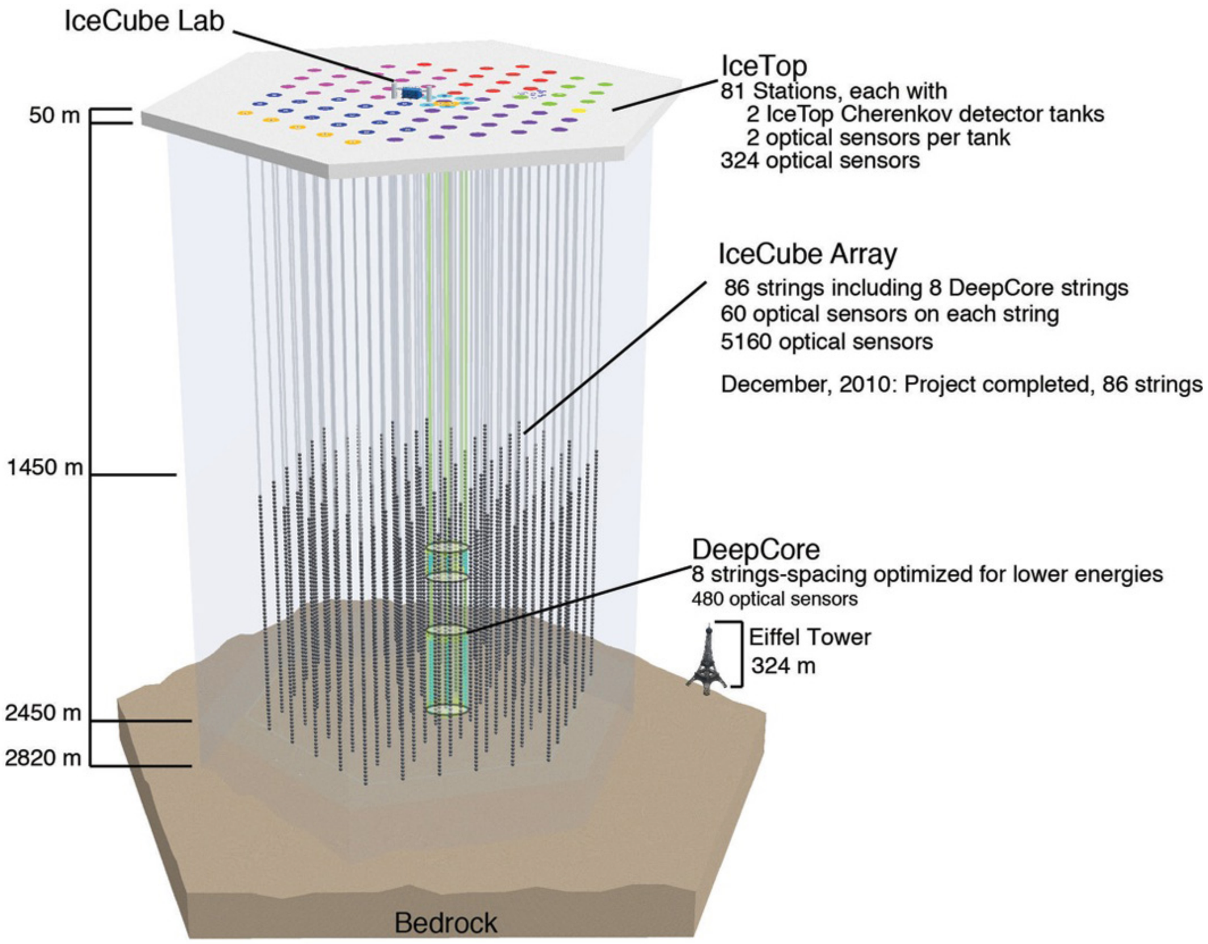
CS145: Intro to Database Management Systems

