Database Systems

Lecture 1: Course Overview

The world is increasingly **driven by data…**

This class teaches **the basics** of how to use & manage data.

Key Questions We Will Answer

- How can we **collect and store** large amounts of data?
  - By building tools and data structures to efficiently index and serve data
- How can we **efficiently query** data?
  - By compiling high-level declarative queries into efficient low-level plans
- How can we **safely update** data?
  - By managing concurrent access to state as it is read and written
- How do different database systems manage **design trade-offs**?
  - e.g., at scale, in a distributed environment?

When you'll use this material

- Building almost any software application
  - e.g., mobile, cloud, consumer, enterprise, analytics, machine learning
  - Corollary: every application you use uses a database
  - Bonus: every program consumes data (even if only the program text!)
- Performing data analytics
  - Business intelligence, data science, predictive modeling
  - (Even if you're using Pandas, you're using relational algebra!)
- Building data-intensive tools and applications
  - Many core concepts power deep learning frameworks to self-driving cars

Today’s Lecture

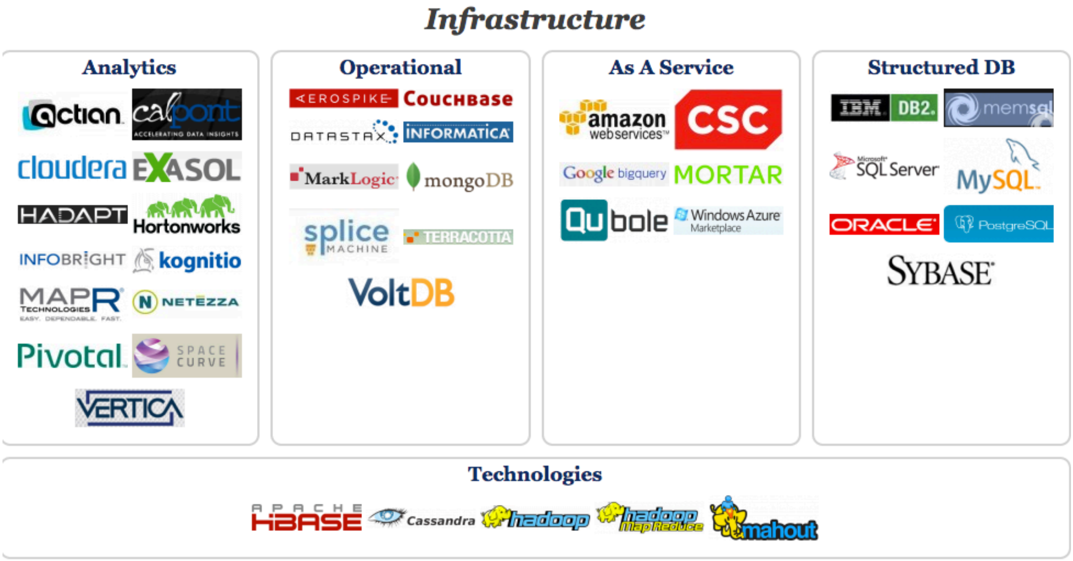
1. Introduction, admin & setup
    - ACTIVITY: Jupyter “Hello World!”
2. Overview of the relational data model
    - ACTIVITY: SQL in Jupyter
3. Overview of DBMS topics: Key concepts & challenges

1. Introduction, admin & setup

What you will learn about in this section

1. Motivation for studying DBs
2. Administrative structure
3. Course logistics
4. Overview of lecture coverage
5. ACTIVITY: Jupyter “Hello World!”

Big Data Landscape… Infrastructure is Changing



New tech. *Same* Principles.

http://www.bigdatalandscape.com/

Why should **you** study databases?

- **Mercenary**- **make more $$$:**
  - Startups need DB talent right away = low employee #
  - Massive industry… Microsoft ORACLE IBM Google
- **Intellectual**:
  - Science: data poor to data rich
    - No idea how to handle the data!
  - Fundamental ideas to/from all of CS:
    - Systems, theory, AI, logic, stats, analysis….

