L5
SQL SQL SQL SQL SQL SQL SQL

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Didn't Lecture 3 Go Over SQL?

Two sublanguages

DDL Data Definition Language
define and modify schema (physical, logical, view)
CREATE TABLE, Integrity Constraints

DML Data Manipulation Language
get and modify data
simple SELECT, INSERT, DELETE
human-readable language

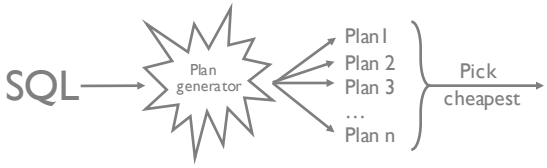
Gritty Details

DDL
NULL, Views

DML
Basics, SQL Clauses, Expressions, Joins, Nested Queries, Aggregation, With, Triggers

Didn't Lecture 3 Go Over SQL?

DBMS makes it run efficiently
Key: precise query semantics
Reorder/modify queries while answers stay same
DBMS estimates costs for different evaluation plans



Didn't Lecture 3 Go Over SQL?

More expressive power than Rel Alg
can be described by extensions of algebra
One key difference: multisets rather than sets
i.e. # duplicates in a table carefully accounted for

Most widely used *query language*, not just relational query language

Today's Database

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Boats

bid	name	color
101	Legacy	red
102	Melon	blue
103	Mars	red

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
2	103	9/14

Is Reserves table correct?

Today's Database

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Boats

bid	name	color
101	Legacy	red
102	Melon	blue
103	Mars	red

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
2	103	9/14

Is Reserves table correct?
Day should be part of key

Follow along at home!

http://w4111db1.cloudapp.net:8000/

or

```
psql -U demo -h w4111db1.cloudapp.net demo
password: demo
```

<30 year old sailors

```
SELECT *
FROM Sailors
WHERE age < 30
```

sid	name	rating	age
1	Eugene	7	22
3	Ken	8	27

```
SELECT name, age
FROM Sailors
WHERE age < 30
```

name	age
Eugene	22
Ken	27

<30 year old sailors

```
SELECT *
FROM Sailors
WHERE age < 30
```

$\sigma_{age<30}$ (Sailors)

```
SELECT name, age
FROM Sailors
WHERE age < 30
```

$\pi_{name,\ age}(\sigma_{age<30}$ (Sailors))

Multiple Relations

```
SELECT S.name
FROM   Sailors AS S, Reserves AS R
WHERE  S.sid = R.sid AND R.bid = 102
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
2	103	9/14

Multiple Relations

```
SELECT S.name
FROM   Sailors AS S, Reserves AS R
WHERE  S.sid = R.sid AND R.bid = 102
```

$\pi_{name}(\sigma_{bid=2}(\text{Sailors} \bowtie_{sid} \text{Reserves}))$

Structure of a SQL Query

DISTINCT
Optional, answer should not have duplicates
Default: duplicates not removed (multiset)

target-list
List of expressions over attrs of tables in relation-list

SELECT [DISTINCT] *target-list*
FROM *relation-list*
WHERE *qualification*

relation-list
List of relation names
Can define range-variable "AS X"

qualification
Boolean expressions
Combined w/ AND,OR,NOT
attr *op* const
$attr_1$ *op* $attr_2$
op is =, <, >, !=, etc

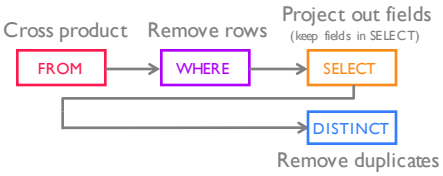
Semantics

SELECT [DISTINCT] *target-list*
FROM *relation-list*
WHERE *qualification*

FROM compute cross product of relations
WHERE remove tuples that fail qualifications
SELECT remove fields not in target-list
DISTINCT remove duplicate rows

Conceptual Query Evaluation

SELECT [DISTINCT] *target-list*
FROM *relation-list*
WHERE *qualification*
GROUP BY *grouping-list*
HAVING *group-qualification*



Not how actually executed! Above is likely very slow

DISTINCT (vol.1)

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
2	103	9/14

```
SELECT   bid
FROM     Reserves
```

bid
102
102
103

```
SELECT   DISTINCT bid
FROM     Reserves
```

bid
102
103

Sailors that reserved 1+ boats

