Lectures 2&3: Introduction to SQL
Announcements!

1. If you still have Jupyter trouble, let us know!

2. Problem Set #1 is released!
Lecture 2: SQL Part I
Today’s Lecture

1. SQL introduction & schema definitions
   • ACTIVITY: Table creation

2. Basic single-table queries
   • ACTIVITY: Single-table queries!

3. Multi-table queries
   • ACTIVITY: Multi-table queries!
1. SQL Introduction & Definitions
What you will learn about in this section

1. What is SQL?
2. Basic schema definitions
3. Keys & constraints intro
4. ACTIVITY: CREATE TABLE statements
SQL Motivation

• Dark times 5 years ago.
  • Are databases dead?

• Now, as before: everyone sells SQL
  • Pig, Hive, Impala

• “Not-Yet-SQL?”
Basic SQL
SQL Introduction

• SQL is a standard language for querying and manipulating data

• SQL is a **very high-level** programming language
  • This works because it is optimized well!

• Many standards out there:
  • ANSI SQL, SQL92 (a.k.a. SQL2), SQL99 (a.k.a. SQL3), ....
  • Vendors support various subsets

*NB*: Probably the world’s most successful parallel programming language (multicore?)
SQL is a...

• Data Definition Language (DDL)
  • Define relational schemata
  • Create/alter/delete tables and their attributes

• Data Manipulation Language (DML)
  • Insert/delete/modify tuples in tables
  • Query one or more tables – discussed next!
A relation or table is a multiset of tuples having the attributes specified by the schema.
Tables in SQL

<table>
<thead>
<tr>
<th>Product</th>
<th>PName</th>
<th>Price</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>$19.99</td>
<td></td>
<td>GizmoWorks</td>
</tr>
<tr>
<td>Powergizmo</td>
<td>$29.99</td>
<td></td>
<td>GizmoWorks</td>
</tr>
<tr>
<td>SingleTouch</td>
<td>$149.99</td>
<td></td>
<td>Canon</td>
</tr>
<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td></td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

A **multiset** is an unordered list (or: a set with multiple duplicate instances allowed)

- List: \([1, 1, 2, 3]\)
- Set: \(\{1, 2, 3\}\)
- Multiset: \(\{1, 1, 2, 3\}\)

i.e. no `next()`, etc. methods!
# Tables in SQL

An **attribute** (or **column**) is a typed data entry present in each tuple in the relation.

---

<table>
<thead>
<tr>
<th>Product</th>
<th>Price</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
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</tr>
<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

**NB:** Attributes must have an **atomic** type in standard SQL, i.e. not a list, set, etc.
### Tables in SQL

#### Product

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
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</tr>
<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

A **tuple** or **row** is a single entry in the table having the attributes specified by the schema.

*Also referred to sometimes as a **record***
# Tables in SQL

## Product

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
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</tr>
<tr>
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<td>$203.99</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

The number of tuples is the **cardinality** of the relation.

The number of attributes is the **arity** of the relation.
Data Types in SQL

• Atomic types:
  • Characters: CHAR(20), VARCHAR(50)
  • Numbers: INT, BIGINT, SMALLINT, FLOAT
  • Others: MONEY, DATETIME, ...

• Every attribute must have an atomic type
  • Hence tables are flat
Table Schemas

• The **schema** of a table is the table name, its attributes, and their types:

```plaintext
Product(Pname: string, Price: float, Category: string, Manufacturer: string)
```

• A **key** is an attribute whose values are unique; we underline a key

```plaintext
Product(Pname: string, Price: float, Category: string, Manufacturer: string)
```
Key constraints

A **key** is a **minimal subset of attributes** that acts as a unique identifier for tuples in a relation.

• A key is an implicit constraint on which tuples can be in the relation.
  
  • i.e. if two tuples agree on the values of the key, then they must be the same tuple!

1. Which would you select as a key?
2. Is a key always guaranteed to exist?
3. Can we have more than one key?
NULL and NOT NULL

• To say “don’t know the value” we use **NULL**
  • NULL has (sometimes painful) semantics, more detail later

```sql
Students(sid: string, name: string, gpa: float)
```

<table>
<thead>
<tr>
<th>sid</th>
<th>name</th>
<th>gpa</th>
</tr>
</thead>
<tbody>
<tr>
<td>123</td>
<td>Bob</td>
<td>3.9</td>
</tr>
<tr>
<td>143</td>
<td>Jim</td>
<td>NULL</td>
</tr>
</tbody>
</table>

*Say, Jim just enrolled in his first class.*

In SQL, we may constrain a column to be NOT NULL, e.g., “name” in this table
General Constraints

• We can actually specify arbitrary assertions
  • E.g. “There cannot be 25 people in the DB class”

• In practice, we don’t specify many such constraints. Why?
  • Performance!

