Database Management Systems
CSEP 544

Lecture 2: SQL

Announcements

- HW1 due tonight (11:59pm)
- PA2 & HW2 released
- Fill out HW3 email account form by tonight!
- Final information posted on piazza
- Check website for up to date OH info

Review

- Data models
  - Instance
  - Schema
  - Language
- Relational data model
  - Relations are flat
  - Tuples are not ordered
- Logical and physical data independence

Reading Assignment 1

Selections in SQL

```
SELECT *
FROM   Product
WHERE  price > 100.0
```

Projections in SQL

```
SELECT CName
FROM   Product
```

```
Product(pname, price, category, manufacturer)
Company(cname, country)
```

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all Japanese products that cost < $150

Product(pname, price, category, manufacturer)
Company(cname, country)

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all Japanese products that cost < $150

```
SELECT pname, price
FROM   Product, Company
WHERE  ...
```

Product(pname, price, category, manufacturer)
Company(cname, country)

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all Japanese products that cost < $150

```
SELECT pname, price
FROM   Product, Company
WHERE  manufacturer=cname AND
       country='Japan' AND price < 150
```

Product(pname, price, category, manufacturer)
Company(cname, country)

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all Japanese products that cost < $150

```
SELECT P.pname, P.price
FROM   Product as P, Company as C
WHERE  P.manufacturer=C.cname AND
       C.country='Japan' AND C.price < 150
```

Product(pname, price, category, manufacturer)
Company(cname, country)

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all USA companies that manufacture "gadget" products

Product(pname, price, category, manufacturer)
Company(cname, country)

Joins in SQL

pname	price	category	manufacturer
MultiTouch	199.99	gadget	Canon
SingleTouch	49.99	photography	Canon
Gizom	50	gadget	GizmoWorks
SuperGizmo	250.00	gadget	GizmoWorks

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

Retrieve all USA companies that manufacture "gadget" products

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

Why DISTINCT?

Joins in SQL

- The standard join in SQL is sometimes called an inner join
  - Each row in the result **must come from both tables in the join**
- Sometimes we want to include rows from only one of the two table: outer join

Joins and Aggregates

(Inner) joins

```
Product(pname, price, category, manufacturer)
Company(cname, country)
-- manufacturer is foreign key to Company
```

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

pname	category	manufacturer	cname	country
Gizmo	gadget	GizmoWorks	GizmoWorks	USA

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

- Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
Camera	Photo	Hitachi
OneClick	Photo	Hitachi

- Company

cname	country
GizmoWorks	USA
Canon	Japan
Hitachi	Japan

(Inner) joins

```
SELECT DISTINCT cname
FROM   Product, Company
WHERE  country='USA' AND category = 'gadget'
       AND manufacturer = cname
```

```
SELECT DISTINCT cname
FROM   Product JOIN Company ON
       country = 'USA' AND category = 'gadget'
       AND manufacturer = cname
```

(Inner) Joins

```
SELECT   x1.a1, x2.a2, … xm.am
FROM     R1 as x1, R2 as x2, … Rm as xm
WHERE    Cond
```

```
for x1 in R1:
  for x2 in R2:
    ...
      for xm in Rm:
        if Cond(x1, x2…):
          output(x1.a1, x2.a2, … xm.am)
```

This is called nested loop semantics since we are interpreting what a join means using a nested loop

Another example

```
Product(pname, price, category, manufacturer)
Company(cname, country)
-- manufacturer is foreign key to Company
```

Retrieve all Japanese companies that manufacture products in both 'gadget' and 'photography' categories

Another example

```
Product(pname, price, category, manufacturer)
Company(cname, country)
-- manufacturer is foreign key to Company
```

Retrieve all Japanese companies that manufacture products in both ‘gadget’ and ‘photography’ categories

```
SELECT DISTINCT cname
FROM Product P1, Product P2, Company
WHERE country = 'Japan' AND P1.category = 'gadget'
      AND P2.category = 'photography'
      AND P1.manufacturer = cname
      AND P2.manufacturer = cname;
```

Self-Joins and Tuple Variables

- Find all companies that manufacture both products in the 'gadgets' and 'photo' category
- Joining Product with Company is insufficient: need to join Product, with Product, and with Company

- When a relation occurs twice in the FROM clause we call it a *self-join*
  - in that case we must use tuple variables (why?)

