Relational Model and SQL

Concepts
Syntax
Basic Queries

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Fall 2023

Reading: R & G Chapter 5

This Lecture

- The Relational Model
- SQL Basics

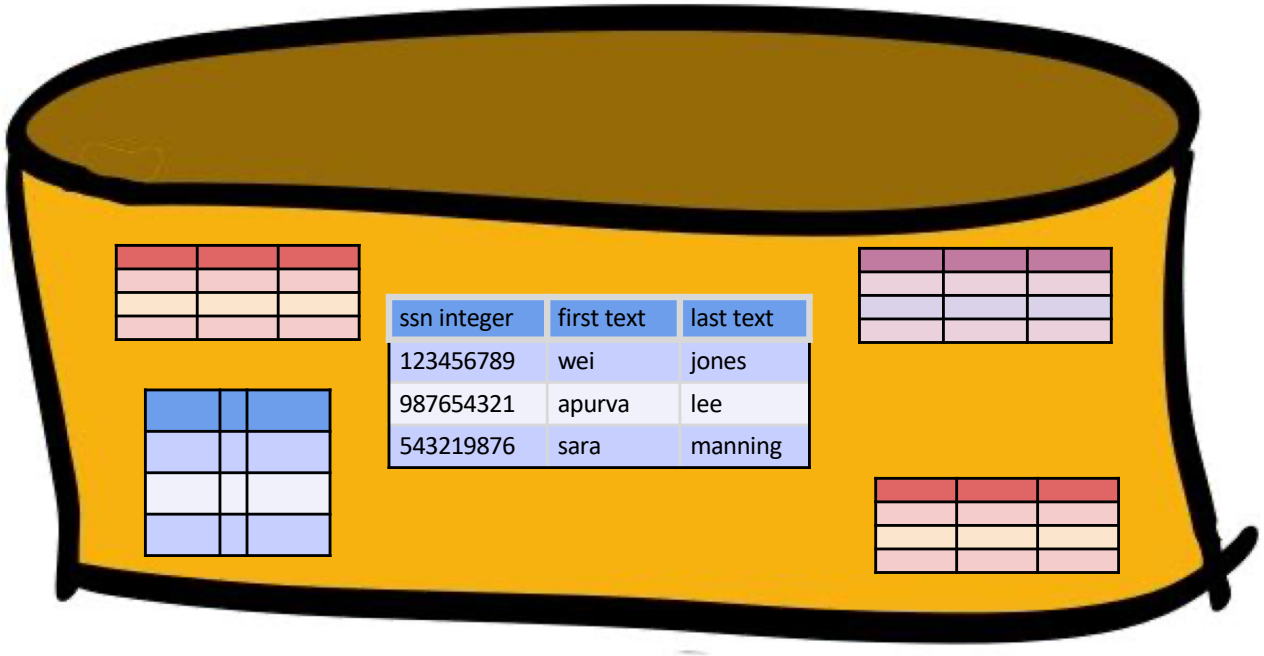
Meta: Goal of Lectures

- Get high-level idea!

- If you are trying to get all the details down, you're doing it wrong
- That's what everything else is for!

Relational Terminology

- ***Database***: Set of named Relations



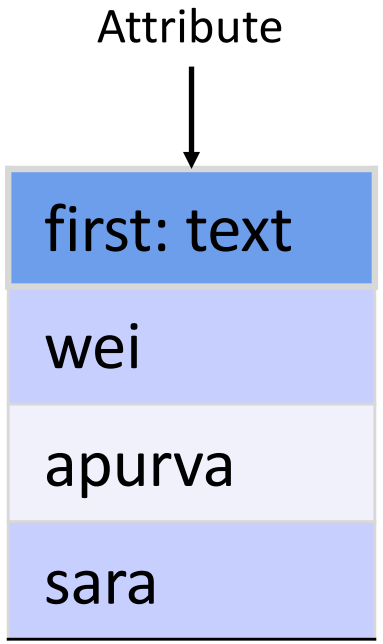
Relational Terminology, Pt 2.