Many great computer systems ideas started in DB.

What this course is (and is not)

- Discuss **fundamentals of data management**
  - How to design databases, query databases, build applications with them.
  - How to debug them when they go wrong!
  - <u>Not</u> how to be a DBA or how to tune Oracle 12g.

- We'll cover **how database management systems work**

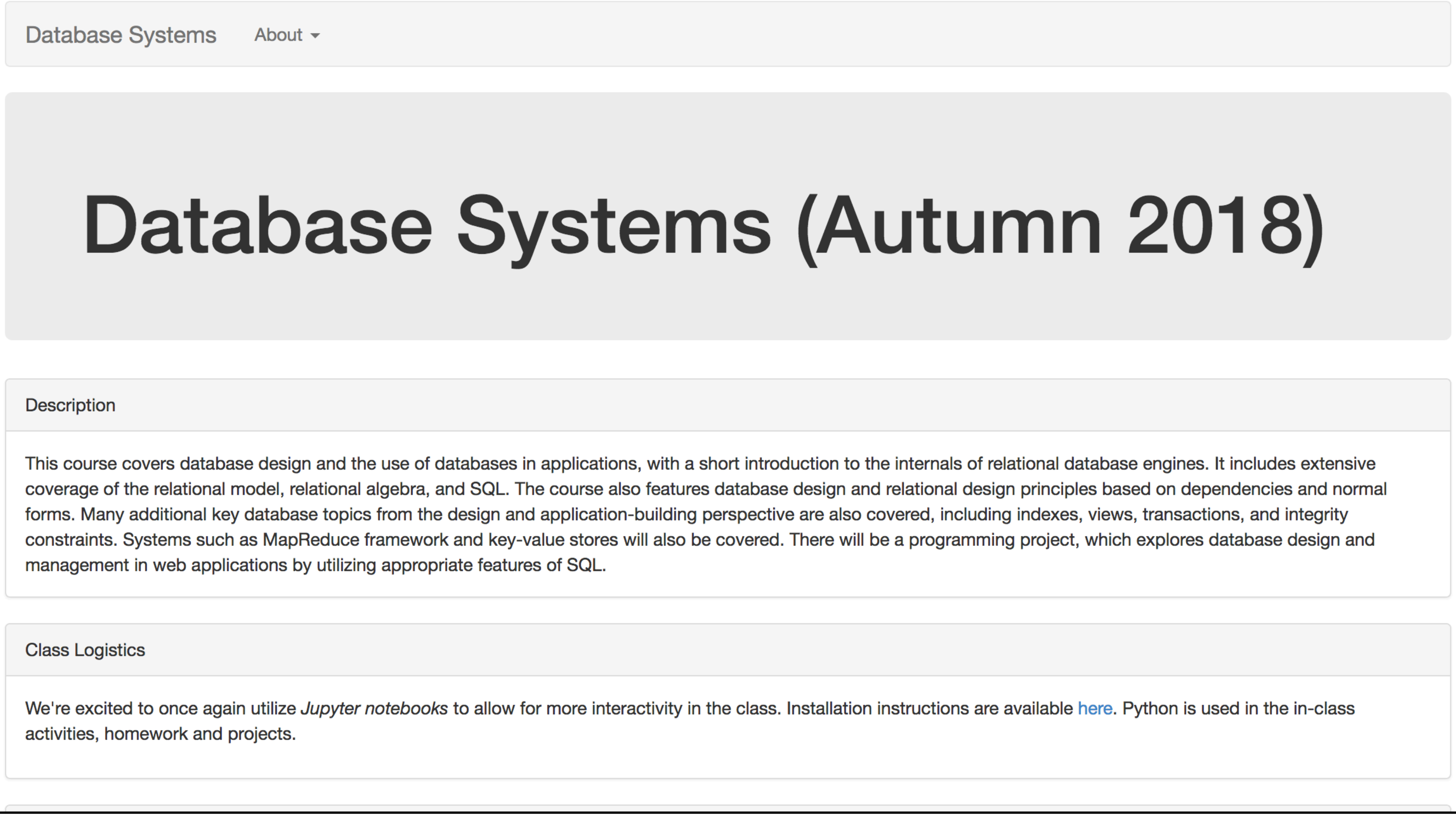
- And some (but not all of) **the principles of how to build** them

