Principles of Database Systems
CSE 544

Lecture #1

Introduction and SQL

Staff

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Class Format

- Lectures Tuesday-Thursday, 12-1:30pm
- 4 Homework Assignments
- Reading assignments
- A mini-research project

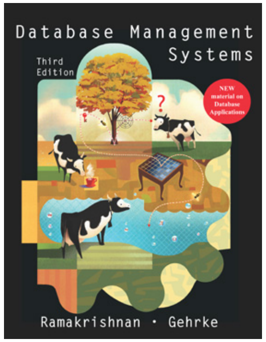
Announcements

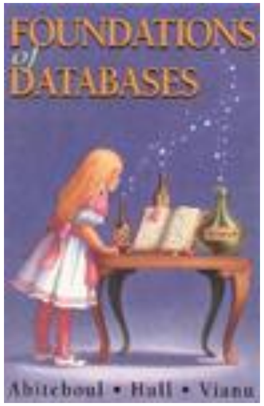
This week is special

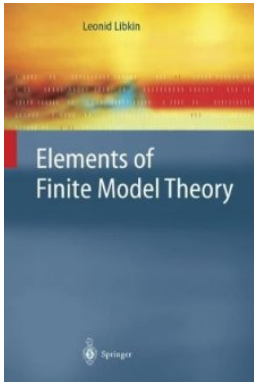
- First lecture on Monday
- No lectures on:
  – Tuesday, April 2
  – Thursday, April 4

Textbook and Papers

- Official Textbook:
  - Database Management Systems. **3rd Ed.**, by Ramakrishnan and Gehrke. McGraw-Hill.
  - Book available on the Kindle too
  - Use it to read background material
  - You may borrow it, no need to buy
- Other Books
  - Foundations of Databases, by Abiteboul, Hull, Vianu
  - Finite Model Theory, by Libkin







Textbook and Papers

- Nine papers to read and review
  - Mix of old seminal papers and new papers
  - Papers available online on class website
  - Most papers available on Kindle
  - Some papers come from the “red book” [no need to get it]

- Plus a couple of optional readings

Resources

- Web page: http://www.cs.washington.edu/education/courses/cse544/13sp/
  - Lectures
  - Reading assignments
  - Homework assignments
  - Projects
- Mailing list:
  - Announcements, group discussions

Content of the Class

- Relational Data Model
  - SQL, Data Models, Relational calculus, Constraints+Views,
- Systems
  - Storage, query execution, query optimization, database statistics, parallel databases
- Theory
  - Query complexity, query containment, datalog, bounded tree-width
- Miscellaneous
  - Transactions, provenance, data privacy

Evaluation

- Assignments 50%:
  - Four assignments: programming + theory
- Project 30%: Groups of 1-3
  - Small research or engineering. Start thinking now!
- Paper reviews, class participation 20%:
  - Individual
  - Due by the evening before the lecture
  - Reading questions are posted on class website

Assignments 50%

- HW1: Data Analysis Pipeline programming
- HW2: Database Systems programming
- HW3: Parallel Data Analytics programming
- HW4: Database Theory theory

We will accept late assignments with valid excuse

Assignments 50%

- HW1: Data Analysis Pipeline – posted!
  - Design schema: E/R diagram, tables
  - Install postres, import the DBLP data
  - Transform DBLP data to your schema – SQL
  - Do data analysis – SQL, SQL, SQL, …
  - Draw graphs – Excel

- Due: Monday, April 22, 11:59pm

Project 30%

- Teams: 1-3 students
- Topics: choose one of:
  - A list of mini-research topics (see Website, check updates)
  - Come up with your own (related to your own research)
- Deliverables (see Website for dates)
  - M1: teams — April 12
  - M2: project proposal — April 26
  - M3: major milestone — May 17
  - M4: presentation on Friday — June 07, CSE 405
  - M5: final report — June 07
- Amount of work may vary widely between groups

Paper Reviews and Class Participation 20%

- Reviews: 1/2 page in length
  - Summary of the main points of the paper
  - Critical discussion of the paper
- Review 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
- Discussions
  - Ask questions, raise issues, think critically
  - Learn to express your opinion
  - Respect other people's opinions
- Grading: credit/no-credit
  - You can skip one review without penalty
  - MUST submit review BEFORE lecture
  - Individual assignments (but feel free to discuss paper with others)

Goals of the Class

This is a CSE graduate level class !

