# Principles of Database Systems CSE 544

Lecture 01

Introduction and SQL

# Staff

- Instructor:  Dan Suciu
  - CSE 662, suciu@cs.washington.edu
  - Office hour:  Wednesdays, 5:30-6:20, CSE 662

- TA:
  - Laurel Orr ljorr1@cs.washington.edu
  - Office hours: Mondays, 5:30-6:20, room TBA

# About Me

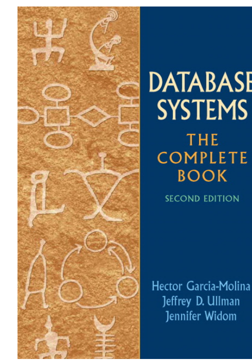
- Joined CSE in 2000
  - Previously at Bell Labs / AT&T Labs
- Research: where math can bring big gains to data management:
  - Probabilistic databases
  - Novel query evaluation algorithms for big data
  - Pricing and enforcing data use agreements
  - Discovering causal relationships in data

# Class Format

- Lectures Mondays, 6:30-9:20
  - Two lecture rooms: CSE and Microsoft
  - Video streamed + archived
- 5 Homework  Assignments
- Several reading assignments
- An online, take-home final (two days), Dec. 9-10

# Textbook and Papers

- Main 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
- Optional Textbook
  – Database Systems: The Complete Book, by Garcia-Molina, Ullman, Widom
- Other Books
  – Foundations of Databases, by Abiteboul, Hull, Vianu


# Textbook and Papers

Several papers to read and review

- Some are short blogs (Stonebraker)
- Most are real papers
- All papers are available from the course Website with your CSE or UWID credentials
- Most are also available online, and on Kindle

# Resources

- Web page: courses.cs.washington.edu/courses/csep544/15au/
  - Lectures + video
  - Homework assignments
  - Reading assignments
  - Information about the final

- Mailing list:
  - Announcements, group discussions
  - Low traffic, must read

- Discussion board:
  - Feel free to post, discuss
  - TA will check regularly

# Content of the Class

- Relational Data Model
  - SQL, Data Models, Relational calculus
- Database internals
  - Storage, query execution/optimization, statistics
- Parallel databases and MapReduce
- Transactions
  - Recovery (Aries), Concurrency control
- Advanced Topics
  - Datalog
  - ColumnStore (maybe NoSQL)

# Evaluation

- Homework Assignments 50%:
  - Three light programming, two theory
- Paper reviews 20%:
  - About ½ page each
- Final exam 30%:
  - Take home, online exam
  - Two days: Wednesday-Thursday, Dec. 9-10

# Homework Assignments 50%

- HW1: SQL — programming
- HW2: RC/RA, DB Design — theory
- HW3: PigLatin on AWS — programming
- HW4: DB Application — programming
- HW5: Transactions — theory

Late days policy:

- 4 late-days in 24-hour chunks, no questions asked
- at most 2 late-days per assignment
- Absolutely no additional extensions granted

# Assignments 50%

HW1: SQL – posted!

- Three Tasks:
  - Create tables
  - Create indexes
  - Compute 11 SQL Queries
- Dataset = a copy of IMDB from 2010
- Install a DMBS on your machine: either Postgres or SQL Server.
- Watch mailing list for a possible update (+Azure)

Due: Tuesday, October 20

# Paper Reviews

- Papers:
  - A few short blogs by Stonebraker
  - Several systems-research papers
- Reviews:
  - Due Mondays, by 3pm
  - Brief (½ page) summary of the lessons you learned from the paper
  - Website has some suggested questions
- Next Monday:
  - Blog on Big Data (what is that??)
  - Paper on data models + perils of inventing new

# Final

## Format

- Take-home, online final
- Opens: Wednesday, Dec. 9 at 8am
- Closes: Thursday, Dec. 10 at 8pm
- No late days/hours/minutes/seconds

# Goals of the Class

This is a graduate level class!

- Deep understanding of traditional material
- Novel material

# Background

**You should have heard about most of:**

- E/R diagrams
- Normal forms (1st, 3rd)
- SQL
- Relational Algebra
- Indexes, search trees
- Search in a binary tree
- Query optimization
- Transactions (e.g. ACID)
- 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: Chapters 5.2 – 5.6 in the textbook

# 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, …

# 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, …

# 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 – Preview

```
SELECT *
FROM  Actor
```

# SQL – Preview

```
SELECT *
FROM  Actor
```

↓

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

# SQL – Preview

```
SELECT *
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```

```
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LIMIT 50
```

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

# SQL – Preview

```
SELECT *
FROM  Actor
```

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

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

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

# SQL – Preview

```
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

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# How Can We Evaluate the Query ?