- ***Database***: Set of named Relations
- ***Relation*** (aka *Table*):
  - ***Schema:*** description ("metadata")
  - ***Instance:*** set of data satisfying the schema

ssn: integer	first: text	last: text
123456789	wei	jones
987654321	apurva	lee
543219876	sara	manning

Relational Terminology, Pt. 3

- ***Database***: Set of named Relations
- ***Relation*** (aka *Table*):
  - ***Schema:*** description ("metadata")
  - ***Instance:*** set of data satisfying the schema
- ***Attribute*** (aka *Column, Field*)



Relational Terminology, Pt. 4

- ***Database***: Set of named Relations
- ***Relation*** (aka *Table*):
  - ***Schema***: description ("metadata")
  - ***Instance***: set of data satisfying the schema
- ***Attribute*** (aka *Column, Field*)
- ***Tuple*** (aka *Record, Row*)

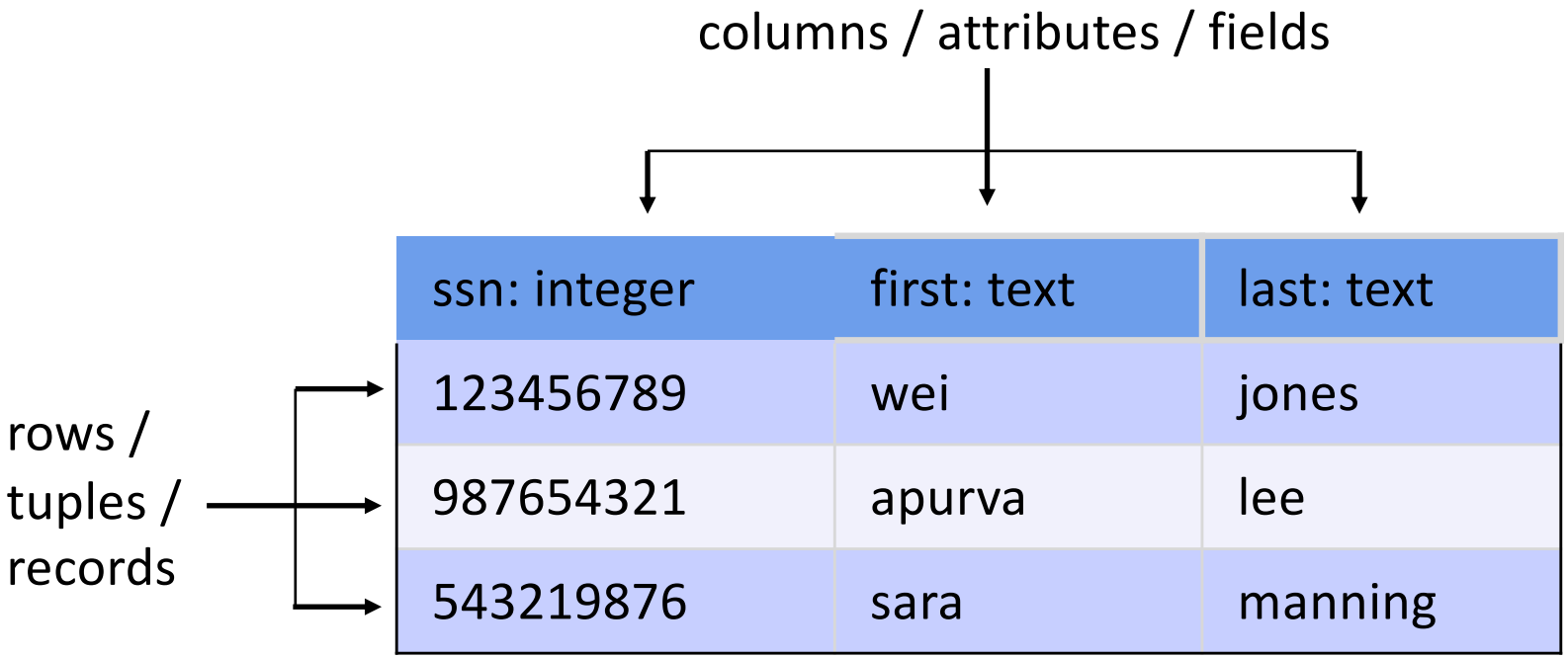
543219876	sara	manning

Tuple

Relational Terminology, Pt. 5

- ***Database***: Set of named Relations
- ***Relation*** (aka *Table*):
  - ***Schema***: description (“metadata”)
  - ***Instance***: set of data satisfying the schema
- ***Attribute*** (aka *Column, Field*)
- ***Tuple*** (aka *Record, Row*)
- ***Cardinality***:
  - # of tuples in a relation