Whenever we do something ugly (or avoid doing something convenient) it’s for the sake of performance
Summary of Schema Information

• Schema and Constraints are how databases understand the semantics (meaning) of data

• They are also useful for optimization

• SQL supports general constraints:
  • Keys and foreign keys are most important
  • We’ll give you a chance to write the others
ACTIVITY: Activity-2-1.ipynb
2. Single-table queries
What you will learn about in this section

1. The SFW query

2. Other useful operators: LIKE, DISTINCT, ORDER BY

3. ACTIVITY: Single-table queries
SQL Query

• Basic form (there are many many more bells and whistles)

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

Call this a **SFW** query.
Simple SQL Query: Selection

Selection is the operation of filtering a relation’s tuples on some condition.

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

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Category</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>$19.99</td>
<td>Gadgets</td>
<td>GizmoWorks</td>
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<tr>
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<td>$149.99</td>
<td>Photography</td>
<td>Canon</td>
</tr>
<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td>Household</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>
**Simple SQL Query: Projection**

**Projection** is the operation of producing an output table with tuples that have a subset of their prior attributes.

```
SELECT Pname, Price, Manufacturer
FROM Product
WHERE Category = 'Gadgets'
```

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Category</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>$19.99</td>
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<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td>Household</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>
Notation

Input schema

```
Product(PName, Price, Category, Manufacturer)
```

Output schema

```
SELECT Pname, Price, Manufacturer 
FROM  Product 
WHERE  Category = 'Gadgets'
```

Answer(PName, Price, Manufacturer)
A Few Details

• SQL **commands** are case insensitive:
  • Same: SELECT, Select, select
  • Same: Product, product

• **Values** are not:
  • Different: ‘Seattle’, ‘seattle’

• Use single quotes for constants:
  • ‘abc’ - yes
  • “abc” - no
LIKE: Simple String Pattern Matching

SELECT * FROM Products WHERE PName LIKE ‘%gizmo%’

• s LIKE p: pattern matching on strings
• p may contain two special symbols:
  • % = any sequence of characters
  • _  = any single character
DISTINCT: Eliminating Duplicates

SELECT DISTINCT Category FROM Product

Versus

SELECT Category FROM Product

Category
Gadgets
Photography
Household

Category
Gadgets
Photography
Household
ORDER BY: Sorting the Results

SELECT PName, Price, Manufacturer
FROM Product
WHERE Category='gizmo' AND Price > 50
ORDER BY Price, PName

Ties are broken by the second attribute on the ORDER BY list, etc.

Ordering is ascending, unless you specify the DESC keyword.
ACTIVITY: Activity-2-2.ipynb
3. Multi-table queries
What you will learn about in this section

1. Foreign key constraints

2. Joins: basics

3. Joins: SQL semantics

4. ACTIVITY: Multi-table queries
Foreign Key constraints

• Suppose we have the following schema:

Students(sid: string, name: string, gpa: float)
Enrolled(student_id: string, cid: string, grade: string)

• And we want to impose the following constraint:
  • ‘Only bona fide students may enroll in courses’ i.e. a student must appear in the Students table to enroll in a class

<table>
<thead>
<tr>
<th>Students</th>
<th>Enrolled</th>
</tr>
</thead>
<tbody>
<tr>
<td>sid</td>
<td>student_id</td>
</tr>
<tr>
<td>101</td>
<td>123</td>
</tr>
<tr>
<td>123</td>
<td>123</td>
</tr>
<tr>
<td>Bob</td>
<td>3.2</td>
</tr>
<tr>
<td>Mary</td>
<td>3.8</td>
</tr>
</tbody>
</table>

We say that student_id is a foreign key that refers to Students
Students(sid: string, name: string, gpa: float)
Enrolled(student_id: string, cid: string, grade: string)

CREATE TABLE Enrolled(
    student_id CHAR(20),
    cid CHAR(20),
    grade CHAR(10),
    PRIMARY KEY (student_id, cid),
    FOREIGN KEY (student_id) REFERENCES Students(sid)
)
Foreign Keys and update operations

Students(sid: string, name: string, gpa: float)
Enrolled(student_id: string, cid: string, grade: string)

• What if we insert a tuple into Enrolled, but no corresponding student?
  • INSERT is rejected (foreign keys are constraints)!

• What if we delete a student?  
  1. Disallow the delete
  2. Remove all of the courses for that student
  3. SQL allows a third via NULL (not yet covered)
Keys and Foreign Keys

Company

<table>
<thead>
<tr>
<th>CName</th>
<th>StockPrice</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>GizmoWorks</td>
<td>25</td>
<td>USA</td>
</tr>
<tr>
<td>Canon</td>
<td>65</td>
<td>Japan</td>
</tr>
<tr>
<td>Hitachi</td>
<td>15</td>
<td>Japan</td>
</tr>
</tbody>
</table>

Product

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Category</th>
<th>Manufacturer</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>MultiTouch</td>
<td>$203.99</td>
<td>Household</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

What is a foreign key vs. a key here?
Joins

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

Ex: Find all products under $200 manufactured in Japan; return their names and prices.

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

Note: we will often omit attribute types in schema definitions for brevity, but assume attributes are always atomic types.
Joins

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

Ex: Find all products under $200 manufactured in Japan; return their names and prices.