- Using databases in research:
  - Data analysis pipeline
  - Expert use of database systems (Postgres) and of novel data analysis tools (MapReduce)
- Some (limited) exposure to database internals
- Using database concepts in research:
  - Algorithms/techniques for massive data processing/ analysis (sequential and/or parallel)
  - Theory of query complexity, datalog
- Exposure to database research:
  - Query processing, provenance, privacy, theory…

Background

You should have heard about most of:

- E/R diagrams
- Normal forms (1^{st}, 3^{rd})
- SQL
- Relational Algebra
- Indexes, search trees
- Search in a binary tree
- Query optimization (e.g. join reordering)
- Transactions
- PTIME, NP, LOGSPACE
- Logic: $\wedge$, $\vee$, $\forall$, $\exists$, $\neg$, $\in$
- Reachability in a graph

We will cover these topics in class, but assume some background

Agenda for Today

- Brief overview of a traditional database systems

- SQL

Databases

What is a database ?

Give examples of databases

Databases

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

Database Management System

What is a DBMS ?

Give examples of DBMS

Database Management System

What is a DBMS ?

- A big C program written by someone else that allows us to manage efficiently a large database and allows it to persist over long periods of time

Give examples of DBMS

- DB2 (IBM), SQL Server (MS), Oracle, Sybase
- MySQL, Postgres, …

Market Shares

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

An Example

The Internet Movie Database
http://www.imdb.com

- Entities:
  Actors (1.5M), Movies (1.8M), Directors

- Relationships:
  who played where, who directed what, …

Note

- In other classes at UW (344, 444, 544p):
  - We use IMDB/sqlite and SQL Server for extensive practice of SQL
- In 544:
  - We will use DBLP/postgres, which is more hands-on and more research'y
- If you want to practice more SQL:
  - Let me know and I will arrange for you to have access to the IMDB database and/or to SQL Server.

Tables

Actor:

id	fName	lName	gender
195428	Tom	Hanks	M
645947	Amy	Hanks	F
. . .			

Casts:

pid	mid
195428	337166
. . .	

Movie:

id	Name	year
337166	Toy Story	1995
. . .	. . .	. ..

SQL

```
SELECT *
FROM  Actor
```

```
SELECT *
FROM  Actor
LIMIT 50
```

```
SELECT count(*)
FROM  Actor
```

```
SELECT *
FROM  Actor
WHERE lName = 'Hanks'
```

SQL

```
SELECT *
FROM  Actor x, Casts y, Movie z
WHERE x.lname='Hanks'
      and x.id = y.pid
      and y.mid=z.id
      and z.year=1995
```

This query has *selections* and *joins*

1.8M actors, 11M casts, 1.5M movies;

How can it be so fast ?

How Can We Evaluate the Query ?

Actor:

id	fName	lName	gender
. . .		Hanks	
. . .			

1.8M actors

Casts:

pid	mid
. . .	
. . .	

11M casts

Movie:

id	Name	year
. . .		1995
. . .		

1.5M movies

Plan 1: . . . . [in class]