To summarize



Cardinality: 3

Relational Tables

- *Schema* is fixed:
  - unique attribute names, *atomic (aka primitive)* types
- Tables are NOT ordered
  - they are sets or multisets (bags)
- Tables are FLAT
  - No nested attributes
- Tables DO NOT prescribe how they are implemented / stored on disk
  - This is called **physical data independence**

Table Implementation

- How would you store this on the disk?

cname	country	no_employees	for_profit
GizmoWorks	USA	20000	True
Canon	Japan	50000	True
Hitachi	Japan	30000	True
HappyCam	Canada	500	False

Table Implementation

- How would you store this on the disk?

cname	country	no_employees	for_profit
GizmoWorks	USA	20000	True
Canon	Japan	50000	True
Hitachi	Japan	30000	True
HappyCam	Canada	500	False

Row major: as an array of objects

GizmoWorks USA 20000 True	Canon Japan 50000 True	Hitachi Japan 30000 True	HappyCam Canada 500 False

Table Implementation

- How would you store this on the disk?

cname	country	no_employees	for_profit
GizmoWorks	USA	20000	True
Canon	Japan	50000	True
Hitachi	Japan	30000	True
HappyCam	Canada	500	False

Column major: as one array per attribute

GizmoWorks	Canon	Hitachi	HappyCam
USA	Japan	Japan	Canada
20000	50000	30000	500
True	True	True	False

Table Implementation

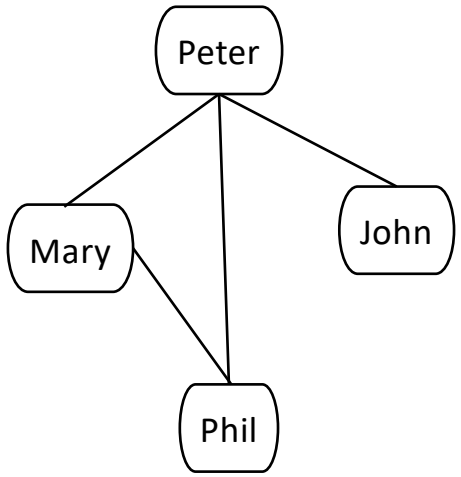
- How would you store this on the disk?

cname	country	no_employees	for_profit
GizmoWorks	USA	20000	True
Canon	Japan	50000	True
Hitachi	Japan	30000	True
HappyCam	Canada	500	False

Physical data independence
The logical definition of the data remains unchanged, even when we make changes to the actual implementation

Relation is not the only data model

Example: storing IG friends



As a graph

OR

Person1: text	Person2: text	is_friend: int
Peter	John	1
John	Mary	0
Mary	Phil	1
Phil	Peter	1
…	…	…

As a relation

We will learn the tradeoffs of different data models in the semester

Quick Check 1

- Why is this not a relation?

num: integer	street: text	zip: integer	
84	Maple Ave	54704	
22	High	Street	76425
75	Hearst Ave	94720	

Quick Check 2

- Why is this not a relation?

num: integer	street: text	num: integer
84	Maple Ave	54704
22	High Street	76425
75	Hearst Ave	94720

First Normal Form

- All relations must be flat: we say that the relation is in *first normal form*

cname	country	no_employees	for_profit
Canon	Japan	50000	Y
Hitachi	Japan	30000	Y

First Normal Form

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- E.g., we want to add products manufactured by each company:

cname	country	no_employees	for_profit
Canon	Japan	50000	Y
Hitachi	Japan	30000	Y

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cname	country	no_employees	for_profit
Canon	Japan	50000	Y
Hitachi	Japan	30000	Y

cname	country	no_employees	for_profit	products
Canon	Japan	50000	Y	pname | price | category SingleTouch | 149.99 | Photography Gadget | 200 | Toy
Hitachi	Japan	30000	Y	pname | price | category AC | 300 | Appliance