Who we are…

Instructor (me) Mohammad Dashti

- Faculty in Software Engineering
- First year at Yazd University, first time teaching Database Systems!
- **Research**: database and machine learning systems

mdashti.com/database-fall2018



Database Systems (Autumn 2018)

Description

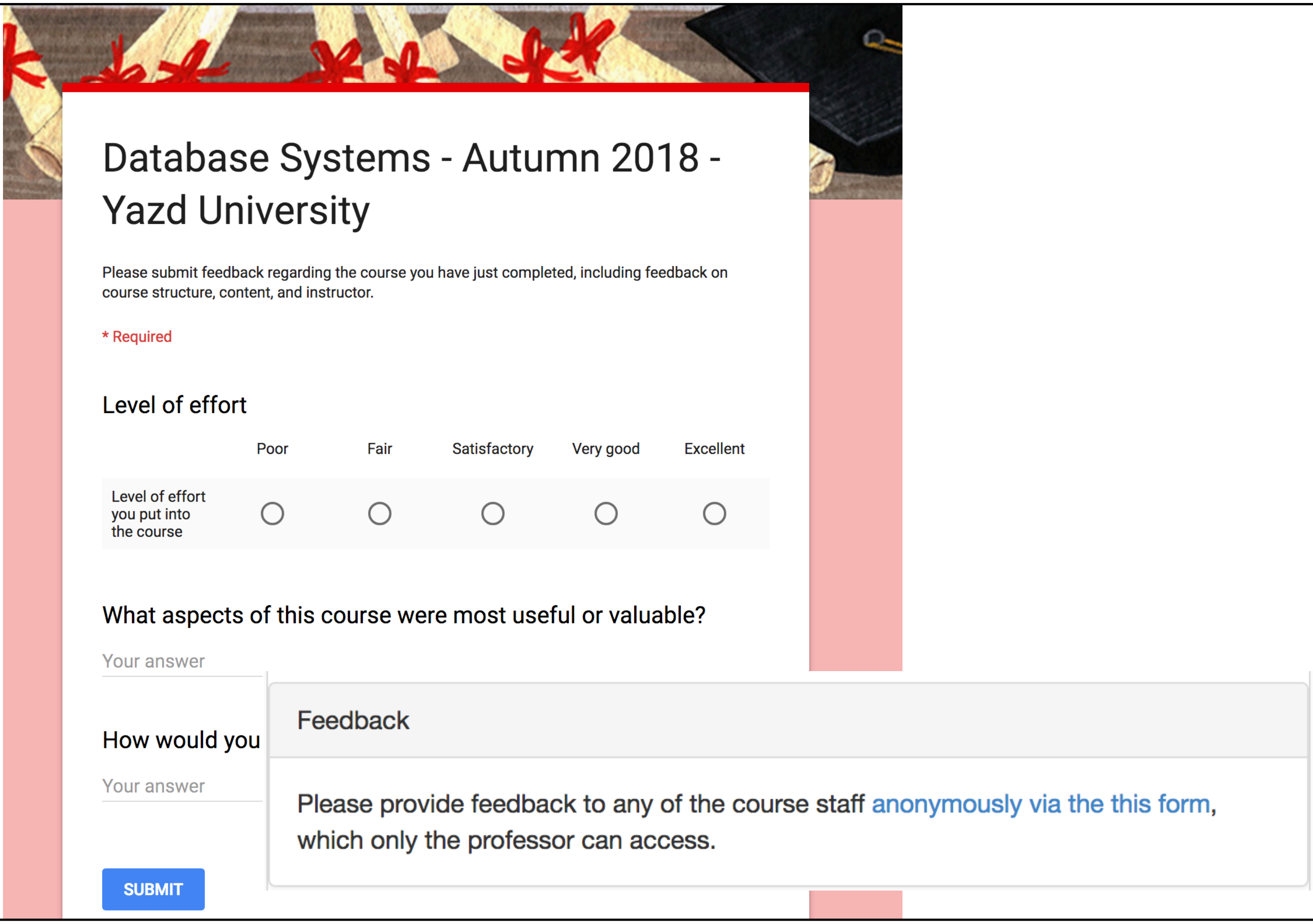
This course covers database design and the use of databases in applications, with a short introduction to the internals of relational database engines. It includes extensive coverage of the relational model, relational algebra, and SQL. The course also features database design and relational design principles based on dependencies and normal forms. Many additional key database topics from the design and application-building perspective are also covered, including indexes, views, transactions, and integrity constraints. Systems such as MapReduce framework and key-value stores will also be covered. There will be a programming project, which explores database design and management in web applications by utilizing appropriate features of SQL.

