         A=1.05*A, B=1.05*B
```

$A_F = 1.05*(A_i-100)$, $B_F = 1.05*(B_i+100)$

› Note that there is another serial schedule.

```
T1:                         A=A-100, B=B+100
T2: A=1.05*A, B=1.05*B
```

$A_F = (1.05*A_i)-100$, $B_F = (1.05*B_i)+100$

Do not care because we already find one

Example of a Non-Serializable Schedule

› Consider the following **interleaved** execution

```
T1: A=A-100,                               B=B+100
T2:              A=1.05*A, B=1.05*B
```

$A_F = (A_i\text{-}100)*1.05,\ B_F = B_i*1.05+100$

› It is not serializable: the result of the above interleaved execution is *not the same* to *either* of the following *two serial* executions.

```
T1: A=A-100, B=B+100
T2:                          A=1.05*A, B=1.05*B
```

$A_F = 1.05*(A_i\text{-}100),\ B_F = 1.05*(B_i+100)!$

```
T1:                          A=A-100, B=B+100
T2: A=1.05*A, B=1.05*B
```

$A_F = (1.05*A_i)\ \text{-}100!,\ B_F = (1.05*B_i)+100$

DBMS's View of a Schedule

› Serializability is *expensive* to *check*

- We need to *check* the *effect* of the schedule on *all* initially consistent databases

› Let us see how we can *analyze* schedules *without* executing them.

› Assume the following schedule:

```
T1: A=A-100,                          B=B+100
T2:            A=1.05*A, B=1.05*B
```

› To do this, we need to see the *DBMS's view of a schedule*

