# 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!

SQL stands for
Structured Query Language

- 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!

# Tables in SQL

**Product**

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

A <u>relation</u> or <u>table</u> 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 <u>multiset</u> 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 <u>cardinality</u> of the relation

The number of attributes is the <u>arity</u> 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(<u>Pname</u>: *string*, Price: *float*, Category: *string*, <u>Manufacturer</u>: *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 <u>SFW</u> query.

# Simple SQL Query: Selection

<u>Selection</u> 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

<u>Projection</u> 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(<u>PName</u>, Price, Category, <u>Manfacturer</u>)

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

Output schema

Answer(PName, Price, Manfacturer)

# A Few Details

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

- **Values** are **not:**
  - <u>Different:</u> ‘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
```

| 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 <u>constraints</u>)!

- What if we delete a student?

  *DBA chooses (syntax in the book)*

  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

| 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.

```
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

```
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)
```

Both equivalent ways to resolve variable ambiguity

```
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

```
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** $x_1$ **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

# An example of SQL semantics

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

| A |
|---|
| 1 |
| 3 |

| B | C |
|---|---|
| 2 | 3 |
| 3 | 4 |
| 3 | 5 |

Cross Product

| A | B | C |
|---|---|---|
| 1 | 2 | 3 |
| 1 | 3 | 4 |
| 1 | 3 | 5 |
| 3 | 2 | 3 |
| 3 | 3 | 4 |
| 3 | 3 | 5 |

Apply Selections / Conditions

| A | B | C |
|---|---|---|
| 3 | 3 | 4 |
| 3 | 3 | 5 |

Apply Projection

*Output*

| A |
|---|
| 3 |
| 3 |

# 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 X B) is the set of all unique tuples in A,B

Ex: {a,b,c} X {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:

   $Z = (y.A,)\ for\ y \in Y$

= 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

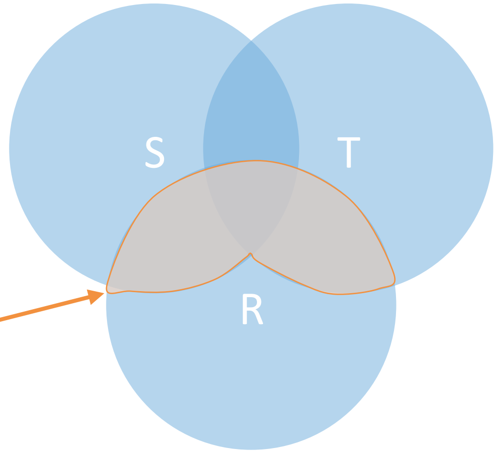
# An Unintuitive Query

```
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

```sql
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?

# Lecture 3: SQL Part II

# Announcements

1. I hope you are set up on Jupyter
    - We’re posting a piazza post about Python help
    - We’re also trying to get some windows tips together.

2. Project 1 will be released on Thursday

# 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

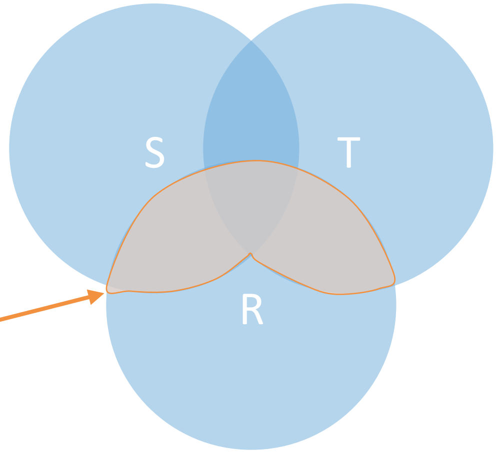
# An Unintuitive Query

```
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
```

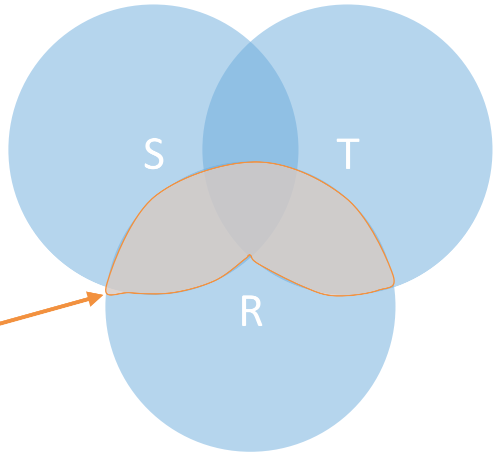
- Recall the semantics!
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection
- If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

