CompSci 516
Database Systems

Lecture 1
Introduction and Data Models

Instructor: Sudeepa Roy

Course Website

- http://www.cs.duke.edu/courses/fall18/compsci516/

- Please check frequently for updates!

Instructor

- Sudeepa Roy
  - sudeepa@cs.duke.edu
  - https://users.cs.duke.edu/~sudeepa/
  - office hour: Thursdays 11 am-12 noon, LSRC D325

- About myself
  - Assistant Professor in CS
  - PhD: UPenn, Postdoc: Univ. of Washington
  - Joined Duke CS in Fall 2015
  - Research interests:
    - Data Analysis, causality, database theory, applications of data, uncertain data, data provenance, crowd sourcing

Two TAs

- Tianpeng Chen
  - tianpeng.chen@duke.edu

- Yuchao Tao
  - yuchao.tao@duke.edu

- Both CompSci 516 veterans!
  - office hours: TBD

Logistics

- Discussion forum: Piazza
  - All enrolled students (by yesterday) are already there
  - Send me an email if you have not received a welcome email from Piazza
- To reach course staff:
  - compsci516-staff@cs.duke.edu
  - Please use piazza as much as possible
- Lecture slides will be uploaded before the class as notes
  - but will be updated after the class

Grading

- Three Homework: 30%
- Project: 15%
- Midterm: 20%
- Final: 30%
- Class participation: 5%

Grading Strategy

- Relative grading
  - The actual grade distribution at the end will depend on the performance of the entire class on all the components.
  - Topper of the class gets A+ irrespective of the number, and only “above expectation” performances get A+.
  - No fixed lowest grade or grade distribution.
  - Everyone can get good grade by working hard!

Homework

- Due in 2-3 weeks after they are posted/previous hw is due
  - ALWAYS start early!
- No late days – contact the instructor if you have a *valid* reason to be late
  - Another exam, project, hw is NOT a valid reason – we will always be fair to all
  - Computer crash/medical issues (following official procedures) may count as valid reasons
  - No guarantee that your request will be granted – again, start early!
- To be done strictly individually

Homework Overview

- You will learn how to use traditional and new database systems in the homework
  - Have to learn them mostly on your own following tutorials available online and with some help from the TA

- HW1: Traditional DBMS
  - SQL and Postgres

- HW2: Distributed data processing
  - Spark and AWS

- HW3: NOSQL
  - MongoDB

Exams

- Midterm – Oct 11 (Thurs)
- Final – Dec 15 (Sat)

- In class
- Closed book, closed notes, no electronic devices
- Total weight: 20 + 30 % = 50 %
- Exams will test your understanding of the material
- Both exams are comprehensive
  - would include every lecture up to the exams

Projects

- 15% weight
- In groups of 3-4
  - You can look for group members through Piazza by announcing your general area of interest or if you have a problem in mind
  - Each group member should do approx. equal work
- Show your creativity and researcher-side!
- Work done should be at least equivalent to
  - one hw * no. of group members

- All group members will get the same grade

Project Topics

- Anything related to "Data"
  - Data management / processing / cleaning
  - Data visualization
  - Data exploration or analysis
  - Applications of data (to any field)
  - Theoretical findings with data
  - New tool for data analysis
- Choose a project according to your own interests
- You can check out major database conferences for ideas, e.g.
  - Demonstrations (build a prototype solving a problem or improving UI)
    - SIGMOD'18: https://sigmod2018.org/sigmod_demo_list.shtml
    - SIGMOD'17 : http://sigmod2017.org/sigmod-program/#posters
    - SIGMOD'16 : http://sigmod2016.org/sigmod_demo_list.shtml
    - VLDB'18: http://vldb2018.lncc.br/accepted-demonstrations.html?demo-a
    - VLDB'17 : http://www.vldb.org/2017/accepted_papers_demo_track.php
    - VLDB'16: http://vldb2016.persistent.com/demonstrations.php
  - Research papers (solve a problem, do experiments with data)
    - Check out papers in SIGMOD and VLDB from recent years
- You can check out previous years of these conferences too, and other conferences from your own research area

