CSE544
Data Management

Lectures 1&2:

Relational Data Model, SQL

Outline

- Introduction, class overview
- Database management systems (DBMS)
- The relational model

Course Staff

- Instructor: Dan Suciu
  - Office hours: Mondays, 11:30-12:20
- TA: Walter Cai
  - Office hours: TBD

Goals of the Class

- Relational Data Model
  - Data models, data independence, declarative query language.
- Relational Database Systems
  - Storage, query execution and optimization
  - Parallel data processing, column-oriented db etc.
- Transactions
  - Optimistic/pessimistic concurrency control
  - ARIES recovery system

A Note for Non-Majors

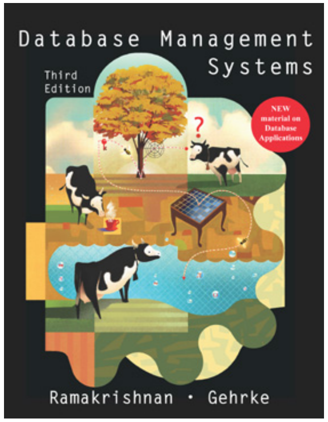
- For the Data Science option: take 414
- For the Advanced Data Science option: take 544

- 544 is an *advanced* class, not intended as an introduction to data management research
- Does not cover fundamentals systematically, yet there is an exam testing those fundamentals

- Unsure? Look at the short quiz on the website.

Readings

- Paper reviews
  - Mix of old seminal papers and new papers
  - Papers are available on class website
- Lecture notes (the slides)
  - Posted on class website after each lecture
- Background from:
  - Database Management Systems. **Third Ed**. Ramakrishnan and Gehrke. McGraw-Hill.



Class Resources

Website: lectures, assignments

- http://www.cs.washington.edu/544

Canvas: zoom, videos

Ed: discussion board

Evaluation

- Assignments 40%
- Reviews 10%
- Project 40%
- Intangibles 10%

Assignments – 40%

- **HW1**: Use a DBMS
- **HW2**: Data analysis in the cloud
- **HW3**: Query Execution and SimpleDB
- **HW4**: Datalog
- [possibly a HW5 on transactions]
- See course calendar for deadlines
- Late assignments w/ ***very*** valid excuse

Paper reviews – 10%

- Recommended length: ½ page – 1 page
  - Summary of the main points of the paper
  - Critical discussion of the paper
- Grading: credit/patial-credit/no-credit
- Submit review _before_ the lecture

Project – 40%

- Topic
  - Best: come up with your own, ideally related to your own research
  - Or choose from a list of mini-research topics
  - 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

- Final deliverables
  - Short, conference-style presentation on Friday, March 12
  - Short, conference-style paper (6 pages)

Project – 40%

- Dates posted on the calendar page:
  - **M1**: form groups
  - **M2**: Project proposal
  - **M3**: Milestone report
  - **M4**: Poster presentation
  - **M5**: Project paper
- We will provide feedback throughout the quarter

Intangibles 10%

- Class participation
- Exceptionally good reviews, or homework, or project
- Etc, etc

How to Turn In

- Homeworks: gitlab
- Project: gitlab
- Reviews: google forms

Now onward to the world of databases!

Data Management

- **Entities**: employees, positions (ceo, manager, cashier), stores, products, sells, customers.

- **Relationships**: employee positions, staff of each store, inventory of each store.

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,…

DBMS Functionality

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

Several types of architectures (next)