First Normal Form

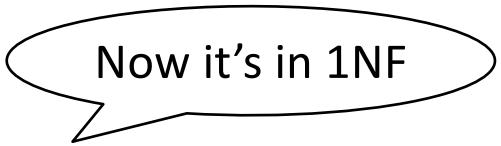
- All relations must be flat: we say that the relation is in *first normal form*
- E.g., we want to add products manufactured by each company:

cname	country	no_employees	for_profit
Canon	Japan	50000	Y
Hitachi	Japan	30000	Y

Non-1NF!

cname	country	no_employees	for_profit	products
Canon	Japan	50000	Y	pname | price | category SingleTouch | 149.99 | Photography Gadget | 200 | Toy
Hitachi	Japan	30000	Y	pname | price | category AC | 300 | Appliance

First Normal Form



Company

cname	country	no_employees	for_profit
Canon	Japan	50000	Y
Hitachi	Japan	30000	Y

Products

pname	price	category	manufacturer
SingleTouch	149.99	Photography	Canon
AC	300	Appliance	Hitachi
Gadget	200	Toy	Canon

SQL Roots

- Developed @IBM Research in the 1970s
  - System R project
  - Vs. Berkeley's Quel language 
- Commercialized/Popularized in the 1980s
  - IBM started the db2 product line
  - IBM beaten to market by a startup called Oracle

SQL Pros and Cons

- Declarative!
  - Say *what* you want, not *how* to get it
- Implemented widely
  - With varying levels of efficiency, completeness
- Constrained
  - Not targeted at Turing-complete tasks
- General-purpose for data computation and feature-rich
  - many years of added features
  - extensible: callouts to other languages, data sources

SQL Language

- Two sublanguages:
  - DDL – Data Definition Language
    - Define and modify schema
  - DML – Data Manipulation Language
    - Queries can be written intuitively

- RDBMS responsible for efficient evaluation
  - Choose and run algorithms for declarative queries
    - Choice of algorithm must not affect query answer.

Example Database

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

Boats

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

Reserves

sid	bid	day
1	102	9/12/2015
2	102	9/13/2015

The SQL DDL: Sailors


```
CREATE TABLE Sailors (
      sid INTEGER,
      sname CHAR(20),
      rating INTEGER,
      age FLOAT)
```

sid	**sname**	**rating**	**age**
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

The SQL DDL: Sailors, Pt. 2


```
CREATE TABLE Sailors (
      sid INTEGER,
      sname CHAR(20),
      rating INTEGER,
      age FLOAT
       PRIMARY KEY (sid));
```

sid	**sname**	**rating**	**age**
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

The SQL DDL: Primary Keys


```
CREATE TABLE Sailors (
      sid INTEGER,
      sname CHAR(20),
      rating INTEGER,
      age FLOAT,
      PRIMARY KEY (sid))
```

sid	**sname**	**rating**	**age**
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

- Primary Key column(s)
  - Provides a unique “lookup key” for the relation
  - Cannot have any duplicate values
  - Can be made up of >1 column
    - E.g. (firstname, lastname)

The SQL DDL: Boats


```
CREATE TABLE Sailors (
      sid INTEGER,
      sname CHAR(20),
      rating INTEGER,
      age FLOAT,
      PRIMARY KEY (sid));

CREATE TABLE Boats (
    bid INTEGER,
    bname CHAR (20),
    color CHAR(10),
    PRIMARY KEY (bid));
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

The SQL DDL: Reserves


```
CREATE TABLE Sailors (
      sid INTEGER,
      sname CHAR(20),
      rating INTEGER,
      age FLOAT,
      PRIMARY KEY (sid));

CREATE TABLE Boats (
    bid INTEGER,
    bname CHAR (20),
    color CHAR(10),
    PRIMARY KEY (bid));