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

A join between tables returns all unique combinations of their tuples which meet some specified join condition.
Joins

Several equivalent ways to write a basic join in SQL:

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

```
SELECT PName, Price
FROM Product
JOIN Company ON Manufacturer = CName
    AND Country='Japan'
WHERE Price <= 200
```

A few more later on...
Joins

### Product

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Category</th>
<th>Manuf</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>$19</td>
<td>Gadgets</td>
<td>GWorks</td>
</tr>
<tr>
<td>Powergizmo</td>
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<tr>
<td>MultiTouch</td>
<td>$203</td>
<td>Household</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

### Company

<table>
<thead>
<tr>
<th>Cname</th>
<th>Stock</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWorks</td>
<td>25</td>
<td>USA</td>
</tr>
<tr>
<td>Canon</td>
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<td>Hitachi</td>
<td>15</td>
<td>Japan</td>
</tr>
</tbody>
</table>

### SQL Query

```
SELECT PName, Price
FROM Product, Company
WHERE Manufacturer = CName
AND Country='Japan'
AND Price <= 200
```
Tuple Variable Ambiguity in Multi-Table

```
Person(name, address, worksfor)
Company(name, address)
```

```
SELECT DISTINCT name, address
FROM Person, Company
WHERE worksfor = name
```

Which “address” does this refer to?
Which “name”s??
Tuple Variable Ambiguity in Multi-Table

Both equivalent ways to resolve variable ambiguity

Person(name, address, worksfor)
Company(name, address)

SELECT DISTINCT Person.name, Person.address
FROM Person, Company
WHERE Person.worksfor = Company.name

SELECT DISTINCT p.name, p.address
FROM Person p, Company c
WHERE p.worksfor = c.name
Meaning (Semantics) of SQL Queries

```sql
SELECT x_1.a_1, x_1.a_2, ..., x_n.a_k
FROM R_1 AS x_1, R_2 AS x_2, ..., R_n AS x_n
WHERE Conditions(x_1, ..., x_n)
```

Answer = {}
```
for x_1 in R_1 do
    for x_2 in R_2 do
        ..... 
        for x_n in R_n do
            if Conditions(x_1, ..., x_n) then Answer = Answer \cup \{(x_1.a_1, x_1.a_2, ..., x_n.a_k)\}
return Answer
```

Note: this is a *multiset* union

Almost never the *fastest* way to compute it!
An example of SQL semantics

```
SELECT R.A
FROM R, S
WHERE R.A = S.B
```

Output

```
A
3
3
```

Cross Product

```
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
```

Apply Selections / Conditions

```
<table>
<thead>
<tr>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
```
Note the **semantics** of a join

1. Take **cross product**:
   \[ X = R \times S \]

2. Apply **selections / conditions**:
   \[ Y = \{(r, s) \in X \mid r.A == r.B\} \]

3. Apply **projections** to get final output:
   \[ Z = (y.A,) \text{ for } y \in Y \]

Recall: Cross product \((A \times B)\) is the set of all unique tuples in \(A,B\)
Ex: \(\{a,b,c\} \times \{1,2\}\)
\[ = \{(a,1), (a,2), (b,1), (b,2), (c,1), (c,2)\}\]

= Filtering!

= Returning only *some* attributes

Remembering this order is critical to understanding the output of certain queries (see later on...)

```
SELECT R.A
FROM R, S
WHERE R.A = S.B
```
Note: we say “semantics” not “execution order”

• The preceding slides show *what a join means*

• Not actually how the DBMS executes it under the covers
A Subtlety about Joins

Find all countries that manufacture some product in the ‘Gadgets’ category.

```
SELECT Country
FROM   Product, Company
WHERE  Manufacturer=CName AND Category='Gadgets'
```
A subtlety about Joins

Product

<table>
<thead>
<tr>
<th>PName</th>
<th>Price</th>
<th>Category</th>
<th>Manuf</th>
</tr>
</thead>
<tbody>
<tr>
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<td>$19</td>
<td>Gadgets</td>
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<td>Gadgets</td>
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<tr>
<td>SingleTouch</td>
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</tr>
<tr>
<td>MultiTouch</td>
<td>$203</td>
<td>Household</td>
<td>Hitachi</td>
</tr>
</tbody>
</table>

Company

<table>
<thead>
<tr>
<th>Cname</th>
<th>Stock</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>GWorks</td>
<td>25</td>
<td>USA</td>
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<tr>
<td>Canon</td>
<td>65</td>
<td>Japan</td>
</tr>
<tr>
<td>Hitachi</td>
<td>15</td>
<td>Japan</td>
</tr>
</tbody>
</table>

```
SELECT Country
FROM Product, Company
WHERE Manufacturer=Cname
    AND Category='Gadgets'
```

What is the problem?
What’s the solution?
ACTIVITY: Lecture-2-3.ipynb
An Unintuitive Query

```
SELECT DISTINCT R.A
FROM R, S, T
WHERE R.A=S.A OR R.A=T.A
```

What does it compute?
An Unintuitive Query

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```

But what if $S = \emptyset$?