```
T1: R1(A),W1(A),                                R1(B),W1(B)
T2:               R2(A),W2(A),R2(B),W2(B)
```

- **R: reading** the content of an object from the database
  - R1 (or R_1): reading by transaction T1
  - R2 (or R_2): reading by transaction T2
- **W: writing** the content of an object into the database
  - W1, W2 are similarly defined

Conflict serializability

- One type of serializability is ***conflict serializability***: A schedule is conflict serializable if it is ***conflict equivalent*** to a **serial** schedule.
- **Conflicts:**
  - Two transactions can ***read two different items in any order: no conflict***
  - Two transactions can ***read*** **the same item in any order:** ***no conflict****.*
  - Two transactions can ***read/write*** **different data items in any order:** ***no conflict*****.**
  - In the event we are ***reading/writing*** **the** ***same data item***, we define the cases when conflicts may occur:
    - A *read* of a transaction T1 followed by a *write* of a transaction T2 **is** ***not semantically*** the same as a *write* of a transaction T2 followed by a *read* of a transaction T1: ***conflict*****.**
    - The order of **two** ***writes*** of *two transactions* ***does matter***. The ***last value*** will depend on which ***write*** **comes last**: ***conflict*****.**
- In summary: ***whenever the order matters, there is a conflict*****.**

Isolation through Conflict Serializability

read or write

- More formally, two operations a_i and a_j of transactions T_i and T_j **conflict** if:

  (1) *they access the same data X,*
  (2) they come from different transactions, and
  (3) at least one of them writes X.
  In this case, (a_i,a_j) is called a **conflict pair**.

  1. $a_i=R(X),a_j=R(X)$ No Conflict
  2. $a_i=R(X),a_j=W(X)$ Conflict
  3. $a_i=W(X),a_j=R(X)$ Conflict
  4. $a_i=W(X),a_j=W(X)$ Conflict

> **Note**
> With SQL:
> **SELECT** corresponds to a ***Read***
> **INSERT** corresponds to a ***Write***
> **DELETE**, **UPDATE** correspond to
> a ***Read*** followed by ***Write***

- A schedule is **conflict serializable** if it is ***conflict equivalent*** to ***some serial schedule***
  - Two schedules are ***conflict equivalent*** if:
    - They involve the *same set of operations* of the *same transactions*
    - They order *every pair of conflicting operations the same way*

Checking conflict-serializability

- How do we check for conflict serializability? Question
  - Since the *order* among *non-conflicting* operations *does not matter*, use *non conflicting swappings*!
- Example: check if this schedule is conflict serializable

在detail PPT上有动画

Time

T1	T2
READ(A)	
WRITE(A)	
READ(B)	
WRITE(B)	
	READ(A)
	WRITE(A)
	READ(B)
	WRITE(B)

1

2

3

- Swap READ(B) of T1 with READ(A) of T2
- Swap WRITE(B) of T1 with WRITE(A) of T2
- Swap WRITE(B) of T1 with READ(A) of T2
- The resulting schedule is serial (T1, T2). Therefore, the two schedules are *conflict equivalent*. This means the above schedule is *conflict-serializable*

Checking conflict-serializability

- Is there another way to test conflict serializability? YES
- Use a *Precedence Graph* (also called the *Serialization Graph Testing* or *SGT*).

- The above edge corresponds to one of the following cases
  - T1 executes write(A) before T2 executes read(A).
  - T1 executes read(A) before T2 executes write(A).
  - T1 executes write(A) before T2 executes write(A).
- Algorithm: Check for **cycles**. If there is ***any cycle*** *within the graph,* then the schedule is ***not*** *conflict serializable*. why?

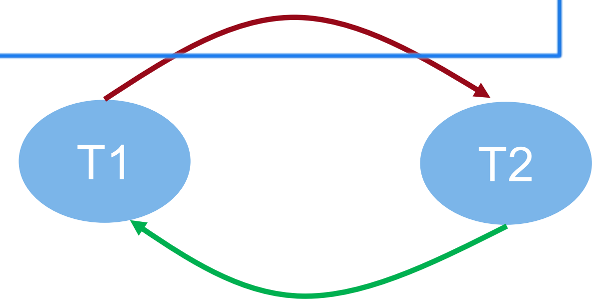
Checking conflict-serializability

- if there is an edge from a transaction T1 to T2, then in the *equivalent serial schedule*, **T1 should come before T2**. A cycle, **however**, means that:
  - 1. T1 should *come before* T2
  - 2. T2 should *come before* T1
- Which is ***impossible*** → **not conflict serializable**.
- If the SGT graph is ***acyclic*** then there is a serial schedule obtained from a ***topological sorting***. This would determine a ***linear order*** consistent witn the **partial order of the precedence graph**.
- **Main issue** with the **SGT** approach:
  - ***expensive*** to maintain SGT graphs: **high overhead** in letting **schedules go unchecked** until a **non-serializable** schedule is **detected**!

Testing for Conflict Serializability

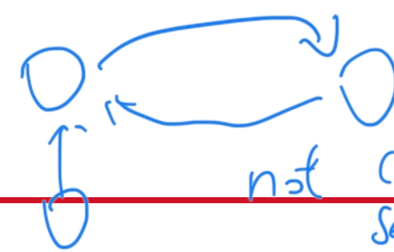
- Consider some schedule of a set of transactions $T_1, T_2, \ldots, T_n$
- **Precedence graph:**
  - direct graph where the vertices are the transactions.
  - edge from T_i to T_j if the two transactions: 1. conflict, and 2. T_i accessed the data item before T_j.
- Central Theorem:
  - A schedule is ***conflict serializable*** *if and only if* its ***precedence graph is acyclic***, **i**.e., there is no cycle.
- Example:

```
T1: R1(A),              W1(A)
T2:           R2(A),W2(A)
```



  - T1 and T2 have 3 conflict pairs:

    (R1(A),W2(A)), (R2(A),W1(A)), (W2(A),W1(A))



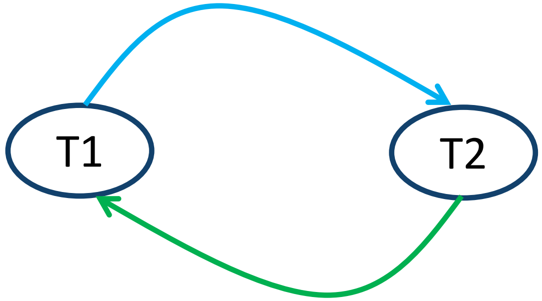
not conflict serializable

Exercise

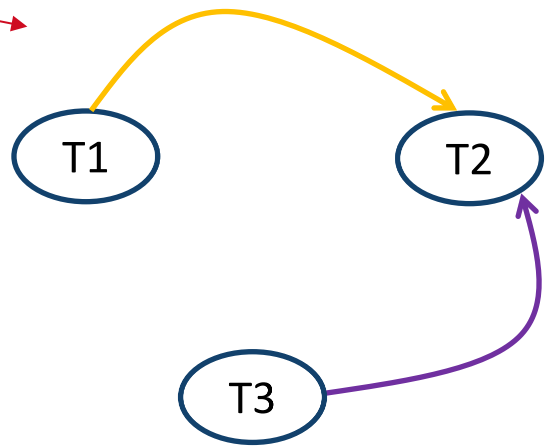
Determine whether each of the following schedules are conflict serializable; justify your answer by drawing the precedence graph. If a schedule is conflict serializable, please give a conflict equivalent serial schedule.

a) R1(x),R2(y),R1(z),R3(z),R2(x),R1(y)

b) R1(x),W2(y),R1(z),W2(x),R1(y)



c) R1(x),W2(y),R1(z),R3(x),W2(x),R2(y)



Solution:

a) All Reads – no conflicts – hence ***conflict serializable***

b) No: It is ***not* conflict serializable**

c) It ***is* conflict serializable** and **<u>equivalent</u>** to **(T1, T3, T2)** or **(T3, T1, T2)**

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swap is not true

Serializability vs Conflict Serializability

› If a schedule is ***conflict serializable***, then ***it must also be serializable***. However, the **converse is not true**! Consider the following schedule S:

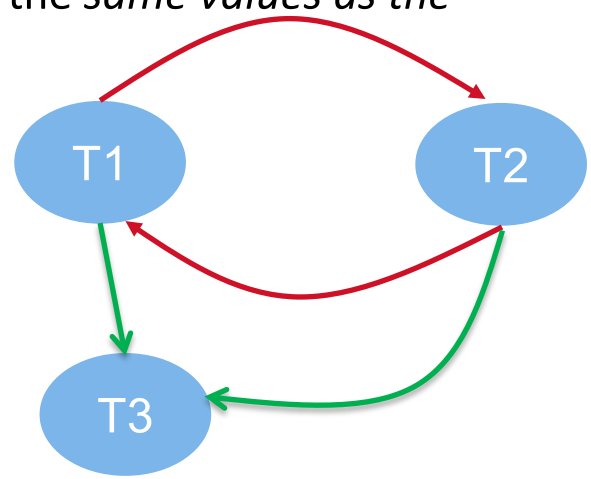
```
T1: W1(B)                W1(A)
T2:           W2(B) W2(A)
T3:                           W3(A)
```

serializable

conflict serializable

- In this schedule, the final value of *A is the value written by T3* and the final value of *B is the value written by T2*.
- Note that the *serial schedule* (T1, T2, T3) leaves A and B with the *same values as the above schedule*. Schedule S is therefore ***serializable.***

```
T1: W1(B) W1(A)
T2:                W2(B) W2(A)
T3:                             W3(A)
```



- However, schedule S is ***not conflict serializable****:*
  - It is ***not conflict equivalent*** to ***any serial schedule***.

  Proof: there is **a cycle** in the **precedence graph**.

Possible Anomalies for *Non-conflict Serializable Schedules*

- Reading Uncommitted Data ("**dirty reads**")

```
T1: R1(A),W1(A),                                    R1(B),W1(B)
T2:                 R2(A),W2(A),R2(B),W2(B)
```

System Crash

- **Unrepeatable Reads**: may not read same value twice

```
T1: R(A),                  R(A)
T2:          R(A),W(A)
```

- Overwriting Data produced (written) by another transaction ("**Lost Update**"):

