Lectures 3:
Introduction to SQL Part II

Announcements!

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

2. Problem Set #1 is released!

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

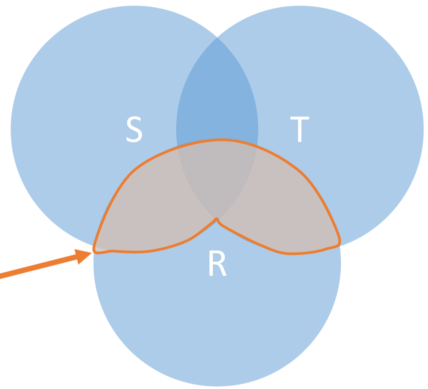
An Unintuitive Query

```
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 ∩ (S ∪ T)

But what if S = ϕ?

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
```

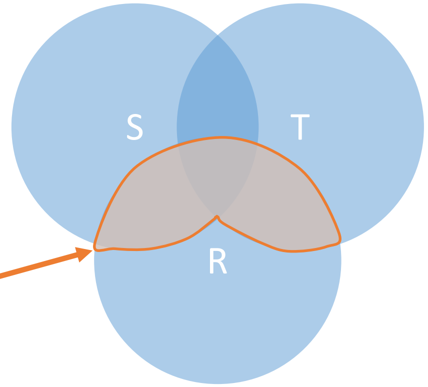
- Recall the semantics!
    1. Take cross-product
    2. Apply selections / conditions
    3. Apply projection
- If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

Must consider semantics here.
Are there more explicit way to do set operations like this?

What does this look like in Python?

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

$R \cap (S \cup T)$

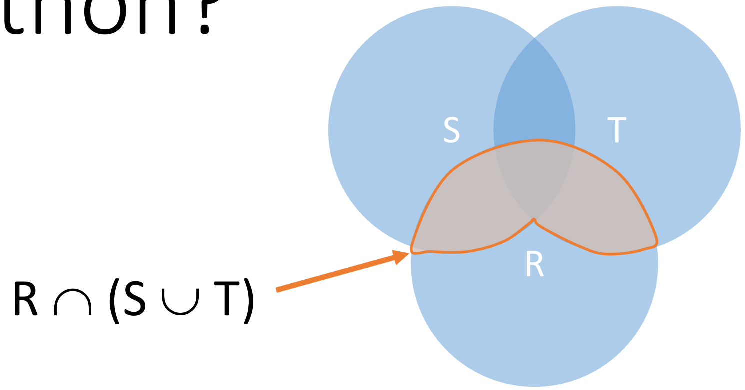


- Semantics:
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection

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

If-then statements!

What does this look like in Python?




```sql
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 = []?

See bonus activity on website!

Multiset Operations

Recall Multisets

$\boldsymbol{\lambda(X)}$= "Count of tuple in X"
(Items not listed have implicit count 0)

Multiset X

Tuple
(1, a)
(1, a)
(1, b)
(2, c)
(2, c)
(2, c)
(1, d)
(1, d)

Equivalent Representations of a <u>Multiset</u>

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	1
(2, c)	3
(1, d)	2

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

Generalizing Set Operations to Multiset Operations

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	0
(2, c)	3
(1, d)	0

$\cap$

Multiset Y

Tuple	$\lambda(Y)$
(1, a)	5
(1, b)	1
(2, c)	2
(1, d)	2

$=$

Multiset Z

Tuple	$\lambda(Z)$
(1, a)	2
(1, b)	0
(2, c)	2
(1, d)	0

$$\boldsymbol{\lambda(Z) = min(\lambda(X), \lambda(Y))}$$

For sets, this is **intersection**

Generalizing Set Operations to Multiset Operations

Multiset X

Tuple	$\lambda(X)$
(1, a)	2
(1, b)	0
(2, c)	3
(1, d)	0

$\cup$

Multiset Y

Tuple	$\lambda(Y)$
(1, a)	5
(1, b)	1
(2, c)	2
(1, d)	2

$=$

Multiset Z

Tuple	$\lambda(Z)$
(1, a)	7
(1, b)	1
(2, c)	5
(1, d)	2

$$\boldsymbol{\lambda(Z) = \lambda(X) + \lambda(Y)}$$

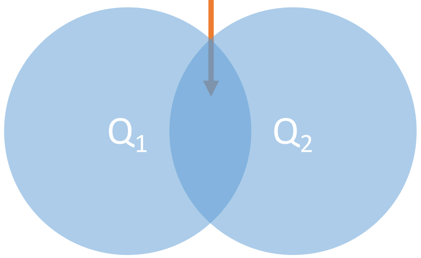
For sets,
this is **union**

Multiset Operations in SQL

Explicit Set Operators: INTERSECT

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

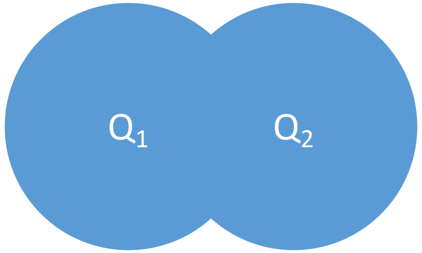
$$\{r.A \mid r.A = s.A\} \cap \{r.A \mid r.A = t.A\}$$



UNION

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

$$\{r.A \mid r.A = s.A\} \cup \{r.A \mid r.A = t.A\}$$



Why aren't there duplicates?

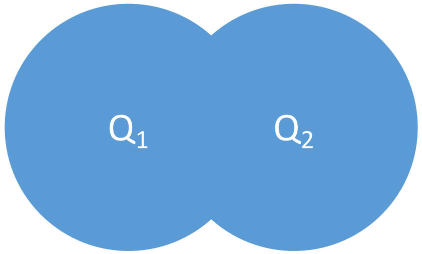
By default:
SQL uses set semantics!

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
```

$\{r.A \mid r.A = s.A\} \cup \{r.A \mid r.A = t.A\}$

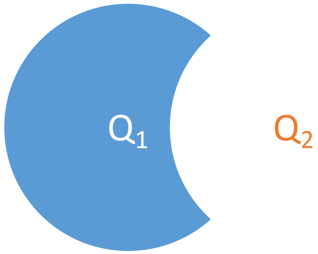


ALL indicates Multiset operations

EXCEPT

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

$$\{r.A \mid r.A = s.A\} \setminus \{r.A \mid r.A = t.A\}$$



What is the multiset version?

