Lectures 2&3: Introduction to SQL

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!

<u>SQL</u> stands for <u>S</u>tructured <u>Q</u>uery <u>L</u>anguage

- 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 **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

A <u>**tuple**</u> or <u>**row**</u> is a single entry in the table having the attributes specified by the schema

Also referred to sometimes as a ***record***

Tables in SQL

Product

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

Why?

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 <u>key</u> 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?
  - <u>Performance!</u>

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

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, Manfacturer)

```
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:**
  - Different: 'Seattle', 'seattle'
- Use single quotes for constants:
  - 'abc' - yes
  - "abc" - no

LIKE: Simple String Pattern Matching

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

- s **LIKE** p: pattern matching on strings
- p may contain two special symbols:
  - % = any sequence of characters
  - _ = any single character

DISTINCT: Eliminating Duplicates

```
SELECT DISTINCT Category
FROM   Product
```

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
)
```

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?

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 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 <u>join</u> 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

```
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

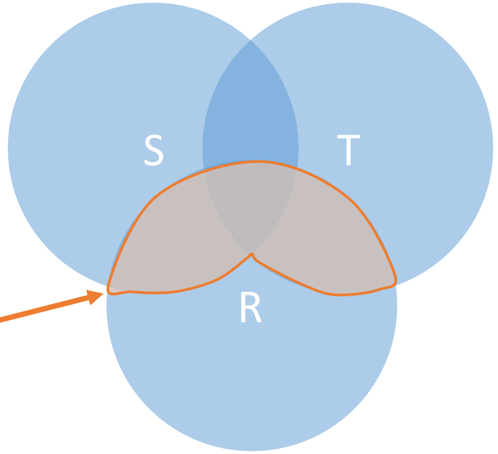
An Unintuitive Query

```
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

```
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?

The coolest people

JOIN TOGETHER

multiple tables with advanced SQL!!!

Lecture 3: SQL Part II

Course announcements

- PS1 is posted online and due at beginning of class on 10/6- **start early!**

- We will now be using an **online queue management system for OHs**- see details on Piazza
  - http://queuestatus.com/organizations/1/queues/6

Created by a former CS145 student + CA ***using databases!!!***

- We will write the **lecture attendance code** on the whiteboard sometime **during** lecture

A note on Piazza posting

- Please post questions **publicly** if possible
  - We will prioritize answering public questions, and **reserve the right to make private posts public**
  - You can always post anonymously if more comfortable!
  - We want everyone to be on the same page, and benefit from others' questions

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

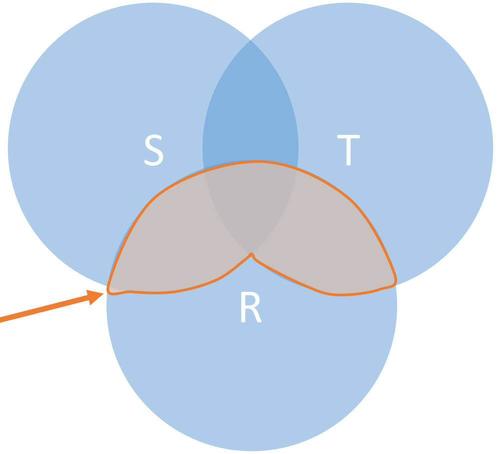
An Unintuitive Query

