CS 6400 A

Database Systems Concepts and Design

Lecture 3

08/26/24

Logistics

Assignment 0 due today @11:59PM

OH starting this week:

- Instructor: Wednesdays 3-4PM, KACB 3322
- TA OH1: Monday 3:30-4:30PM, common space near KACB 3322
- TA OH2: Thursday 3:30-4:30PM, common space near KACB 3322

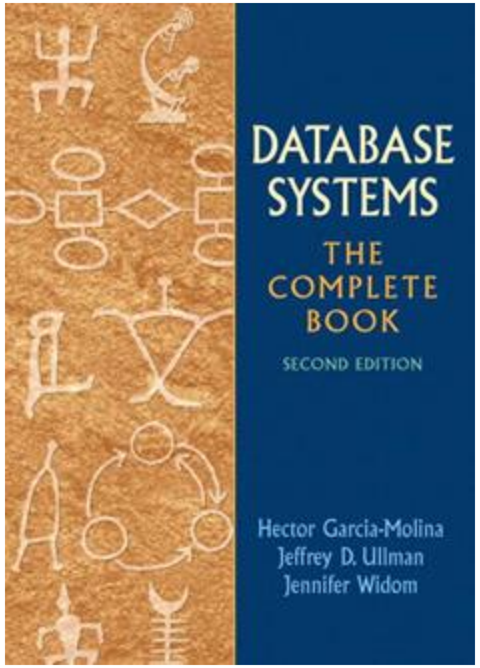
Agenda

1. Set operators & nested queries
2. Aggregation & GROUP BY
3. Advanced SQL-izing

Reading Materials

Database Systems: The Complete Book (2nd edition)

- Chapter 6: The Database Language SQL (6.2-6.4)



Acknowledgement: The following slides have been adapted from CS145 (Intro to Big Data Systems) taught by Peter Bailis.

1. Set Operators & Nested Queries

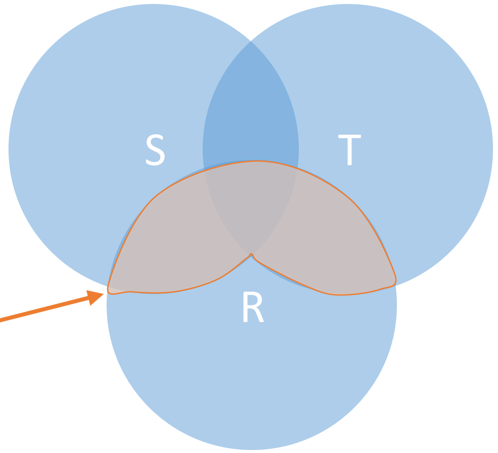
An Unintuitive Query

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

What does it compute?

An Unintuitive Query

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



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

But what if $S = \phi$?

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 = {}!

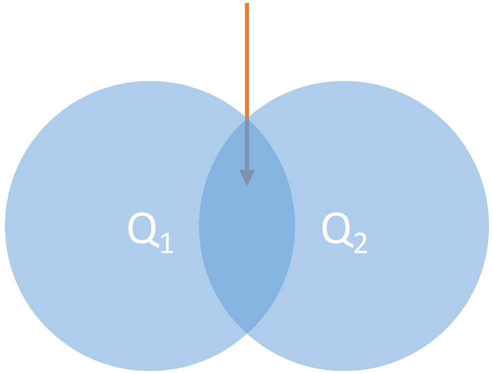
Must consider semantics here.
Are there more explicit way to do set operations like this?

Set 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
```

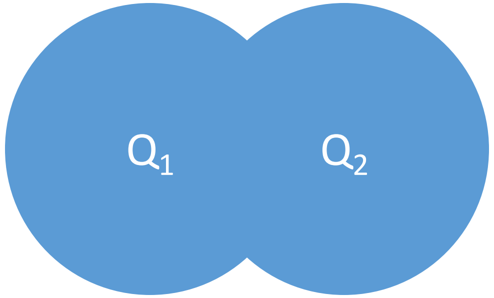
$$\{r.A \mid r.A = s.A\} \cap \{r.A \mid r.A = t.A\}$$



UNION

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

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



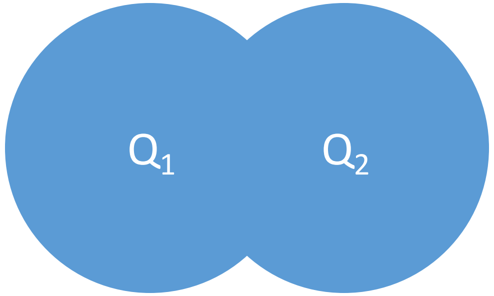
By default:
SQL uses set semantics!

What if we want duplicates?

UNION ALL

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

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

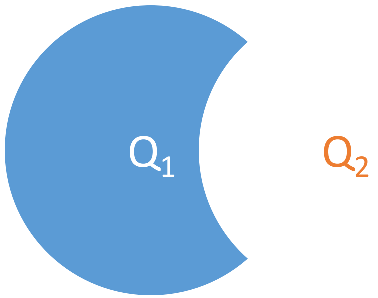


ALL indicates Multiset operations

EXCEPT

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

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



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 products in US AND China"

What can go wrong here?

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!

One Solution: **Nested Queries**

Company(<u>name</u>, hq_city)
Product(<u>pname</u>, 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 products in US AND China"

High-level note on nested queries

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

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

This is <u>extremely</u> powerful!

Nested queries: Sub-queries Return Relations

Another example:

Company(name, city)
Product(name, maker)
Purchase(id, product, buyer)

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

"Cities where one can find companies that manufacture products bought by Joe Blow"

Nested Queries

Are these queries equivalent?

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

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

Beware of duplicates!

Nested Queries

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

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

Now they are equivalent (both use set semantics)

Subqueries Return Relations

You can also use operations of the form:

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

ANY and ALL not supported by SQLite.

Ex: Product(name, price, category, maker)

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

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

Subqueries Returning Relations

You can also use operations of the form:

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

Ex: Product(name, price, category, maker)

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

<> means !=

Find 'copycat' products, i.e. products made by competitors with the same names as products made by "Gizmo-Works"

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!

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)

Correlated vs Regular Subqueries

In terms of execution

- Regular: executed once for the entire outer query
- Correlated: executed once for each row processed by the outer query (due to the dependence between inner and outer queries)

This means that correlated subqueries are usually very slow

- When possible, rewrite using JOINs for better performance

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

```
SELECT DISTINCT m1.title
FROM Movie m1 JOIN Movie m2
          ON m1.title = m2.title
WHERE m1.year <> m2.year
```

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.

2. Aggregation & GROUP BY

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

SELECT

Product	TotalSales
Bagel	50
Banana	15

HAVING Clause

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

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

HAVING clauses contains conditions on aggregates

Whereas WHERE clauses condition on individual tuples…

General form of Grouping and Aggregation

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

- 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(<u>login</u>, 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!

3. Advanced SQL-izing

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
```

Does this query include all rows in the table?

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!

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

Summary

SQL is a rich programming language that handles the way data is processed <u>declaratively</u>