

# 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

SQL stands for  
Structured Query Language

*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!

# Tables in SQL

Product

PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

A relation or table is a multiset of tuples having the attributes specified by the schema

Let's break this definition down

# Tables in SQL

Product

PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

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

**Product**

PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

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

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

# Tables in SQL

**Product**

PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

*Also referred to sometimes as a record*

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

# Tables in SQL

**Product**

PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks
SingleTouch	\$149.99	Canon
MultiTouch	\$203.99	Hitachi

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:

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

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

```
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!

**Students(sid:string, name:string, gpa: float)**

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

**Students(sid:string, name:string, gpa: float)**

sid	name	gpa
123	Bob	3.9
143	Jim	NULL

*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>
```

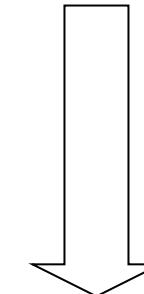
Call this a SFW query.

# Simple SQL Query: Selection

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

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

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



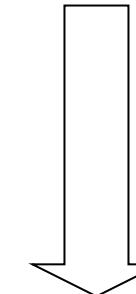
PName	Price	Category	Manufacturer
Gizmo	\$19.99	Gadgets	GizmoWorks
Powergizmo	\$29.99	Gadgets	GizmoWorks

# Simple SQL Query: Projection

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

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

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



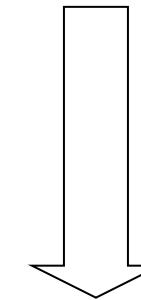
PName	Price	Manufacturer
Gizmo	\$19.99	GizmoWorks
Powergizmo	\$29.99	GizmoWorks

# Notation

Input schema

Product(PName, Price, Category, Manufacturer)

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



Output schema

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

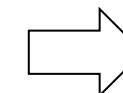
# LIKE: Simple String Pattern Matching

```
SELECT *
FROM   Products
WHERE  PName LIKE '%gizmo%'
```

- $s \text{ } \text{LIKE} \text{ } p$ : pattern matching on strings
- $p$  may contain two special symbols:
  - $\%$  = any sequence of characters
  - $_$  = any single character

# DISTINCT: Eliminating Duplicates

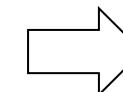
```
SELECT DISTINCT Category  
FROM Product
```



Category
Gadgets
Photography
Household

Versus

```
SELECT Category  
FROM Product
```



Category
Gadgets
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

Students

sid	name	gpa
101	Bob	3.2
123	Mary	3.8

Enrolled

student_id	cid	grade
123	564	A
123	537	A+

student\_id alone is not a key- what is?

We say that student\_id is a foreign key that refers to Students

# Declaring Foreign Keys

```
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*)

*DBA chooses (syntax in the book)*

# Keys and Foreign Keys

## Company

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

What is a foreign key vs. a key here?

## Product

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

# Joins

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

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

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

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

# 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

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

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...

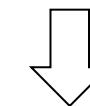
# Joins

## Product

PName	Price	Category	Manuf
Gizmo	\$19	Gadgets	GWorks
Powergizmo	\$29	Gadgets	GWorks
SingleTouch	\$149	Photography	Canon
MultiTouch	\$203	Household	Hitachi

Company

Cname	Stock	Country
GWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan



```

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

PName	Price
SingleTouch	\$149.99

# 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

```
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
```

Both equivalent  
ways to resolve  
variable  
ambiguity

# Meaning (Semantics) of SQL Queries

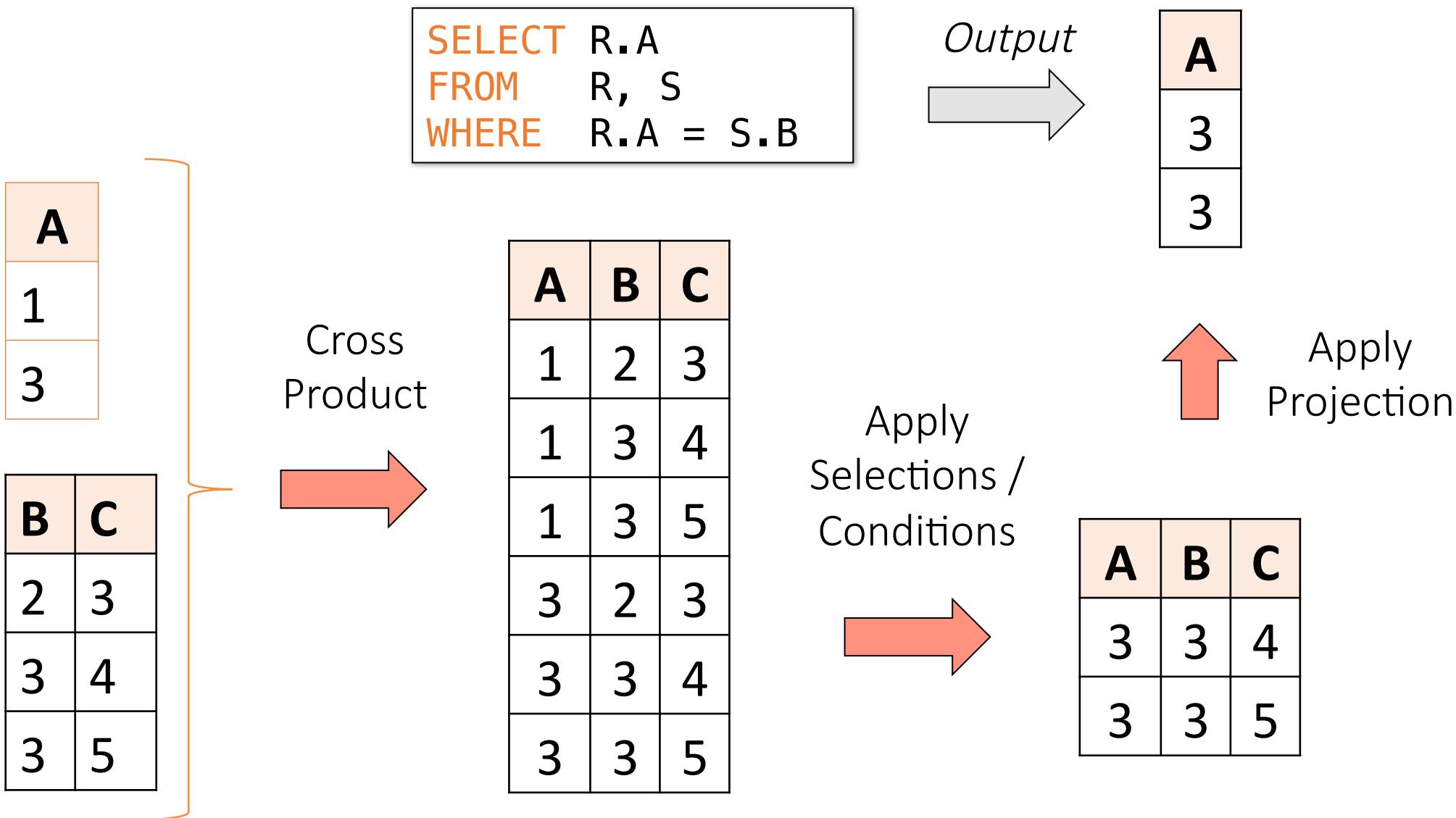
```
SELECT x1.a1, x1.a2, ..., xn.ak
FROM R1 AS x1, R2 AS x2, ..., Rn AS xn
WHERE Conditions(x1, ..., xn)
```

Almost never the *fastest* way  
to compute it!

```
Answer = {}
for x1 in R1 do
  for x2 in R2 do
    ....
    for xn in Rn do
      if Conditions(x1, ..., xn)
        then Answer = Answer  $\cup$  {(x1.a1, x1.a2, ..., xn.ak)}
return Answer
```

Note: this is a *multiset* union

# An example of SQL semantics



# Note the *semantics* of a join

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

## 1. Take cross product:

$$X=R \times S$$

Recall: Cross product ( $A \times B$ ) is the set of all unique tuples in  $A, B$

Ex:  $\{a,b,c\} \times \{1,2\}$   
 $= \{(a,1), (a,2), (b,1), (b,2), (c,1), (c,2)\}$

## 2. Apply selections / conditions:

$$Y=\{(r,s) \in X \mid r.A == r.B\}$$

= Filtering!