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

z

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

z

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

z

cname	country
GizmoWorks	USA
Hitachi	Japan

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

z

cname	country
GizmoWorks	USA
Hitachi	Japan

x.pname	x.category	x.manufacturer	y.pname	y.category	y.manufacturer	z.cname	z.country
Gizmo	gadget	GizmoWorks	MultiTouch	Photo	GizmoWorks	GizmoWorks	USA

Self-joins

```
SELECT DISTINCT z.cname
FROM   Product x, Product y, Company z
WHERE  z.country = 'USA'
       AND x.category = 'gadget'
       AND y.category = 'photo'
       AND x.manufacturer = cname
       AND y.manufacturer = cname;
```

Product

x

y

pname	category	manufacturer
Gizmo	gadget	GizmoWorks
SingleTouch	photo	Hitachi
MultiTouch	Photo	GizmoWorks

Company

z

cname	country
GizmoWorks	USA
Hitachi	Japan

x.pname	x.category	x.manufacturer	y.pname	y.category	y.manufacturer	z.cname	z.country
Gizmo	gadget	GizmoWorks	MultiTouch	Photo	GizmoWorks	GizmoWorks	USA

Outer joins

```
Product(name, category)
Purchase(prodName, store)

-- prodName is foreign key
```

```
SELECT Product.name, Purchase.store
FROM   Product, Purchase
WHERE  Product.name = Purchase.prodName
```

We want to include products that are never sold, but some are not listed! Why?

Outer joins

```
Product(name, category)
Purchase(prodName, store)

-- prodName is foreign key
```

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

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

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 JOIN Purchase ON
       Product.name = Purchase.prodName
```

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 JOIN Purchase ON
       Product.name = Purchase.prodName
```

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz
Camera	Ritz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz

Output

Name	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz
OneClick	NULL

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

Product

Name	Category
Gizmo	gadget
Camera	Photo
OneClick	Photo

Purchase

ProdName	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz
Phone	Foo

Output

Name	Store
Gizmo	Wiz
Camera	Ritz
Camera	Wiz
OneClick	NULL
NULL	Foo

Outer Joins

```
tableA (LEFT/RIGHT/FULL) OUTER JOIN tableB ON p
```

- Left outer join:
  - Include tuples from `tableA` even if no match
- Right outer join:
  - Include tuples from `tableB` even if no match
- Full outer join:
  - Include tuples from both even if no match

- In all cases:
  - Patch tuples without matches using `NULL`

Comment about SQLite

- Cannot load NULL values such that they are actually loaded as null values

- So we need to use two steps:
  - Load null values using some type of special value
  - Update the special values to actual null values

```
update Purchase
  set price = null
  where price = 'null'
```

Simple Aggregations

Five basic aggregate operations in SQL

```
select count(*) from Purchase
select sum(quantity) from Purchase
select avg(price) from Purchase
select max(quantity) from Purchase
select min(quantity) from Purchase
```

Except count, all aggregations apply to a single attribute

Aggregates and NULL Values

Null values are not used in aggregates

```
insert into Purchase
values(12, 'gadget', NULL, NULL, 'april')
```

Try the following at home:

```
select count(*) from Purchase
select count(quantity) from Purchase

select sum(quantity) from Purchase

select count(*)
from Purchase
where quantity is not null;
```

Counting Duplicates

`COUNT` applies to duplicates, unless otherwise stated:

```
SELECT count(product)
FROM   Purchase
WHERE  price > 4.99
```

same as `count(*)` if no nulls

We probably want:

```
SELECT count(DISTINCT product)
FROM   Purchase
WHERE  price > 4.99
```

More Examples

```
SELECT  Sum(price * quantity)
FROM     Purchase
```

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

What do they mean ?