**Actor:**

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| . . . | | | |

1.8M actors

**Casts:**

| pid | mid |
|---|---|
| . . . | |
| . . . | |

11M casts

**Movie:**

| id | Name | year |
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| . . . | | 1995 |
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1.5M movies

```
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WHERE x.lname='Hanks'
      and x.id = y.pid
      and y.mid=z.id
      and z.year=1995
```

Plan 1: . . . . [ in class ]

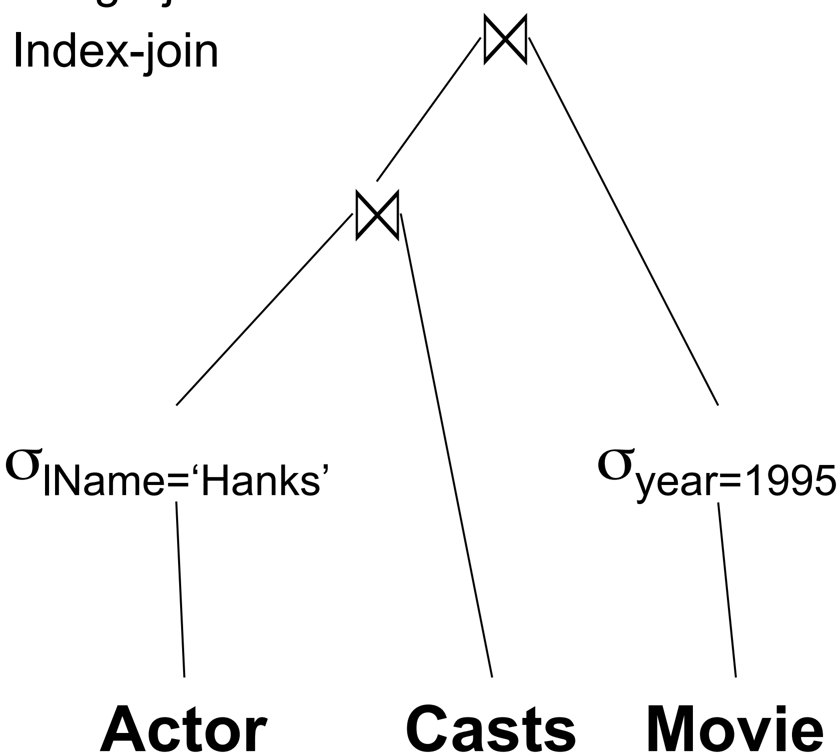
Plan 2: . . . . [ in class ]