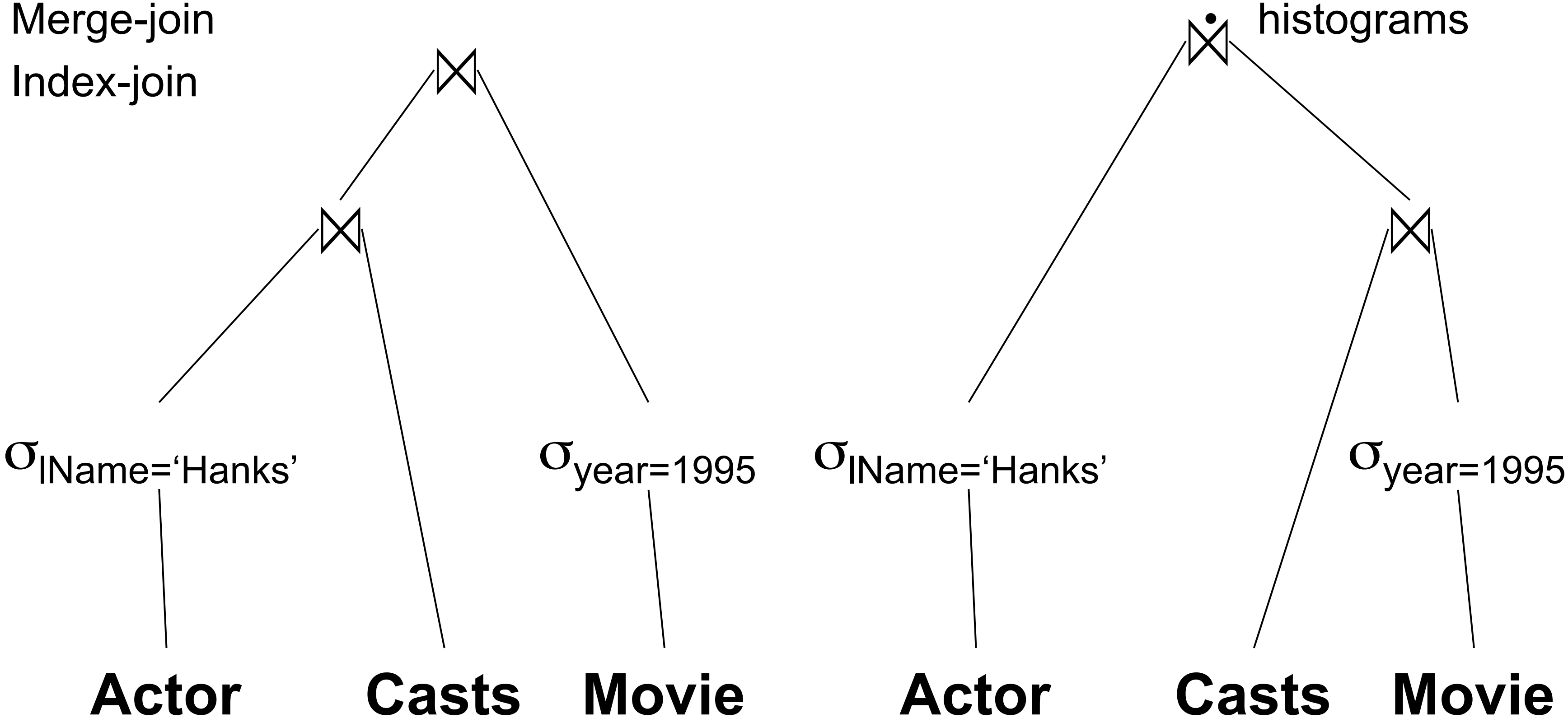
Plan 2: . . . . [in class]

Evaluating Tom Hanks

Classical query execution
- Index-based selection
- Hash-join
- Merge-join
- Index-join

Classical query optimizations:
- Pushing selections down
- Join reorder

Classical statistics
- Table cardinalities
- # distinct values
- histograms



Terminology for Query Workloads

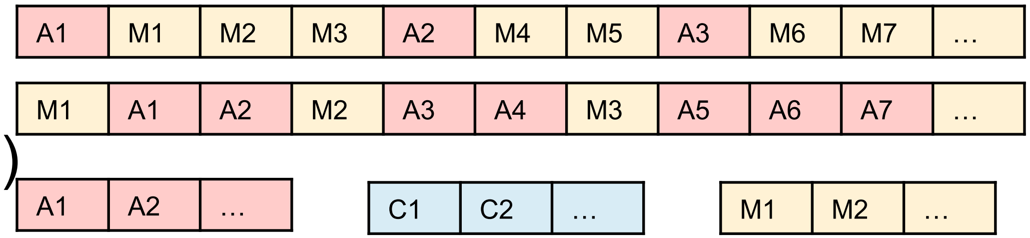
- OLTP (OnLine-Transaction-Processing)
  - Many updates: transactions are critical
  - Many “point queries”: access record by key
  - Commercial applications

- Decision-Support
  - Many aggregate/group-by queries.
  - Sometimes called *data warehouse*
  - Data analytics

Physical Data Independence

Physical data independence:

- Applications are isolated from changes to the physical organization:
  - Adding or dropping an index
  - (Actor,Movie*)* v.s.
    (Movie,Actor*)* v.s.
    (Movie*, Casts*, Actor*)



Translating WHAT to HOW:

- SQL = WHAT we want = declarative
- Relational algebra = HOW to get it = algorithm
- RDBMS are about translating WHAT to HOW

Transactions

- Recovery + Concurrency control
- ACID =
  - Atomicity (= recovery)
  - Consistency
  - Isolation (= concurrency control)
  - Durability

- Transactions are critical in business apps, but less important in data analytics and research in general
  - In 544 we discuss them only towards the end
  - In 344, 444, 544p we cover them early and extensively

Client/Server Architecture

- One server: stores the database
  - called DBMS or RDBMS
  - Usually a beefed-up system:
    - Can be cluster of servers, or parallel DBMS
    - In 544 you will install the postgres server on your own computer
- Many clients: run apps and connect to DBMS
  - Interactive: psql (postgres), Management Studio (SQL Server)
  - Java/C++/C#/… applications
  - Connection protocol: ODBC/JDBC

- Exceptions exists; e.g. SQL Lite

SQL

- Will discuss SQL rather quickly in 1.5 lectures
- Resources for learning SQL:
  - The slides in this lecture and in CSEP544
  - The textbook
  - Postgres: type \h or \?
- Start working on HW1 !