Project Deliverables

1. Project proposal (due: 9/20 (Th), 1-3 pages)
   - problem selection is part of the project
   - 3 weeks from now
   - but start asap, look for problems, do related work study, find an interesting question, let me know your initial thoughts, all by the deadline
2. Midterm progress report (due: 10/25 (Th), 3-5 pages)
3. Final project report (due: 11/27 (T), 4-8 pages)
4. A final 5-10 mins project presentation and/or demonstration (in the last 1-2 classes)

Project Evaluation Criteria

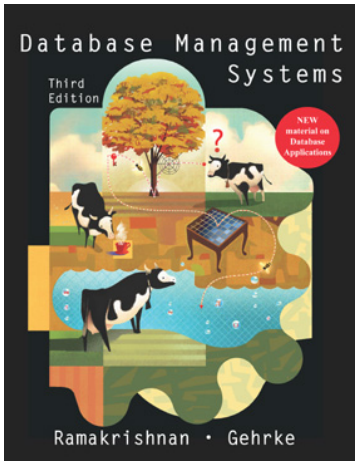
Approximate weights in a scale of 100:

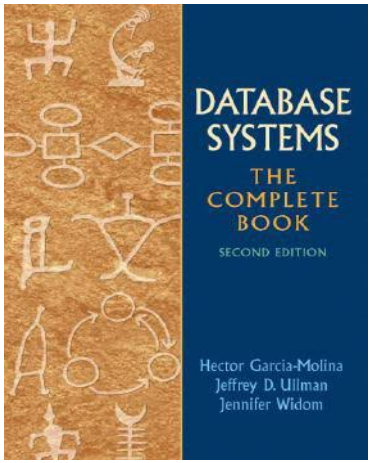
1. Well-motivated? 10
2. Novel? 10
3. Comprehensive related work survey? 10
4. Quality of writing? 10
   - should reflect all other factors too except class presentation
5. Class presentation/demo? 15
   - should reflect all other factors too except writing
6. Technical contributions? 45
   - Problem formulation / Algorithms / Experiments / Theory / System / User interface / Efficiency / Usability / Dataset exploration etc.

Class Participation

- 5% weight
- Pop-up quiz
  - Participation (2.5%) + correct answering (2.5%)
  - lowest score will be dropped
- In general, actively participate in the class!
  - Ask questions in class and on piazza
  - Stop me as many times as you need to understand the lectures
  - Answer each other's questions on piazza
- Also send (anonymous or not) feedback, suggestions, or concerns on Piazza
  - there is a "feedback" folder

Reading Material





- Will mostly follow the ”cowbook” by Ramakrishnan-Gehrke
  - The chapter numbers will be posted
- You do not have to buy the books, but it will be good to consult them from time to time
- You should be prepared to do quite a bit of reading from various books and papers

What is this course about?

- This is a graduate-level database course in CS
- We will cover principles, internals, and applications of database systems in depth
- We will also have an introduction to a few advanced research topics in databases (later in the course)

A Quick Survey

- Have you taken an undergrad database course earlier
  - CS 316/equivalent?
- Are you familiar with
  - SQL?
  - RA? (σ, Π, ×, ⋈, ρ, ∪, ∩, -)
  - Keys, foreign keys?
  - Index in databases?
  - Logic: ∧, ∨, ∀, ∃, ¬, ∈, =>
  - Transactions?
  - Map-reduce/Spark?
- Have you ever worked with a dataset?
  - relational database, text, csv, XML
- Have you ever used a database system?
  - PostGres, MySQL, SQL Server, SQL Azure

What will be covered?