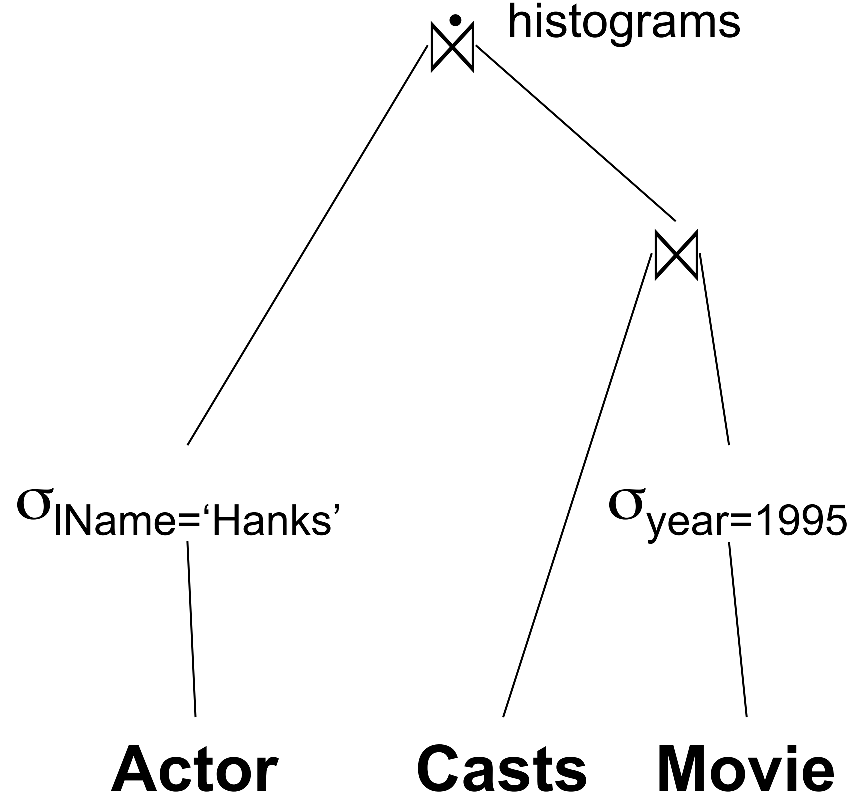
# Query Plans – Preview

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



# Physical Data Independence

See *Goes around…* paper, due next week

Physical data independence:

- Applications should be isolated from changes to the physical organization
- E.g. add/drop index

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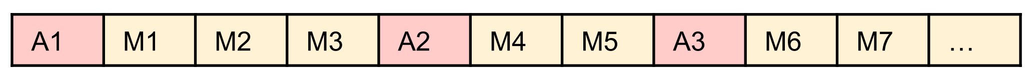
(Actor,Movie*)*



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## Physical data independence:

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- E.g. Different storage organization:

(Actor,Movie*)*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| A1 | M1 | M2 | M3 | A2 | M4 | M5 | A3 | M6 | M7 | … |

(Movie,Actor*)*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| M1 | A1 | A2 | M2 | A3 | A4 | M3 | A5 | A6 | A7 | … |

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## Physical data independence:

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|---|---|---|---|---|---|---|---|---|---|---|
| A1 | M1 | M2 | M3 | A2 | M4 | M5 | A3 | M6 | M7 | … |

(Movie,Actor*)*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| M1 | A1 | A2 | M2 | A3 | A4 | M3 | A5 | A6 | A7 | … |

(Movie*, Casts*, Actor*)

| | | |
|---|---|---|
| A1 | A2 | … |

| | | |
|---|---|---|
| C1 | C2 | … |

| | | |
|---|---|---|
| M1 | M2 | … |

# Physical Data Independence

Query optimizer = Translate WHAT to HOW:

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

# Client/Server Architecture

- Server: stores the database
  - Single server or cluster of servers
  - Postgres: runs server on your own computer
- Clients: run apps and connect to DBMS
- Connection Protocol: ODBC/JDBC

- Others:
  - Three-tier architecture: add the app server
  - Embedded in app (e.g. SQLite): no server

Why is client/server preferable to embedded in app?

# SQL

- Will cover SQL rather quickly today

- Will not finish discussing all slides in class:
  please read the rest on your own!

- Other resources for learning SQL:
  - Textbook
  - Office hours
  - Postgres help: type \h or \?
  - SQL Server help
  - Discussion board

- Start working on HW1!

# 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

# 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

# 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), TEXT
  - 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?

- 1NF is an exception. Other NF's refer to splitting a wide table into smaller tables:
  - Boyce Codd Normal Form (BCNF)
  - Third Normal Form (3NF)
- We will discuss BCNF later in class

# Selections in SQL

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

# Selections in SQL

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

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

# Selections in SQL

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

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

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

# Selections 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%'
```

# Projections (and Selections) in SQL

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

# Projections (and Selections) in SQL

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

```
SELECT   category
FROM     Product
```

# Projections (and Selections) in SQL

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

```
SELECT   category
FROM     Product
```

Need DISTINCT
(why?)

```
SELECT DISTINCT category
FROM     Product
```

# “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
```

Postgres uses LIMIT k
SQL Server uses TOP k

# Keys and Foreign Keys

Company

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

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 |

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 a1, a2, …, ak
FROM   R1 AS x1, R2 AS x2, …, Rn AS xn
WHERE  Conditions
```

# Semantics of SQL Queries

```
SELECT a1, a2, …, ak
FROM   R1 AS x1, R2 AS x2, …, Rn AS xn
WHERE  Conditions
```

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* or a *nested query* is another SQL query nested inside a larger query
- A subquery may occur in:

SELECT
FROM } Examples at the end of the lecture
WHERE } Examples on following slides

> Avoid writing nested queries when possible;
> keep in mind that sometimes it's impossible

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

# Running Example

Run this in postgres, then try the examples on the following slides.