Computes $R \cap (S \cup T)$

Go back to the semantics!
An Unintuitive Query

```
SELECT DISTINCT R.A
FROM   R, S, T
WHERE  R.A=S.A OR R.A=T.A
```

• Recall the semantics!
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection

• If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

Must consider semantics here. Are there more explicit way to do set operations like this?
Lecture 3: SQL Part II
Announcements

1. Please let us know if you’re stuck on Jupyter!
2. Lectures:
   1. I’m working to talk slower 😊 (PB note: poll here!)
   2. I will repeat questions (please hold me accountable!)
3. Office hours: SCPD is on Google Hangouts (see Piazza)
4. Submission info: probably still in .txt format
5. Project 1 will be released on Thursday
<table>
<thead>
<tr>
<th>Name</th>
<th>Email</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peter Ballis</td>
<td></td>
</tr>
<tr>
<td>Tara BalaKrishnan</td>
<td><a href="mailto:taragbi@stanford.edu">taragbi@stanford.edu</a></td>
</tr>
<tr>
<td>Aarti Bagal</td>
<td></td>
</tr>
<tr>
<td>Dev Bhargava</td>
<td></td>
</tr>
<tr>
<td>William Chen</td>
<td></td>
</tr>
<tr>
<td>Sorosh Hemmati</td>
<td></td>
</tr>
<tr>
<td>Woncheol (Dennis) Jaong</td>
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<tr>
<td>Lintong Sun</td>
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</tr>
<tr>
<td>Stephanie Tang</td>
<td></td>
</tr>
<tr>
<td>Anelia Vu</td>
<td></td>
</tr>
</tbody>
</table>
A note on quality, not quantity:

We are following Chris Ré’s course material and format (he revised this course *in depth* several years ago...
...I learned I’m now teaching this course as of three weeks ago)

We will follow Chris’s material *but*
I want to make sure you understand the **big ideas** in this course

So, from now on:
- -- Please come with questions and/or post on Piazza before class to begin lecture!
- -- We may not cover everything that Chris did in one lecture; if we fall behind, I will cut less essential material from the course (still in slides, can come to OH, but not responsible for on exams, etc.)
Today’s Lecture

1. Set operators & nested queries
   • ACTIVITY: Set operator subtleties

2. Aggregation & GROUP BY
   • ACTIVITY: Fancy SQL Part I

3. Advanced SQL-izing
   • ACTIVITY: Fancy SQL Part II
1. Set Operators & Nested Queries
What you will learn about in this section

1. Multiset operators in SQL
2. Nested queries
3. ACTIVITY: Set operator subtleties
An Unintuitive Query

```
SELECT DISTINCT R.A
FROM    R, S, T
WHERE   R.A=S.A OR R.A=T.A
```

What does it compute?
An Unintuitive Query

```
SELECT DISTINCT R.A
FROM R, S, T
WHERE R.A=S.A OR R.A=T.A
```

Computes \( R \cap (S \cup T) \)

But what if \( S = \emptyset \)?

Go back to the semantics!
An Unintuitive Query

SELECT DISTINCT R.A
FROM R, S, T
WHERE R.A=S.A OR R.A=T.A

• Recall the semantics!
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection

• If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

Must consider semantics here.
Are there more explicit way to do set operations like this?
What does this look like in Python?

\[
\text{SELECT DISTINCT R.A} \\
\text{FROM R, S, T} \\
\text{WHERE R.A=S.A OR R.A=T.A}
\]

• Semantics:
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection

\( R \cap (S \cup T) \)

Joints / cross-products are just nested for loops (in simplest implementation)!

If-then statements!
What does this look like in Python?

```
SELECT DISTINCT R.A
FROM    R, S, T
WHERE   R.A=S.A OR R.A=T.A
```

```python
output = {}
for r in R:
    for s in S:
        for t in T:
            if r['A'] == s['A'] or r['A'] == t['A']:
                output.add(r['A'])
return list(output)
```

Can you see now what happens if S = []?
Multiset Operations
Recall Multisets

Equivalent Representations of a Multiset

\[ \lambda(X) = \text{“Count of tuple in } X \text{”} \]

\[ \text{(Items not listed have implicit count 0)} \]

Note: In a set all counts are \{0, 1\}. 

<table>
<thead>
<tr>
<th>Tuple</th>
<th>( \lambda(X) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>2</td>
</tr>
<tr>
<td>(1, b)</td>
<td>1</td>
</tr>
<tr>
<td>(2, c)</td>
<td>3</td>
</tr>
<tr>
<td>(1, d)</td>
<td>2</td>
</tr>
</tbody>
</table>

Multiset X

<table>
<thead>
<tr>
<th>Tuple</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
</tr>
<tr>
<td>(1, a)</td>
</tr>
<tr>
<td>(1, b)</td>
</tr>
<tr>
<td>(2, c)</td>
</tr>
<tr>
<td>(2, c)</td>
</tr>
<tr>
<td>(2, c)</td>
</tr>
<tr>
<td>(1, d)</td>
</tr>
<tr>
<td>(1, d)</td>
</tr>
</tbody>
</table>
Generalizing Set Operations to Multiset Operations

Multiset $X$

<table>
<thead>
<tr>
<th>Tuple</th>
<th>$\lambda(X)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>2</td>
</tr>
<tr>
<td>(1, b)</td>
<td>0</td>
</tr>
<tr>
<td>(2, c)</td>
<td>3</td>
</tr>
<tr>
<td>(1, d)</td>
<td>0</td>
</tr>
</tbody>
</table>