Grouping and Query Evaluation

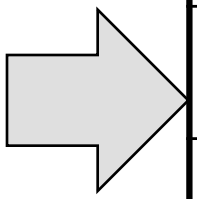
Grouping and Aggregation

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

Find total quantities for all sales over $1, by product.

Grouping and Aggregation

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	0.5	50
Banana	2	10
Banana	4	10



Product	TotalSales
Bagel	40
Banana	20

```
SELECT    product, Sum(quantity) AS TotalSales
FROM      Purchase
WHERE     price > 1
GROUP BY  product
```

Other Examples

Compare these two queries:

```
SELECT   product, count(*)
FROM     Purchase
GROUP BY product
```

```
SELECT   month, count(*)
FROM     Purchase
GROUP BY month
```

```
SELECT   product,
         sum(quantity) AS SumQuantity,
         max(price) AS MaxPrice
FROM     Purchase
GROUP BY product
```

What does it mean ?

Need to be Careful…

```
SELECT product,
       max(quantity)
FROM   Purchase
GROUP BY product
```

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
```

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	0.5	50
Banana	2	10
Banana	4	10

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
```

Need to be Careful…

```
SELECT   product
FROM     Purchase
GROUP BY product
```

```
SELECT   quantity
FROM     Purchase
```

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	0.5	50
Banana	2	10
Banana	4	10

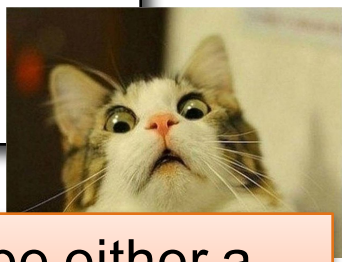
Product
Bagel
Banana

+

???

Quantity
20
20
50
10
10

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
```



Everything in SELECT must be either a GROUP-BY attribute, or an aggregate

Need to be Careful…

```
SELECT product,
       max(quantity)
FROM   Purchase
GROUP BY product
```

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
```

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	0.5	50
Banana	2	10
Banana	4	10

sqlite is WRONG on this query.

Advanced DBMS (e.g. SQL Server) gives an error

Grouping and Aggregation

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

Find total quantities for all sales over $1, by product.

```
SELECT   product, Sum(quantity) AS TotalSales
FROM     Purchase
WHERE    price > 1
GROUP BY product
```

How is this query processed?

Grouping and Aggregation

1. Compute the FROM and WHERE clauses.

2. Group by the attributes in the GROUPBY

3. Compute the SELECT clause:
   grouped attributes and aggregates.

FWGS™

1,2: From, Where

FWGS

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	~~0.5~~	~~50~~
Banana	2	10
Banana	4	10

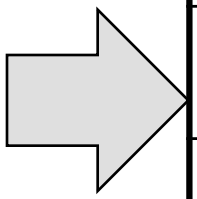
WHERE price > 1

```
SELECT    product, Sum(quantity) AS TotalSales
FROM      Purchase
WHERE     price > 1
GROUP BY  product
```

3,4. Grouping, Select

FWGS

Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	~~0.5~~	~~50~~
Banana	2	10
Banana	4	10



Product	TotalSales
Bagel	40
Banana	20

```
SELECT    product, Sum(quantity) AS TotalSales
FROM      Purchase
WHERE     price > 1
GROUP BY  product
```

Purchase(pid, product, price, quantity, month)

Ordering Results

```
SELECT product, sum(price*quantity) as rev
FROM    Purchase
GROUP BY product
ORDER BY rev desc
```

FWGOS™

Note: some SQL engines
want you to say `ORDER BY sum(price*quantity) desc`

Purchase(pid, product, price, quantity, month)

HAVING Clause

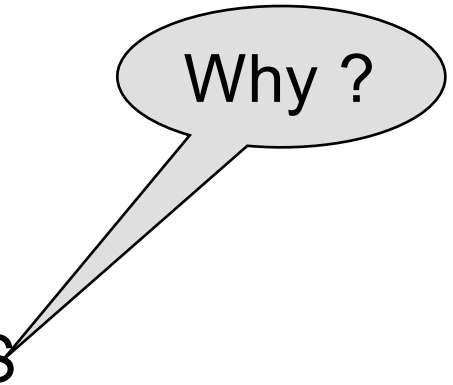
Same query as before, except that we consider only products that had at least 30 sales.

```
SELECT   product, sum(price*quantity)
FROM     Purchase
WHERE    price > 1
GROUP BY product
HAVING   sum(quantity) > 30
```

HAVING clause contains conditions on aggregates.