```
create table company(cname text primary key, city text);
create table product(pname text primary key, price int, company text references company);

insert into company values('abc', 'seattle');
insert into company values('cde', 'seattle');
insert into company values('fgh', 'portland');
insert into company values('klm', 'portland');

insert into product values('p1',  10, 'abc');
insert into product values('p2', 200, 'abc');
insert into product values('p3',  10, 'cde');
insert into product values('p4',  20, 'cde');

insert into product values('p5',  10, 'fgh');
insert into product values('p6', 200, 'fgh');
insert into product values('p7',  10, 'klm');
insert into product values('p8', 220, 'klm');
```

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

# Existential Quantifiers

Find cities that have a company
that manufacture *some* product with price < 100

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

# Existential Quantifiers

Find cities that have a company
that manufacture *some* product with price < 100

```
SELECT DISTINCT  c.city
FROM      Company c, Product p
WHERE  c.cname = p.company
     and  p.price < 100
```

Existential quantifiers are easy! ☺

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

# Universal Quantifiers

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

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

# Universal Quantifiers

Find cities that have a company
such that *all* 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 week

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

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

# Universal Quantifiers

De Morgan's Laws:

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

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

$\neg \forall x.\ P(x) = \exists x.\ \neg P(x)$

$\neg \exists x.\ P(x) = \forall x.\ \neg P(x)$

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

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

# Universal Quantifiers

De Morgan's Laws:

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

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$\neg \forall x. P(x) = \exists x. \neg P(x)$

$\neg \exists x. P(x) = \forall x. \neg P(x)$

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

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

=

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

# Universal Quantifiers

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

=

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

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

# Universal Quantifiers

De Morgan's Laws:

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

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

=

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

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

# Universal Quantifiers: NOT IN

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

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

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

# Universal Quantifiers: NOT EXISTS

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

```
SELECT DISTINCT  c.city
FROM      Company c
WHERE  NOT EXISTS (SELECT *
                   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)
```

# Question for Database Fans and their Friends

- Can we unnest this query ?

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

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

# Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any existing tuples

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

# Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any existing tuples

Product

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c003 |
| Camera | 149.99 | c001 |

Company

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |
| c002 | DB Inc. | Lyon |
| c003 | Builder | Lodtz |

Q ⇒

| A | B |
|---|---|
| 149.99 | Lodtz |
| 19.99 | Lyon |

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

# Monotone Queries

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Company

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |
| c002 | DB Inc. | Lyon |
| c003 | Builder | Lodtz |

Q

| A | B |
|---|---|
| 149.99 | Lodtz |
| 19.99 | Lyon |

Product

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c003 |
| Camera | 149.99 | c001 |
| iPad | 499.99 | c001 |

Company

| cid | cname | city |
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Product (pname, price, cid)
Company(cid, cname, city)

# Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any existing tuples

Product

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
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Q →

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Is the mystery query monotone?

Product

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c003 |
| Camera | 149.99 | c001 |
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Company

| cid | cname | city |
|---|---|---|
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Product (pname, price, cid)
Company(cid, cname, city)

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Company

| cid | cname | city |
| --- | --- | --- |
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Q ⇒

| A | B |
| --- | --- |
| 149.99 | Lodtz |
| 19.99 | Lyon |

Is the mystery query monotone?

NO!

Product

| pname | price | cid |
| --- | --- | --- |
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c003 |
| Camera | 149.99 | c001 |
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Company

| cid | cname | city |
| --- | --- | --- |
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Q ⇒

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# Monotone Queries

**Theorem**: If Q is a SELECT-FROM-WHERE query that does not have subqueries, and no aggregates, then it is monotone.

```
SELECT a1, a2, …, ak
FROM   R1 as x1, R2 as x2, …, Rn as xn
WHERE  Conditions
```

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```
SELECT a1, a2, …, ak
FROM   R1 as x1, R2 as x2, …, Rn as xn
WHERE  Conditions
```

**Proof**. We use the nested loop semantics: if we insert a tuple in a relation $R_i$, then $x_i$ will take all the old values, in addition to the new value.

```
for x1 in R1 do
    for x2 in R2 do
        …..
            for xn in Rn do
                if Conditions
                    output (a1,…,ak)
```

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

# Monotone Queries

This query is not monotone:

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

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

# Monotone Queries

This query is not monotone:

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

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |

⇒

| cname |
|---|
| Sunworks |

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c001 |

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |

⇒

| cname |
|---|
| |

Product (pname, price, cid)