SQL

- Data Manipulation Language (DML)
  – Querying: SELECT-FROM-WHERE
  – Modifying: INSERT/DELETE/UPDATE

- Data Definition Language (DDL)
  – CREATE/ALTER/DROP
  – Constraints: will discuss these in class

Tables in SQL

Table name

Attribute names

Key

Product

PName	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Tuples or rows

Creating Tables, Importing Data

```
CREATE TABLE Product (
  pname varchar(10) primary key,
  price float,
  category char(20),
  manufacturer text
);
```

```
INSERT INTO Product VALUES ('Gizmo', 19.99, 'Gadgets','GizmoWorks');
INSERT INTO Product VALUES ('Powergizmo',29.99,'Gadgets','GizmoWorks');
INSERT INTO Product VALUES ('SingleTouch',149.99,'Photography','Canon');
INSERT INTO Product VALUES ('MultiTouch', 203.99,'Household','Hitachi');
```

Better: bulk insert (but database specific!)

```
COPY Product FROM '/my/directory/datafile.txt';  -- postgres only!
```

Other Ways to Bulk Insert

```
CREATE TABLE Product (
   pname varchar(10) primary key,
   price float,
   category char(20),
   manufacturer text
);
```

```
INSERT into Product (
     SELECT …
     FROM …
     WHERE…
);
```

Quick method: create AND insert

```
CREATE TABLE Product AS
     SELECT …
     FROM …
     WHERE…
```

Data Types in SQL

- Atomic types:
  - Characters: CHAR(20), VARCHAR(50)
  - Numbers: INT, BIGINT, SMALLINT, FLOAT
  - Others: MONEY, DATETIME, …
  - Note: an attribute cannot be another table!
- Record (aka tuple)
  - Has atomic attributes
- Table (relation)
  - A set of tuples

No nested tables! (Discussion next…)

Normal Forms

- First Normal Form
  - All tables must be flat tables
  - Why?
- Boyce Codd Normal Form
  - The only functional dependencies are from a key
  - What is a “functional dependency”?
  - Why?
- Third Normal Form
  - The only functional dependencies are from keys, except … [boring technical condition here]
  - Why?

Normal Forms

- First Normal Form
  - All tables must be flat tables
  - Why? Physical data independence!
- Boyce Codd Normal Form
  - The only functional dependencies are from a key
  - What is a “functional dependency”?
  - Why? Avoid data anomalies (redundancy, update, delete)
- Third Normal Form
  - The only functional dependencies are from keys, except … [boring technical condition here]
  - Why? Because that’s how we can recover all FD’s.

Your schema in HW1 should be in BCNF (easier than it sounds)

Simple Selection Queries in SQL

```
SELECT   *
FROM     Product
WHERE    category='Gadgets'
```

```
SELECT   *
FROM     Product
WHERE    category LIKE 'Ga%'
```

```
SELECT   *
FROM     Product
WHERE    category > 'Gadgets'
```

```
SELECT   *
FROM     Product
WHERE category LIKE '%dg%'
```

"selection"

"DISTINCT", "ORDER BY", "LIMIT"

```
SELECT   DISTINCT category
FROM     Product
```

```
SELECT   pname, price, manufacturer
FROM     Product
WHERE    category='gizmo' AND price > 50
ORDER BY price, pname
LIMIT 20
```

Keys and Foreign Keys

Company

Key

CName	StockPrice	Country
GizmoWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan

Product

PName	Price	Category	Manufacturer
Gizmo	$19.99	Gadgets	GizmoWorks
Powergizmo	$29.99	Gadgets	GizmoWorks
SingleTouch	$149.99	Photography	Canon
MultiTouch	$203.99	Household	Hitachi

Foreign key

Joins

Product (PName, Price, Category, Manufacturer)
Company (CName, stockPrice, Country)

Find all products under $200 manufactured in Japan;

```
SELECT  x.PName, x.Price
FROM    Product x, Company y
WHERE   x.Manufacturer=y.CName
    AND y.Country='Japan'
    AND x.Price <= 200
```