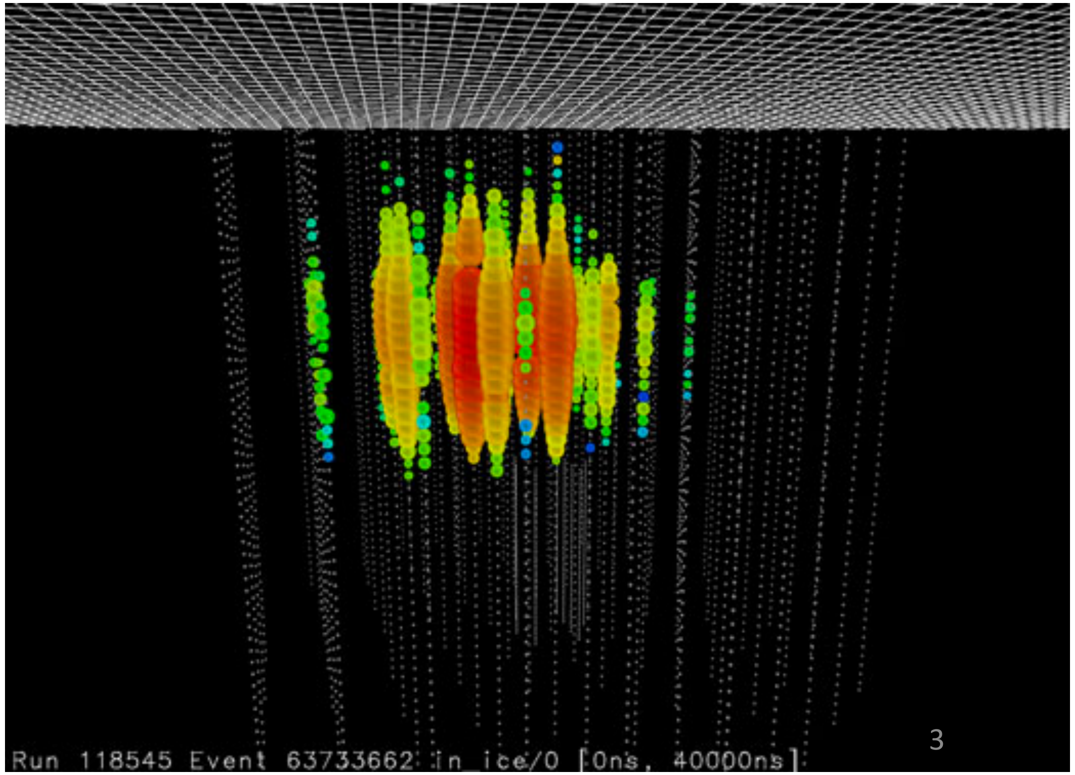
Lecture 1: Course Overview

“Data is the Future”

- My cab driver in Pittsburg

IceCube Neutrino Observatory.


IceCube Lab
IceTop
81 Stations, each with
2 IceTop Cherenkov detector tanks
2 optical sensors per tank
324 optical sensors
IceCube Array
86 strings including 8 DeepCore strings
60 optical sensors on each string
5160 optical sensors
December, 2010: Project completed, 86 strings
DeepCore
8 strings-spacing optimized for lower energies
480 optical sensors
Eiffel Tower
324 m
50 m
1450 m
2450 m
2820 m
Bedrock



Big science is data driven.

DeepDive

All of society is online.

DARPA MEMEX

Data analysis in the fight against human trafficking.

New York DA use MEMEX Data for all trafficking investigations this year.

Increasingly many companies see themselves as **data driven**.

Even more “traditional” companies…

https://www.youtube.com/watch?v=iH9C_ylGOq4

I wanted to show you “Smart Pipe from Comedy Central’s Infomercial” but Alex said it’s a bad idea (it’s also 11 minutes long)

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

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

This year: Turing Award for Innovations in RDBMSs

"The Nobel of Computing"

- 2014 A.M. Turing Award Winner: Michael Stonebraker

- Helped to invent many RDBMS (Relational DBMS) concepts:
  - Query modification
  - The Object-Relational model
  - More recently: work on column-store, streaming data

- Made / helped to start many popular RDBMS implementations:
  - Postgres, Vertica, Streambase, VoltDB, …

The relational data model is one of the most important concepts in computing!