Company(cid, cname, city)

# Monotone Queries

This query is not monotone:

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

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|---|---|---|
| Gizmo | 19.99 | c001 |

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |

⇒

| cname |
|---|
| Sunworks |

| pname | price | cid |
|---|---|---|
| Gizmo | 19.99 | c001 |
| Gadget | 999.99 | c001 |

| cid | cname | city |
|---|---|---|
| c001 | Sunworks | Bonn |

⇒

| cname |
|---|
| |

Consequence: we cannot write it as a SELECT-FROM-WHERE query without nested subqueries

# NULLS in SQL

- Whenever we don't have a value, we can put a NULL

- Can mean many things:
  - Value does not exists
  - Value exists but is unknown
  - Value not applicable
  - Etc.

- The schema specifies for each attribute if can be null (*nullable* attribute) or not

# Null Values

height unknown

Person(<u>name</u>, age, height, weight)

```
INSERT INTO Person VALUES('Joe',20,NULL,200)
```

# Null Values

height unknown

Person(name, age, height, weight)

INSERT INTO Person VALUES('Joe',20,NULL,200)

Rules for computing with NULLs

- If x is NULL then x+7 is still NULL
- If x is 2 then x>5 is FALSE
- If x is NULL then x>5 is UNKNOWN
- If x is 10 then x>5 is TRUE

# Null Values

Person(name, age, height, weight)

height unknown

INSERT INTO Person VALUES('Joe',20,NULL,200)

Rules for computing with NULLs

- If x is NULL then x+7 is still NULL
- If x is 2 then x>5 is FALSE
- If x is NULL then x>5 is UNKNOWN
- If x is 10 then x>5 is TRUE

| | | |
|---|---|---|
| FALSE | = | 0 |
| UNKNOWN | = | 0.5 |
| TRUE | = | 1 |

# Null Values

- C1 AND C2 = min(C1, C2)
- C1 OR C2 = max(C1, C2)
- NOT C1 = 1 – C1

# Null Values

- C1 AND C2 = min(C1, C2)
- C1 OR C2 = max(C1, C2)
- NOT C1 = 1 – C1

```
SELECT *
FROM Person
WHERE  (age < 25) AND
            (height > 6 OR weight > 190)
```

E.g.
age=20
height=NULL
weight=200

Rule in SQL: result includes only tuples that yield TRUE

# Null Values

Unexpected behavior:

```
SELECT *
FROM    Person
WHERE  age < 25  OR  age >= 25
```

Some Persons not included !

# Null Values

Can test for NULL explicitly:

x IS NULL

x IS NOT NULL

```
SELECT *
FROM    Person
WHERE  age < 25  OR  age >= 25 OR age IS NULL
```

Now all Person are included

# Detour into DB Research

Imielinski&Libski, *Incomplete Databases*, 1986

- Database = is in one of several states, or *possible worlds*
  - Number of possible worlds is exponential in size of db
- Query semantics = return the *certain answers*

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Very influential paper:

- Incomplete DBs used in probabilistic databases, *what-if* scenarios, data cleaning, data exchange

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- Query semantics = return the *certain answers*

Very influential paper:

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In SQL, NULLs are the simplest form of incomplete database:

- Database: NULL takes independently any possible value
- Query semantics: not exactly certain answers (why?)

Product(name, category)
Purchase(prodName, store)

# Outerjoins

An "inner join":

```
SELECT x.name, y.store
FROM   Product x, Purchase y
WHERE  x.name = y.prodName
```

Same as:

```
SELECT x.name, y.store
FROM   Product x JOIN Purchase y ON
                   x.name = y.prodName
```

But Products that never sold will be lost

Product(name, category)
Purchase(prodName, store)

# Outerjoins

If we want the never-sold products, need a "left outer join":

```
SELECT x.name, y.store
FROM   Product x LEFT OUTER JOIN Purchase y ON
              x.name = y.prodName
```

Product(<u>name</u>, category)
Purchase(prodName, store)

## Product

| <u>name</u> | category |
| --- | --- |
| Gizmo | gadget |
| Camera | Photo |
| OneClick | Photo |

## Purchase

| prodName | store |
| --- | --- |
| Gizmo | Wiz |
| Camera | Ritz |
| Camera | Wiz |

| name | store |
| --- | --- |
| Gizmo | Wiz |
| Camera | Ritz |
| Camera | Wiz |
| OneClick | NULL |