```
T1: R(A),                   W(A)
T2:           R(A),W(A)
```

Outline

- Consistency
- Atomicity
- Durability
- **Isolation**
  - What, why, and how?
  - Isolation through conflict serializability
  - Lock-based concurrency control

Lock-based Concurrency Control

- So far, we have been optimistic about the *rise of conflicts* in schedules, i.e., we focused on the detection of conflicts.
- **Lock-based** protocol: an implementation scheduler that is part of the family of pessimistic protocols
- Issues:
  - Need a notion of ***locking*** (to prevent conflict) to lock an item *before we use* it
    - If another transaction has a lock, the second transaction requesting that same item *will have to wait*
    - ***Lock manager*** maintains a **lock table**
  - Problem: determining the **granularity** of **locks**
    - **Large**: (too **coarse**) - **no effective concurrency**
    - **Small**: (too **fine**) - lock **overhead high**

Lock Compatibility Matrix

Note: Can we have *more concurrency* by *differentiating* between *Read* and *Write* locks? YES!

Read locks: "**Shared**" lock (S)
Write locks: "**Exclusive**" lock (X)

Held by T1 / T2 Requests	**Shared** read	**Exclusive** write
Shared read	OK	T2 wait on T1
Exclusive write	T2 wait on T1	T2 wait on T1

Issues with unlocking

- Problem: *unlocking* data items - *when* should we *release* a lock on an item?
  - One way is to do it is *as soon as* we have used that item
  - However, this may leave database in an *inconsistent* state.
- Example: Consider an airline reservation system where two airline agents are trying to make a booking on the same flight. A schedule could look like this:

too early

T_1	T_2
LOCK(X)	
READ(X)	
UNLOCK(X)	
$X = X + 1$	
	LOCK(X)
	READ(X)
	UNLOCK(X)
	$X = X + 1$
LOCK(X)	
WRITE(X)	
UNLOCK(X)	
	LOCK(X)
	WRITE(X)
	UNLOCK(X)

- This schedule would result in making one single reservation instead of 2!

Two-Phase Locking

- **Basic Two-Phase Locking (2PL)**
- algorithm:
  - for every transaction
    - *obtain locks*
    - *perform computations*
    - *release locks* and *commit*
- **Idea** behind **2PL**: insist that *all locks* be granted before *any* are *released*; in essence the **two-phase locking** consists of a:
  - **Growing** phase (the number of locks ***may only increase*** but ***not decrease***)
  - **Shrinking** phase (once a lock *has been released*, the number of locks ***can only decrease*** until *no more locks exist*).
  - **Commit** the changes to the database
- ***Strict* 2PL**: all locks are **released *after* commit**.

Goals of two-Phase Locking

- Goals of two-phase locking
  - Prevents partial results from being seen (i.e., used) by some other transactions to prevent *dirty reads*.
  - Assuming *no* deadlocks and failures, 2PL implements *conflict-serializability* and therefore *ensures serializability*.

- Example: Is this a two-phase locking schedule?
  - No!

after release lock you cannot get lock

TIME

T_1	T_2
LOCKX(B)	
READ(B)	
B=B-50	
WRITE(B)	
UNLOCK(B)	
	LOCKS(A)
	READ(A)
	UNLOCK(A)
	LOCKS(B)
	READ(B)
	UNLOCK(B)
	DISPLAY(A+B)
LOCKX(A)	
READ(A)	
A=A+50	
WRITE(A)	
UNLOCK(A)	

Deadlock with two-phase locking

› Consider the following two transactions:

```
T1: R(A),W(A),R(B),W(B)
T2: R(B),W(B),R(A),W(A)
```

› A schedule with locks might be:

```
T1: S(A),R(A), X(A),W(A),                              S(B)?
T2:                       S(B),R(B),X(B),W(B),  S(A)?
```

› What is happening here?

- T1 waiting on T2 to release lock on B
- T2 waiting on T1 to release lock on A

DEADLOCK!!

Deadlock definition

› **Deadlock** occurs whenever a transaction

- T1 holds a lock on an item A and is requesting a (conflicting) lock on an item B and
- T2 holds a lock on item B and is requesting a (conflicting) lock on item A. (Note: item A and item B could be the same item!).

› **In two phase locking, deadlocks may occur.**

Two ways of dealing with deadlocks:

2 solution for dead lock

› Deadlock **prevention**

- ***Static* 2-phase locking**:
  - Each transaction pre-declares its *readset* (shared locks) and *writeset* (exclusive locks) and gets ***all locks or none***.

› Deadlock **detection**

› A transaction in the **waiting cycle** must be **aborted** by DBMS

- DBMS uses deadlock detection algorithms/timeout to deal with this issue

Example

› Consider the following table, named ***Offerings***:

uosCode	year	semester	lecturerId
COMP5138	2012	S1	4711
INFO2120	2011	S2	4711

› Two (2) transactions, T1 and T2

- Each row is an object
- Statements interleaved as below.

› Consider the following schedule:

T1	**SELECT** * **FROM** Offerings **WHERE** lecturerId = 4711
T2	**SELECT** year **INTO** yr **FROM** Offerings **WHERE** uosCode = 'COMP5138'
T1	**UPDATE** Offerings **SET** year=year+1 **WHERE** lecturerId = 4711 **AND** uosCode = 'COMP5138'
T2	**UPDATE** Offerings **SET** year=yr.year +2 **FROM** yr **WHERE** uosCode = 'INFO2120'
T1	**COMMIT**
T2	**COMMIT**

Example

uosCode	year	semester	lecturerId	
COMP5138	2012	S1	4711	A
INFO2120	2011	S2	4711	B

- Consider the previous schedule of two transactions, T1 and T2
  - Each row is an object

T1	**SELECT** * **FROM** Offerings **WHERE** lecturerId = 4711
T2	**SELECT** year **INTO** yr **FROM** Offerings **WHERE** uosCode = 'COMP5138'
T1	**UPDATE** Offerings **SET** year=year+1 **WHERE** lecturerId = 4711 **AND** uosCode = 'COMP5138'
T2	**UPDATE** Offerings **SET** year=yr.year+2 **FROM** yr **WHERE** uosCode = 'INFO2120'
T1	**COMMIT**
T2	**COMMIT**

R1(A),R1(B)

R2(A)

R1(A),W1(A)

R2(B) W2(B)

Time

Example

uosCode	year	semester	lecturerId	
COMP5138	2012	S1	4711	A
INFO2120	2011	S2	4711	B

- Assume **strict 2PL** and **row-level locking** is used.
  - How would the following **schedule** be **affected**?
  - Convert **Reads** and **Writes** into **S** and **X** locks:

T1	**SELECT** * **FROM** Offerings **WHERE** lecturerId = 4711	S1(A),S1(B)
T2	**SELECT** year **INTO** yr **FROM** Offerings **WHERE** uosCode = 'COMP5138'	S2(A)
T1	**UPDATE** Offerings **SET** year=year+1 **WHERE** lecturerId = 4711 **AND** uosCode = 'COMP5138'	S1 (A) Request X1(A), wait
T2	**UPDATE** Offerings **SET** year=yr.year+2 **FROM** yr **WHERE** uosCode = 'INFO2120'	S2(B) Request X2(B), wait
T1	**COMMIT**	
T2	**COMMIT**	

We have a deadlock!

Summary

- Let us return to our two transactions:
  - Transaction T1 is transferring \$100 from account *A* to account *B*.
  - T2 credits both accounts with a 5% interest payment.

T1:	BEGIN	A=A-100,	B=B+100	COMMIT
T2:	BEGIN	A=1.05*A,	B=1.05*B	COMMIT

- *Atomicity requirement*
  - *all updates* of a transaction are reflected in the database or none.
- *Consistency requirement*
  - T1 *does not change* the total sum of *A* and *B*, and after T2, *this total sum* is 5% higher.
- *Isolation requirement*
  - There is no guarantee that T1 will execute before T2, if both are submitted together. However, the actions of T1 *should not affect* those of T2, or vice-versa.
- *Durability requirement*
  - once a transaction has completed, the updates to the database by this transaction must persist *despite failures*

Key Skills

You should be able to:

› Explain how ACID properties define correct transaction behaviour

› Identify update anomalies when ACID properties are not enforced

› Explain whether an execution schedule is conflict serializable

› Explain how locking provides isolation.

3 types

References

- **Ramakrishnan /Gehrke – Chapter 16, details in Ch. 17 & 18**
- Kifer/Bernstein/Lewis – Chapter 18
- Ullman/Widom – Chapter 6.6
- Transactions & JDBC – [JDBC] JDBC documentation
  - Docs for java.sql.connection (with commit, rollback and setAutoCommit) http://docs.oracle.com/javase/6/docs/api/java/sql/Connection.html
  - See also tutorial http://docs.oracle.com/javase/tutorial/jdbc/basics/transactions.html
- Transactions & DB-API:
  - Python DB-API: https://www.python.org/dev/peps/pep-0249/

In two weeks

- Storage and Indexing
  - Storing data in a database
  - Retrieving records from a database
  - B^+ Tree index
- Kifer/Bernstein/Lewis
  - Chapter 9 (9.1-9.5)
- Ramakrishnan/Gehrke
  - Chapter 8
- Ullman/Widom
  - Chapter 8 (8.3 onwards)
- Silberschatz/Korth/Sudarshan (5th ed)
  - Chapter 11 and 12

See you during the quiz and the best of luck!