Semantics of SQL Queries

SELECT $a_1, a_2, \ldots, a_k$
FROM R_1 AS x_1, R_2 AS x_2, …, R_n AS x_n
WHERE Conditions

Answer = {}
for x_1 **in** R_1 **do**
    for x_2 **in** R_2 **do**
        …..
            for x_n **in** R_n **do**
                if Conditions
                    then Answer = Answer $\cup$ $\{(a_1,\ldots,a_k)\}$
return Answer

Subqueries

- A *subquery* is another SQL query nested inside a larger query
- Also called *nested queries*
- A subquery may occur in:
  - SELECT
  - FROM
  - WHERE

Rule of thumb: avoid writing nested queries when possible; keep in mind that sometimes it's impossible

Product (<u>pname</u>, price, company)
Company(<u>cname</u>, city)

Universal Quantifiers

Find cities that have a company
such that *<u>all</u>* its products have price < 100

Universal quantifiers are hard ! ☹

Product (pname, price, company)
Company(cname, city)

Universal Quantifiers

Find cities that have a company such that *all* its products have price < 100

Relational Calculus (a.k.a. First Order Logic) – next lecture

$$q(y)= \exists x. \text{Company}(x,y) \wedge (\forall z. \forall p. \text{Product}(z,p,x) \rightarrow p < 100)$$

Product (pname, price, company)
Company(cname, city)

Universal Quantifiers

De Morgan's Laws:

$$\neg(A \land B) = \neg A \lor \neg B$$
$$\neg(A \lor B) = \neg A \land \neg B$$
$$\neg \forall x.\ P(x) = \exists x.\ \neg P(x)$$
$$\neg \exists x.\ P(x) = \forall x.\ \neg P(x)$$

$$\neg(A \rightarrow B) = A \land \neg B$$

$$q(y) = \exists x.\ Company(x,y) \land (\forall z. \forall p.\ Product(z,p,x) \rightarrow p < 100)$$

=

$$q(y) = \exists x.\ Company(x,y) \land \neg(\exists z \exists p.\ Product(z,p,x) \land p \geq 100)$$

=

$$theOtherCompanies(x) = \exists z \exists p.\ Product(z,p,x) \land p \geq 100$$
$$q(y) = \exists x.\ Company(x,y) \land \neg\ theOtherCompanies(x)$$

Product (pname, price, company)
Company(cname, city)

Universal Quantifiers: NOT IN

theOtherCompanies(x) = $\exists z \exists p.$ Product(z,p,x) $\wedge$ $p \geq 100$
q(y) = $\exists x.$ Company(x,y) $\wedge$ $\neg$ theOtherCompanies(x)

```
SELECT DISTINCT  c.city
FROM      Company c
WHERE  c.cname NOT IN (SELECT p.company
                        FROM Product p
                        WHERE p.price >= 100)
```

Product (pname, price, company)
Company(cname, city)

Universal Quantifiers: NOT EXISTS

$$\text{theOtherCompanies}(x) = \exists z \exists p.\ \text{Product}(z,p,x) \wedge p \geq 100$$
$$q(y) = \exists x.\ \text{Company}(x,y) \wedge \neg\ \text{theOtherCompanies}(x)$$

```
SELECT DISTINCT  c.city
FROM      Company c
WHERE  NOT EXISTS (SELECT p.company
                   FROM Product p
                   WHERE c.cname = p.company AND p.price >= 100)
```

Correlated subquery!

Product (pname, price, company)
Company(cname, city)

Universal Quantifiers: ALL

```
SELECT DISTINCT  c.city
FROM     Company c
WHERE 100 > ALL  (SELECT p.price
                  FROM Product p
                  WHERE p.company = c.cname)
```

A Taste of Theory

- Can we unnest the *universal quantifier* query ?
  - Can we write it as a simple SELECT-FROM-WHERE query?

Monotone Queries

- A query Q is monotone if:
  - Whenever we add tuples to one or more of the tables…
  - … the answer to the query cannot contain fewer tuples
- **Fact**: all unnested queries are monotone
  - Proof: using the "nested for loops" semantics
- **Fact**: A query a universal quantifier is not monotone
- **Consequence**: we cannot unnest a query with a universal quantifier

Queries that must be nested

- Queries with universal quantifiers or with negation
- The drinkers-bars-beers example next
- This is a famous example from textbook on databases by Ullman

Rule of Thumb:

Non-monotone queries cannot be unnested. In particular, queries with a universal quantifier cannot be unnested