Single Client

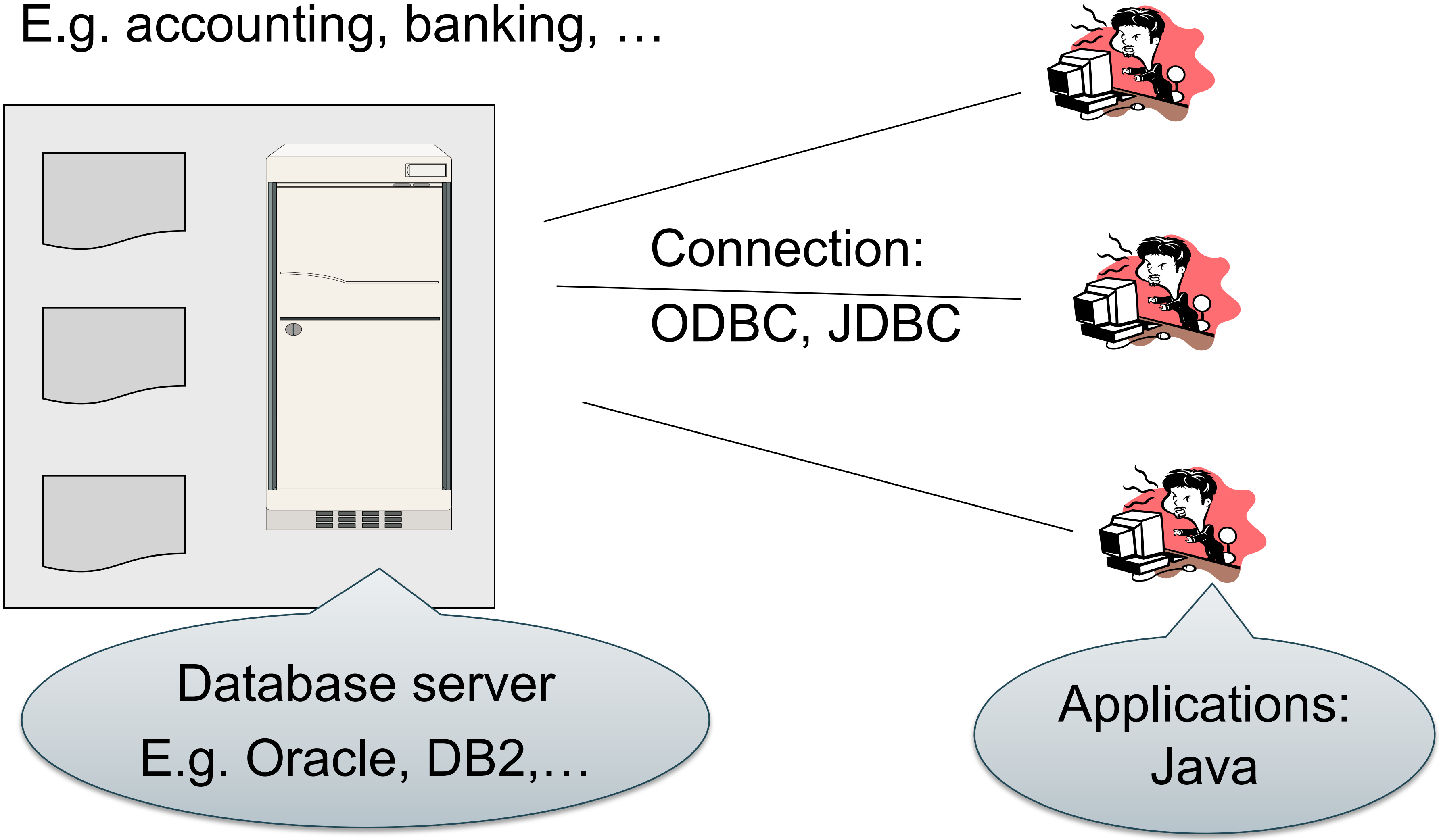
E.g. data analytics

Application and database
on the same computer

E.g. sqlite, postgres

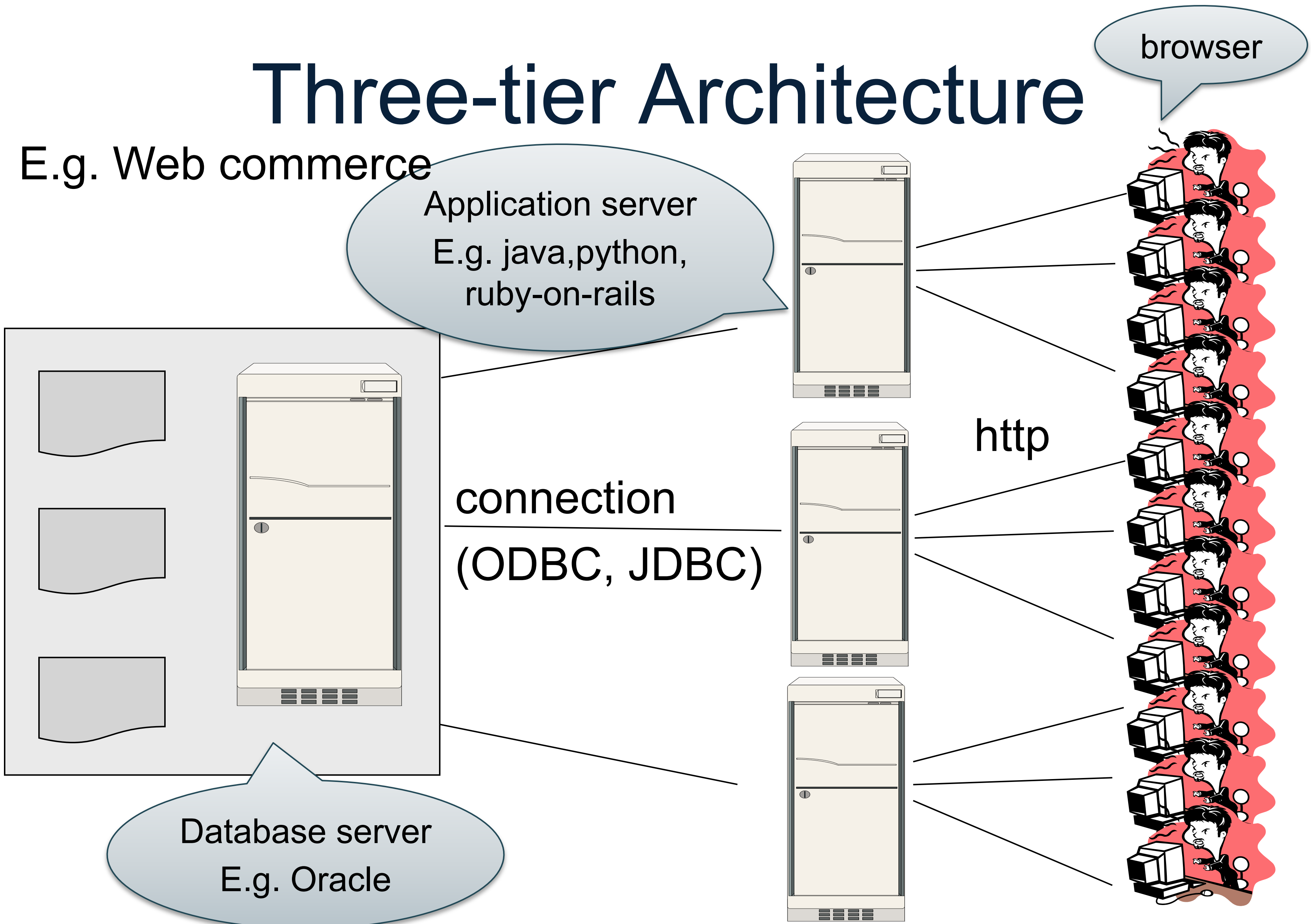
Two-tier Architecture
Client-Server

E.g. accounting, banking, …

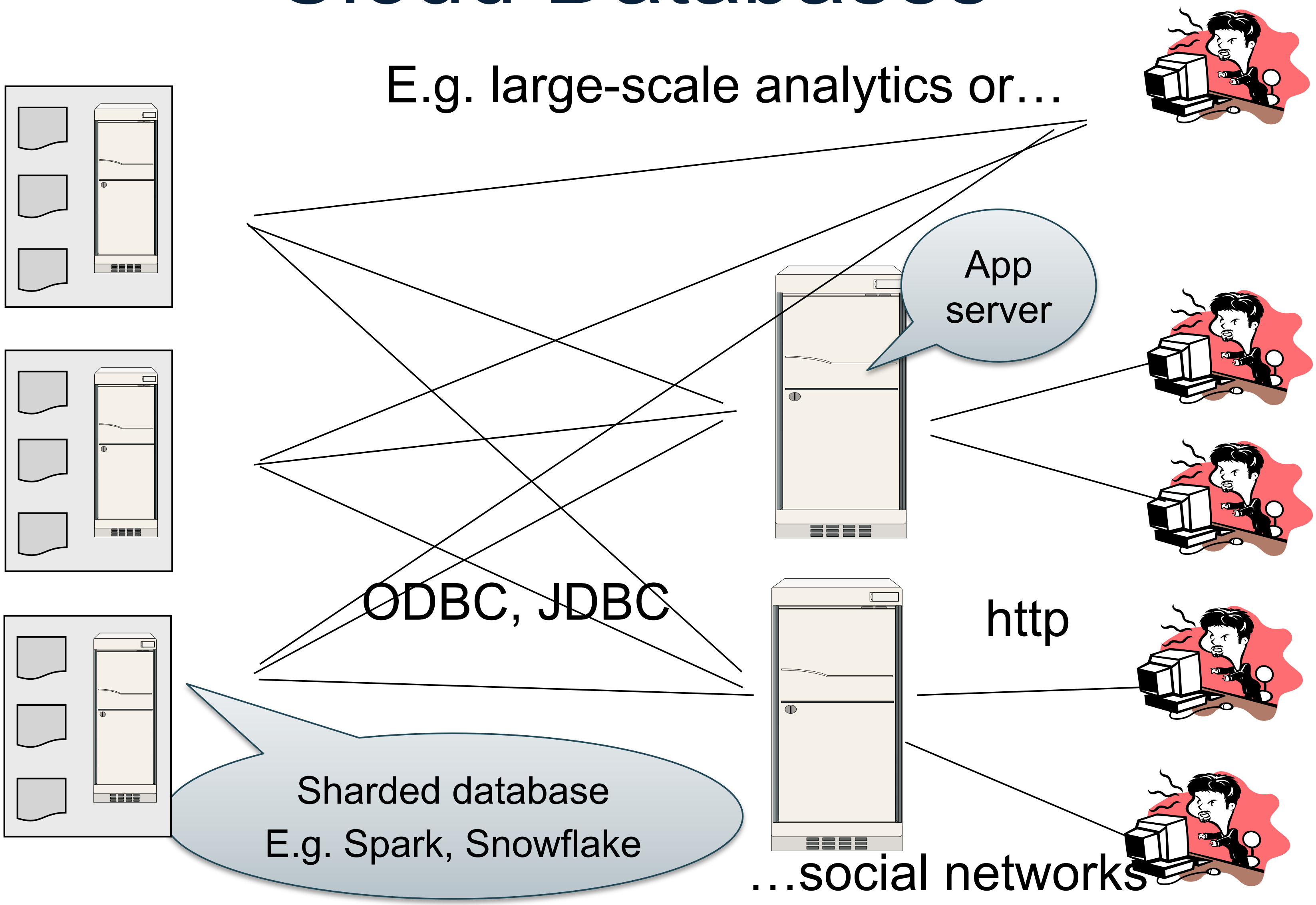


Three-tier Architecture

E.g. Web commerce



Cloud Databases



Workloads

- OLTP – online transaction processing
- OLAP – online analytics processing, a.k.a. Decision Support