Class Logistics

We're excited to once again utilize *Jupyter notebooks* to allow for more interactivity in the class. Installation instructions are available here. Python is used in the in-class activities, homework and projects.

Communication w/ Course Staff

- *By appointment!*



Database Systems - Autumn 2018 - Yazd University

Please submit feedback regarding the course you have just completed, including feedback on course structure, content, and instructor.

* Required

Level of effort

	Poor	Fair	Satisfactory	Very good	Excellent
Level of effort you put into the course	○	○	○	○	○

What aspects of this course were most useful or valuable?

Your answer

How would you

Your answer

Feedback

Please provide feedback to any of the course staff anonymously via the this form, which only the professor can access.

Course Website:

mdashti.com/database-fall2018

(will announce a permanent sit later)

Lectures

- Lecture slides cover **essential material**
  - This is your best reference.
  - We are trying to get away from book, but do have pointers

- Try to cover same thing in **many ways**: Lecture, lecture notes, homework, exams (no shock)
  - Attendance is mandatory

Attendance

- I dislike mandatory attendance… but in the past we noticed…
  - People who did not attend did worse ☹
  - People who did not attend used more course resources ☹
  - People who did not attend were less happy with the course ☹

- Thus: mandatory attendance

Graded Elements

- Problem Sets and Programming projects (30%)
- Midterm (30%)
- Final exam (40%)

Assignments are typically due Tuesday before class, typically 2 weeks to complete

Un-Graded Elements

- Readings provided to help you!
  - Only items in lecture, homework, or project are fair game.
- Activities are again mainly to help / be fun!
  - Will occur during class- not graded, but count as part of lecture material (fair game as well)
- Jupyter Notebooks provided
  - These are optional but hopefully helpful.
  - Designed in a way that you can ‘interactively replay’ parts of lecture

What is expected from you

- **Attend lectures**
  - If you don’t, it’s <u>at your own peril</u>

- **Be active and think critically**
  - Ask questions during the class (no question is answered after the class), post comments on forums

- **Do programming and homework projects**
  - Start early and <u>be honest</u>

- **Study for tests and exams**

Lectures: 1st half - from a user's perspective

1. **Foundations:** Relational data models & SQL
    - Lectures 2-3
    - How to manipulate data with SQL, a declarative language
        - *reduced expressive power but the system can do more for you*

2. **Database Design**: Design theory and constraints
    - Lectures 4-6
    - Designing relational schema to keep your data from getting corrupted

3. **Transactions:** Syntax & supporting systems
    - Lectures 7-8
    - A programmer's abstraction for data consistency

Lectures: 2nd half - understanding how it works

4. Introduction to database systems

- Lectures 12-16
- Indexing
- External Memory Algorithms (IO model) for sorting, joins, etc.
- Basics of query optimization (Cost Estimates)
- Relational algebra

5. Specialized and New Data Processing Systems

- Lectures 17-19
- Key-Value Stores
- Hadoop and its 11 year anniversary
- SparkSQL. The re-rise of SQL
- Next-gen analytics systems & current intersections with ML & AI

Lectures: A note about format of notes

Take note!!

