CSE 544
Principles of Database Management Systems

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Fall 2015

Lecture 1 - Introduction and the Relational Model

Outline

- Introduction
- Class overview
- Why database management systems (DBMS)?
- The relational model

Course Staff

- Instructor: Alvin Cheung
  - Office hours: Wednesdays 2:30pm-3:30pm (or by appointment)
  - Location: CSE 530

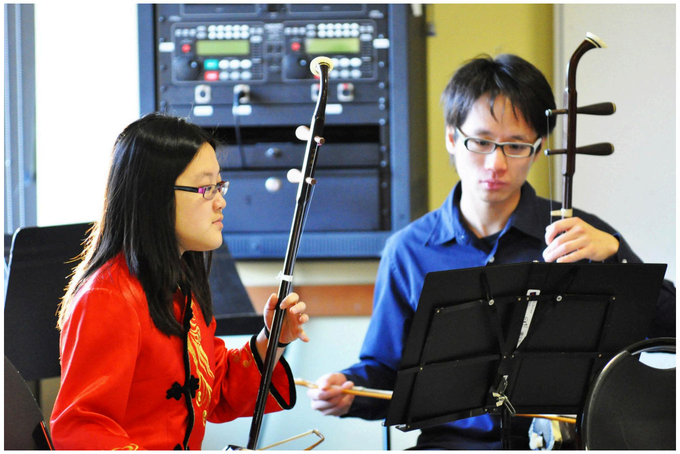
- TA Extraordinaire: Shumo Chu
  - Graduate student in the database group
  - 544 ~~survivor~~ veteran
  - Office hours and location: to be announced on course website

- Use `cse544-staff@cs.washington.edu` to reach us

Who I think I am

- Assistant professor (arrived 9 months ago)
- PhD from MIT
- Research interests: database management systems
- Current research focus
  - New database architectures
  - Database applications
- Research interests: programming systems
- Current research focus
  - Domain-specific languages and compilers
  - Program synthesis
- Hint: Take CSE 501 next time it's offered!

Who I think I am



My Teaching Style

- I speak fast (and sometimes in a weird accent)
  - Especially when I get excited
- But I care a ton about your progress in class
- When you look bored, I speed up
  - If no one asks questions, I go even faster!
- If you are bored, feel free to sleep (at your peril)
- If you are bored, feel free to check your email / facebook / etc (at your peril)
- If you are lost, ask me a question!
  - Or just yell “HELP!”

Goals of the Class/Class Content

- Study principles of data management
  - Data models, data independence, declarative query language, etc.
- Study key Database Mgmt Systems (DBMS) design issues
  - Storage, query execution and optimization, transactions
  - Parallel data processing, data warehousing, streaming data, etc.
- Study some current, hot research topics
- Ensure that
  - You are comfortable using a DBMS locally and in the cloud
  - You have an idea about how to build a DBMS
  - You know a bit about current research topics in data management
  - You get to explore in depth a data management problem (project)

Class Format

- Two lectures per week: Tues & Thurs @ 10:30am

- Mix of lecture and discussion
  - Mostly based on papers
    - Must read papers before lecture and submit a paper review
  - Come prepared to discuss the papers assigned for the class
    - Class participation counts for a non-negligible part of your grade

Class Topics

- Fundamentals
  - Relational algebra
  - Physical design
  - Query optimization
- Transactions (aka how Amazon / airlines / banks work)
  - Concurrency control
  - Recovery
- Analytics (aka big data?)
  - Data warehousing
  - Parallel processing frameworks
- Advanced topics
  - New architectures
  - Database applications

The Originators

Magdalena Balazinska

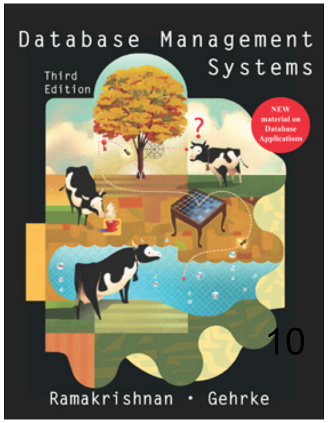
Dan Suciu

Readings and Notes

- Readings are based on papers
  - Mix of old seminal papers and new papers
  - **Papers available online on class website**
  - Some come from the “red book” [no need to get it]
  - Three types of readings
    - Mandatory, additional resources