Most of this course

Relational Data Model

Relational Data Model

- A Database is a collection of relations
- A Relation is a set of tuples
  - Also called Table
- A Tuple t is an element of $\mathbf{Dom_1 \times Dom_2 \times \ldots \times Dom_n}$
  - $\mathbf{Dom_i}$ is the domain of attribute **i**
  - **n** is number of attributes of the relation
  - Also called Row or Record

Discussion

- Rows in a relation:
  - Ordering immaterial (a relation is a set)
  - All rows are distinct – set semantics
  - Query answers may have duplicates – bag semantics

Data independence!

- Columns in a tuple:
  - Ordering is significant
  - Applications refer to columns by their names

Or is it?

- Domain of each column is a primitive type

Schema

- Relation schema: describes column heads
  - Relation name
  - Name of each field (or column, or attribute)
  - Domain of each field
  - The *arity* of the relation = # attributes

- Database schema: set of all relation schemas

Instance

- Relation instance: concrete table content
  - Set of records matching the schema
  - The *cardinality* or *size* of the relation = # tuples

- Database instance: set of all relation instances

What is the schema?
What is the instance?

Supplier

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

What is the schema?
What is the instance?

Relation schema

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

Supplier

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

} instance

Relational Query Language

- Set-at-a-time:
  - Query inputs and outputs are relations
- Two variants of the query language:
  - Relational algebra: specifies order of operations
  - Relational calculus / SQL: declarative

SQL

- Standard query language
- Introduced late 70's, now it ballooned
- We briefly review "core SQL" (whatever that means); study more on you own!
- Read by Wed: *A case against SQL*

Structured Query Language: SQL

- Data definition language: DDL
  - Statements to create, modify tables and views
  - CREATE TABLE …,
    CREATE VIEW …,
    ALTER TABLE…

Review on your own

- Data manipulation language: DML
  - Statements to issue queries, insert, delete data
  - SELECT-FROM-WHERE…,
    INSERT…,
    UPDATE…,
    DELETE…

We quickly review this

SQL Query

Basic form: (plus many many more bells and whistles)

```
SELECT  <attributes>
FROM    <one or more relations>
WHERE   <conditions>
```

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Quick Review of SQL

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Quick Review of SQL

```
SELECT DISTINCT  z.pno, z.pname
FROM      Supplier x, Supply y, Part z
WHERE     x.sno = y.sno
      and y.pno = z.pno
      and x.scity = 'Seattle'
      and y.price < 100
```

What does this query compute?

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Terminology

- Selection: return a subset of the rows:
  - SELECT * FROM Supplier
    WHERE scity = 'Seattle'

- Projection: return subset of the columns:
  - SELECT DISTINCT scity FROM Supplier;

- Join: refers to combining two or more tables
  - SELECT * FROM Supplier, Supply, Part …

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Self-Joins

Find the Parts numbers available both from suppliers in Seattle, and suppliers in Portland

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Self-Joins

Find the Parts numbers available both from suppliers in Seattle, and suppliers in Portland

```
SELECT DISTINCT  y1.pno
FROM      Supplier x1, Supplier x2, Supply y1, Supply y2
WHERE     x1.scity = 'Seattle'
          and x1.sno = y1.sno
          and x2.scity = 'Portland'
          and x2.sno = y2.sno
          and y1.pno = y2.pno
```

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Self-Joins

Find the Parts numbers available both from suppliers in Seattle, and suppliers in Portland

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SELECT DISTINCT  y1.pno
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WHERE     x1.scity = 'Seattle'
          and x1.sno = y1.sno
          and x2.scity = 'Portland'
          and x2.sno = y2.sno
          and y1.pno = y2.pno
```

Self-join

Nested-Loop Semantics of SQL

```
SELECT a_1, a_2, …, a_k
FROM   R_1 AS x_1, R_2 AS x_2, …, R_n AS x_n
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

This SEMANTICS!
It is NOT how the engine computes the query!

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

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

More SQL: Aggregates

```
SELECT count(*)
FROM   Part
```

What do these queries compute?

```
SELECT x.scity, avg(psize)
FROM   Supplier x, Supply y, Part z
WHERE  x.sno = y.sno  and y.pno = z.pno
GROUP BY x.scity
```

```
SELECT x.scity, avg(psize)
FROM   Supplier x, Supply y, Part z
WHERE  x.sno = y.sno  and y.pno = z.pno
GROUP BY x.scity
HAVING count(*) > 200
```

Discussion

- SQL Aggregates = simple data analytics
- Semantics:
  1. FROM-WHERE (nested-loop semantics)
  2. Group answers by GROUP BY attrs
  3. Apply HAVING predicates on groups
  4. Apply SELECT aggregates on groups
- Aggregate functions:
  – count, sum, min, max, avg
- DISTINCT same as GROUP BY

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

prodName is foreign Key

Outer joins

Retrieve all product names, categories, and stores where they were purchased. Include products that never sold

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Outer joins

Retrieve all product names, categories, and stores where they were purchased. Include products that never sold

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

```
Product(name, category)
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Outer joins

Retrieve all product names, categories, and stores where they were purchased. Include products that never sold

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

```
Product(name, category)
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Outer joins

Retrieve all product names, categories, and stores where they were purchased. Include products that never sold

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

missing

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Category	Store
Gizmo	gadget	Wiz
Camera	Photo	Ritz
Camera	Photo	Wiz

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

prodName is foreign Key

Outer joins

Retrieve all product names, categories, and stores where they were purchased. Include products that never sold

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Category	Store
Gizmo	gadget	Wiz
Camera	Photo	Ritz
Camera	Photo	Wiz
OneClick	Photo	NULL

Now it's present

Joins

- **Inner join** = includes only matching tuples (i.e. regular join)
- **Left outer join** = includes everything from the left
- **Right outer join** = includes everything from the right
- **Full outer join** = includes everything

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

prodName is foreign Key

ON v.s. WHERE

- Outer join condition in the ON clause
- Different from the WHERE clause
- Compare:

```
SELECT x.name, y.store
FROM   Product x
LEFT OUTER JOIN Purchase y
ON     x.name = y.prodName
   AND y.price < 10
```

```
SELECT x.name, y.store
FROM   Product x
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Product(<u>name</u>, category)
Purchase(prodName, store)

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```
SELECT x.name, y.store
FROM   Product x
LEFT OUTER JOIN Purchase y
ON       x.name = y.prodName
   AND y.price < 10
```