General form of Grouping and Aggregation

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



S = may contain attributes $a_1,\ldots,a_k$ and/or any aggregates but NO OTHER ATTRIBUTES

C1 = is any condition on the attributes in $R_1,\ldots,R_n$

C2 = is any condition on aggregate expressions and on attributes $a_1,\ldots,a_k$

Semantics of SQL With Group-By

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

FWGHOS

Evaluation steps:

1. Evaluate FROM-WHERE using Nested Loop Semantics
2. Group by the attributes $a_1,\ldots,a_k$
3. Apply condition C2 to each group (may have aggregates)
4. Compute aggregates in S and return the result

```
Purchase(pid, product, price, quantity, month)
```

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
Purchase(pid, product, price, quantity, month)
```

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
FROM      Purchase
```

Purchase(pid, product, price, quantity, month)

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
FROM        Purchase
GROUP BY    month
```

Purchase(pid, product, price, quantity, month)

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
FROM        Purchase
GROUP BY    month
HAVING      sum(quantity) < 10
```

Purchase(pid, product, price, quantity, month)

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
SELECT   month, sum(price*quantity),
         sum(quantity) as TotalSold
FROM     Purchase
GROUP BY month
HAVING   sum(quantity) < 10
```

Purchase(pid, product, price, quantity, month)

Exercise

Compute the total income per month
Show only months with less than 10 items sold
Order by quantity sold and display as “TotalSold”

```
SELECT     month, sum(price*quantity),
           sum(quantity) as TotalSold
FROM       Purchase
GROUP BY   month
HAVING     sum(quantity) < 10
ORDER BY   sum(quantity)
```

WHERE vs HAVING

- WHERE condition is applied to individual rows
  - The rows may or may not contribute to the aggregate
  - No aggregates allowed here
- HAVING condition is applied to the entire group
  - Entire group is returned, or not at all
  - May use aggregate functions in the group

Purchase(pid, product, price, quantity, month)

Mystery Query

What do they compute?

```
SELECT    month, sum(quantity), max(price)
FROM      Purchase
GROUP BY  month
```

```
SELECT    month, sum(quantity)
FROM      Purchase
GROUP BY  month
```

```
SELECT    month
FROM      Purchase
GROUP BY  month
```

Purchase(pid, product, price, quantity, month)

Mystery Query

What do they compute?

```
SELECT    month, sum(quantity), max(price)
FROM      Purchase
GROUP BY  month
```

```
SELECT    month, sum(quantity)
FROM      Purchase
GROUP BY  month
```

```
SELECT    month
FROM      Purchase
GROUP BY  month
```

Lesson:
DISTINCT is
a special case
of GROUP BY

```
Product(pid,pname,manufacturer)
Purchase(id,product_id,price,month)
```

Aggregate + Join

For each manufacturer, compute how many products with price > $100 they sold

```
Product(pid,pname,manufacturer)
Purchase(id,product_id,price,month)
```

Aggregate + Join

For each manufacturer, compute how many products with price > $100 they sold

Problem: price is in Purchase, manufacturer is in Product...

```
Product(pid,pname,manufacturer)
Purchase(id,product_id,price,month)
```

Aggregate + Join

For each manufacturer, compute how many products with price > $100 they sold

Problem: price is in Purchase, manufacturer is in Product...

```
-- step 1: think about their join
SELECT ...
FROM Product x, Purchase y
WHERE x.pid = y.product_id
  and y.price > 100
```

manu facturer	...	price	...
Hitachi		150	
Canon		300	
Hitachi		180	

```
Product(pid,pname,manufacturer)
Purchase(id,product_id,price,month)
```

Aggregate + Join

For each manufacturer, compute how many products with price > $100 they sold

Problem: price is in Purchase, manufacturer is in Product...