- Database concepts
  - Data Models, SQL, Views, Constraints, RA, Normalization
- Principles and internals of database management systems (DBMS)
  - Indexing, Query Execution-Algorithms-Optimization, Transactions, Parallel and Distributed Query Processing, Map Reduce
- Advanced and research topics in databases
  - e.g. Datalog, NOSQL, Data mining, Data warehouse
  - More will be added in the "TBD" lectures
- We will go fast for some basic topics in databases covered in undergrad db courses
  - Data model, SQL, RA
  - But ask me to slow down if you are not familiar with them

What this course is NOT about

- Spark, AWS, cluster computing…
  - Partially covered in a HW and a lecture
- Machine learning based analytics
- Statistical methods for data analytics
- Python, R, …
- Programming

Background

- You should have some understanding (at the CS undergraduate level)
  - data structure, discrete maths, algorithms
  - databases
  - or have to learn these yourself as necessary
- Need to pickup new coding framework and programming languages on your own
  - and how to process data using them
  - Homework assignments will mostly be self-taught
  - …with help from the TA
- Will involve some mathematical and analytical reasoning too

Why should we care about databases?

- We are in a data-driven world
- Data = Currency, Data = Power, Data = Fun
- "Big Data" is supposed to change the mode of operation for almost every single field
  - Science, Technology, Healthcare, Business, Manufacturing, Journalism, Government, Education, …
- We must know how to collect, store, process, and analyze such data

Why should we care about databases?

- From "Big Data" wiki: Science

  "The Large Hadron Collider experiments represent about 150 million sensors delivering data 40 million times per second. There are nearly 600 million collisions per second. If all sensor data were recorded in LHC, …. this is equivalent to 500 quintillion (5×10^{20}) bytes per day, almost 200 times more than all the other sources combined in the world."

Why should we care about databases?

Technology

- From "Big Data" wiki:
  - eBay.com uses two data warehouses at 7.5 PB (x 10^{12}) and 40PB as well as a 40PB Hadoop cluster for search, consumer recommendations, and merchandising
  - Facebook handles 50 billion photos from its user base
  - As of August 2012, Google was handling roughly 100 billion searches per month

Why should we care about databases?

- From "Big Data" wiki:
  - Healthcare: digitization of patient's data, prescriptive analytics
  - Media: Tailor articles and advertisements that reach targeted people, validate claims
    - "Computational Journalism" project in Duke DB group
  - Manufacturing: supply planning
  - Sports: improve training, understanding competitors

Healthcare
Media
Manufacturing
Sports
.....

Why should we care about databases?

- Democratization of Data!
- More data relevant to the society is collected
  - smart phones, cars, sensors, roads, social media, crime reports…
- Many people are interested in data, but not everyone knows how to analyze them
- Learning about data processing and database systems = a step forward

Why should we care about databases?

- Moore's Law:
  - Processing power doubles every 18 months
- Amount of data doubles every 9 months too!
  - Disk sales (# of bits) doubles every 9 months
- Parkinson's Law:
  - Data expands to fill the space available for storage
- Moore' Law is reversed
- But we have limited time in a day
- Need smarter data management and processing systems!

Slide ack: Prof. Jun Yang

Why should we care about databases?

- Simply storing large datasets in a flat file stops working at some point
  - Need efficient model, storage, and processing
- A DBMS takes care of common issues – the user only has to run queries to process such datasets
  - much simpler than writing low level code

Today

- DBMS
- Data Models

- [RG] 1.1, 1.3-1.5

What is a Database?

And what does it contain?

- A database is a collection of data
  - typically related and describing activities of an organization
- A database may contain information about
  - Entities
    - students, faculty, courses, classroom
  - Relationships between entities
    - students' enrollment, faculty teaching courses, rooms for courses

Why use a DBMS

- i.e. why not use file system and a programming language?
- Suppose a company has a large collection of data on employees, departments, products, sales etc.
- Requirements:
  - Quickly answer questions on data
    - Note that all the data may not fit in main memory
  - Concurrent access: apply changes consistently
  - Restricted access (e.g. salary)

Why use a DBMS?

- A DBMS is a piece of software (i.e. a big program written by someone else) that makes these tasks easier
  - Quick access
  - Robust access
  - Safe access
  - Simpler access

- Next: some nice properties of a DBMS

Why use a DBMS?

1. Data Independence
   - Application programs should not be exposed to the data representation and storage
   - DBMS provides an abstract view of the data

2. Efficient Data Access
   - A DBMS utilizes a variety of sophisticated techniques to store and retrieve data (from disk) efficiently

Why use a DBMS?