Includes products that were never purchased with price < 10

```
SELECT x.name, y.store
FROM   Product x
LEFT OUTER JOIN Purchase y
ON       x.name = y.prodName
WHERE y.price < 10
```

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

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Includes products that were never purchased with price < 10

```
SELECT x.name, y.store
FROM   Product x
LEFT OUTER JOIN Purchase y
ON     x.name = y.prodName
WHERE y.price < 10
```

Includes products that were never purchased, *then* checks price <10

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

prodName is foreign Key

ON v.s. WHERE

- Outer join condition in the ON clause
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- Compare:

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SELECT x.name, y.store
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ON     x.name = y.prodName
   AND y.price < 10
```

Includes products that were never purchased with price < 10

```
SELECT x.name, y.store
FROM   Product x
LEFT OUTER JOIN Purchase y
ON     x.name = y.prodName
WHERE y.price < 10
```

Includes products that were never purchased, *then* checks price <10

Same as inner join!

NULLs in SQL

- A NULL value means missing, or unknown, or undefined, or inapplicable
- We can specify whether attributes may or may not be NULL:

```
CREATE TABLE product
   (pid int NOT NULL,
    pname text NOT NULL,
    price int                – may be NULL
   );
```

Three-Valued Logic

- False=0, Unknown=0.5, True=1
- Result of a comparison A=B is
  - False or True when both A, B are not null
  - Unknown otherwise
- AND, OR, NOT are min, max.
- Return tuples whose condition is True

Three-Valued Logic

- False=0, Unknown=0.5, True=1
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  - Unknown otherwise
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- Return tuples whose condition is True

```
select *
from Product
where (price <= 100) or (price > 100)
```

pid	Pname	price
1	iPhone	500
2	iPod	80
3	iPad	NULL

Three-Valued Logic

- False=0, Unknown=0.5, True=1
- Result of a comparison A=B is
  - False or True when both A, B are not null
  - Unknown otherwise
- AND, OR, NOT are min, max.
- Return tuples whose condition is True

```
select *
from Product
where (price <= 100) or (price > 100)
```

```
where (price <= 100) or (price > 100)
      or isNull(price)
```

pid	Pname	price
1	iPhone	500
2	iPod	80
3	iPad	NULL

Likbkin’s Critique Of SQL

- Libkin’s slides: *A Case Against SQL*
- In class: discuss some of the main inconsistencies in SQL

Other use of Relational Data

- Sparse vectors, matrics
- Graph databases

Sparse Matrix

$$A = \begin{bmatrix} 5 & 0 & -2 \\ 0 & 0 & -1 \\ 0 & 7 & 0 \end{bmatrix}$$

How can we represent it as a relation?

Sparse Matrix

$$A = \begin{bmatrix} 5 & 0 & -2 \\ 0 & 0 & -1 \\ 0 & 7 & 0 \end{bmatrix}$$

Row	Col	Val
1	1	5
1	3	-2
2	3	-1
3	2	7

Matrix Multiplication in SQL

$C = A \cdot B$

Matrix Multiplication in SQL

$C = A \cdot B$

$$C_{ik} = \sum_j A_{ij} \cdot B_{jk}$$

Matrix Multiplication in SQL

$$C = A \cdot B \qquad\qquad C_{ik} = \sum_j A_{ij} \cdot B_{jk}$$

```
SELECT A.row, B.col, sum(A.val*B.val)
FROM A, B
WHERE A.col = B.row
GROUP BY A.row, B.col;
```

Discussion

- Matrix multiplication = join + group-by
- Many operations can be written in SQL
- E.g. try at home: write in SQL

  $$Tr(A \cdot B \cdot C)$$

  where the trace is defined as:

  $$Tr(X) = \sum_i X_{ii}$$

- Surprisingly, $A + B$ is a bit harder…

Matrix Addition in SQL

$$C = A + B$$

Matrix Addition in SQL

$$C = A + B$$

```
SELECT A.row, A.col, A.val + B.val as val
FROM    A, B
WHERE   A.row = B.row and A.col = B.col
```

Matrix Addition in SQL

$$C = A + B$$

```
SELECT A.row, A.col, A.val + B.val as val
FROM   A, B
WHERE  A.row = B.row and A.col = B.col
```

Why is this wrong?

Solution 1: Outer Joins

$$C = A + B$$

```
SELECT



FROM A full outer join B ON A.row = B.row and A.col = B.col;
```

Solution 1: Outer Joins

$$C = A + B$$

```
SELECT


 (CASE WHEN A.val is null THEN 0 ELSE A.val END) +
 (CASE WHEN B.val is null THEN 0 ELSE B.val END)  as val
FROM A full outer join B ON A.row = B.row and A.col = B.col;
```

Solution 1: Outer Joins

$$C = A + B$$

```
SELECT
 (CASE WHEN A.row is null THEN B.row ELSE A.row END) as row,

 (CASE WHEN A.val is null THEN 0 ELSE A.val END) +
 (CASE WHEN B.val is null THEN 0 ELSE B.val END)  as val
FROM A full outer join B ON A.row = B.row and A.col = B.col;
```

Solution 1: Outer Joins

$$C = A + B$$