```
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
```

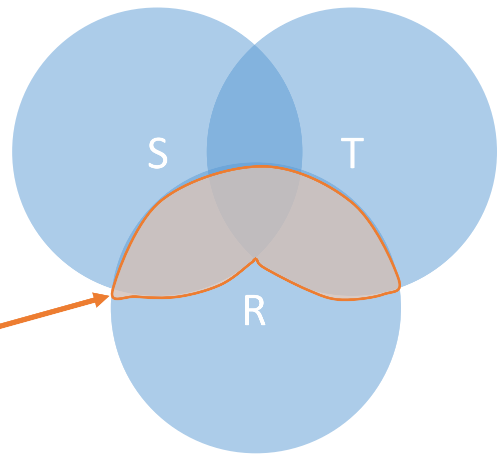
- Recall the semantics!
  1. Take cross-product
  2. Apply selections / conditions
  3. Apply projection
- If S = {}, then the cross product of R, S, T = {}, and the query result = {}!

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)!

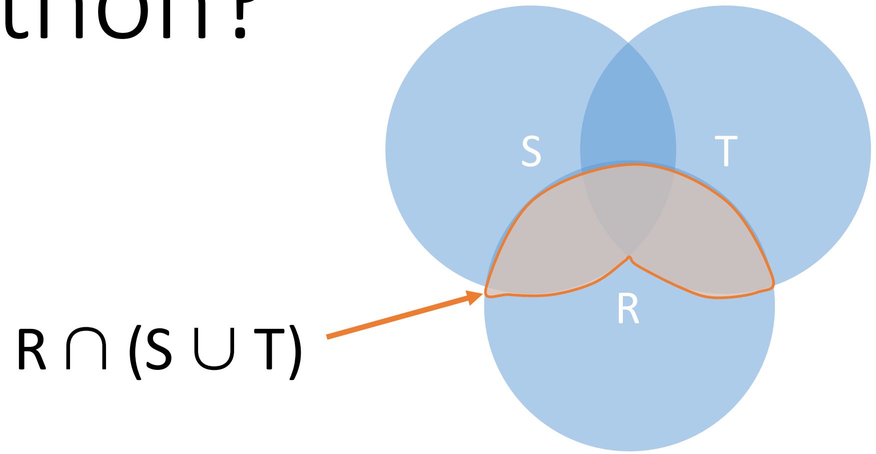
  2. Apply <u>selections</u> / <u>conditions</u>

     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
```




```
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

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

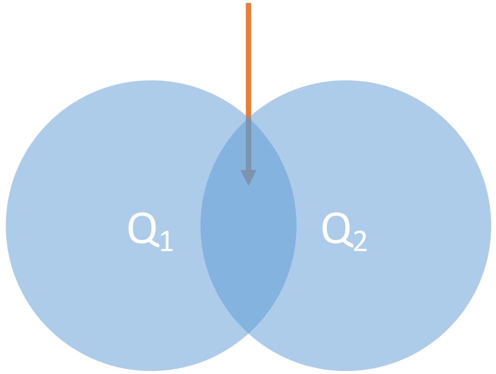
For sets,
this is **union**

Multiset Operations in SQL

Explicit Set Operators: INTERSECT

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

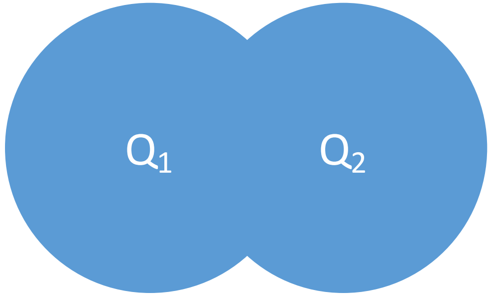
$$\{r.A \mid r.A = s.A\} \cap \{r.A \mid r.A = t.A\}$$



UNION

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

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



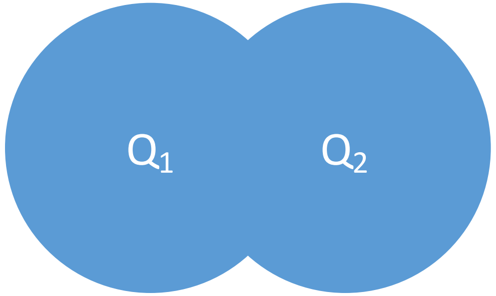
Why aren't there duplicates?

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
```

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

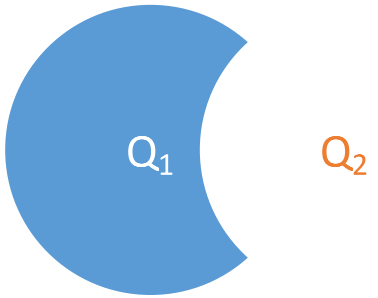


ALL indicates Multiset operations

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 X P =

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

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 X P =

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

Hq_city = U.S.

Hq_city = U.S.

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 X P =

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

Hq_city = U.S. ∩ Hq_city = U.S.

Hq_city = U.S.

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 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

```sql
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’
```

```sql
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

ANY and ALL not supported by SQLite.

You can also use operations of the form:

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

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?)

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 not monotone

Correlated Queries

Movie(<u>title</u>, <u>year</u>, 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)
```

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

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

Can be very powerful (also much harder to optimize)

Basic SQL Summary

- SQL provides a high-level declarative language for manipulating data (DML)
- The workhorse is the SFW block
- Set operators are powerful but have some subtleties
- Powerful, nested queries also allowed.

[Activity-3-1.ipynb]

2. Aggregation & GROUP BY

What you will learn about in this section

1. Aggregation operators

2. GROUP BY

3. GROUP BY: with HAVING, semantics

4. ACTIVITY: Fancy SQL Pt. I

Aggregation

```
SELECT AVG(price)
FROM   Product
WHERE  maker = “Toyota”
```

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

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

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

<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

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 $R_1,\ldots,R_n$
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!

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:

```
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