## 3. Apply projections to get final output:

$$Z=(y.A) \text{ for } y \in Y$$

= Returning only *some* attributes

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

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

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

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

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

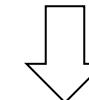
# A subtlety about Joins

Product

PName	Price	Category	Manuf
Gizmo	\$19	Gadgets	GWorks
Powergizmo	\$29	Gadgets	GWorks
SingleTouch	\$149	Photography	Canon
MultiTouch	\$203	Household	Hitachi

Company

Cname	Stock	Country
GWorks	25	USA
Canon	65	Japan
Hitachi	15	Japan



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

Country
?
?

What is the problem ?  
What's the solution ?

ACTIVITY: [Lecture-2-3.ipynb](#)

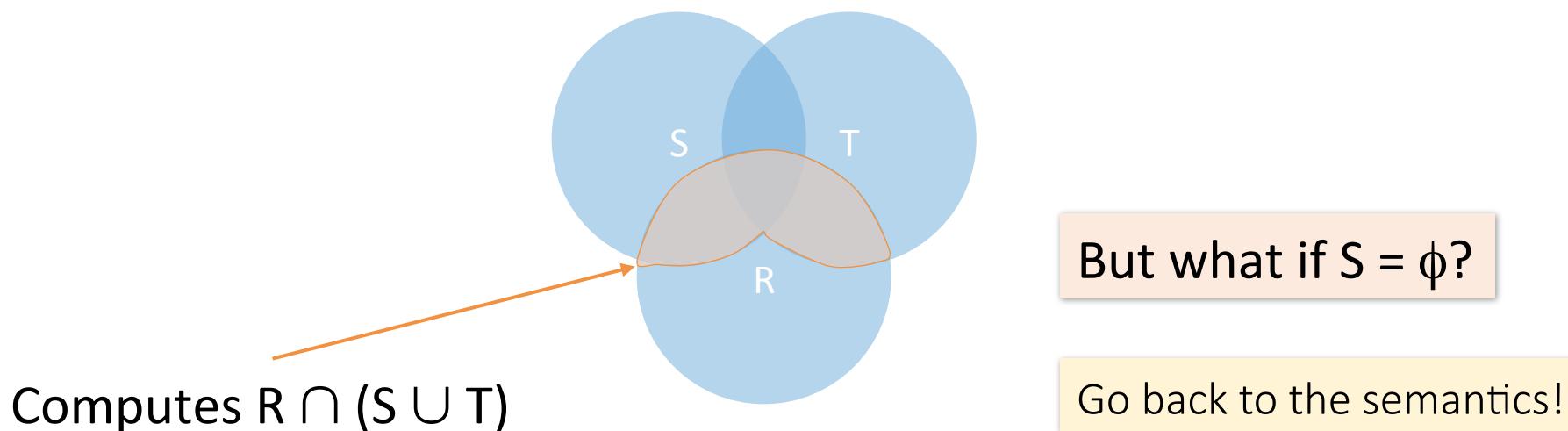
# An Unintuitive Query

```
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  
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```



# 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?

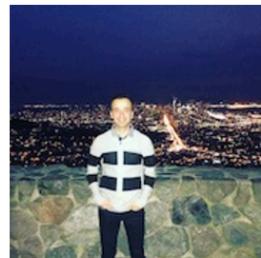
# Lecture 3: SQL Part II

# 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



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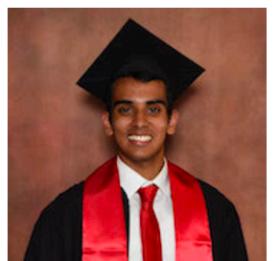
Woncheol (Dennis) Jeong



Aarti Bagul



Lingtong Sun



Dev Bhargava



Stephanie Tang



William Chen



Amelia Vu

## 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

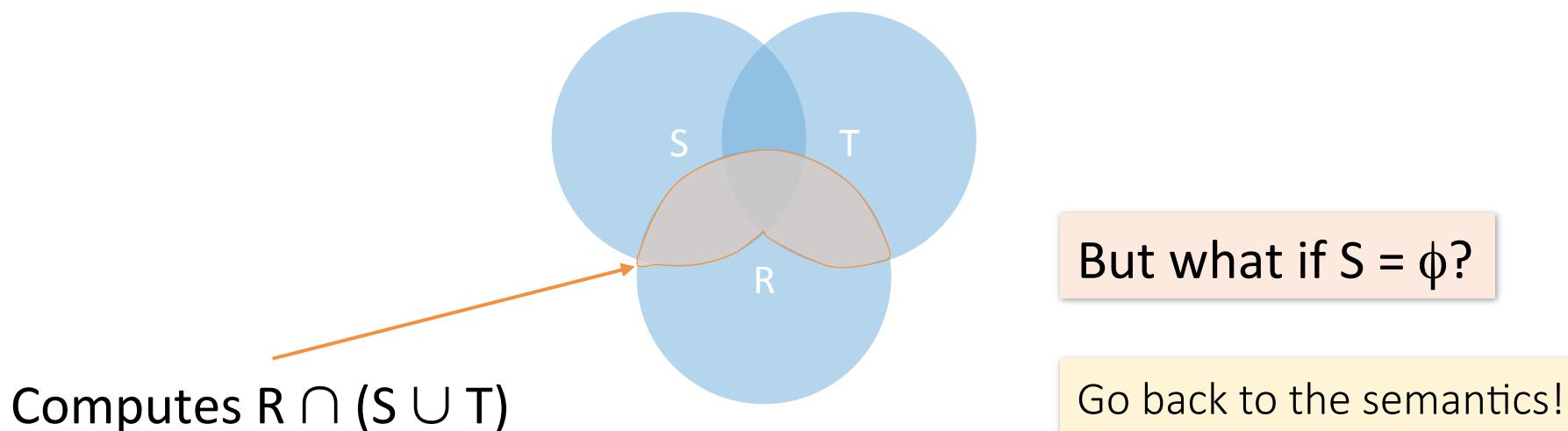
# An Unintuitive Query