```
SELECT
 (CASE WHEN A.row is null THEN B.row ELSE A.row END) as row,
 (CASE WHEN A.col is null THEN B.col ELSE A.col END) as col,
 (CASE WHEN A.val is null THEN 0 ELSE A.val END) +
 (CASE WHEN B.val is null THEN 0 ELSE B.val END)  as val
FROM A full outer join B ON A.row = B.row and A.col = B.col;
```

Solution 2: Group By

$$C = A + B$$

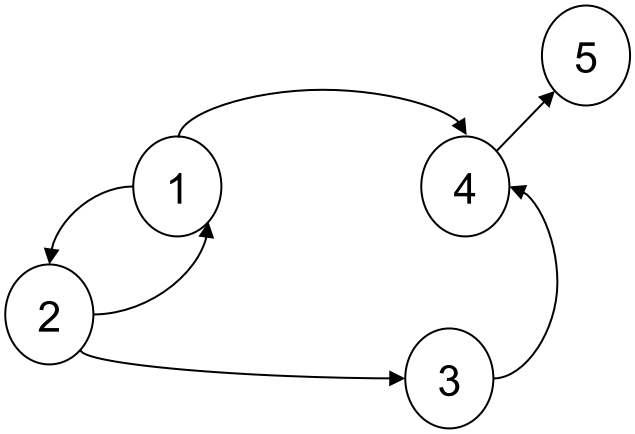
```
SELECT m.row, m.col, sum(m.val)
FROM (SELECT * FROM A
          UNION ALL
        SELECT * FROM B) as m
GROUP BY m.row, m.col;
```

Graph Databases

- Graph databases systems are a niche category of products specialized for processing large graphs
- E.g. Neo4J, TigerGraph
- A graph is a special case of a relation, and can be processed using SQL

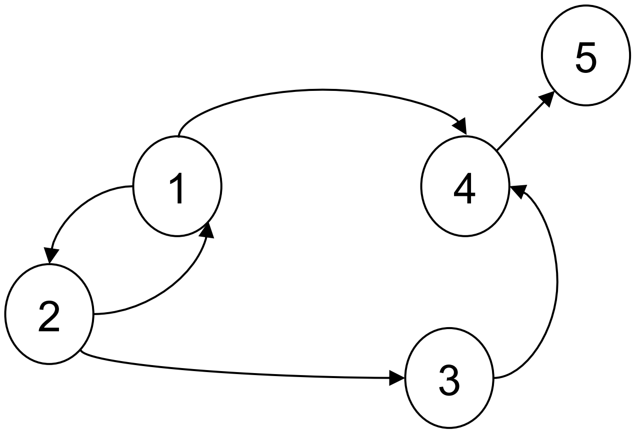
Graph Databases

A graph:



Graph Databases

A graph:



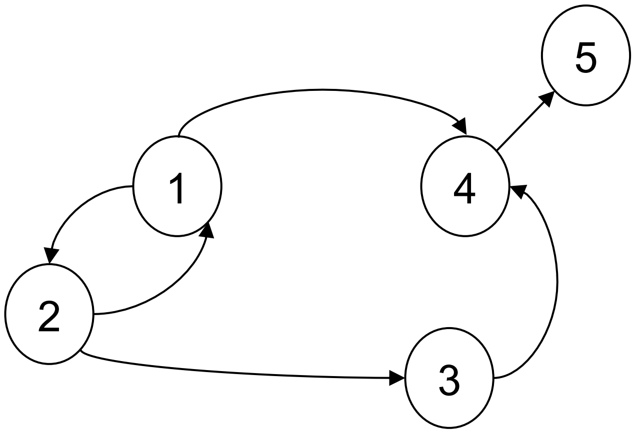
A relation:

Edge

src	dst
1	2
2	1
2	3
1	4
3	4
4	5

Graph Databases

A graph:



A relation: Edge

src	dst
1	2
2	1
2	3
1	4
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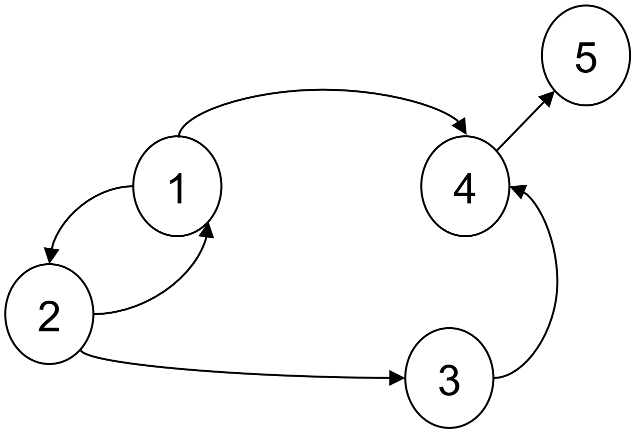
4	5

Find nodes at distance 2: $\{(x,z) | \exists y\ Edge(x,y) \wedge Edge(y,z)\}$

Graph Databases

A graph:



A relation: Edge

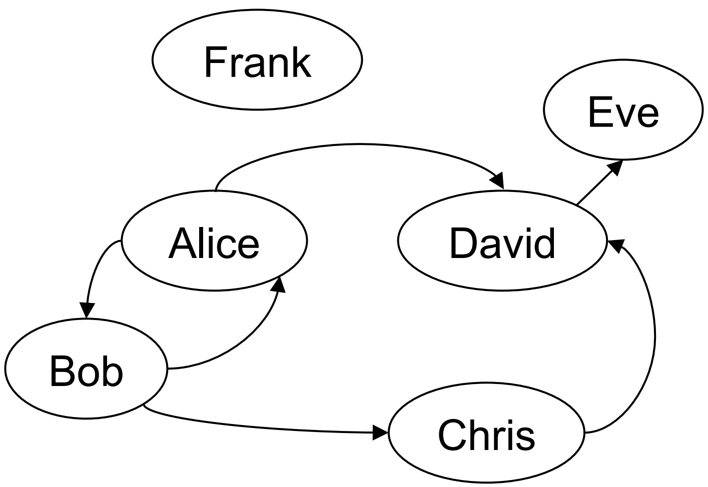
src	dst
1	2
2	1
2	3
1	4
3	4
4	5

Find nodes at distance 2: $\{(x, z) | \exists y \; Edge(x, y) \wedge Edge(y, z)\}$

```
SELECT DISTINCT e1.src as X, e2.dst as Z
FROM Edge e1, Edge e2
WHERE e1.dst = e2.src;
```

Other Representation

Representing nodes separately;
needed for “isolated nodes” e.g. Frank



Node

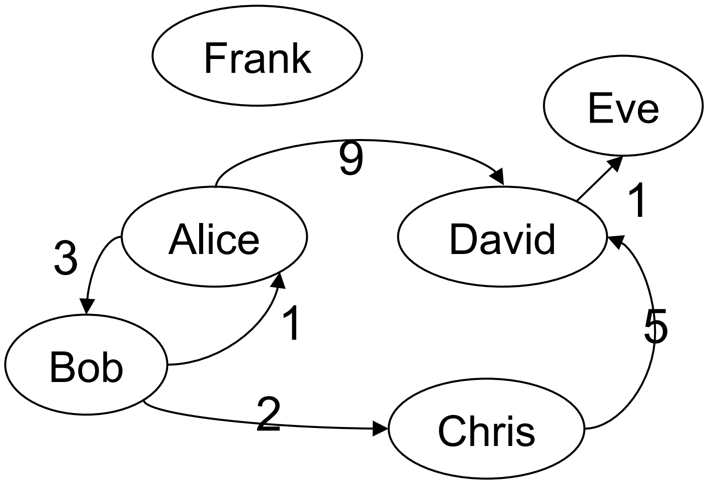
src
Alice
Bob
Chris
David
Eve
Frank

Edge

src	dst
Alice	Bob
Bob	Alice
Bob	Chris
Alice	David
Chris	David
David	Eve

Other Representation

Adding edge labels
Adding node labels…



Node

src
Alice
Bob
Chris
David
Eve
Frank

Edge

src	dst	weight
Alice	Bob	3
Bob	Alice	1
Bob	Chris	2
Alice	David	9
Chris	David	5
David	Eve	1

Discussion: SQL and Logic

- First Order Logic is the language consisting of: $\forall, \ \exists, \ \vee, \ \wedge, \ \neg, \ \Rightarrow$
- In class: what do these sentences say?
  - $\forall x \forall y \big(E(x,y) \Rightarrow E(y,x)\big)$
  - $\exists x (E(\text{“}Alice\text{”}, x) \wedge E(\text{“}Bob\text{”}, x))$
  - $\forall x \forall y \forall z (E(x,y) \wedge E(y,z) \Rightarrow E(x,z))$
  - $\forall x \forall y (E(x,y) \Rightarrow (x \neq y) \wedge \exists z (E(x,z) \wedge E(z,y))$

Possible in a finite graph?

- **Theorem**: every FO sentence can be written in SQL

Limitations of SQL

- No recursion! Examples requiring recursion:
  - Gradient descent
  - Connected components in a graph
- Advanced systems *do* support recursion
- Practical solution: use some external driver, e.g. pyton

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	0
3	6	3	0
5	5	9	1
9	3	3	1
…	…	…	
…	…	…	

Example: Logistic Regression

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…	…	…	
…	…	…	

Switched (following Mitchell)

$$P(Y = 0|X) = \frac{1}{1 + exp\left(w_0 + \sum_{i=1,3} w_i X_i\right)}$$

$$P(Y = 1|X) = \frac{exp\left(w_0 + \sum_{i=1,3} w_i X_i\right)}{1 + exp\left(w_0 + \sum_{i=1,3} w_i X_i\right)}$$

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(following Mitchell)

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Train weights w_0, w_1, w_2, w_3 to minimize loss:

$$L(w_0, \dots, w_3) = \sum_{\ell=1,N} \left(Y^\ell \cdot \ln P\left(Y=1|X^\ell\right) + (1 - Y^\ell) \cdot \ln P\left(Y=0|X^\ell\right)\right)$$

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	0
3	6	3	0
5	5	9	1
9	3	3	1
…	…	…	
…	…	…	

Gradient Descent:

$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^{\ell}\left(Y^{\ell} - P(Y = 1|X^{\ell})\right)$$

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
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```
CREATE TABLE W (k int primary key, w0 real, w1 real, w2 real, w3 real);
INSERT INTO W VALUES (1, 0, 0, 0, 0);
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
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6	2	2	0
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```
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```