Today’s Lecture

1. Introduction, admin & setup
   - ACTIVITY: IPython “Hello World!”

2. Overview of the relational data model
   - ACTIVITY: SQL in IPython

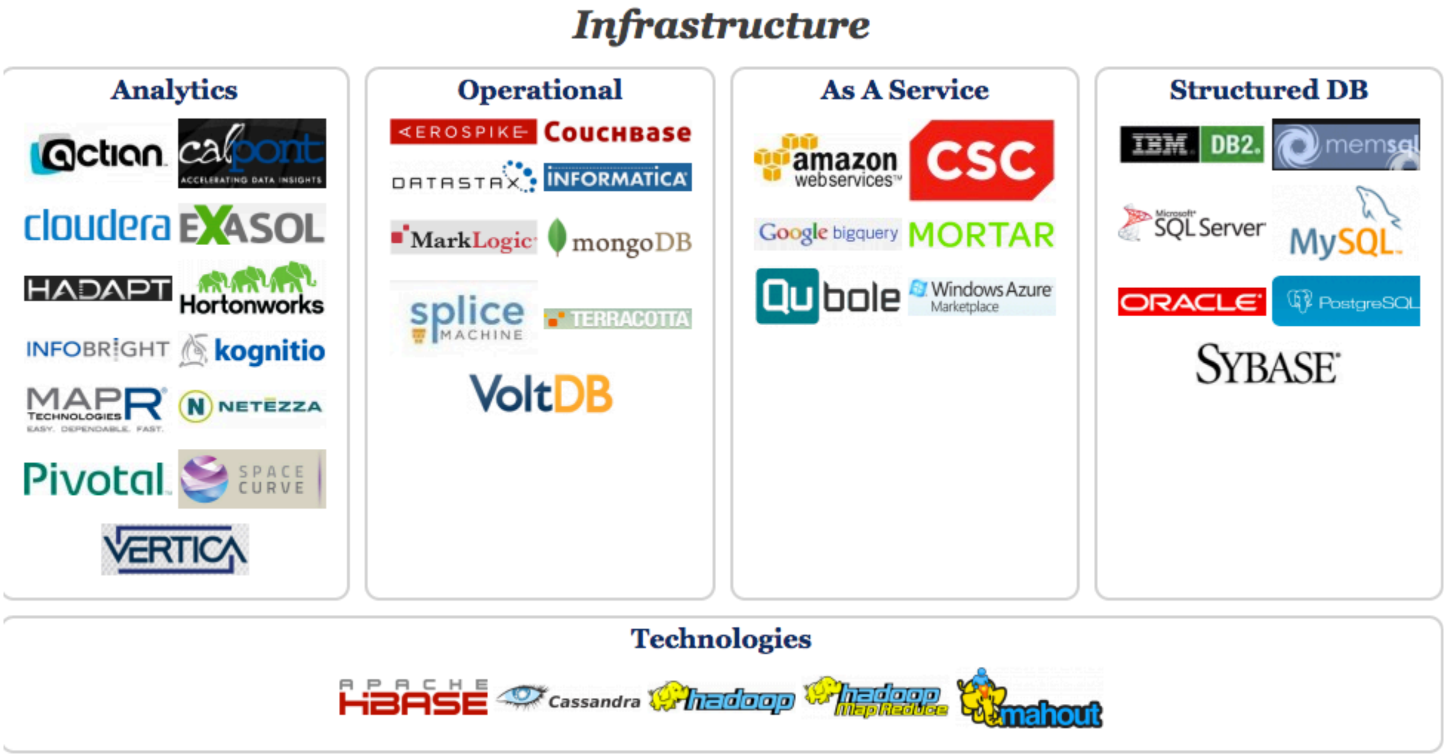
3. Overview of DBMS topics: Key concepts & challenges

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: IPython “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!
  - Not how to be a DBA or how to tune Oracle 12g.

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

- But not **the principles of how to build** them ☹
  - see 245, 345, and 346.

Who we are…

Instructor (me) Chris Ré

Sounds like "Ray"

- Faculty in the InfoLab
- Research: theory of data processing, statistical analytics, and machine reading.
- chrismre@cs.stanford.edu
- Office hours: T/Th 4:30-5:30, Gates 433

Course Assistants (CAs)

“Remember, CAs are people too!”

- Probably some CA

Alex

Ari

Yuchen

Stephanie

Arun

Vishnu

Shubham

Kevin

Cagla

Jed

Communication w/ Course Staff

- Piazza
- Office hours
- *By appointment!*

All are (or will be soon) listed on the course page!

Piazza

The goal is to get you to answer each other's questions so you can benefit and learn from each other.

If I troll you on Piazza, take it as a sign of ***love***.

Important!

Students with documented disabilities should send in their accommodation letter from O.A.E. (Office of Accessible Education) by the **end of this week** to *Alex Ratner (Head TA) & cc’ me.*

Course Website:

cs145.stanford.edu

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 makes your life easier…
    - 8 lectures + all guest lectures are mandatory!

Graded Elements

- Attendance (10%)
- Problem Sets (20%)
- Programming project (20%)
  - Auction base. Up now!
  - Experience with a database application.
- Midterm (20%)
- Final exam (30%)

All but the final assignment are due on Tuesday before class.