```
-- step 1: think about their join
SELECT ...
FROM Product x, Purchase y
WHERE x.pid = y.product_id
  and y.price > 100
```

manu facturer	…	price	…
Hitachi		150	
Canon		300	
Hitachi		180	

```
-- step 2: do the group-by on the join
SELECT x.manufacturer, count(*)
FROM Product x, Purchase y
WHERE x.pid = y.product_id
  and y.price > 100
GROUP BY  x.manufacturer
```

manu facturer	count(*)
Hitachi	2
Canon	1
…	

Product(pid,pname,manufacturer)
Purchase(id,product_id,price,month)

Aggregate + Join

Variant:

For each manufacturer, compute how many products with price > $100 they sold in each month

```
SELECT x.manufacturer, y.month, count(*)
FROM Product x, Purchase y
WHERE x.pid = y.product_id
  and y.price > 100
GROUP BY  x.manufacturer, y.month
```

manu facturer	month	count(*)
Hitachi	Jan	2
Hitachi	Feb	1
Canon	Jan	3
...		

FWGHOS

Including Empty Groups

- In the result of a group by query, there is one row per group in the result

Count(*) is never 0

```
SELECT x.manufacturer, count(*)
FROM Product x, Purchase y
WHERE x.pname = y.product
GROUP BY x.manufacturer
```

Including Empty Groups

```
SELECT x.manufacturer, count(y.pid)
FROM Product x LEFT OUTER JOIN Purchase y
ON x.pname = y.product
GROUP BY x.manufacturer
```

Count(pid) is 0 when all pid's in the group are NULL

Nested Queries

What have we learned so far

- Data models
- Relational data model
  - Instance: relations
  - Schema: table with attribute names
  - Language: SQL

What have we learned so far

- SQL features
  - Projections
  - Selections
  - Joins (inner and outer)
  - Aggregates
  - Group by
  - Inserts, updates, and deletes

- Make sure you read the textbook!

Subqueries

- A subquery is a SQL query nested inside a larger query
- Such inner-outer queries are called nested queries
- A subquery may occur in:
  - A `SELECT` clause
  - A `FROM` clause
  - A `WHERE` clause

- Rule of thumb: avoid writing nested queries when possible
  - But sometimes it's impossible, as we will see

Subqueries…

- Can appear as computed values in a `SELECT` clause
- Can appear in `FROM` clauses and aliased using a tuple variable that represents the tuples in the result of the subquery
- Can return a single constant to be compared with another value in a `WHERE` clause
- Can return relations to be used in `WHERE` clauses

1. Subqueries in SELECT

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

For each product return the city where it is manufactured

```
SELECT X.pname, (SELECT Y.city
                 FROM Company Y
                 WHERE Y.cid=X.cid) as City
FROM  Product X
```

"correlated subquery"

What happens if the subquery returns more than one city?

We get a runtime error

(and SQLite simply ignores the extra values…)

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

1. Subqueries in SELECT

Whenever possible, don't use nested queries:

```
SELECT X.pname, (SELECT Y.city
                 FROM Company Y
                 WHERE Y.cid=X.cid) as City
FROM  Product X
```



```
SELECT X.pname, Y.city
FROM   Product X, Company Y
WHERE  X.cid=Y.cid
```

We have "unnested" the query

Product (pname, price, cid)
Company (cid, cname, city)

1. Subqueries in SELECT

Compute the number of products made by each company

```
SELECT DISTINCT C.cname, (SELECT count(*)
                          FROM Product P
                          WHERE P.cid=C.cid)
FROM  Company C
```

Product (pname, price, cid)
Company (cid, cname, city)

1. Subqueries in SELECT

Compute the number of products made by each company

```
SELECT DISTINCT C.cname, (SELECT count(*)
                          FROM Product P
                          WHERE P.cid=C.cid)
FROM  Company C
```

Better: we can unnest using a GROUP BY

```
SELECT C.cname, count(*)
FROM   Company C, Product P
WHERE  C.cid=P.cid
GROUP BY C.cname
```

Product (pname, price, cid)
Company (cid, cname, city)

1. Subqueries in SELECT

But are these really equivalent?