```
FROM data d, W
WHERE W.k=1
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Gradient Descent:

$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^\ell \left(Y^\ell - P(Y=1|X^\ell)\right)$$

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3	5	7	1
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3	6	3	0

```
CREATE TABLE W (k int primary key, w0 real, w1 real, w2 real, w3 real);
INSERT INTO W VALUES (1, 0, 0, 0, 0);
```

```
SELECT
  W.w0+0.01*sum(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3))) as w0,



FROM data d, W
WHERE W.k=1
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	0
3	6	3	0

Gradient Descent:

$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^{\ell}\left(Y^{\ell} - P(Y=1|X^{\ell})\right)$$

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  W.w1+0.01*sum(d.X1*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w1,


FROM data d, W
WHERE W.k=1
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	[illegible]
3	6	3	[illegible]

Gradient Descent:

$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^{\ell}\left(Y^{\ell} - P(Y=1|X^{\ell})\right)$$

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```

```sql
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  W.w0+0.01*sum(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3))) as w0,
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  W.w2+0.01*sum(d.X2*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w2,
  W.w3+0.01*sum(d.X3*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w3
FROM data d, W
WHERE W.k=1
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Gradient Descent:

$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^\ell \left(Y^\ell - P(Y = 1|X^\ell)\right)$$

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	[illegible]
3	6	3	[illegible]

```
CREATE TABLE W (k int primary key, w0 real, w1 real, w2 real, w3 real);
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```
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  W.w2+0.01*sum(d.X2*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w2,
  W.w3+0.01*sum(d.X3*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w3
FROM data d, W
WHERE W.k=1
GROUP BY W.k, W.w0, W.w1, W.w2, W.w3;
```

Example: Logistic Regression

Tom Mitchell: Machine Learning

Data

X1	X2	X3	Y
3	9	3	0
3	5	7	1
6	2	2	0
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$$w_i \leftarrow w_i + \eta \sum_{\ell=1,N} X_i^\ell \left(Y^\ell - P(Y=1|X^\ell)\right)$$

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  W.w1+0.01*sum(d.X1*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w1,
  W.w2+0.01*sum(d.X2*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w2,
  W.w3+0.01*sum(d.X3*(d.Y - 1 + 1/(1+exp(W.w0+W.w1*d.X1+W.w2*d.X2+W.w3*d.X3)))) as w3
FROM data d, W
WHERE W.k=1
GROUP BY W.k, W.w0, W.w1, W.w2, W.w3;
```

Update W, then repeat this
e.g. using python

Discussion

SQL in Data Science:

- Used primarily to prepare the data
  - ETL – Extract/Transform/Load
  - Join tables, process columns, filter rows
- Can also be used in training
  - Much less convenient than ML packages
  - But can be the best option if data is huge

SQL – Summary

- Very complex: >1000 pages,
  - No vendor supports full standard; (in practice, people use postgres as *de facto* standard)
  - Much more than DML
- It is a <u>*declarative*</u> language:
  - we say what we want
  - we don't say how to get it
- Relational algebra says how to get it

Relational Algebra

- Queries specified in an operational manner
  - A query gives a step-by-step procedure

- Relational operators
  - Take one or two relation instances as input
  - Return one relation instance as result
  - Easy to compose into relational algebra expressions

Five Basic Relational Operators

- Selection: $\sigma_{condition}(S)$
  - Condition is Boolean combination ($\wedge$,$\vee$) of atomic predicates (<, <=, =, ≠, >=, >)
- Projection: $\pi_{list\text{-}of\text{-}attributes}(S)$
- Union ($\cup$)
- Set difference (–),
- Cross-product/cartesian product ($\times$), Join: $R \bowtie_{\theta} S = \sigma_{\theta}(R \times S)$

Other operators: anti-semijoin, renaming

Extended Operators of Relational Algebra

- Duplicate elimination (δ)
  - Since commercial DBMSs operate on multisets not sets
- Group-by/aggregate (γ)
  - Min, max, sum, average, count
  - Partitions tuples of a relation into “groups”
  - Aggregates can then be applied to groups
- Sort operator (τ)

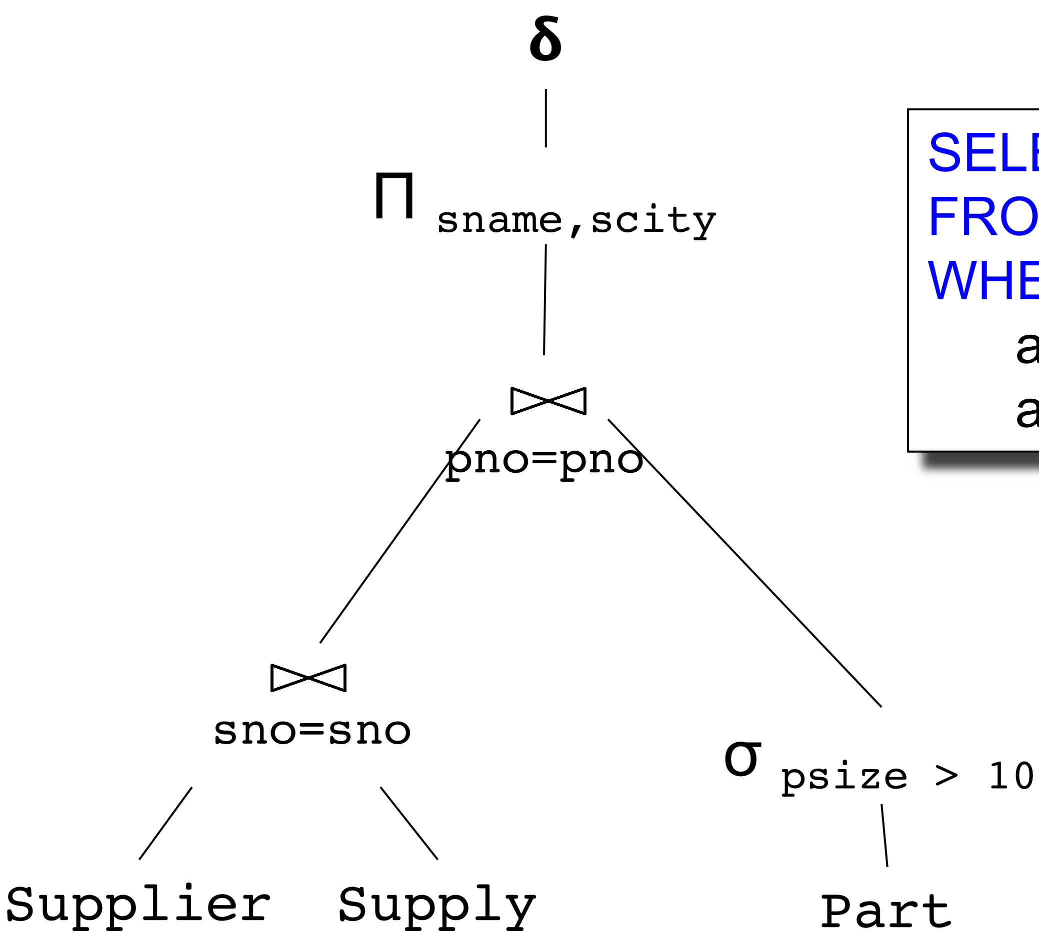
```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Logical Query Plans

```sql
SELECT DISTINCT x.sname, x.scity
FROM Supplier x, Supply y, Part z
WHERE x.sno=y.sno
    and  y.pno=z.pno
    and z.psize > 10;
```

```
Supplier(sno,sname,scity,sstate)
Supply(sno,pno,qty,price)
Part(pno,pname,psize,pcolor)
```