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 <u>cross-product</u>

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

  2. Apply <u>selections</u> / <u>conditions</u>

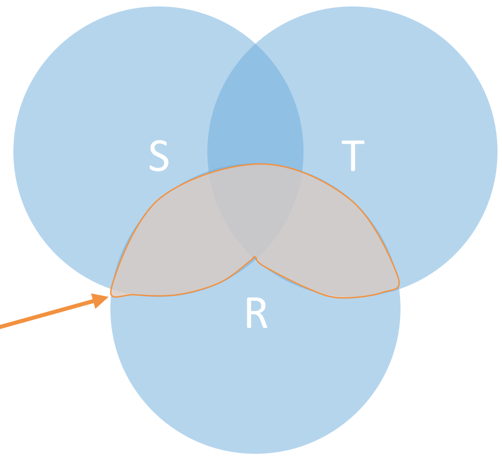
     *If-then statements!*

  3. Apply <u>projection</u>

# 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
```

$R \cap (S \cup T)$




```
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

*$\lambda(X)$= "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 |

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

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 |

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

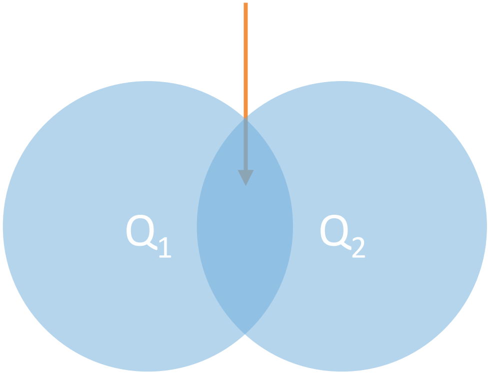
For sets,
this is **union**

# Multiset Operations in SQL

# Explicit Set Operators: INTERSECT

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

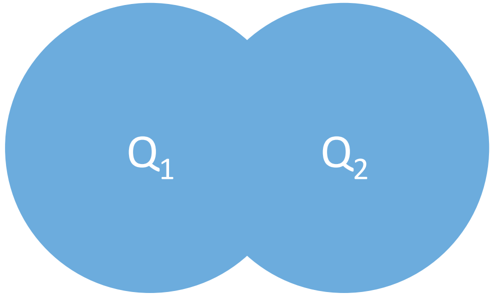
$r.A \quad r.A=s.A \cap \{r.A \mid r.A=t.A\}$



# UNION

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

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



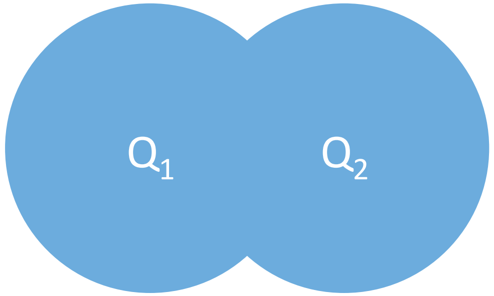

Why aren't there duplicates?

What if we want duplicates?

# UNION ALL

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

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

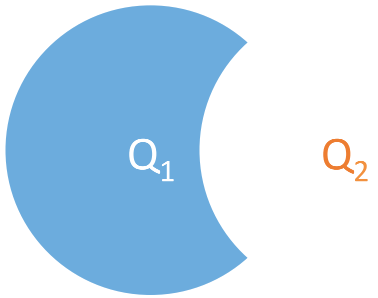



*ALL indicates Multiset operations*

# EXCEPT

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

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




*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 factor 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 Returning 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

Is this query equivalent?

```
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

# Subqueries Returning 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)
```

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)
```

# A question for Database Fans & Friends

- Can we express the previous nested queries as single SFW queries?

- Hint: show that all SFW queries are monotone (roughly: more tuples, more answers).
  - A query with **ALL** is often not monotone

# Correlated Queries

```
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
```

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

What do these mean?

# 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 |

SELECT →

| 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

```
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 $R_1,\dots,R_n$
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 ≥ 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!

# 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
```

Find all companies that make <u>some</u> products with price < 100

An <u>**existential quantifier**</u> 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:

```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

```
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

# [Activity-3-3.ipynb]

# Summary

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