For SCPD students only: Attendance will not be a component of grading; distribution will be scaled amongst the rest proportionately

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)
- IPython Notebooks provided
  - These are optional but hopefully helpful.
  - Redesigned so that you can ‘interactively replay’ parts of lecture

What is expected from you

- **Attend lectures**
  - If you don’t, it’s at your own peril
- **Be active and think critically**
  - Ask questions, post comments on forums
- **Do programming and homework projects**
  - Start early and be honest
- **Study for tests and exams**

Going beyond the requirements…

SIGMOD15 Undergrad Research Award Winners.

http://www.sigmod.org/sigmod-awards/sigmod-awards#undergraduate

Adam Perelman *Dunce Cap: Compiling Worst–Case Optimal Query Plans and Beyond*

Former CS 145'ers!

Susan Tu *Dunce Cap: Query Plans Using Generalized Hypertree Decompositions*

SIGMOD15 was in Australia

To encourage more awesomeness

Github for course material & bonus projects… Some extremes…

1. **I was hung over when I took the test**. *Intended to make up for silly mistakes.*

2. **I want to make it easier for future generations.** Visualizations & improvements to advanced topics.

3. ***I want to be a research star!*** These are challenging assignments that could indicate possible publication.

If your pull request is approved, TA will give you bonus points.

Optional Elements

- Tutorials for github on course page.
- Please use Piazza for questions on the topics (not github).
- These are **optional** elements of the course.

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 4-5, 7
   - Designing relational schema to keep your data from getting corrupted

3. **Transactions:** Syntax & supporting systems
   - Lectures 8-9
   - 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 10 year anniversary
- SparkSQL. The re-rise of SQL
- “Dark data” 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 **<u>concept being defined</u>** bold & underlined

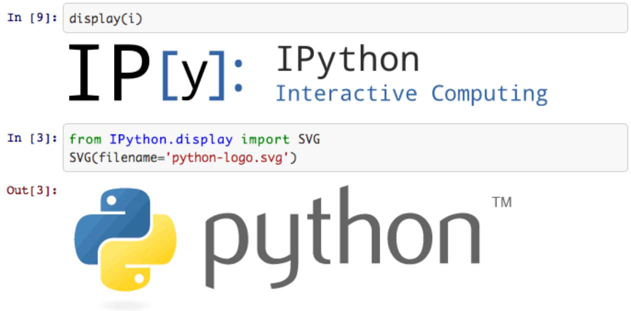
Main point of slide / key takeaway at bottom

Warnings- pay attention here!

IPython Notebook “Hello World”

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

FYI: IPython Notebook is now called “Jupyter Notebook” and handles other languages too. Same thing basically.



```
In [9]: display(i)
```

```
In [3]: from IPython.display import SVG
        SVG(filename='python-logo.svg')
Out[3]:
```

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

Note: you **<u>do</u> need to know or learn python** for this course!

IPython Notebook Setup

On your laptop: *Preferred method!!*

1. *Make sure Python, pip & git installed*
2. *Open a terminal and do:*

```
> git clone https://github.com/HazyResearch/cs145-
notebooks.git

> cd cs145-notebooks

> pip install ––user --upgrade "ipython[notebook]"
jupyter ipython-sql

> ipython notebook
```

On *corn.stanford.edu*:

1. *Make sure X11 is installed on your laptop*
2. *Open a terminal and do:*

```
> ssh –Y <your-sunet-id>@corn

> git clone https://github.com/HazyResearch/cs145-
notebooks.git

> cd cs145-notebooks

> pip install ––user --upgrade "ipython[notebook]"
jupyter ipython-sql

> ipython notebook
```

CAs will be coming around to help with setup & installation

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: IPython + SQL

What is a DBMS?

- A large, integrated collection of data

- Models a real-world *enterprise*
  - *Entities* (e.g., Students, Courses)
  - *Relationships* (e.g., Alice is enrolled in 145)