INTERSECT: Still some subtle problems…

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

```
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!

```
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'
```

Example: C JOIN P on maker = name

C.name	C.hq_city	P.pname	P.maker	P.factory_loc
X Co.	Seattle	X	X Co.	U.S.
Y Inc.	Seattle	X	Y Inc.	China

INTERSECT: Remember the semantics!

```
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'
```

Example: C JOIN P on maker = name

C.name	C.hq_city	P.pname	P.maker	P.factory_loc
X Co.	Seattle	X	X Co.	U.S.
Y Inc.	Seattle	X	Y Inc.	China

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 <u>extremely</u> powerful!

Nested queries: Sub-queries Return Relations

Another example:

```
Company(name, city)
Product(name, maker)
Purchase(id, product, 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!

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 > ALL R
- s < ANY R
- EXISTS R

ANY and ALL not supported by SQLite.

Ex:

```
Product(name, price, category, maker)
```

```
SELECT  name
FROM    Product
WHERE   price > ALL(
        SELECT  price
        FROM    Product
        WHERE   maker = ‘Gizmo-Works’)
```

Find products that are more expensive than all those produced by “Gizmo-Works”

Subqueries Returning Relations

You can also use operations of the form:

- s > ALL R
- s < ANY R
- EXISTS R

Ex:

```
Product(name, price, category, maker)
```

```
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)
```

<> means !=

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!

```
(SELECT R.A, R.B
 FROM   R)
INTERSECT
(SELECT S.A, S.B
 FROM   S)
```

⇨

```
SELECT R.A, R.B
FROM   R
WHERE EXISTS(
       SELECT *
       FROM S
       WHERE R.A=S.A AND R.B=S.B)
```

```
(SELECT R.A, R.B
 FROM   R)
EXCEPT
(SELECT S.A, S.B
 FROM   S)
```

⇨

```
SELECT R.A, R.B
FROM   R
WHERE NOT EXISTS(
       SELECT *
       FROM S
       WHERE R.A=S.A AND R.B=S.B)
```

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

Correlated Queries Using External Vars in Internal Subquery

```
Movie(title, year, director, length)
```

```
SELECT DISTINCT title
FROM   Movie AS m
WHERE  year <> ANY(
          SELECT  year
          FROM    Movie
          WHERE   title = m.title)
```

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

```
Product(name, price, category, maker, year)
```

```
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.

[DB-WS03a.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

Except COUNT, all aggregations apply to a single attribute

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
```

What do these mean?

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

Simple Aggregations

Purchase

Product	Date	Price	Quantity
bagel	10/21	1	20
banana	10/3	0.5	10
banana	10/10	1	10
bagel	10/25	1.50	20

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

⇒ 50 (= 1*20 + 1.50*20)

Grouping and Aggregation

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

```
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

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

FROM

Product	Date	Price	Quantity
Bagel	10/21	1	20
Bagel	10/25	1.50	20
Banana	10/3	0.5	10
Banana	10/10	1	10

2. Group by the attributes in the GROUP BY

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

Product	Date	Price	Quantity
Bagel	10/21	1	20
Bagel	10/25	1.50	20
Banana	10/3	0.5	10
Banana	10/10	1	10

GROUP BY

<table>
<tr><th>Product</th><th>Date</th><th>Price</th><th>Quantity</th></tr>
<tr><td rowspan="2">Bagel</td><td>10/21</td><td>1</td><td>20</td></tr>
<tr><td>10/25</td><td>1.50</td><td>20</td></tr>
<tr><td rowspan="2">Banana</td><td>10/3</td><td>0.5</td><td>10</td></tr>
<tr><td>10/10</td><td>1</td><td>10</td></tr>
</table>

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
```

Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10

SELECT →

Product	TotalSales
Bagel	50
Banana	15

HAVING Clause

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

Same query as before, except that we consider only products that have more than 100 buyers

HAVING clauses contains conditions on **aggregates**

*Whereas WHERE clauses condition on **individual tuples…***

General form of Grouping and Aggregation

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

Why?

- 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 C_1 on the attributes in $R_1,\ldots,R_n$
2. GROUP BY the attributes $a_1,\ldots,a_k$
3. Apply condition C_2 to each group (may have aggregates)
4. Compute aggregates in S and return the result

Group-by v.s. Nested Query

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

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

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

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
```

This is
SQL by
an expert

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 <u>much</u> more efficient!

DB-WS03b.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)
```

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

Find all companies that make <u>some</u> products with 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 = NULL then 4*(3-x)/7 is still NULL

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

FALSE	**=**	**0**
UNKNOWN	**=**	**0.5**
TRUE	**=**	**1**

  - If x= NULL then x="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:

```
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

```
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:

```
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

name	category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

prodName	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

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

name	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Note: another equivalent way to write an INNER JOIN!

LEFT OUTER JOIN:

Product

name	category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

prodName	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

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

name	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz
OneClick	NULL

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

DB-WS03c.ipynb

Summary

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