Logical Query Plans




```
SELECT DISTINCT x.sname, x.scity
FROM Supplier x, Supply y, Part z
WHERE x.sno=y.sno
      and  y.pno=z.pno
      and z.psize > 10;
```

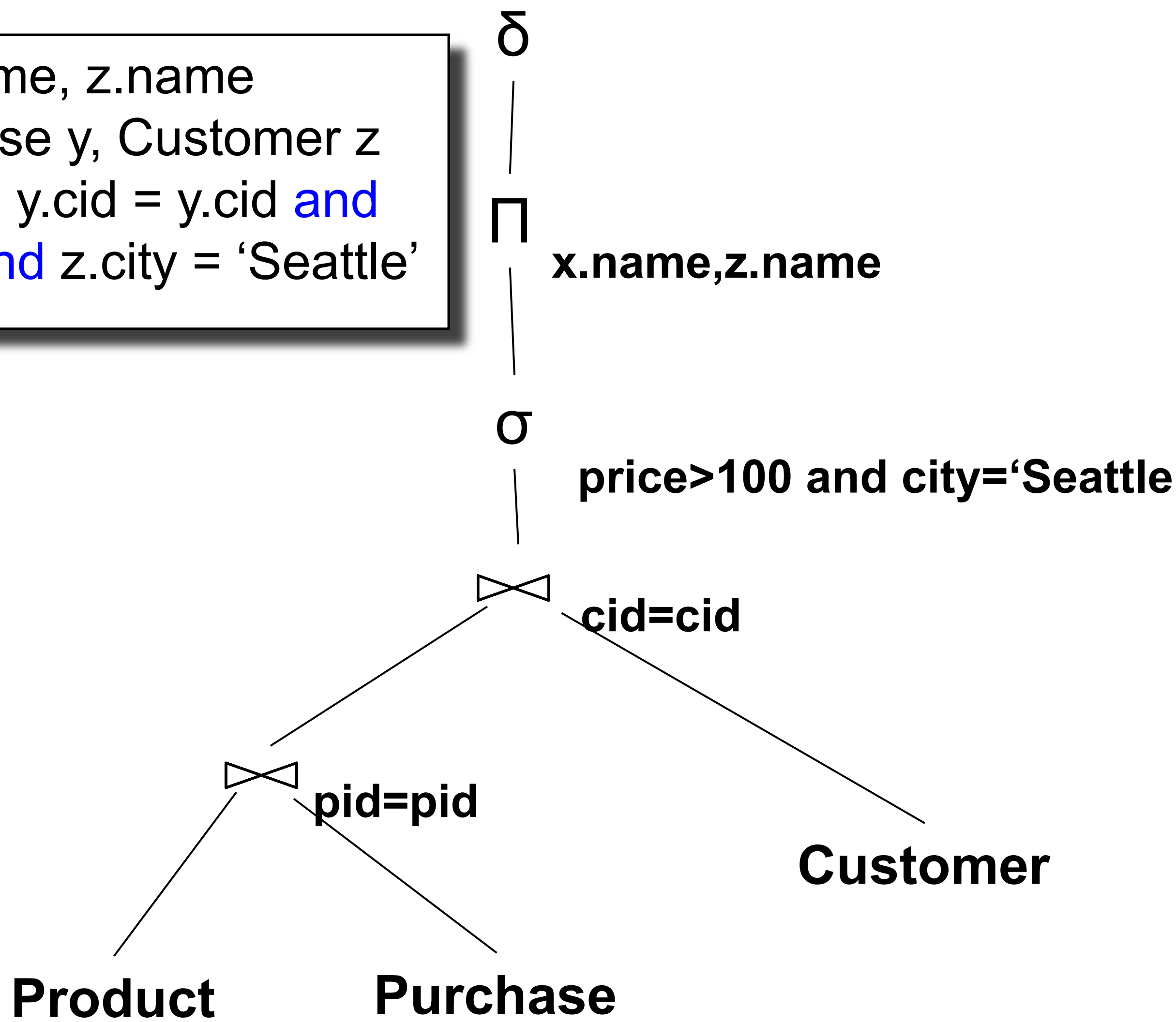
Query Optimizer

- Rewrite one relational algebra expression to a better one
- Very brief review now, more details next lectures

Product(pid, name, price)
Purchase(pid, cid, store)
Customer(cid, name, city)

Optimization

```
SELECT DISTINCT x.name, z.name
FROM Product x, Purchase y, Customer z
WHERE x.pid = y.pid and y.cid = y.cid and
          x.price > 100 and z.city = 'Seattle'
```



Product(pid, name, price)
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Optimization