CREATE TABLE Reserves (
    sid INTEGER,
    bid INTEGER,
    day DATE,
    PRIMARY KEY (sid, bid, day);
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

sid	bid	day
1	102	9/12
2	102	9/13

The SQL DDL: Reserves Pt. 2


```
CREATE TABLE Sailors (
       sid INTEGER,
       sname CHAR(20),
       rating INTEGER,
       age FLOAT,
       PRIMARY KEY (sid));

CREATE TABLE Boats (
    bid INTEGER,
    bname CHAR (20),
    color CHAR(10),
    PRIMARY KEY (bid));

CREATE TABLE Reserves (
    sid INTEGER,
    bid INTEGER,
    day DATE,
    PRIMARY KEY (sid, bid, day),
    FOREIGN KEY (sid) REFERENCES Sailors,
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

sid	bid	day
1	102	9/12
2	102	9/13

The SQL DDL: Foreign Keys


```
CREATE TABLE Sailors (
       sid INTEGER,
       sname CHAR(20),
       rating INTEGER,
       age FLOAT,
       PRIMARY KEY (sid));

CREATE TABLE Boats (
    bid INTEGER,
    bname CHAR (20),
    color CHAR(10),
    PRIMARY KEY (bid));

CREATE TABLE Reserves (
    sid INTEGER,
    bid INTEGER,
    day DATE,
    PRIMARY KEY (sid, bid, day),
    FOREIGN KEY (sid) REFERENCES Sailors,
    FOREIGN KEY (bid) REFERENCES Boats);
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

sid	bid	day
1	102	9/12
2	102	9/13

The SQL DDL: Foreign Keys Pt. 2

- Foreign key references a table
  - Via the primary key of that table
- Doesn't need to have the same name as the referenced primary key

```
CREATE TABLE Reserves (
    sid INTEGER,
    bid INTEGER,
    day DATE,
    PRIMARY KEY (sid, bid, day),
    FOREIGN KEY (sid) REFERENCES Sailors,
    FOREIGN KEY (bid) REFERENCES Boats);
```

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

sid	bid	day
1	102	9/12
2	102	9/13

The SQL DML

- Find all 27-year-old sailors:

```
SELECT *
FROM  Sailors AS S
WHERE S.age=27;
```

• To find just names and rating, replace the first line to:

```
SELECT S.sname,
S.rating
```

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

Basic Single-Table Queries


- ```
  SELECT [DISTINCT] <column expression list>
  FROM <single table>
  [WHERE <predicate>]
  ```

- In this simple version:
  - Produce all tuples in the table that satisfy the predicate
  - Output the expressions in the `SELECT` list
  - Expression can be a column reference, or an arithmetic expression over column refs
  ```

Distinct and Alias


```
SELECT DISTINCT S.name, S.gpa
FROM students [AS] S
WHERE S.dept = 'CS'
```

- Return all unique (name, GPA) pairs from students
- `DISTINCT` specifies removal of duplicate rows before output
- Can refer to the students table as `S`, this is called an *alias*

Ordering


```
SELECT S.name, S.gpa, S.age*2 AS a2
FROM Students S
WHERE S.dept = 'CS'
ORDER BY S.gpa, S.name, a2;
```

- `ORDER BY` clause specifies output to be sorted
  - Numeric ordering for “number-like” attributes (int, real, etc)
  - ***Lexicographic*** ordering otherwise (!!) (varchar, blob, etc)
- Obviously must refer to columns in the output
  - Note the `AS` clause for naming output columns!

Ordering


- ```
  SELECT  S.name, S.gpa, S.age*2 AS a2
  FROM Students S
  WHERE S.dept = 'CS'
  ORDER BY S.gpa DESC, S.name ASC, a2;
  ```

- Ascending order by default, but can be overridden
  - `DESC` flag for descending, `ASC` for ascending
  - Can mix and match, lexicographically
  ```

Setting limits


- ```
  SELECT  S.name, S.gpa, S.age*2 AS a2
  FROM Students S
  WHERE S.dept = 'CS'
  ORDER BY S.gpa DESC, S.name ASC, a2
  LIMIT 3;
  ```