Multiset $Y$

<table>
<thead>
<tr>
<th>Tuple</th>
<th>$\lambda(Y)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>5</td>
</tr>
<tr>
<td>(1, b)</td>
<td>1</td>
</tr>
<tr>
<td>(2, c)</td>
<td>2</td>
</tr>
<tr>
<td>(1, d)</td>
<td>2</td>
</tr>
</tbody>
</table>

Multiset $Z$

<table>
<thead>
<tr>
<th>Tuple</th>
<th>$\lambda(Z)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>2</td>
</tr>
<tr>
<td>(1, b)</td>
<td>0</td>
</tr>
<tr>
<td>(2, c)</td>
<td>2</td>
</tr>
<tr>
<td>(1, d)</td>
<td>0</td>
</tr>
</tbody>
</table>

$\lambda(Z) = \min(\lambda(X), \lambda(Y))$

For sets, this is intersection
Generalizing Set Operations to Multiset Operations

**Multiset X**

<table>
<thead>
<tr>
<th>Tuple</th>
<th>( \lambda(X) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>2</td>
</tr>
<tr>
<td>(1, b)</td>
<td>0</td>
</tr>
<tr>
<td>(2, c)</td>
<td>3</td>
</tr>
<tr>
<td>(1, d)</td>
<td>0</td>
</tr>
</tbody>
</table>

**Multiset Y**

<table>
<thead>
<tr>
<th>Tuple</th>
<th>( \lambda(Y) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>5</td>
</tr>
<tr>
<td>(1, b)</td>
<td>1</td>
</tr>
<tr>
<td>(2, c)</td>
<td>2</td>
</tr>
<tr>
<td>(1, d)</td>
<td>2</td>
</tr>
</tbody>
</table>

**Multiset Z**

<table>
<thead>
<tr>
<th>Tuple</th>
<th>( \lambda(Z) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1, a)</td>
<td>7</td>
</tr>
<tr>
<td>(1, b)</td>
<td>1</td>
</tr>
<tr>
<td>(2, c)</td>
<td>5</td>
</tr>
<tr>
<td>(1, d)</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ \lambda(Z) = \lambda(X) + \lambda(Y) \]

For sets, this is **union**
Multiset Operations in SQL
Explicit Set Operators: INTERSECT

\[
\text{SELECT } R.A \\
\text{FROM } R, S \\
\text{WHERE } R.A = S.A \\
\text{INTERSECT} \\
\text{SELECT } R.A \\
\text{FROM } R, T \\
\text{WHERE } R.A = T.A
\]

\[\{r.A \mid r.A = s.A\} \cap \{r.A \mid r.A = t.A\}\]
UNION

\[
\{r.A \mid r.A = s.A\} \cup \{r.A \mid r.A = t.A\}
\]

Why aren’t there duplicates?

By default: SQL uses set semantics!

What if we want duplicates?
UNION ALL

SELECT R.A
FROM R, S
WHERE R.A = S.A
UNION ALL
SELECT R.A
FROM R, T
WHERE R.A = T.A

\{r.A | r.A = s.A\} \cup \{r.A | r.A = t.A\}

ALL indicates Multiset operations
**EXCEPT**

```
SELECT  R.A
FROM    R, S
WHERE   R.A=S.A
EXCEPT  SELECT  R.A
FROM    R, T
WHERE   R.A=T.A
```

\[\{r.A | r.A = s.A\}\{r.A|r.A = t.A\}\]

**What is the multiset version?**
INTERSECT: Still some subtle problems...

```
SELECT hq_city
FROM Company, Product
WHERE maker = name
    AND factory_loc = 'US'
INTERSECT
SELECT hq_city
FROM Company, Product
WHERE maker = name
    AND factory_loc = 'China'
```

“Headquarters of companies which make gizmos in US AND China”

What if two companies have HQ in US: BUT one has factory in China (but not US) and vice versa? What goes wrong?
INTERSECT: Remember the semantics!

Example: C JOIN P on maker = name

<table>
<thead>
<tr>
<th>C.name</th>
<th>C.hq_city</th>
<th>P.pname</th>
<th>P.maker</th>
<th>P.factory_loc</th>
</tr>
</thead>
<tbody>
<tr>
<td>X Co.</td>
<td>Seattle</td>
<td>X</td>
<td>X Co.</td>
<td>U.S.</td>
</tr>
<tr>
<td>Y Inc.</td>
<td>Seattle</td>
<td>X</td>
<td>Y Inc.</td>
<td>China</td>
</tr>
</tbody>
</table>

**Company(name, hq_city) AS C**

**Product(pname, maker, factory_loc) AS P**

```
SELECT hq_city
FROM Company, Product
WHERE maker = name
AND factory_loc=‘US’
INTERSECT
SELECT hq_city
FROM Company, Product
WHERE maker = name
AND factory_loc=‘China’
```
INTERSECT: Remember the semantics!