```
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
```



# An Unintuitive Query

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

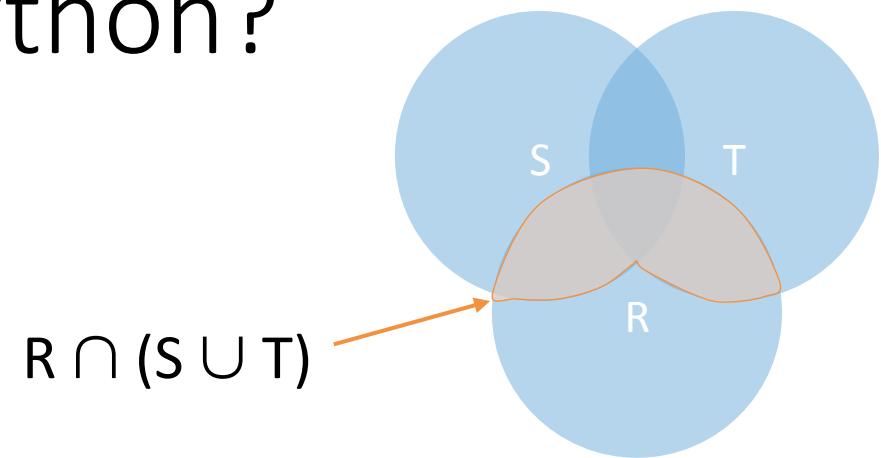
- Recall the semantics!
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection
- If  $S = \{\}$ , then the cross product of  $R, S, T = \{\}$ , and the query result =  $\{\}$ !

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
```



