Intro to Databases

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

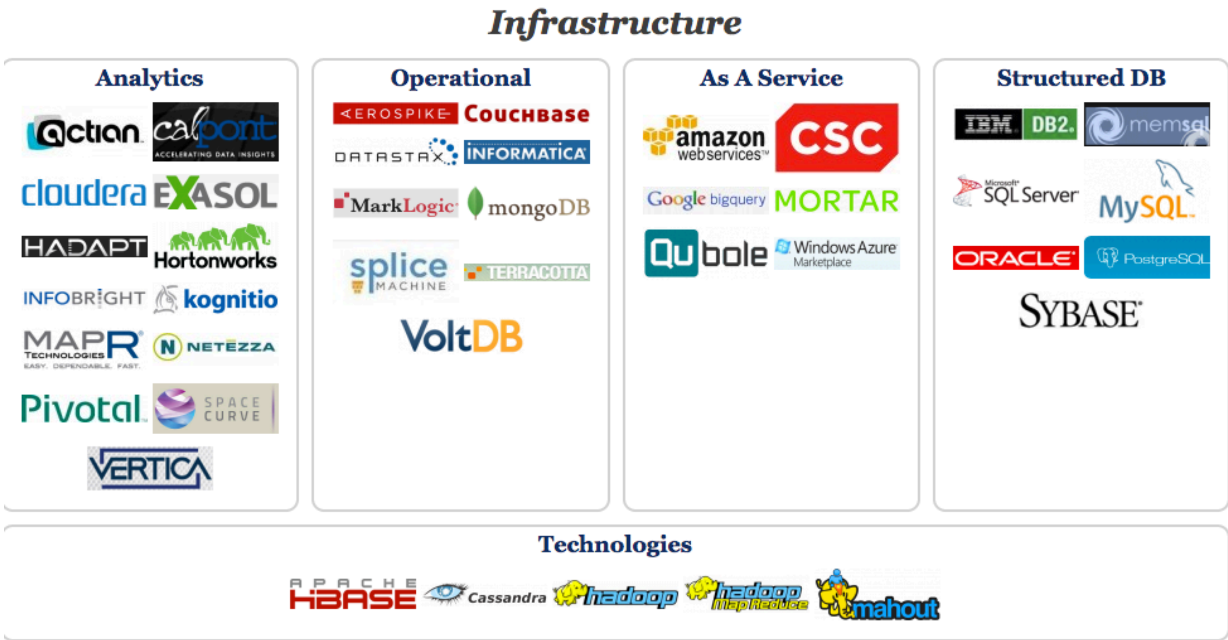
3. Overview of DBMS topics: Key concepts & challenges

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…
- **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) Seongjin Lee

- Office hours: Tuesday: 18:00-19:00, 407-314
- Or make an appointment
- Or send an email: insight at gnu dot ac dot kr

open.gnu.ac.kr

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Database 2018-02

Class Information

	Class Info
Class	ETA00137 - 데이터베이스
Lecturer	Seongjin Lee
Time and Place	407-507 Tuesday 16:00-18:00 407-507 Thursday 16:00-17:00
Office Hour	Tuesday: 18:00-19:00
Contacts	Office: 407-314
	Email: insight at gnu dot ac dot kr

Course Introduction

Communication w/ Course Staff

- Piazza
- Office hours
- *By appointment!*

Piazza

Discussion

Please provide your info on this link.

All discussions and assignments are to be submitted in Piazza. Enroll into the class through the following link

https://piazza.com/class/jkt5x58qttc3u9

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

Course Website:

open.gnu.ac.kr

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…

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 ☹

Graded Elements

- Attendance (10%)
- Quiz (10%)
- Problem Sets (10%)
- Programming project (10%)
- Midterm (30%)
- Final exam (30%)

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.
  - 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**

Lectures: 1^{st} 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 10 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 / Piazza

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 Piazza!

3. Come to our **Installation Office Hours** after this class and tomorrow**!**

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

http://open.gnu.ac.kr/mediawiki/index.php?title=Database_2018-02

Ask help for setup & installation

DB-WS01a.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., 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*

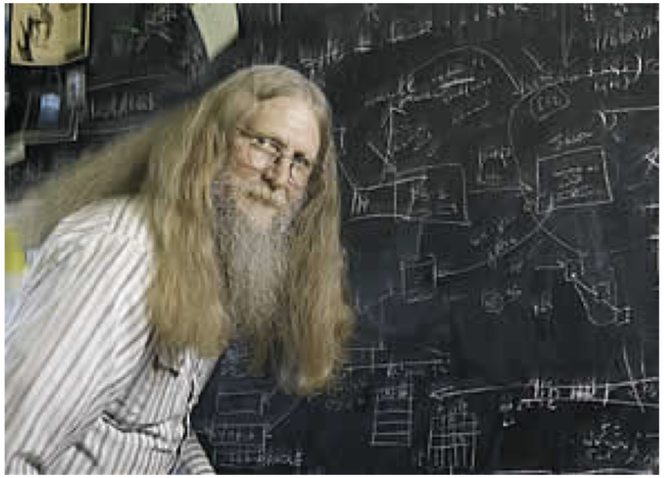
  - Who takes what
  - Who teaches what

  } *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
expert in designing database management systems

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

DB-WS01b.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?**

  - <u>Security</u>: Different users, different roles

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

  - <u>Performance</u>: Need to provide concurrent access

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

  - <u>Consistency</u>: 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!

<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!

Challenge: 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 <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!**