Example: C JOIN P on maker = name

<table>
<thead>
<tr>
<th>C.name</th>
<th>C.hq_city</th>
<th>P.pname</th>
<th>P.maker</th>
<th>P.factory_loc</th>
</tr>
</thead>
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<td>X Co.</td>
<td>Seattle</td>
<td>X</td>
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</tr>
<tr>
<td>Y Inc.</td>
<td>Seattle</td>
<td>Y Inc.</td>
<td>China</td>
<td></td>
</tr>
</tbody>
</table>

X Co has a factory in the US (but not China)
Y Inc. has a factory in China (but not US)

But Seattle is returned by the query!

We did the INTERSECT on the wrong attributes!
One Solution: Nested Queries

Company(name, hq_city)
Product(pname, maker, factory_loc)

SELECT DISTINCT hq_city
FROM Company, Product
WHERE maker = name
AND name IN (  
    SELECT maker  
    FROM Product  
    WHERE factory_loc = 'US')
AND name IN (  
    SELECT maker  
    FROM Product  
    WHERE factory_loc = 'China')

“Headquarters of companies which make gizmos in US AND China”

Note: If we hadn’t used DISTINCT here, how many copies of each hq_city would have been returned?
High-level note on nested queries

• We can do nested queries because SQL is *compositional*:

  • Everything (inputs / outputs) is represented as multisets- the output of one query can thus be used as the input to another (nesting)!

• This is extremely powerful!
Nested queries: Sub-queries Return Relations

Another example:

Company\((\text{name}, \text{city})\)
Product\((\text{name}, \text{maker})\)
Purchase\((\text{id}, \text{product}, \text{buyer})\)

```
SELECT  c.city
FROM     Company  c
WHERE    c.name  IN (  
    SELECT  pr.maker
    FROM     Purchase  p, Product  pr
    WHERE    p.product  =  pr.name
             AND  p.buyer  =  'Joe Blow'
)
```

“Cities where one can find companies that manufacture products bought by Joe Blow”
Nested Queries

Are these queries equivalent?

SELECT c.city  
FROM Company c  
WHERE c.name IN (  
SELECT pr.maker  
FROM Purchase p, Product pr  
WHERE p.name = pr.product  
AND p.buyer = 'Joe Blow' )

SELECT c.city  
FROM Company c,  
Product pr,  
Purchase p  
WHERE c.name = pr.maker  
AND pr.name = p.product  
AND p.buyer = 'Joe Blow'

Beware of duplicates!
Lecture 3  >  Section 1  >  Nested Queries

Nested Queries

```
SELECT DISTINCT c.city
FROM Company c,
    Product pr,
    Purchase p
WHERE c.name = pr.maker
    AND pr.name = p.product
    AND p.buyer = 'Joe Blow'
```

```
SELECT DISTINCT c.city
FROM Company c
WHERE c.name IN (  
    SELECT pr.maker
    FROM Purchase p, Product pr
    WHERE p.product = pr.name
        AND p.buyer = 'Joe Blow'
)
```

Now they are equivalent (both use set semantics)
Subqueries Return Relations

You can also use operations of the form:

- \( s > \text{ALL} R \)
- \( s < \text{ANY} R \)
- \( \text{EXISTS} R \)

Ex: \( \text{Product(name, price, category, maker)} \)

```
SELECT name
FROM Product
WHERE price > ALL(
    SELECT price
    FROM Product
    WHERE maker = 'Gizmo-Works')
```
Subqueries Returning Relations

You can also use operations of the form:

- $s > \text{ALL } R$
- $s < \text{ANY } R$
- $\text{EXISTS } R$

Ex:  \textit{Product(name, price, category, maker)}

```sql
SELECT p1.name
FROM Product p1
WHERE p1.maker = 'Gizmo-Works'
AND EXISTS(
  SELECT p2.name
  FROM Product p2
  WHERE p2.maker != 'Gizmo-Works'
  AND p1.name = p2.name)
```

Find ‘copycat’ products, i.e. products made by competitors with the same names as products made by “Gizmo-Works”
Nested queries as alternatives to INTERSECT and EXCEPT

INTERSECT and EXCEPT not in some DBMSs!

If R, S have no duplicates, then can write without sub-queries (HOW?)

Lecture 3 > Section 1 > Nested Queries
Correlated Queries Using External Vars in Internal Subquery

Find movies whose title appears more than once.

Note the scoping of the variables!

Note also: this can still be expressed as single SFW query...
Complex Correlated Query

```sql
SELECT DISTINCT x.name, x.maker
FROM Product AS x
WHERE x.price > ALL(
    SELECT y.price
    FROM Product AS y
    WHERE x.maker = y.maker
    AND y.year < 1972)
```

Find products (and their manufacturers) that are more expensive than all products made by the same manufacturer before 1972.