```
SELECT   S.sid
FROM     Sailors AS S, Reserves AS R
WHERE    S.sid = R.sid
```

Would DISTINCT change anything in this query?
What if SELECT clause was SELECT S.name?

Range Variables

Disambiguate relations
same table used multiple times (self join)

```
SELECT   sid
FROM     Sailors, Sailors
WHERE    age > age
```

```
SELECT   S1.sid
FROM     Sailors AS S1, Sailors AS S2
WHERE    S1.age > S2.age
```

Range Variables

Disambiguate relations

same table used multiple times (self join)

```
SELECT   sid
FROM     Sailors, Sailors
WHERE    age > age
```

```
SELECT   S1.name, S1.age, S2.name, S2.age
FROM     Sailors AS S1, Sailors AS S2
WHERE    S1.age > S2.age
```

Expressions (Math)

```
SELECT   S.age, S.age – 5 AS age2, 2*S.age AS age3
FROM     Sailors AS S
WHERE    S.name = 'eugene'
```

```
SELECT   S1.name AS name1, S2.name AS name2
FROM     Sailors AS S1, Sailors AS S2
WHERE    S1.rating*2 = S2.rating - 1
```

Expressions (Strings)

```
SELECT   S.name
FROM     Sailors AS S
WHERE    S.name LIKE 'e_%'
```

'_' any one character (. in regex)

'%' 0 or more characters of any kind (.* in regex)

Most DBMSes have rich string manipulation support e.g., regex

PostgreSQL documentation
http://www.postgresql.org/docs/9.1/static/functions-string.html

Expressions (Date/Time)

```
SELECT   R.sid
FROM     Reserves AS R
WHERE    now() - R.date < interval '1 day'
```

TIMESTAMP, DATE, TIME types

now() returns timestamp at start of transaction

DBMSes provide rich time manipulation support

exact support may vary by vender

Postgresql Documentation
http://www.postgresql.org/docs/9.1/static/functions-datetime.html

Expressions

Constant	1
Col reference	Sailors.name
Arithmetic	Sailors.sid * 10
Unary operators	NOT, EXISTS
Binary operators	AND, OR, IN
Function calls	abs(), sqrt(), ...
Casting	1.7::int, '10-12-2015'::date

sid of Sailors that reserved red or blue boat

```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND
         (B.color = 'red' OR B.color = 'blue')
```

OR

```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'red'
UNION ALL
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'blue'
```

sid of Sailors that reserved red or blue boat

```
SELECT   DISTINCT R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND
         (B.color = 'red' OR B.color = 'blue')
```

OR

```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'red'
UNION
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'blue'
```

sid of Sailors that reserved red and blue boat

```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND
         (B.color = 'red' AND B.color = 'blue')
```

```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'red'
INTERSECT ALL
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'blue'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

```
SELECT   R.sid
FROM     Boats B1, Reserves R1
WHERE
         B1.bid = R1.bid AND

         B1.color = 'red'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

```
SELECT   R.sid
FROM     Boats B1, Reserves R1, Boats B2,Reserves R2
WHERE
         B1.bid = R1.bid AND

         B1.color = 'red'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

```
SELECT   R.sid
FROM     Boats B1, Reserves R1, Boats B2,Reserves R2
WHERE
         B1.bid = R1.bid AND
         B2.bid = R2.bid AND
         B1.color = 'red' AND B2.color = 'blue'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

```
SELECT   R.sid
FROM     Boats B1, Reserves R1, Boats B2,Reserves R2
WHERE    R1.sid = R2.sid AND
         B1.bid = R1.bid AND
         B2.bid = R2.bid AND
         B1.color = 'red' AND B2.color = 'blue'
```

sids of sailors that haven't reserved a boat

```
SELECT   S.sid
FROM     Sailors S

EXCEPT

SELECT   S.sid
FROM     Sailors S, Reserves R
WHERE    S.sid = R.sid
```

Can we write EXCEPT using more basic functionality?

SET Comparison Operators

UNION, INTERSECT, EXCEPT

EXISTS, NOT EXISTS
IN, NOT IN
UNIQUE, NOT UNIQUE

op ANY, *op* ALL
op ∈ { <, >, =, ≤, ≥, ≠, ...}

Many of these rely on Nested Query Support

Nested Queries