- Background readings from the following book
  - Database Management Systems. **Third Ed**. Ramakrishnan and Gehrke. McGraw-Hill. [recommended]

- Lecture notes (the slides)
  - Posted on class website after each lecture



Class Resources

- Website: lectures, assignments, projects
  http://www.cs.washington.edu/544
  List of all the **deadlines**

- Mailing list on course website: Make sure you register
  - Your @uw.edu email address is already on the list

- Discussion board: Discuss assignments, papers, weather, stock, etc
  - **HW: Introduce yourself to everyone by posting a new message on discussion board**

Evaluation

- **Class participation & paper reviews 20%**
  - Paper reviews are due by the beginning of each lecture
  - Reading questions are posted on class website
  - You need to speak up in class from time to time
- **Assignments 35%: **Individual****
  - HW1: Using a DBMS / data analysis pipeline
  - HW2: Building a simple DBMS
  - HW3: Analyzing a large dataset with a cloud DBMS
- **Project 45%: Groups of up to three students**
  - Small research or engineering. Start to think about it now!

Class Participation

- An important part of your grade
- Because
  - We want you to read & think about papers throughout quarter
  - Important to learn to discuss papers
- Expectations
  - Ask questions, raise issues, think critically
  - Learn to express your opinion
  - Respect other people's opinions

Paper reviews

- Between 1/2 page and 1 page in length
  - Summary of the main points of the paper
  - Critical discussion of the paper
  - Guidelines on course website
- Reading questions
  - For some papers, we will **post reading questions** to help you figure out what to focus on when reading the paper
  - Please address these questions in your reviews
- Grading: credit/no-credit
  - **MUST submit review 12 HOURS BEFORE lecture**
  - Individual assignments (but feel free to discuss paper with others)

Assignments

- Goals:
  - Hands-on experience using a DBMS, building a simple DBMS, and using a cloud DBMS for data analysis
- **HW1**: Use a DBMS
- **HW2**: Build a simple DBMS
- **HW3**: Large-scale data analysis with a cloud DBMS
- See course calendar for deadlines
- HW1 will be posted on next week
- We will accept late assignments with valid excuse

Project Overview

- Topic
  - Choose from a list of mini-research topics
  - Or come up with your own
  - Can be related to your ongoing research
  - Can be related to a project in another course
  - Must be related to databases / data management
  - Must involve either research or significant engineering
  - Open ended

Amazon AWS credits available!

- Final deliverables
  - Short conference-style paper (6 pages)
  - Conference-style presentation or posters depending on nb groups

Project Goals

- Study **in depth** a data management problem that you find interesting
  - Understand and model the problem
  - Research and understand related work (no need to be exhaustive)
  - Propose some new approach or some interesting eng. problem
  - Implement some parts
  - Evaluate your solution
  - Write-up and present your results
- Amount of work may vary widely between groups

Project Milestones

- Dates will be posted on course website
  - Project proposal
  - Milestone report
  - Final report
  - Final presentation
- More details will be on the website, including ideas & examples
- We will provide feedback throughout the quarter

Now onward to the world of databases!

Let's get started

- What is a database?
  - A collection of files storing related data

- Give examples of databases
  - Accounts database; payroll database; UW's students database; Amazon's products database; airline reservation database

  - Your ORCA card transactions, Facebook friends graph, past tweets, etc

Data Management

- Data is valuable but hard and costly to manage

- Example: database for a store
  - **Entities**: employees, positions (ceo, manager, cashier), stores, products, sells, customers.
  - **Relationships**: employee positions, staff of each store, inventory of each store.

- What operations do we want to perform on this data?
- What functionality do we need to manage this data?