Can be very powerful (also much harder to optimize)
Basic SQL Summary

• SQL provides a high-level declarative language for manipulating data (DML)

• The workhorse is the SFW block

• Set operators are powerful but have some subtleties

• Powerful, nested queries also allowed.
Activity-3-1.ipynb
2. Aggregation & GROUP BY
What you will learn about in this section

1. Aggregation operators

2. GROUP BY

3. GROUP BY: with HAVING, semantics

4. ACTIVITY: Fancy SQL Pt. I
Aggregation

SELECT AVG(price)
FROM Product
WHERE maker = "Toyota"

SELECT COUNT(*)
FROM Product
WHERE year > 1995

• SQL supports several **aggregation** operations:
  • SUM, COUNT, MIN, MAX, AVG
Aggregation: COUNT

- COUNT applies to duplicates, unless otherwise stated

```
SELECT COUNT(category)
FROM Product
WHERE year > 1995
```

Note: Same as COUNT(*).

Why?

We probably want:

```
SELECT COUNT(DISTINCT category)
FROM Product
WHERE year > 1995
```
More Examples

```
Purchase(product, date, price, quantity)
```

```
SELECT SUM(price * quantity)
FROM Purchase
```

```
SELECT SUM(price * quantity)
FROM Purchase
WHERE product = 'bagel'
```

What do these mean?
Simple Aggregations

Purchase

<table>
<thead>
<tr>
<th>Product</th>
<th>Date</th>
<th>Price</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>bagel</td>
<td>10/21</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td>banana</td>
<td>10/3</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td>banana</td>
<td>10/10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>bagel</td>
<td>10/25</td>
<td>1.50</td>
<td>20</td>
</tr>
</tbody>
</table>

```
SELECT SUM(price * quantity) 
FROM Purchase 
WHERE product = 'bagel'
```

50 (= 1*20 + 1.50*20)
Grouping and Aggregation

```sql
SELECT product, 
      SUM(price * quantity) AS TotalSales 
FROM Purchase 
WHERE date > '10/1/2005' 
GROUP BY product
```

Find total sales after 10/1/2005 per product.

Let’s see what this means…
Grouping and Aggregation

Semantics of the query:

1. Compute the **FROM** and **WHERE** clauses

2. Group by the attributes in the **GROUP BY**

3. Compute the **SELECT** clause: grouped attributes and aggregates
1. Compute the **FROM** and **WHERE** clauses

```sql
SELECT product, SUM(price*quantity) AS TotalSales
FROM Purchase
WHERE date > '10/1/2005'
GROUP BY product
```

**Table:**

<table>
<thead>
<tr>
<th>Product</th>
<th>Date</th>
<th>Price</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>10/21</td>
<td>1</td>
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<tr>
<td>Bagel</td>
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<td>1.50</td>
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<tr>
<td>Banana</td>
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<td>Banana</td>
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<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>
2. Group by the attributes in the **GROUP BY**

```sql
SELECT product, SUM(price*quantity) AS TotalSales
FROM Purchase
WHERE date > '10/1/2005'
GROUP BY product
```
3. Compute the **SELECT** clause: grouped attributes and aggregates

```
SELECT product, SUM(price*quantity) AS TotalSales
FROM Purchase
WHERE date > '10/1/2005'
GROUP BY product
```

<table>
<thead>
<tr>
<th>Product</th>
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<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>10/21</td>
<td>1</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>10/25</td>
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<td>20</td>
</tr>
<tr>
<td>Banana</td>
<td>10/3</td>
<td>0.5</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>10/10</td>
<td>1</td>
<td>10</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Product</th>
<th>TotalSales</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bagel</td>
<td>50</td>
</tr>
<tr>
<td>Banana</td>
<td>15</td>
</tr>
</tbody>
</table>
GROUP BY v.s. Nested Queries

```
SELECT product, Sum(price*quantity) AS TotalSales
FROM Purchase
WHERE date > '10/1/2005'
GROUP BY product

SELECT DISTINCT x.product,
    (SELECT Sum(y.price*y.quantity)
     FROM Purchase y
     WHERE x.product = y.product
     AND y.date > '10/1/2005') AS TotalSales
FROM Purchase x
WHERE x.date > '10/1/2005'
```
HAVING Clause

**Example Query**: Same query as before, except that we consider only products that have more than 100 buyers.

```
SELECT product, SUM(price*quantity)
FROM Purchase
WHERE date > '10/1/2005'
GROUP BY product
HAVING SUM(quantity) > 100
```

- **HAVING clauses contain conditions on aggregates**
- **WHERE clauses condition on individual tuples**
General form of Grouping and Aggregation

\[
\text{SELECT } S \quad \text{FROM } \quad R_1, \ldots, R_n \\
\text{WHERE } \quad C_1 \\
\text{GROUP BY } \quad a_1, \ldots, a_k \\
\text{HAVING } \quad C_2
\]

- \( S \) = Can ONLY contain attributes \( a_1, \ldots, a_k \) and/or aggregates over other attributes
- \( C_1 \) = is any condition on the attributes in \( R_1, \ldots, R_n \)
- \( C_2 \) = is any condition on the aggregate expressions
General form of Grouping and Aggregation

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

Evaluation steps:
1. Evaluate **FROM-WHERE**: apply condition $C₁$ on the attributes in $R₁,...,Rₙ$
2. **GROUP BY** the attributes $a₁,...,aₖ$
3. **Apply condition** $C₂$ to each group (may have aggregates)
4. **Compute aggregates** in $S$ and return the result
Group-by v.s. Nested Query