# Outer Joins

- Left outer join:
  - Include the left tuple even if there's no match
- Right outer join:
  - Include the right tuple even if there's no match
- Full outer join:
  - Include both left and right tuples even if there's no match

# Aggregations

Five basic aggregate operations in SQL

- count
- sum
- avg
- max
- min

Purchase(product, price, quantity)

# Counting Duplicates

COUNT applies to duplicates, unless otherwise stated:

```
SELECT  count(product)
FROM    Purchase
WHERE   price>3.99
```

Same as count(*)

Except if some product is NULL

We probably want:

```
SELECT  count(DISTINCT product)
FROM    Purchase
WHERE   price>3.99
```

Purchase(product, price, quantity)

# Grouping and Aggregation

Find total quantities for all sales over $1, by product.

```
SELECT      product, sum(quantity) AS TotalSales
FROM        Purchase
WHERE       price > 1
GROUP BY    product
```

| product | price | quantity |
|---|---|---|
| Bagel | 3 | 20 |
| Bagel | 1.50 | 20 |
| Banana | 0.5 | 50 |
| Banana | 2 | 10 |
| Banana | 4 | 10 |

What is the answer?

# Grouping and Aggregation

1. Compute the FROM and WHERE clauses.

2. Group by the attributes in the GROUP BY

3. Compute the SELECT clause: group attrs and aggregates.

# 1&2. FROM-WHERE-GROUPBY

| Product | Price | Quantity |
|---|---|---|
| Bagel | 3 | 20 |
| Bagel | 1.50 | 20 |
| Banana | ~~0.5~~ | ~~50~~ |
| Banana | 2 | 10 |
| Banana | 4 | 10 |

```
SELECT      product, sum(quantity) AS TotalSales
FROM        Purchase
WHERE       price > 1
GROUP BY    product
```

# 3. SELECT: Each Group → One Answer

| Product | Price | Quantity |
|---|---|---|
| Bagel | 3 | 20 |
| Bagel | 1.50 | 20 |
| Banana | ~~0.5~~ | ~~50~~ |
| Banana | 2 | 10 |
| Banana | 4 | 10 |

→

| Product | TotalSales |
|---|---|
| Bagel | 40 |
| Banana | 20 |

```
SELECT      product, sum(quantity) AS TotalSales
FROM        Purchase
WHERE       price > 1
GROUP BY  product
```

# Ordering Results

```
SELECT product, sum(quantity) as TotalSales
FROM   purchase
GROUP BY product
ORDER BY TotalSales DESC
LIMIT 20
```

```
SELECT product, sum(quantity) as TotalSales
FROM   purchase
GROUP BY product
ORDER BY sum(quantity) DESC
LIMIT 20
```

Equivalent, but not all systems accept both syntax forms

# HAVING Clause

Same query as earlier, except that we consider only products that had at least 30 sales.

```
SELECT      product, sum(quantity)
FROM        Purchase
WHERE       price > 1
GROUP BY product
HAVING      count(*) > 30
```

HAVING clause contains conditions on aggregates.

# WHERE vs HAVING

- WHERE condition: applied to individual rows
  - Determine which rows contributed to the aggregate
  - All attributes are allowed
  - No aggregates functions allowed
- HAVING condition: applied to the entire group
  - Entire group is returned, or not al all
  - Only group attributes allowed
  - Aggregate functions allowed

# General form of Grouping and Aggregation

```
SELECT    S
FROM      R1,…,Rn
WHERE     C1
GROUP BY  a1,…,ak
HAVING    C2
```

Why ?

S = may contain attributes $a_1,\ldots,a_k$ and/or any aggregates but NO OTHER ATTRIBUTES

C1 = is any condition on the attributes in $R_1,\ldots,R_n$

C2 = is any condition on aggregate expressions and on attributes $a_1,\ldots,a_k$

# Semantics of SQL With Group-By

```
SELECT     S
FROM       R1,…,Rn
WHERE      C1
GROUP BY   a1,…,ak
HAVING     C2
```

Evaluation steps:

1. Evaluate FROM-WHERE using Nested Loop Semantics
2. Group by the attributes $a_1,\ldots,a_k$
3. Apply condition C2 to each group (may have aggregates)
4. Compute aggregates in S and return the result