```
SELECT   S.sid
FROM     Sailors S
WHERE    S.sid IN (SELECT   R.sid
                   FROM     Reserves R
                   WHERE    R.bid = 101)
```

Many clauses can contain SQL queries
WHERE, FROM, HAVING, SELECT

Conceptual model:
for each Sailors tuple
run the subquery and evaluate qualification

Nested Correlated Queries

```
SELECT   S.sid
FROM     Sailors S
WHERE    EXISTS (SELECT   *
                 FROM     Reserves R
                 WHERE    R.bid = 101 AND
                          S.sid = R.sid)
```

Outer table referenced in nested query

Conceptual model:
for each Sailors tuple
run the subquery and evaluate qualification

Nested Correlated Queries

```
SELECT   S.sid
FROM     Sailors S
WHERE    UNIQUE (SELECT   *
                 FROM     Reserves R
                 WHERE    R.bid = 101 AND
                          S.sid = R.sid)
```

UNIQUE checks that there are no duplicates

What does this do?

Nested Correlated Queries

```
SELECT   S.sid
FROM     Sailors S
WHERE    UNIQUE (SELECT   R.sid
                 FROM     Reserves R
                 WHERE    R.bid = 101 AND
                          S.sid = R.sid)
```

UNIQUE checks that there are no duplicates

What does this do?

Sailors whose rating is greater than any sailor named "Bobby"

```
SELECT  S1.name
FROM    Sailors  S1
WHERE   S1.rating  > ANY (SELECT     S2.rating
                           FROM     Sailors  S2
                           WHERE    S2.name  = 'Bobby')
```

What about this?

```
SELECT  S1.name
FROM    Sailors  S1
WHERE   S1.rating  > ALL (SELECT     S2.rating
                          FROM     Sailors  S2
                          WHERE    S2.name  = 'Bobby')
```

Rewrite INTERSECT using IN

```
SELECT  S.sid
FROM    Sailors S
WHERE   S.rating > 2
INTERSECT
SELECT  R.sid
FROM    Reserves R
```

```
SELECT  S.sid
FROM    Sailors S
WHERE   S.rating > 2 AND
        S.sid IN (
    SELECT  R.sid
    FROM    Reserves R
)
```

Similar trick for EXCEPT → NOT IN

What if want *names* instead of sids?

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

```
SELECT      S.name
FROM        Sailors  S
WHERE       NOT  EXISTS  (

    (SELECT    B.bid  FROM    Boats  B)

    EXCEPT

    (SELECT    R.bid
     FROM Reserves  R
     WHERE R.sid  = S.sid)
)
```

HW1 bugs

Conflicting CHECK constraints

```
Prof(
  type  text,
  check(text  in ('junior',  'senior')),
  check(text  = 'junior'  and  hired  is  not  null),
  check(text  = 'senior'  and  tenure_year  is  not  null)
)
```

conflicting

HW1 bugs

At most once *per semester* translated as at most once

```
CREATE  TABLE  Offers  (
  deptid  text,
  courseid  text,
  semester  text,
  year  int,
  . . .
  PRIMARY  KEY(deptid,  courseid)
);
```

Wrong

HW1 bugs

At most once *per semester* translated as at most once

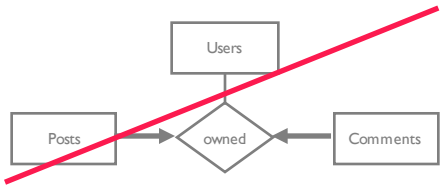
```
CREATE TABLE Offers (
   deptid text,
   courseid text,
   semester text,
   year int,
   . . .
   PRIMARY KEY(deptid, courseid, semester, year)
);
```

HW1 bugs

Reddit:

Comments owned by one user

Posts owned by one user



HW1 bugs

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Comments owned by one user

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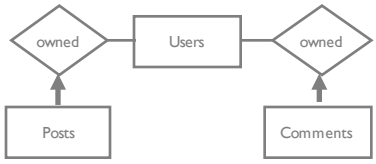


Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

```
SELECT S.name
FROM   Sailors S
WHERE  NOT EXISTS (
```

Sailors S such that

There's no boat without

A reservation by S

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

```
SELECT S.name
FROM   Sailors S
WHERE  NOT EXISTS (SELECT B.bid
                   FROM   Boats B
                   WHERE NOT EXISTS (
```

Sailors S such that

There's no boat without

A reservation by S

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