- Find authors who wrote ≥ 10 documents:
- Attempt 1: with nested queries

```sql
SELECT DISTINCT Author.name
FROM Author
WHERE COUNT(
    SELECT Wrote.url
    FROM Wrote
    WHERE Author.login = Wrote.login)
> 10
```

Author(login, name)
Wrote(login, url)

This is SQL by a novice
Group-by v.s. Nested Query

• Find all authors who wrote at least 10 documents:
• Attempt 2: SQL style (with GROUP BY)

```
SELECT Author.name
FROM Author, Wrote
WHERE Author.login = Wrote.login
GROUP BY Author.name
HAVING COUNT(Wrote.url) > 10
```

No need for DISTINCT: automatically from GROUP BY
Group-by vs. Nested Query

Which way is more efficient?

• Attempt #1- *With nested*: How many times do we do a SFW query over all of the Wrote relations?

• Attempt #2- *With group-by*: How about when written this way?

With GROUP BY can be **much** more efficient!
Activity-3-2.ipynb
3. Advanced SQL-izing
What you will learn about in this section

1. Quantifiers
2. NULLs
3. Outer Joins
4. ACTIVITY: Fancy SQL Pt. II
Quantifiers

Product(name, price, company)
Company(name, city)

Find all companies that make some products with price < 100

```
SELECT DISTINCT Company.cname
FROM Company, Product
WHERE Company.name = Product.company
    AND Product.price < 100
```

An existential quantifier is a logical quantifier (roughly) of the form “there exists”

Existential: easy 😊
Quantifiers

Product(name, price, company)
Company(name, city)

SELECT DISTINCT Company.cname
FROM Company
WHERE Company.name NOT IN (SELECT Product.company
FROM Product.price >= 100)

A universal quantifier is of the form “for all”

Find all companies with products all having price < 100

Equivalent

Find all companies that make only products with price < 100

Universal: hard 😞
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

• How does SQL cope with tables that have NULLs?
Null Values

• *For numerical operations*, NULL -> NULL:
  • If $x = \text{NULL}$ then $4(3-x)/7$ is still NULL

• *For boolean operations*, in SQL there are three values:

  \[
  \begin{align*}
  \text{FALSE} &= 0 \\
  \text{UNKNOWN} &= 0.5 \\
  \text{TRUE} &= 1
  \end{align*}
  \]

  • If $x = \text{NULL}$ then $x=\text{"Joe"}$ is UNKNOWN
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 AND weight > 190)

Won’t return e.g. (age=20 height=NULL weight=200)!

Rule in SQL: include only tuples that yield TRUE (1.0)
Null Values

Unexpected behavior:

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

Some Persons are not included!
Null Values

Can test for NULL explicitly:

- x IS NULL
- x IS NOT NULL

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

Now it includes all Persons!
RECAP: Inner Joins

By default, joins in SQL are "inner joins":

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

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

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

Both equivalent: Both INNER JOINS!
Inner Joins + NULLS = Lost data?

By default, joins in SQL are “inner joins”:

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

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

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

However: Products that never sold (with no Purchase tuple) will be lost!
Outer Joins

• An **outer join** returns tuples from the joined relations that don’t have a corresponding tuple in the other relations
  • I.e. If we join relations A and B on \( a.X = b.X \), and there is an entry in A with \( X=5 \), but none in B with \( X=5 \)...
    • A LEFT OUTER JOIN will return a tuple (a, NULL)!

• Left outer joins in SQL:

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

Now we’ll get products even if they didn’t sell
INNER JOIN:

**Product**

<table>
<thead>
<tr>
<th>name</th>
<th>category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>gadget</td>
</tr>
<tr>
<td>Camera</td>
<td>Photo</td>
</tr>
<tr>
<td>OneClick</td>
<td>Photo</td>
</tr>
</tbody>
</table>

**Purchase**

<table>
<thead>
<tr>
<th>prodName</th>
<th>store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>Wiz</td>
</tr>
<tr>
<td>Camera</td>
<td>Ritz</td>
</tr>
<tr>
<td>Camera</td>
<td>Wiz</td>
</tr>
</tbody>
</table>

**SQL Query**

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

Note: another equivalent way to write an INNER JOIN!
### LEFT OUTER JOIN:

**Product**

<table>
<thead>
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<th>category</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Camera</td>
<td>Photo</td>
</tr>
<tr>
<td>OneClick</td>
<td>Photo</td>
</tr>
</tbody>
</table>

**Purchase**

<table>
<thead>
<tr>
<th>prodName</th>
<th>store</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gizmo</td>
<td>Wiz</td>
</tr>
<tr>
<td>Camera</td>
<td>Ritz</td>
</tr>
<tr>
<td>Camera</td>
<td>Wiz</td>
</tr>
</tbody>
</table>

**SELECT** `Product.name, Purchase.store`

**FROM** `Product`

**LEFT OUTER JOIN** `Purchase`

**ON** `Product.name = Purchase.prodName`
Other 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 the both left and right tuples even if there’s no match
Activity-3-3.ipynb
Summary

SQL is a rich programming language that handles the way data is processed *declaratively*.