These are asides / notes (still need to know these in general!)

Definitions in blue with **concept being defined** bold & underlined

Main point of slide / key takeaway at bottom

Warnings- pay attention here!

Jupyter Notebook “Hello World”

- Jupyter notebooks are interactive shells which **save output in a nice notebook format**
  - They also can display markdown, LaTeX, HTML, js…

FYI: “Jupyter Notebook” are also called iPython notebooks but they handle other languages too.

- You’ll use these for
  - in-class activities
  - interactive lecture supplements/recaps
  - homeworks, projects, etc.- if helpful!

Note: you **do need to know or learn python** for this course!

Jupyter Notebook Setup

1. **HIGHLY RECOMMENDED.** Install **on your laptop** via the instructions on the next slide

2. Other options running via one of the alternative methods:
   1. **Ubuntu VM.**
   2. **Corn**

Please help out your peers by posting issues / solutions on the forum (once it's created!)

As a general policy in upper-level CS courses, Windows is not officially supported. However we are making a best-effort attempt to provide some solutions here!

Jupyter Notebook Setup

https://github.com/yazduni-cs/database-fall2018/blob/master/jupyter_install.md

Activity-1-1.ipynb

2. Overview of the relational data model

What you will learn about in this section

1. Definition of DBMS

2. Data models & the relational data model

3. Schemas & data independence

4. ACTIVITY: Jupyter + SQL

What is a DBMS?

- A large, integrated collection of data

- Models a real-world ***enterprise***
  - *Entities* (e.g., Students, Courses)
  - *Relationships* (e.g., Ali is enrolled in the Database Systems course)

A **Database Management System (DBMS)** is a piece of software designed to store and manage databases

A Motivating, Running Example

- Consider building a course management system (**CMS**):
  - Students
  - Courses
  - Professors

Entities

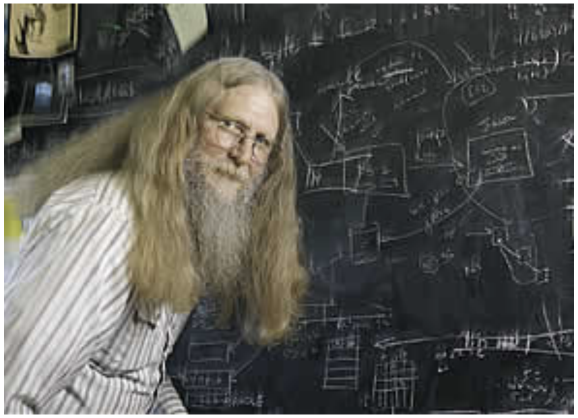
  - Who takes what
  - Who teaches what

Relationships

Data models

- A **data model** is a collection of concepts for describing data
  - The relational model of data is the most widely used model today
    - Main Concept: the *relation*- essentially, a table

- A **schema** is a description of a particular collection of data, **using the given data model**
  - E.g. every *relation* in a relational data model has a *schema* describing types, etc.