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SELECT DISTINCT x.name, z.name
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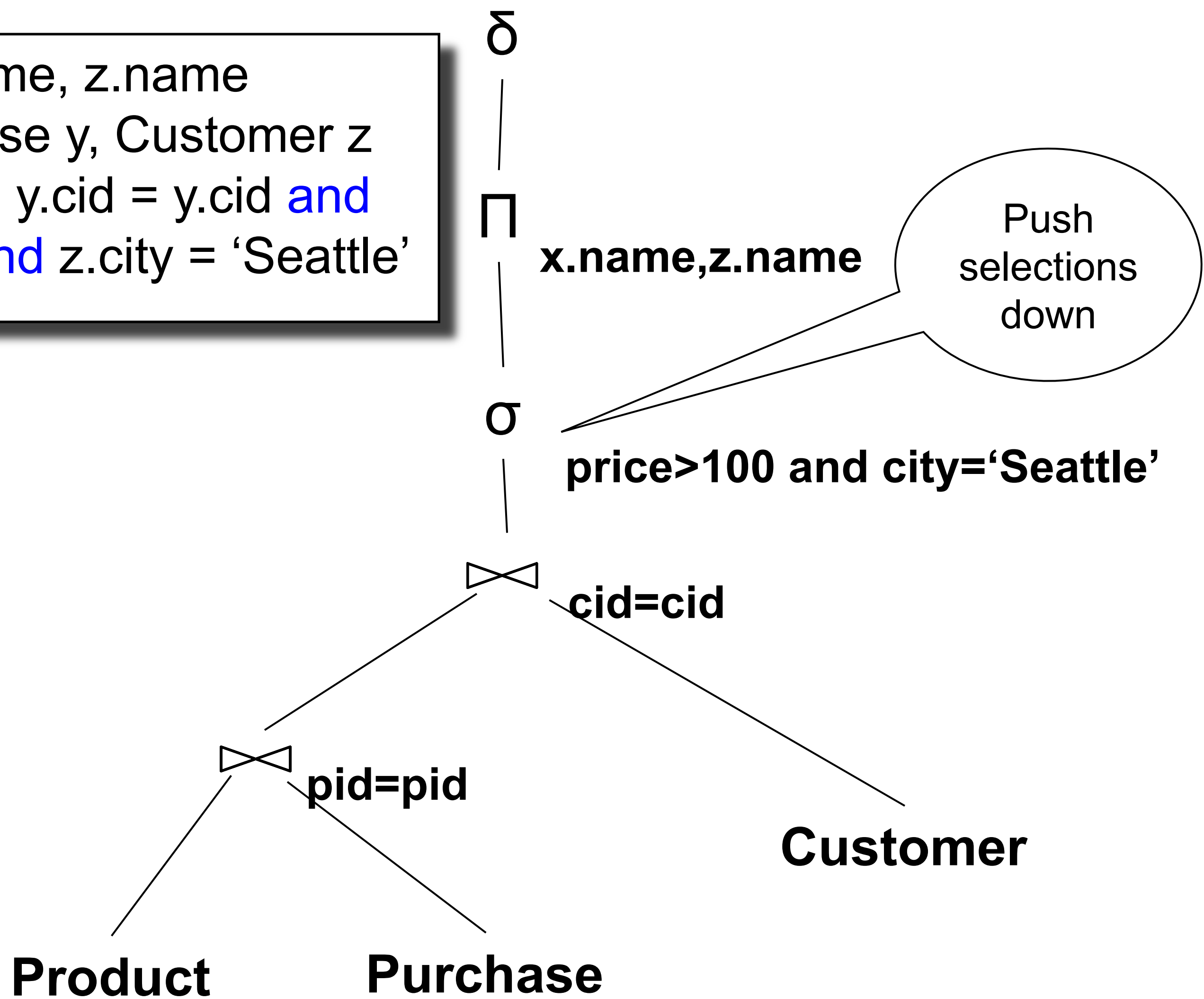

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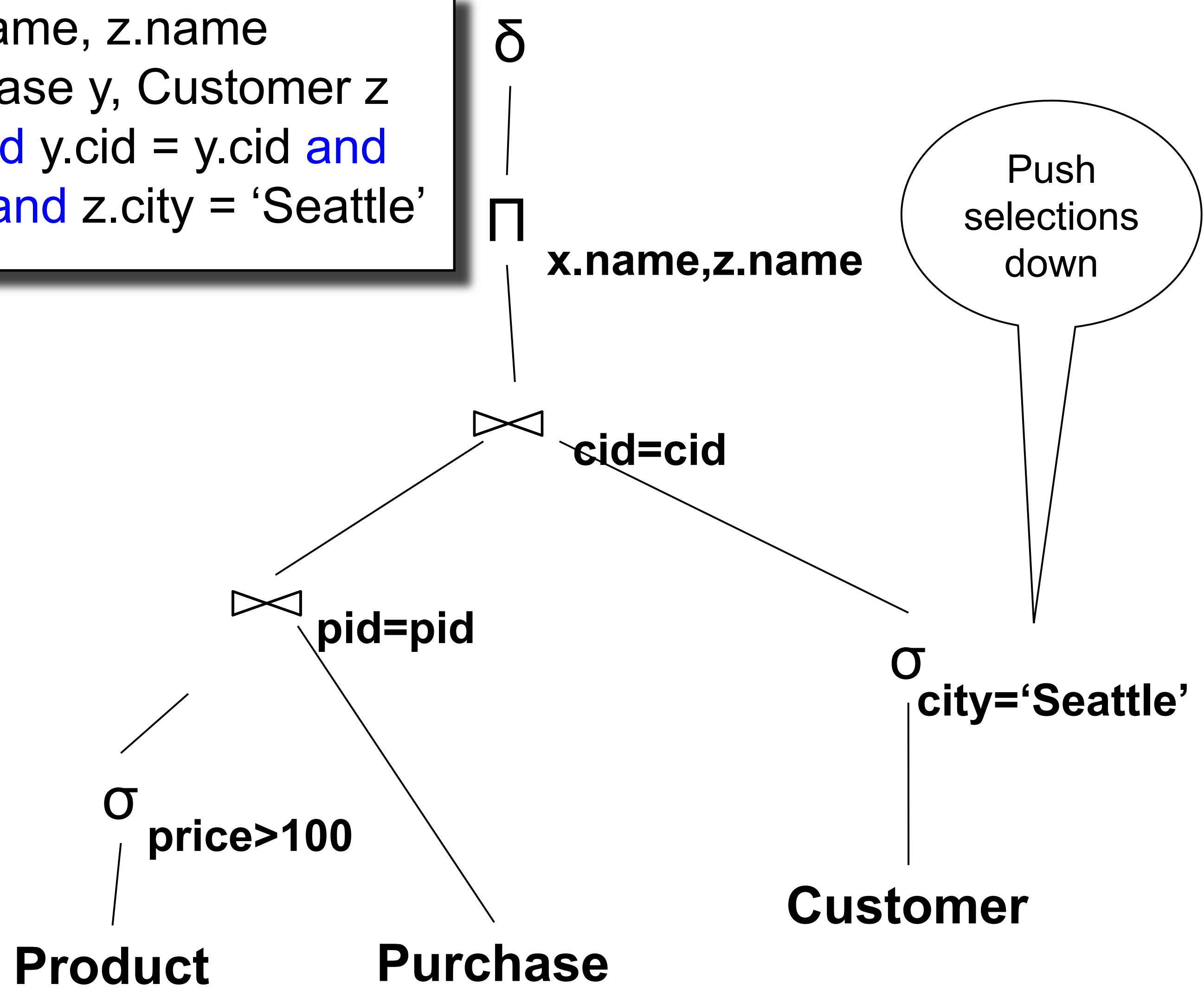

More about this next lecture

Benefits of Relational Model

- Physical data independence
  - Can change how data is organized on disk without affecting applications
- Logical data independence
  - Can change the logical schema without affecting applications (not 100%... consider updates)

Physical Data Independence

Supplier

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

```
SELECT DISTINCT sname
FROM Supplier
WHERE scity = 'Seattle'
```

How is the data stored on disk?
(e.g. row-wise, column-wise)

The SQL query works the same, regardless of the answers to these questions

Is there an index on scity?
(e.g. no index, unclustered index, clustered index)

Lecture on Monday

- Data model – what’s so hard about it?
- Review “What goes around…