- Only produces the first <integer> output rows
- Typically used with `ORDER BY`
  - Otherwise the output is *non-deterministic*
  - Not a “pure” declarative construct in that case – output set depends on algorithm for query processing
  ```

Aggregates


- ```
  SELECT [DISTINCT] AVG(S.gpa)
  FROM Students S
  WHERE S.dept = 'CS'
  ```

- Before producing output, compute a summary (aka an *aggregate*) of some arithmetic expression
- Produces 1 row of output
  - with one column in this case
- Other aggregates: `SUM`, `COUNT`, `MAX`, `MIN` (and others)
  ```

DISTINCT Aggregates

Are these the same or different?

```
SELECT COUNT(DISTINCT S.name)
FROM Students S
WHERE S.dept = 'CS';
```

```
SELECT DISTINCT COUNT(S.name)
FROM Students S
WHERE S.dept = 'CS’;
```

GROUP BY


```
SELECT [DISTINCT] AVG(S.gpa), S.dept
FROM Students S
GROUP BY S.dept
```

- Partition table into groups with same `GROUP BY` column values
  - Can group by a list of columns
- Produce an aggregate result per group
  - Cardinality of output = # of distinct group values

- Note: only grouping columns or aggregated values can appear in the `SELECT` list

Need to be Careful with GROUP BY…


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

Purchase

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

Need to be Careful with GROUP BY…

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

Purchase

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

Product	Max(quantity)
Bagel	20
Banana	50

Need to be Careful with GROUP BY…

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

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
-- what does this mean?
```

Purchase

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

Product	Max(quantity)
Bagel	20
Banana	50

Need to be Careful with GROUP BY…

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

```
SELECT   product, quantity
FROM     Purchase
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-- what does this mean?
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Purchase

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

Product	Max(quantity)
Bagel	20
Banana	50

Product	Quantity
Bagel	20
Banana	??

Need to be Careful with GROUP BY…

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

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
-- what does this mean?
```

Purchase

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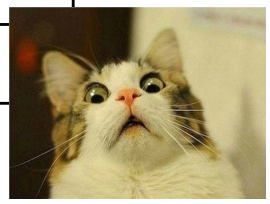
Banana	0.5	50
Banana	2	10
Banana	4	10

Product	Max(quantity)
Bagel	20
Banana	50

Product	Quantity
Bagel	20
Banana	??



Need to [illegible] with GROUP BY…

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

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

```
SELECT   product, quantity
FROM     Purchase
GROUP BY product
-- what does this mean?
```

Purchase

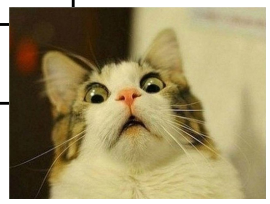
Product	Price	Quantity
Bagel	3	20
Bagel	1.50	20
Banana	0.5	50
Banana	2	10
Banana	4	10

But SQLite allows this!

Lesson: don't trust everything SQLite does!

Product	Max(quantity)
Bagel	20
Banana	50

Product	Quantity
Bagel	20
Banana	??



HAVING


```
SELECT [DISTINCT] AVG(S.gpa), S.dept
FROM Students S
GROUP BY S.dept
HAVING COUNT(*) > 2
```

- The `HAVING` predicate filters groups
- `HAVING` is applied *after* grouping and aggregation
  - Hence can contain anything that could go in the `SELECT` list
  - i.e., aggs or `GROUP BY` columns
- `HAVING` can only be used in aggregate queries
- It's an optional clause

SQL DML:
General Single-Table Queries

- **SELECT [DISTINCT]** *<column expression list>*
  FROM *<single table>*
  [**WHERE** *<predicate>*]
  [**GROUP BY** *<column list>*
  [**HAVING** *<predicate>*]]
  [**ORDER BY** *<column list>*]
  [**LIMIT** <integer>];

Summary

- Many query languages available for the relational data model
  - SQL is one of them that we will focus in this class
- Modern SQL extends set-based relational model
  - some extra goodies for duplicate row (bags), non-atomic types…
- Typically, many ways to write a query
  - DBMS figures out a fast way to execute a query, regardless of how it is written