Required Functionality

1. Describe real-world entities in terms of stored data
2. Create & persistently store large datasets
3. Efficiently query & update
    1. Must handle complex questions about data
    2. Must handle sophisticated updates
    3. Performance matters
4. Change structure (e.g., add attributes)
5. Concurrency control: enable simultaneous updates
6. Crash recovery
7. Access control, security, integrity

Difficult and costly to implement all these features

We will cover all these topics this quarter

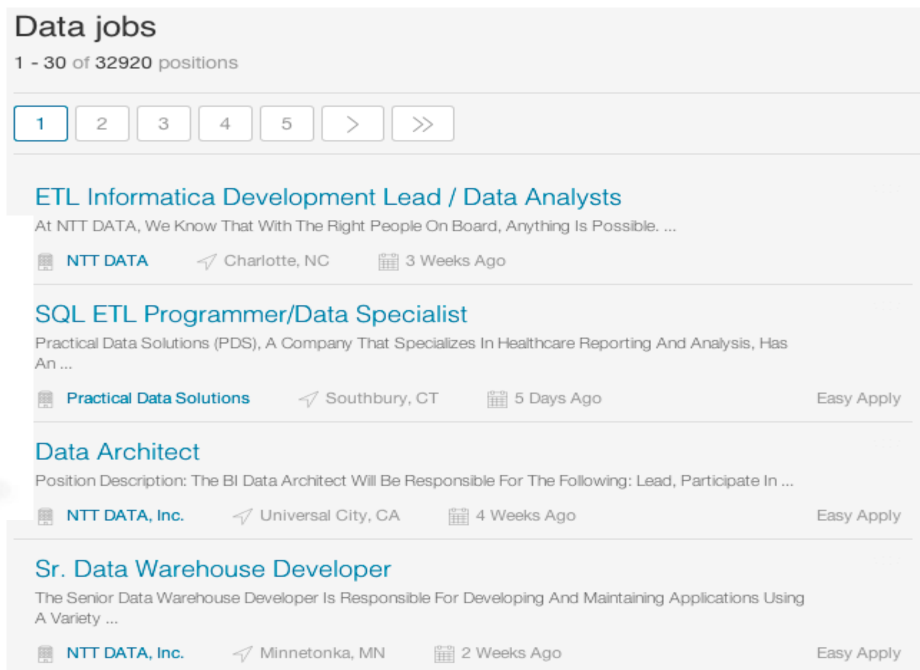
Database Management System

- A DBMS is a software system designed to provide data management services

- Examples of DBMS
  – Oracle, DB2 (IBM), SQL Server (Microsoft),
  – PostgreSQL, MySQL,…