3. Data Integrity and Security

- DBMS enforces "integrity constraints" – e.g. check whether total salary is less than the budget
- DBMS enforces "access controls" – whether salary information can be accesses by a particular user

4. Data Administration

- Centralized professional data administration by experienced users can manage data access, organize data representation to minimize redundancy, and fine tune the storage

Why use a DBMS?

5. Concurrent Access and Crash Recovery
   - DBMS schedules concurrent accesses to the data such that the users think that the data is being accessed by only one user at a time
   - DBMS protects data from system failures

6. Reduced Application Development Time
   - Supports many functions that are common to a number of applications accessing data
   - Provides high-level interface
   - Facilitates quick and robust application development

When NOT to use a DBMS?

- DBMS is optimized for certain kind of workloads and manipulations
- There may be applications with tight real-time constraints or a few well-defined critical operations
- Abstract view of the data provided by DBMS may not suffice
- To run complex, statistical/ML analytics on large datasets

Data Model

- Applications need to model some real world units
- Entities:
  - Students, Departments, Courses, Faculty, Organization, Employee, …
- Relationships:
  - Course enrollments by students, Product sales by an organization

- A data model is a collection of high-level data description constructs that hide many low-level storage details

Data Model

Can Specify:

1. Structure of the data
   - like arrays or structs in a programming language
   - but at a higher level (conceptual model)

2. Operations on the data
   - unlike a programming language, not any operation can be performed
   - allow limited sets of queries and modifications
   - a strength, not a weakness!

3. Constraints on the data
   - what the data can be
   - e.g. a movie has exactly one title

Important Data Models

- Structured Data
- Semi-structured Data
- Unstructured Data

What are these?

Important Data Models

- Structured Data
  - All elements have a fixed format
  - Relational Model (table)
- Semi-structured Data
  - Some structure but not fixed
  - Hierarchically nested tagged-elements in tree structure
  - XML
- Unstructured Data
  - No structure
  - text, image, audio, video

Relational Data Model

- Proposed by Edward (Ted) Codd in 1970
  - won Turing award for it!

- Motivation:
  - Simplicity
  - Better logical and physical data independence

Relational Data Model

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8
53831	Madayan	madayan@music	11	1.8
53832	Guldu	guldu@music	12	2.0

- The data description construct is a Relation
  - Represented as a "table"
  - Basically a "set" of records (set semantic)
  - order does not matter
  - and all records are distinct
- however, it is true for the relational model, not for standard DBM
  - allow duplicate rows (bag semantic)
  - unless restricted by key constraints. Why?

Bag: {1, 1, 2, 2, 3, 2, 1, 5, 6, 1}
Set: {1, 2, 3, 5, 6}

Bag vs. Set

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
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- Why "bag semantic" and not "set semantic" in standard DBMSs?
  - Primarily performance reasons
  - Duplicate elimination is expensive (requires sorting)
  - Some operations like "projection"s are much more efficient on bags than sets

Relational Data Model

Students

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Attribute/ Column/ Field

Tuple/ Row/ Record

Value

What is a poorly chosen attribute in this relation?

- Relational database = a set of relations
- A Relation : made up of two parts
  1. Schema
  2. Instance