```
SELECT DISTINCT C.cname, (SELECT count(*)
                          FROM Product P
                          WHERE P.cid=C.cid)
FROM  Company C
```

```
SELECT C.cname, count(*)
FROM   Company C, Product P
WHERE  C.cid=P.cid
GROUP BY C.cname
```

Product (pname, price, cid)
Company (cid, cname, city)

1. Subqueries in SELECT

But are these really equivalent?

```
SELECT DISTINCT C.cname, (SELECT count(*)
                          FROM Product P
                          WHERE P.cid=C.cid)
FROM  Company C
```

```
SELECT C.cname, count(*)
FROM   Company C, Product P
WHERE  C.cid=P.cid
GROUP BY C.cname
```

No! Different results if a company has no products

```
SELECT C.cname, count(pname)
FROM Company C LEFT OUTER JOIN Product P
ON   C.cid=P.cid
GROUP BY C.cname
```

Product (pname, price, cid)
Company (cid, cname, city)

2. Subqueries in FROM

Find all products whose prices is > 20 and < 500

```
SELECT X.pname
FROM (SELECT *
      FROM Product AS Y
      WHERE price > 20) as X
WHERE X.price < 500
```

Side note: This is not a correlated subquery. (why?)

Try unnest this query !

2. Subqueries in FROM

At the end of the lecture we will see that sometimes we really need a subquery and one option will be to put it in the `FROM` clause.

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Product (pname, price, cid)
Company (cid, cname, city)

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Using EXISTS:

```
SELECT DISTINCT  C.cname
FROM   Company C
WHERE  EXISTS (SELECT *
               FROM Product P
               WHERE C.cid = P.cid and P.price < 200)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Using IN

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE C.cid IN (SELECT P.cid
                FROM Product P
                WHERE P.price < 200)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Using ANY:

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE 200 > ANY (SELECT price
                 FROM Product P
                 WHERE P.cid = C.cid)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Using ANY:

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE 200 > ANY (SELECT price
                 FROM Product P
                 WHERE P.cid = C.cid)
```

Not supported in sqlite

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Now let's unnest it:

```
SELECT DISTINCT  C.cname
FROM   Company C, Product P
WHERE  C.cid = P.cid and P.price < 200
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies that make some products with price < 200

Existential quantifiers

Now let's unnest it:

```
SELECT DISTINCT  C.cname
FROM   Company C, Product P
WHERE  C.cid = P.cid and P.price < 200
```

Existential quantifiers are easy! ☺

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

same as:

Find all companies that make only products with price < 200

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

same as:

Find all companies that make only products with price < 200

Universal quantifiers

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

same as:

Find all companies that make only products with price < 200

Universal quantifiers

Universal quantifiers are hard! ☹

Product (pname, price, cid)
Company (cid, cname, city)

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

1. Find *the other* companies that make some product ≥ 200

```
SELECT DISTINCT  C.cname
FROM   Company C
WHERE  C.cid IN (SELECT P.cid
                 FROM Product P
                 WHERE P.price >= 200)
```

Product (pname, price, cid)
Company (cid, cname, city)

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

1. Find *the other* companies that make some product ≥ 200

```
SELECT DISTINCT  C.cname
FROM   Company C
WHERE  C.cid IN (SELECT P.cid
                 FROM Product P
                 WHERE P.price >= 200)
```

2. Find all companies s.t. all their products have price < 200

```
SELECT DISTINCT  C.cname
FROM   Company C
WHERE  C.cid NOT IN (SELECT P.cid
                     FROM Product P
                     WHERE P.price >= 200)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

Universal quantifiers

Using EXISTS:

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE NOT EXISTS (SELECT *
                  FROM Product P
                  WHERE P.cid = C.cid and P.price >= 200)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

Universal quantifiers

Using ALL:

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE 200 >= ALL (SELECT price
                  FROM Product P
                  WHERE P.cid = C.cid)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

3. Subqueries in WHERE

Find all companies s.t. all their products have price < 200

Universal quantifiers

Using ALL:

```
SELECT DISTINCT  C.cname
FROM  Company C
WHERE 200 >= ALL (SELECT price
                  FROM Product P
                  WHERE P.cid = C.cid)
```

Not supported in sqlite

Question for Database Theory Fans and their Friends

- Can we unnest the *universal quantifier* query?

- We need to first discuss the concept of *monotonicity*

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any of the tuples

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any of the tuples

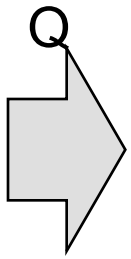
---

Product

pname	price	cid
Gizmo	19.99	c001
Gadget	999.99	c004
Camera	149.99	c003

Company

cid	cname	city
c002	Sunworks	Bonn
c001	DB Inc.	Lyon
c003	Builder	Lodtz



pname	city
Gizmo	Lyon
Camera	Lodtz

Product (pname, price, cid)
Company (cid, cname, city)

Monotone Queries

- Definition A query Q is monotone if:
  - Whenever we add tuples to one or more input tables, the answer to the query will not lose any of the tuples

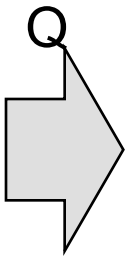
---

Product

pname	price	cid
Gizmo	19.99	c001
Gadget	999.99	c004
Camera	149.99	c003

Company

cid	cname	city
c002	Sunworks	Bonn
c001	DB Inc.	Lyon
c003	Builder	Lodtz



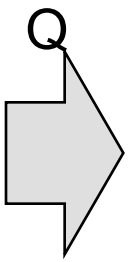
pname	city
Gizmo	Lyon
Camera	Lodtz

Product

pname	price	cid
Gizmo	19.99	c001
Gadget	999.99	c004
Camera	149.99	c003
iPad	499.99	c001

Company

cid	cname	city
c002	Sunworks	Bonn
c001	DB Inc.	Lyon
c003	Builder	Lodtz



pname	city
Gizmo	Lyon
Camera	Lodtz
iPad	Lyon

Monotone Queries

- Theorem: If Q is a SELECT-FROM-WHERE query that does not have subqueries, and no aggregates, then it is monotone.

Monotone Queries

- Theorem: If Q is a SELECT-FROM-WHERE query that does not have subqueries, and no aggregates, then it is monotone.

- Proof. We use the nested loop semantics: if we insert a tuple in a relation R_i, this will not remove any tuples from the answer

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

```
for x1 in R1 do
  for x2 in R2 do
    …
    for xn in Rn do
      if Conditions
        output (a1,…,ak)
```

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

Monotone Queries

- The query:

Find all companies s.t. all their products have price < 200

is not monotone

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

Monotone Queries

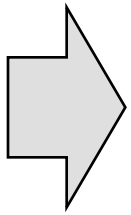
- The query:

Find all companies s.t. all their products have price < 200

is not monotone

pname	price	cid
Gizmo	19.99	c001

cid	cname	city
c001	Sunworks	Bonn



cname
Sunworks

```
Product (pname,  price, cid)
Company (cid, cname, city)
```

Monotone Queries

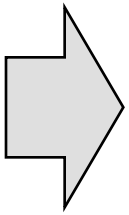
- The query:

Find all companies s.t. all their products have price < 200

is not monotone

pname	price	cid
Gizmo	19.99	c001

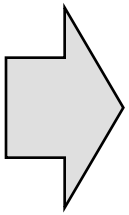
cid	cname	city
c001	Sunworks	Bonn



cname
Sunworks

pname	price	cid
Gizmo	19.99	c001
Gadget	999.99	c001

cid	cname	city
c001	Sunworks	Bonn



cname

- Consequence: If a query is not monotonic, then we cannot write it as a SELECT-FROM-WHERE query without nested subqueries

Queries that must be nested

- Queries with universal quantifiers or with negation

- Queries that use aggregates in certain ways
  - `sum(..)` and `count(*)` are NOT monotone, because they do not satisfy set containment
  - `select count(*) from R` is not monotone!