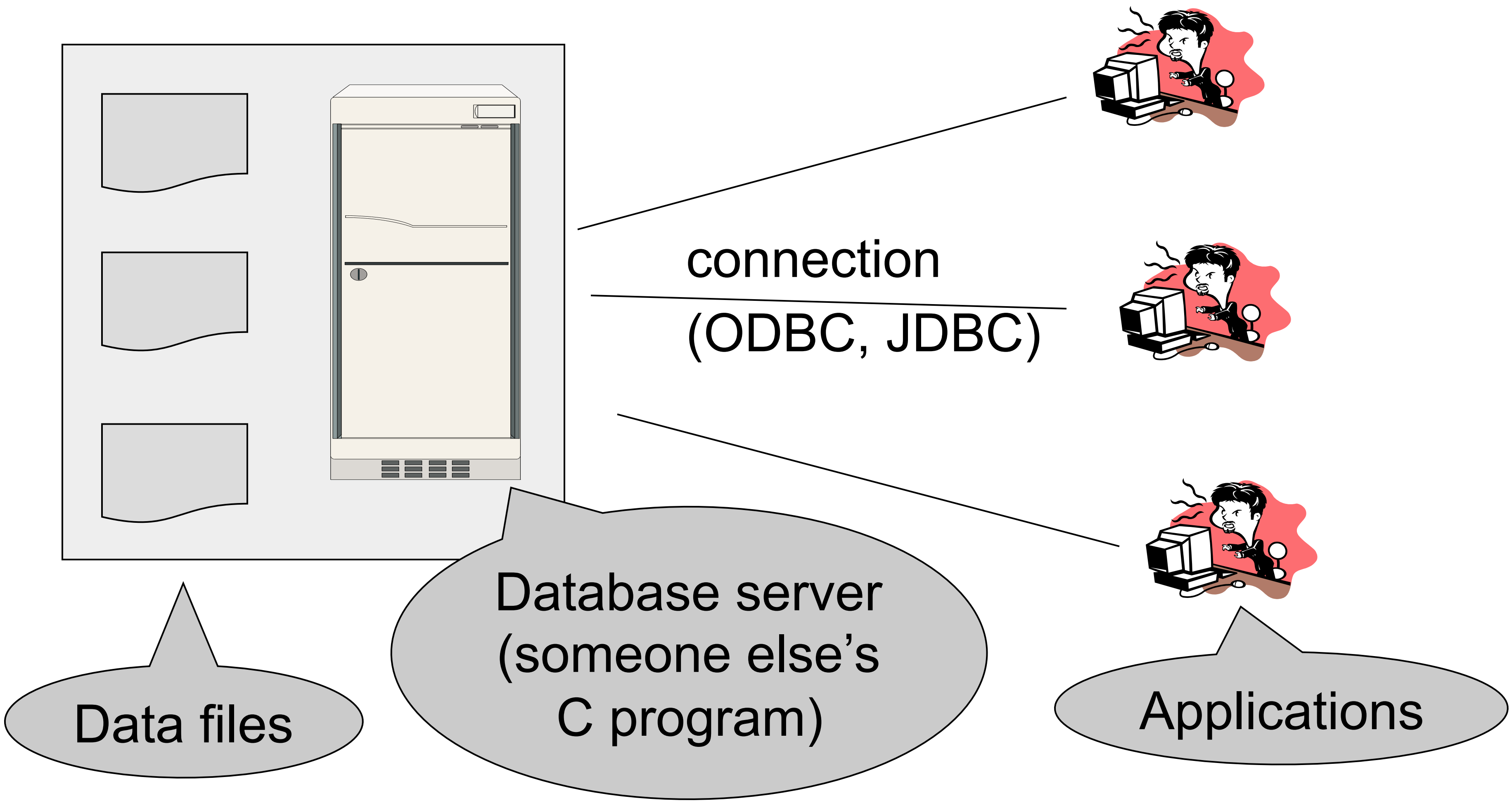
Why should you care?

- From 2006 Gartner report:
  - IBM: 21% market with $3.2BN in sales
  - Oracle: 47% market with $7.1BN in sales
  - Microsoft: 17% market with $2.6BN in sales
- Rise of big data



Typical System Architecture

"Two tier system" or "client-server"



Main DBMS Features

- Data independence
  - Data model
  - Data definition language
  - Data manipulation language
- Efficient data access
- Data integrity and security
- Data administration
- Concurrency control
- Crash recovery
- Reduced application development time

> How to decide what features should go into the DBMS?

When not to use a DBMS?

- DBMS is optimized for a certain workload
- Some applications may need
  - A completely different data model
  - Completely different operations
  - A few time-critical operations
- Example
  - Highly optimized scientific simulations

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Relation Definition

- **Database is collection of relations**
- Relation is a table with rows & columns
  – SQL uses the term "table" to refer to a relation
- **Relation R is subset of S_1 x S_2 x … x S_n**
  – Where $\mathbf{S_i}$ is the domain of attribute **i**
  – **n** is number of attributes of the relation

Properties of a Relation

- Each row represents an n-tuple of R
- Ordering of rows is immaterial
- **All rows are distinct**
- Ordering of columns is significant
  - Because two columns can have same domain
  - But columns are labeled so
  - Applications need not worry about order
  - They can simply use the names
- Domain of each column is a primitive type

- Relation consists of a **relation schema** and **instance**

More Definitions

- **Relation schema**: describes column names
  - Relation name
  - Name of each field (or column, or attribute)
  - Domain of each field

- **Degree (or arity) of relation**: number of attributes

- **Database schema**: set of all relation schemas

Even More Definitions

- **Relation instance**: concrete table content
  - Set of tuples (also called records) matching the schema
- **Cardinality of relation instance**: number of tuples
- **Database instance**: set of all relation instances