# Empty Groups Running Example

For the next slides, run this in postgres:

```
create table Purchase(pid int primary key, product text, price float, quantity int, month varchar(15));
create table Product (pid int primary key, pname text, manufacturer text);

insert into Purchase values(01,'bagel',1.99,20,'september');
insert into Purchase values(02,'bagel',2.50,12,'december');
insert into Purchase values(03,'banana',0.99,9,'september');
insert into Purchase values(04,'banana',1.59,9,'february');
insert into Purchase values(05,'gizmo',99.99,5,'february');
insert into Purchase values(06,'gizmo',99.99,3,'march');
insert into Purchase values(07,'gizmo',49.99,3,'april');
insert into Purchase values(08,'gadget',89.99,3,'january');
insert into Purchase values(09,'gadget',89.99,3,'february');
insert into Purchase values(10,'gadget',49.99,3,'march');
insert into Purchase values(11,'orange',null,5,'may');

insert into product values(1,'bagel','Sunshine Co.');
insert into product values(2,'banana','BusyHands');
insert into product values(3,'gizmo','GizmoWorks');
insert into product values(4,'gadget','BusyHands');
insert into product values(5,'powerGizmo','PowerWorks');
```

Purchase(product, price, quantity)
Product(pname, manufacturer)

# Empty Group Problem

**Query**: for each manufacturer, compute the total number of purchases for its products

**Problem**: a group can never be empty!
In particular, count(*) is never 0

```
SELECT x.manufacturer, count(*)
FROM Product x, Purchase y
WHERE x.pname = y.product
GROUP BY x.manufacturer
```

Purchase(product, price, quantity)

Product(pname, manufacturer)

# Solution 1: Outer Join

**Query**: for each manufacturer, compute the total number of purchases for its products

Use a LEFT OUTER JOIN.

Make sure you count an attribute that may be NULL

```
SELECT x.manufacturer, count(y.product)
FROM Product x LEFT OUTER JOIN Purchase y
ON x.pname = y.product
GROUP BY x.manufacturer
```

Purchase(product, price, quantity)

Product(pname, manufacturer)

# Solution 2: Nested Query

**Query**: for each manufacturer, compute the total number of purchases for its products

Use a subquery in the SELECT clause

Notice second use of Product. Why?

```
SELECT DISTINCT x.manufacturer,
       (SELECT count(*)
        FROM Product z, Purchase y
        WHERE x.manufacturer = z.manufacturer
            and   z.pname = y.product)
FROM Product x
```

Purchase(product, price, quantity)

Product(pname, manufacturer)

# Finding Witnesses

**Query**: for each manufacturer, find its most expensive product

Finding the maximum price is easy:

Purchase(product, price, quantity)

Product(<u>pname</u>, manufacturer)

# Finding Witnesses

**<u>Query</u>**: for each manufacturer, find its most expensive product

Finding the maximum price is easy:

```
SELECT x.manufacturer, max(y.price)
FROM Product x, Purchase y
WHERE x.pname = y.product
GROUP BY x.manufacturer
```

…but we need to find the product that sold at that price!

Purchase(product, price, quantity)

Product(pname, manufacturer)

# Finding Witnesses

**Query**: for each manufacturer, find its most expensive product

Use a subquery in the FROM clause:

```
SELECT DISTINCT u.manufacturer, u.pname
FROM Product u, Purchase v,
        (SELECT x.manufacturer, max(y.price) as mprice
         FROM Product x, Purchase y
         WHERE x.pname = y.product
         GROUP BY x.manufacturer) z
WHERE u.pname = v.product
    and  u.manufacturer = z.manufacturer
    and  v.price = z.mprice
```

Purchase(product, price, quantity)
Product(pname, manufacturer)

# Finding Witnesses

**Query**: for each manufacturer, find its most expensive product

Using WITH :

```
WITH Temp as (SELECT x.manufacturer, max(y.price) as mprice
              FROM Product x, Purchase y
              WHERE x.pname = y.product
              GROUP BY x.manufacturer)
SELECT DISTINCT u.manufacturer, u.pname
FROM Product u, Purchase v, Temp z
WHERE u.pname = v.product
   and  u.manufacturer = z.manufacturer
   and  v.price = z.mprice
```

# Terminology for Query Workloads

- OLTP (OnLine-Transaction-Processing)
  - Many updates: transactions are critical
  - Many “point queries”: access record by key
  - Commercial applications
- Decision-Support
  or OLAP (Online Analytical Processing)
  - Many aggregate/group-by queries.
  - Sometimes called *data warehouse*
  - Data analytics