Schema and Instance

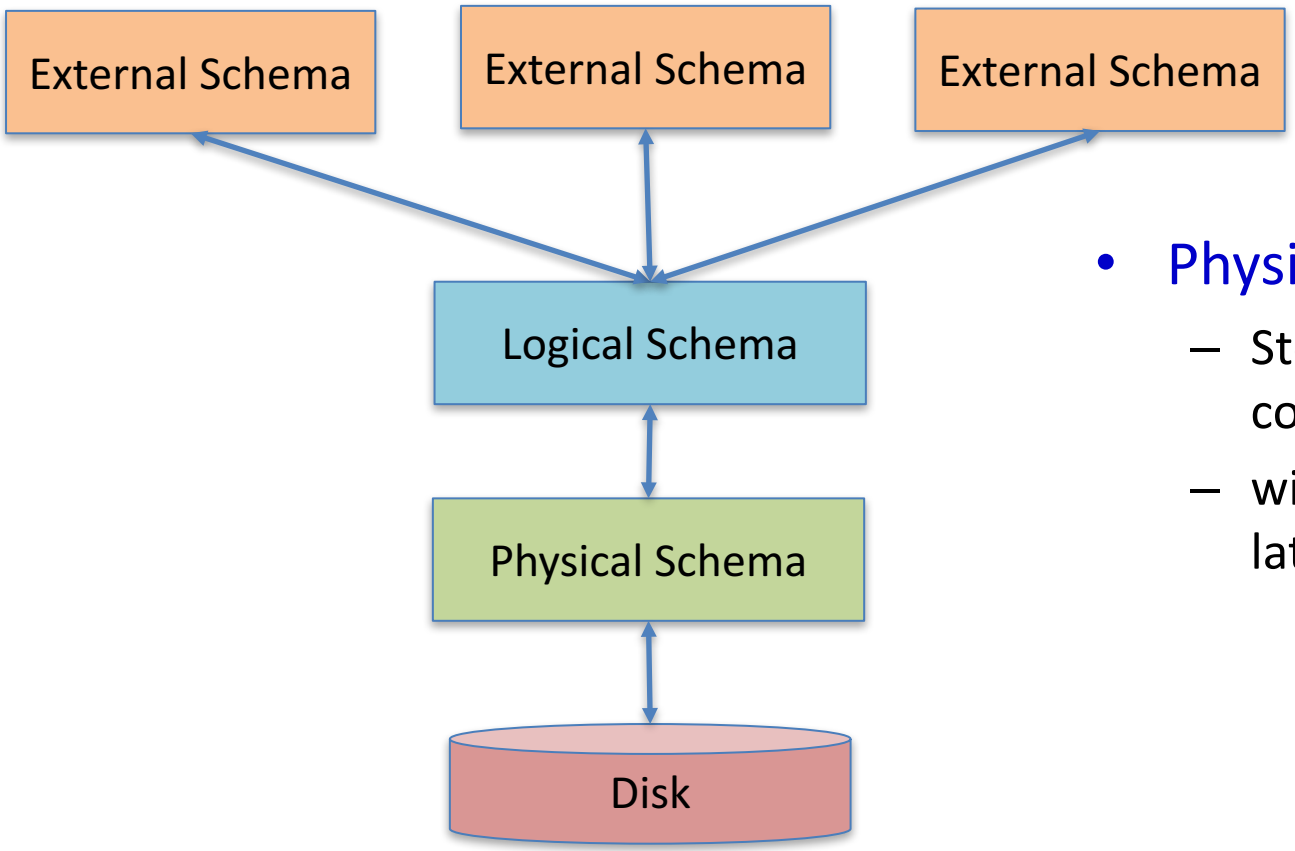
- One schema can have multiple instances
- Schema:
  - A template for describing an entity/relationship (e.g. students)
  - specifies name of relation + name and type of each column

  e.g. Students(sid: string, name: string, login: string, age: integer, gpa: real).
- Instance:
  - When we fill in actual data values in a schema
  - a table, has rows and columns
  - each row/tuple follows the schema and domain constraints
  - #Rows = cardinality, #fields = degree or arity
  - example below

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2
53650	Smith	smith1@math	19	3.8