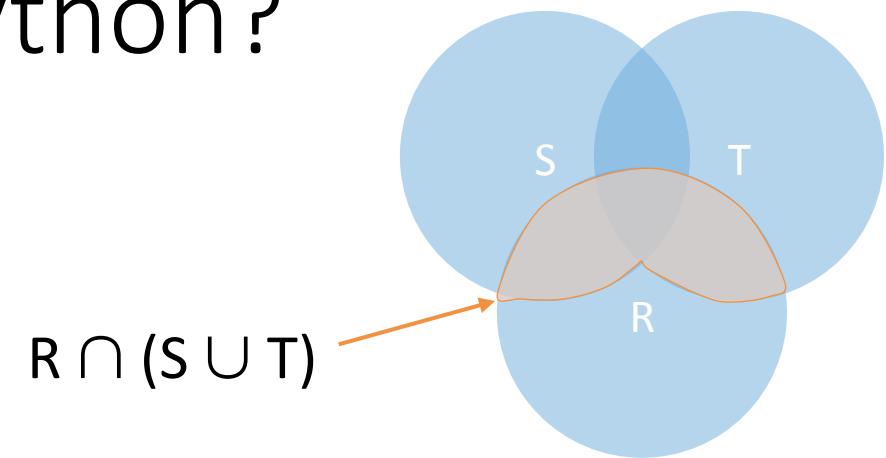
- Semantics:
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection

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

*If-then statements!*

# What does this look like in Python?

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



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

Can you see now what happens if  $S = []$ ?

See bonus activity on website!

# Multiset Operations

# Recall Multisets

Multiset X

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



Equivalent  
Representations  
of a Multiset

$\lambda(X)$  = “Count of tuple in X”  
(Items not listed have implicit count 0)

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

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

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

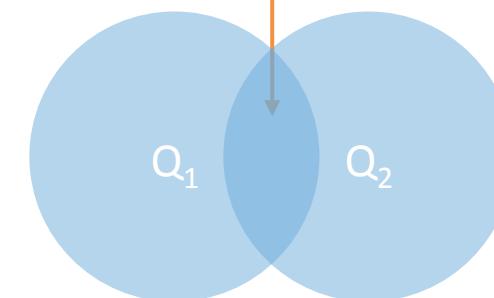
$$\lambda(Z) = \lambda(X) + \lambda(Y)$$

For sets,  
this is union

# Multiset Operations in SQL

# Explicit Set Operators: INTERSECT

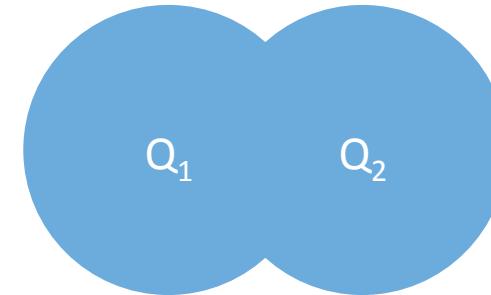
```
SELECT R.A  
FROM   R, S  
WHERE  R.A=S.A  
INTERSECT  
SELECT R.A  
FROM   R, T  
WHERE  R.A=T.A
```

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


# UNION

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

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



Why aren't there duplicates?

By default:  
SQL uses set  
semantics!

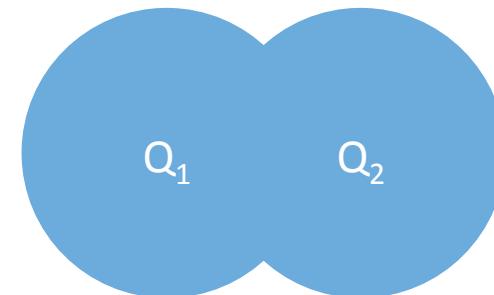
74

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
```

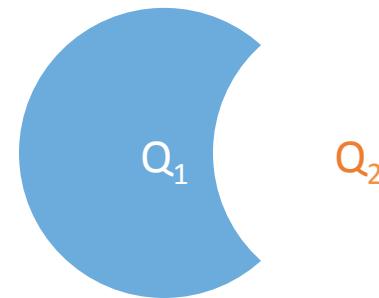
$$r.A \ r.A=s.A \cup \{r.A \mid r.A=t.A\}$$



*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
```

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


*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 extremely 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:

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

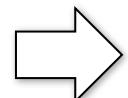
$\text{<>}$  means  $\neq$

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!