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

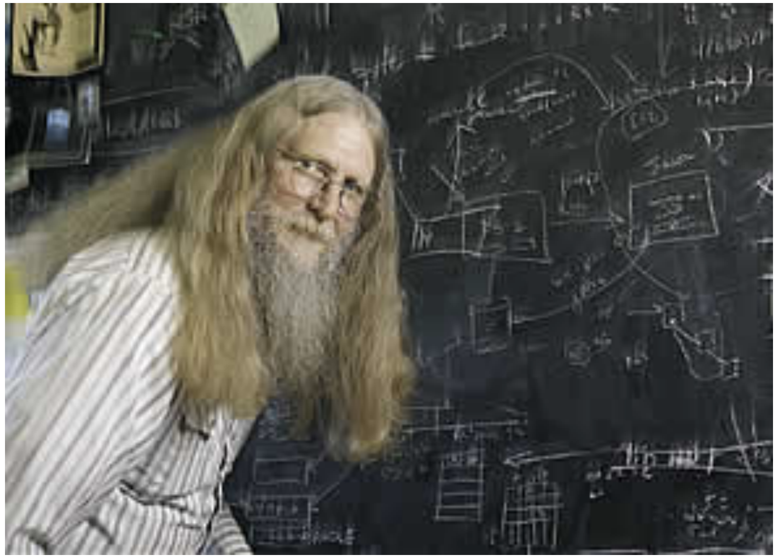
  - Who takes what
  - Who teaches what

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

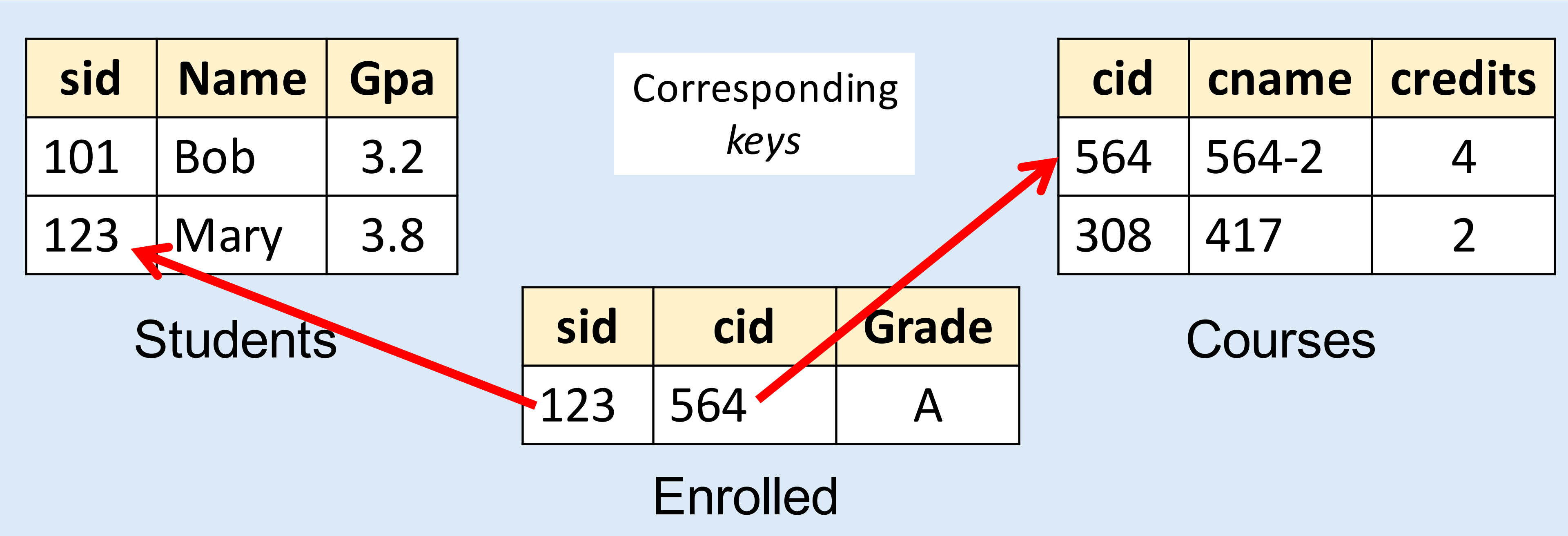
Courses

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*)
  - Enrolled(sid: *string,* cid*: string,* grade*: string*)



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)

⬆ Administrators

- *Logical Schema:* Previous slide

⬇ Applications

- *External Schema*: (Views)
  - Course_info(cid: *string*, enrollment: *integer*)
  - Derived from other tables

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
    - Performance: Need to provide concurrent access
    - Consistency: Concurrency can lead to update problems

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

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

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)
  - If a user cancels a TXN, it should be as if nothing happened!

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

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

<u>Consistency</u>: 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!

Scheduling Concurrent Transactions

- The DBMS ensures that the execution of $\{T_1,\ldots,T_n\}$ 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 isolated 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!**