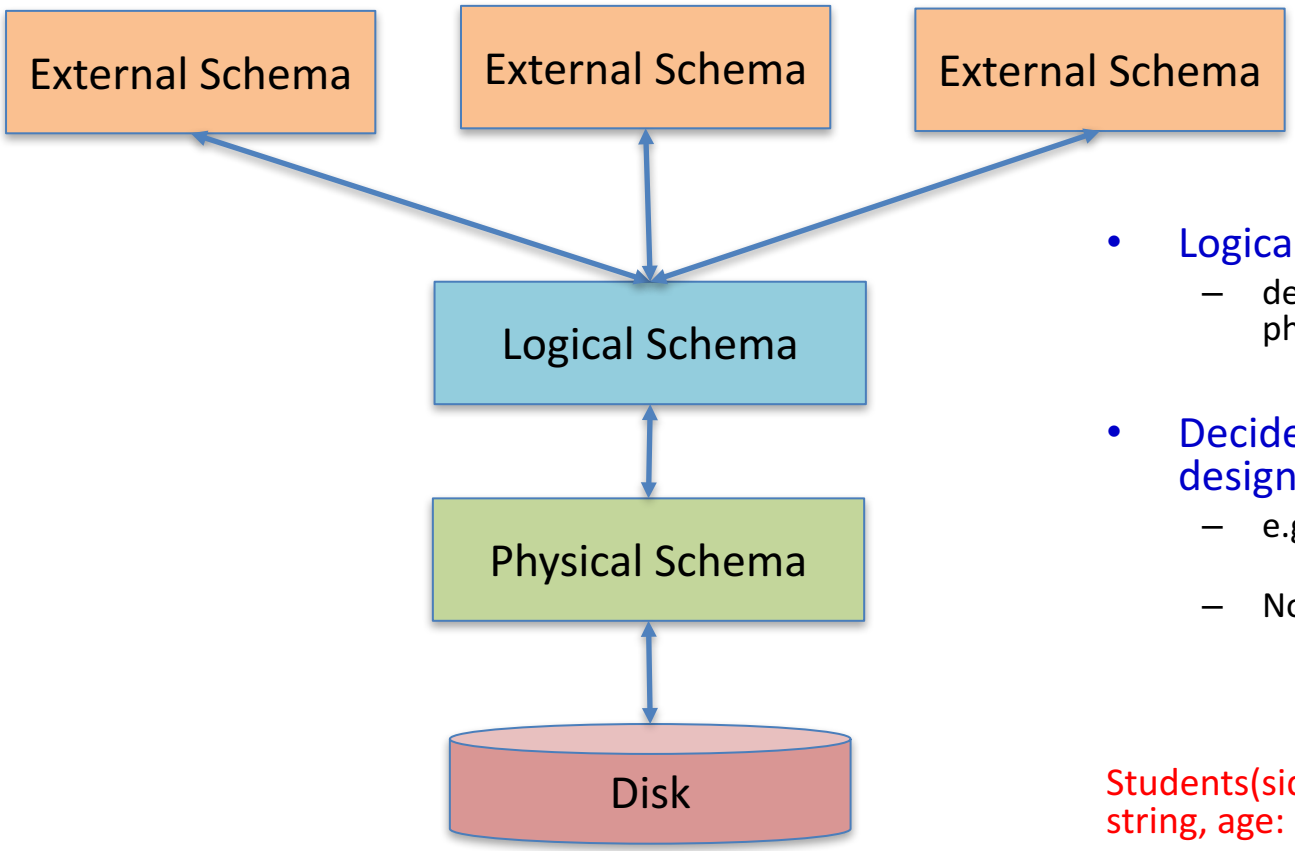
Cardinality = 3, degree = 5

Levels of Abstractions in a DBMS



- Physical schema
  - Storage as files, row vs. column store, indexes
  - will discuss these in later lectures