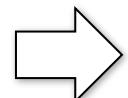
```
(SELECT R.A, R.B
FROM R)
INTERSECT
(SELECT S.A, S.B
FROM S)
```



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

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

```
(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)
```

# 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.

# 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

*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?

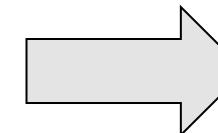
```
SELECT SUM(price * quantity)
FROM Purchase
WHERE product = 'bagel'
```

# 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

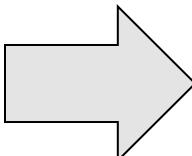
Semantics of the query:

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



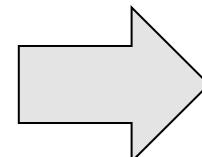
Product	Date	Price	Quantity
Bagel	10/21	1	20
Bagel	10/25	1.50	20
Banana	10/3	0.5	10
Banana	10/10	1	10

## 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**

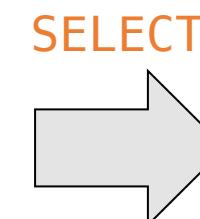


Product	Date	Price	Quantity
Bagel	10/21	1	20
	10/25	1.50	20
Banana	10/3	0.5	10
	10/10	1	10

### 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



Product	TotalSales
Bagel	50
Banana	15

# GROUP BY v.s. Nested Quereis

```
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

```
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

<b>SELECT</b>	$S$
<b>FROM</b>	$R_1, \dots, R_n$
<b>WHERE</b>	$C_1$
<b>GROUP BY</b>	$a_1, \dots, a_k$
<b>HAVING</b>	$C_2$

Why?

- $S$  = Can ONLY contain attributes  $a_1, \dots, a_k$  and/or aggregates over other attributes
- $C_1$  = is any condition on the attributes in  $R_1, \dots, R_n$
- $C_2$  = is any condition on the aggregate expressions

# General form of Grouping and Aggregation

<b>SELECT</b>	S
<b>FROM</b>	$R_1, \dots, R_n$
<b>WHERE</b>	$C_1$
<b>GROUP BY</b>	$a_1, \dots, a_k$
<b>HAVING</b>	$C_2$

Evaluation steps:

1. Evaluate **FROM-WHERE**: apply condition  $C_1$  on the attributes in  $R_1, \dots, R_n$
2. **GROUP BY** the attributes  $a_1, \dots, a_k$
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  $\geq 10$  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 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)
```

```
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 ! 😊

Find all companies that make some products with price < 100

# Quantifiers

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

Find all companies  
with products all  
having price < 100

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



Equivalent

Find all companies  
that make only  
products with price  
< 100

A universal quantifier is of  
the form “for all”

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*,  $\text{NULL} \rightarrow \text{NULL}$ :
  - If  $x = \text{NULL}$  then  $4*(3-x)/7$  is still  $\text{NULL}$
- *For boolean operations*, in SQL there are three values:

**FALSE**        =        0

**UNKNOWN**    =        0.5

**TRUE**          =        1

- If  $x = \text{NULL}$  then  $x = \text{"Joe"}$  is UNKNOWN

# Null Values

- $C1 \text{ AND } C2 = \min(C1, C2)$
- $C1 \text{ OR } C2 = \max(C1, C2)$
- $\text{NOT } C1 = 1 - C1$

```
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  $(a, \text{NULL})$ !
- 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
```

Note: another equivalent way to write an  
INNER JOIN!



name	store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

# 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

# Activity-3-3.ipynb

# Summary

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