“Relational databases form the bedrock of western civilization”

- Bruce Lindsay, IBM Research

Modeling the CMS

- *Logical Schema*
  - Students(sid: *string*, name: *string*, gpa: *float*)
  - Courses(cid: *string*, cname: *string*, credits: *int*)
  - Enrolled(sid: *string,* cid*: string,* grade*: string*)

Relations

sid	Name	Gpa
101	Bob	3.2
123	Mary	3.8

Students

cid	cname	credits
564	564-2	4
308	417	2

Courses

sid	cid	Grade
123	564	A

Enrolled

Modeling the CMS

- *Logical Schema*
  - Students(sid: *string*, name: *string*, gpa: *float*)
  - Courses(cid: *string*, cname: *string*, credits: *int*)
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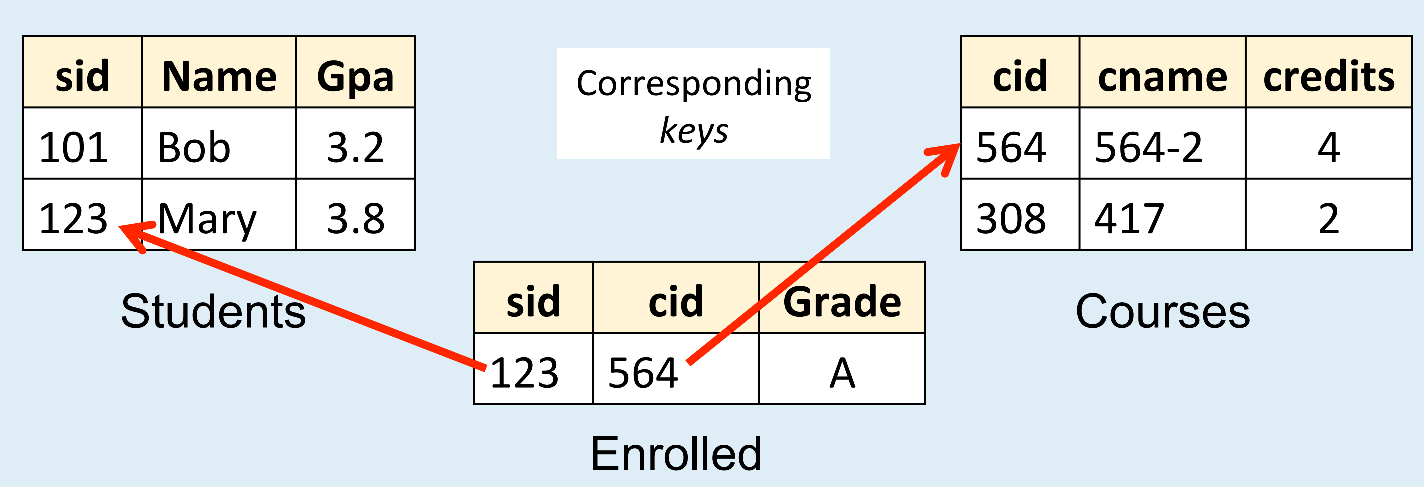


sid	Name	Gpa
101	Bob	3.2
123	Mary	3.8

Students

Corresponding *keys*

cid	cname	credits
564	564-2	4
308	417	2

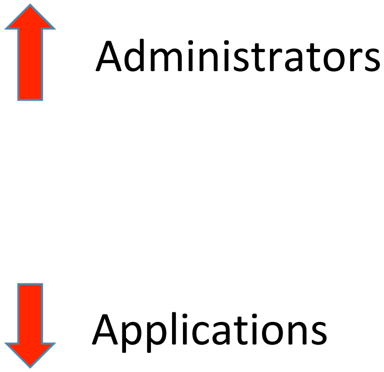
Courses

sid	cid	Grade
123	564	A

Enrolled

Other Schemata…

- *Physical Schema*: describes data layout
  - Relations as unordered files
  - Some data in sorted order (index)
- *Logical Schema:* Previous slide
- *External Schema*: (Views)
  - Course_info(cid: *string*, enrollment: *integer*)
  - Derived from other tables



Administrators

Applications

Data independence

<u>Concept:</u> Applications do not need to worry about *how the data is structured and stored*

<u>Logical data independence:</u> protection from changes in the *logical structure of the data*

I.e. should not need to ask: can we add a new entity or attribute without rewriting the application?