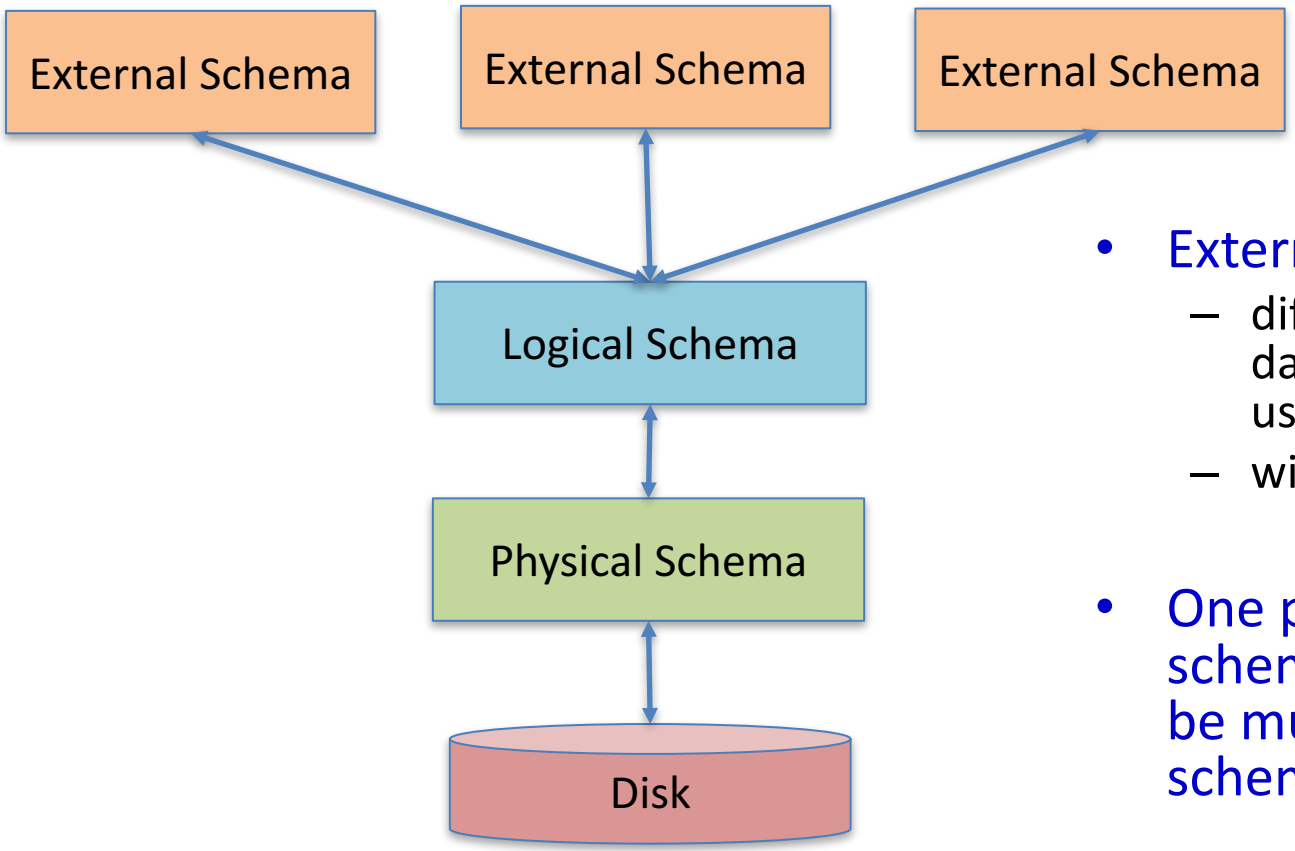
Levels of Abstractions in a DBMS



- Logical/Conceptual schema
  - describes the stored data in the physical schema
- Decided by conceptual schema design
  - e.g. ER Diagram
    - not covered in this course
  - Normalization
    - will be covered

Students(sid: string, name: string, login: string, age: integer, gpa: real)

Levels of Abstractions in a DBMS



- External schema
  - different "views" of the database to different users
  - will discuss views later
- One physical and logical schema but there can be multiple external schemas

Data Independence

- Application programs are insulated from changes in the way the data is structured and stored
- A very important property of a DBMS
- Logical and Physical

Logical Data Independence

- Users can be shielded from changes in the logical structure of data
- e.g. Students:

  Students(sid: string, name: string, login: string, age: integer, gpa: real)
- Divide into two relations

  Students_public(sid: string, name: string, login: string)

  Students_private(sid: string, age: integer, gpa: real)
- Still a "view" Students can be obtained using the above new relations
  - by "joining" them with sid
- A user who queries this view Students will get the same answer as before

Physical Data Independence

- The logical/conceptual schema insulates users from changes in physical storage details
  - how the data is stored on disk
  - the file structure
  - the choice of indexes

- The application remains unaltered
  - But the performance may be affected by such changes

Very important

Understand the Course-Policy

See “what is allowed/not allowed”

will be reminded in every hw assignment too