Example

- Relation schema

  Supplier(<u>sno: integer</u>, sname: string, scity: string, sstate: string)

- Relation instance

sno	sname	scity	sstate
1	s1	city 1	WA
2	s2	city 1	WA
3	s3	city 2	MA
4	s4	city 2	MA

Integrity Constraints

- **Integrity constraint**
  - Condition specified on a database schema
  - Restricts data that can be stored in db instance
- DBMS enforces integrity constraints
  - Ensures only legal database instances exist
- Simplest form of constraint is domain constraint
  - Attribute values must come from attribute domain

Key Constraints

- **Key constraint:** "certain minimal subset of fields is a unique identifier for a tuple"
- **Candidate key**
  - Minimal set of fields
  - That uniquely identify each tuple in a relation
- **Primary key**
  - One candidate key can be selected as primary key

Foreign Key Constraints

- A relation can refer to a tuple in another relation
- **Foreign key**
  - Field that refers to tuples in another relation
  - Typically, this field refers to the primary key of other relation
  - Can pick another field as well

Key Constraint SQL Examples

```
CREATE TABLE Part (
  pno integer,
  pname varchar(20),
  psize integer,
  pcolor varchar(20),
  PRIMARY KEY (pno)
);
```

Key Constraint SQL Examples

```
CREATE TABLE Supply(
   sno integer,
   pno integer,
   qty integer,
   price integer
);
```

Key Constraint SQL Examples

```
CREATE TABLE Supply(
   sno integer,
   pno integer,
   qty integer,
   price integer,
   PRIMARY KEY (sno,pno)
);
```

Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer,
  PRIMARY KEY (sno,pno),
  FOREIGN KEY (sno) REFERENCES Supplier,
  FOREIGN KEY (pno) REFERENCES Part
);
```

Key Constraint SQL Examples

```
CREATE TABLE Supply(
  sno integer,
  pno integer,
  qty integer,
  price integer,
  PRIMARY KEY (sno,pno),
  FOREIGN KEY (sno) REFERENCES Supplier
                     ON DELETE NO ACTION,
  FOREIGN KEY (pno) REFERENCES Part
                     ON DELETE CASCADE
);
```

General Constraints

- Table constraints serve to express complex constraints over a single table

```
CREATE TABLE Part (
  pno integer,
  pname varchar(20),
  psize integer,
  pcolor varchar(20),
  PRIMARY KEY (pno),
  CHECK ( psize > 0 )
);
```

- It is also possible to create constraints over many tables

Relational Queries

- **Query inputs and outputs are relations**

- Query evaluation
  - Input: instances of input relations
  - Output: instance of output relation

Relational Algebra

- **Query language** associated with relational model
- **Queries specified in an operational manner**
  - A query gives a step-by-step procedure
- **Relational operators**
  - Take one or two relation instances as argument
  - Return one relation instance as result
  - Easy to **compose** into **relational algebra expressions**

Relational Operators

- Selection: $\sigma_{condition}(S)$
  - Condition is Boolean combination ($\wedge$, $\vee$) of terms
  - Term is: attr. op constant, attr. op attr.
  - Op is: <, <=, =, ≠, >=, or >
- Projection: $\pi_{list\text{-}of\text{-}attributes}(S)$
- Union ($\cup$), Intersection ($\cap$), Set difference (–),
- Cross-product or cartesian product ($\times$)
- Join: $R \bowtie_{\theta} S = \sigma_{\theta}(R \times S)$
- Division: R/S
- Rename $\rho(R(F),E)$

Selection & Projection Examples

Patient

no	name	zip	disease
1	p1	98125	flu
2	p2	98125	heart
3	p3	98120	lung
4	p4	98120	heart

$\pi_{zip,disease}$(Patient)

zip	disease
98125	flu
98125	heart
98120	lung
98120	heart

$\sigma_{disease=\text{'heart'}}$(Patient)

no	name	zip	disease
2	p2	98125	heart
4	p4	98120	heart

π_{zip} ($\sigma_{disease=\text{'heart'}}$(Patient))

zip
98120
98125