<u>Physical data independence:</u> protection from *physical layout changes*

I.e. should not need to ask: which disks are the data stored on? Is the data indexed?

One of the most important reasons to use a DBMS

Activity-1-2.ipynb

3. Overview of DBMS topics

Key concepts & challenges

What you will learn about in this section

1. Transactions

2. Concurrency & locking

3. Atomicity & logging

4. Summary

Challenges with Many Users

- Suppose that our CMS application serves 1000's of users or more- what are some **challenges?**

  - Security: Different users, different roles

We won't look at too much in this course, but is extremely important

  - Performance: Need to provide concurrent access

Disk/SSD access is slow, DBMS hide the latency by doing more CPU work concurrently

  - Consistency: Concurrency can lead to update problems

DBMS allows user to write programs as if they were the **only** user

Transactions

- A key concept is the **transaction (TXN)**: an **atomic** sequence of db actions (reads/writes)

<u>Atomicity</u>: An action either completes *entirely* or *not at all*

Acct	Balance
a10	20,000
a20	15,000

Transfer $3k from a10 to a20:

1. Debit $3k from a10
2. Credit $3k to a20

Acct	Balance
a10	17,000
a20	18,000

Written naively, in which states is **atomicity** preserved?

- Crash before 1,
- After 1 but before 2,
- After 2.

DB Always preserves atomicity!

Transactions

- A key concept is the **transaction (TXN)**: an **atomic** sequence of db actions (reads/writes)
    - If a user cancels a TXN, it should be as if nothing happened!

Atomicity: An action either completes *entirely* or *not at all*

- Transactions leave the DB in a **consistent** state
    - Users may write integrity constraints, e.g., ‘each course is assigned to exactly one room’

Consistency: An action results in a state which conforms to all integrity constraints

However**,** note that the DBMS does not understand the *real* meaning of the constraints– consistency burden is still on the user!

Challenge: Scheduling Concurrent Transactions

- The DBMS ensures that the execution of {T_1,…,T_n} is equivalent to some **serial** execution
- One way to accomplish this: **Locking**
  - Before reading or writing, transaction requires a lock from DBMS, holds until the end
- **Key Idea***:* If T_i wants to write to an item x and T_j wants to read x, then T_i, T_j **conflict***.* Solution via locking:
  - only one winner gets the lock
  - loser is blocked (waits) until winner finishes

A set of TXNs is <u>isolated</u> if their effect is as if all were executed serially

What if T_i and T_j need X and Y, and T_i asks for X before $T_{j,}$ and T_j asks for Y before T_i? -> *Deadlock!* One is aborted…

All concurrency issues handled by the DBMS…

Ensuring Atomicity & Durability

- DBMS ensures **atomicity** even if a TXN crashes!
- One way to accomplish this: **Write-ahead logging (WAL)**
- **Key Idea***:* Keep a log of all the writes done.
  - After a crash, the partially executed TXNs are undone using the log

Write-ahead Logging (WAL): Before any action is finalized, a corresponding log entry is forced to disk

We assume that the log is on "stable" storage

All atomicity issues also handled by the DBMS…

A Well-Designed DBMS makes many people happy!

- End users and DBMS vendors
  - Reduces cost and makes money
- DB application programmers
  - Can handle more users, faster, for cheaper, and with better reliability / security guarantees!
- Database administrators (DBA)
  - Easier time of designing logical/physical schema, handling security/authorization, tuning, crash recovery, and more…

Must still understand DB internals

Summary of DBMS

- DBMS are used to maintain, query, and manage large datasets.
  - Provide concurrency, recovery from crashes, quick application development, integrity, and security

- Key abstractions give **data independence**

- DBMS R&D is one of the broadest, most exciting fields in CS. **Fact!**