```
SELECT S.name
FROM   Sailors S
WHERE  NOT EXISTS (SELECT B.bid
                   FROM   Boats B
                   WHERE NOT EXISTS (SELECT R.bid
                                     FROM Reserves R
                                     WHERE R.sid = S.sid))
```

Sailors S such that

There's no boat without

A reservation by S

NULL

Field values sometimes unknown or inapplicable
SQL provides a special value *null* for such situations.

The presence of null complicates many issues e.g.,
Is age = null true or false?
Is null = null true or false?
Is null = 8 OR 1 = 1 true or false?

Special syntax "IS NULL" and "IS NOT NULL"
3 Valued Logic (true, false, unknown)

How does WHERE remove rows?
if qualification doesn't evaluate to true
New operators (in particular, outer joins) possible/needed.

NULL

(null > 0) = null
(null + 1) = null
(null = 0) = null
(null AND true) = null
null is null = true

Some truth tables

AND	T	F	NULL
T	T	F	NULL
F	F	F	F
NULL	NULL	F	NULL

OR	T	F	NULL
T	T	T	T
F	T	F	NULL
NULL	T	NULL	NULL

JOINS

```
SELECT [DISTINCT] target_list
FROM table_name
    [INNER | {LEFT |RIGHT | FULL } {OUTER}] JOIN table_name
    ON qualification_list
WHERE ...
```

INNER is default
Difference in how to deal with NULL values

PostgreSQL documentation:
http://www.postgresql.org/docs/9.4/static/tutorial-join.html

Inner/Natural Join

```
SELECT s.sid, s.name, r.bid
FROM   Sailors S, Reserves r
WHERE  s.sid = r.sid
```

```
SELECT s.sid, s.name, r.bid
FROM   Sailors s INNER JOIN Reserves r
ON     s.sid = r.sid
```

```
SELECT s.sid, s.name, r.bid
FROM   Sailors s NATURAL JOIN Reserves r
```

All Equivalent!

Natural Join means equi-join for each pair of attrs with same name

Sailor names and their reserved boat ids

```
SELECT s.sid, s.name, r.bid
FROM   Sailors s INNER JOIN Reserves r
ON     s.sid = r.sid
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Sailor names and their reserved boat ids

```
SELECT s.sid, s.name, r.bid
FROM   Sailors s INNER JOIN Reserves r
ON     s.sid = r.sid
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Prefer INNER JOIN over NATURAL JOIN. Why?

Sailor names and their reserved boat ids

```
SELECT  s.sid, s.name, r.bid
FROM    Sailors s INNER JOIN Reserves r
ON      s.sid = r.sid
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Notice: No result for Ken!

Left Outer Join (or No Results for Ken)

Returns all matched rows *and all unmatched rows from table on left of join clause*

(*at least one* row for each row in left table)

```
SELECT  s.sid, s.name, r.bid
FROM    Sailors s LEFT OUTER JOIN Reserves r
ON      s.sid = r.sid
```

All sailors & bid for boat in their reservations
Bid set to NULL if no reservation

Left Outer Join

```
SELECT  s.sid, s.name, r.bid
FROM    Sailors s LEFT OUTER JOIN Reserves r
ON      s.sid = r.sid
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102
3	Ken	NULL

Can Left Outer Join be expressed with Cross-Product?

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

sid	bid	day

Sailors x Reserves

Result

sid	name	bid

```
Sailors s LEFT OUTER JOIN Reserves r
ON  s.sid = r.sid
```

Result

sid	name	bid
1	Eugene	NULL
2	Luis	NULL
3	Ken	NULL

Can Left Outer Join be expressed with Cross-Product?

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

sid	bid	day

Sailors ⋈ Reserves

U

(Sailors – (Sailors ⋈ Reserves)) x {(null, …)}

How to compute this with a query?

Right Outer Join

Same as LEFT OUTER JOIN, but guarantees result for rows in table on right side of JOIN

```
SELECT  s.sid, s.name, r.bid
FROM    Reserves r RIGHT OUTER JOIN Sailors S
ON      s.sid = r.sid
```

FULL OUTER JOIN

Returns all matched *or* unmatched rows from both sides of JOIN

```
SELECT  s.sid, s.name, r.bid
FROM    Sailors s FULL OUTER JOIN Reserves r
ON      s.sid = r.sid
```

FULL OUTER JOIN

```
SELECT  s.sid, s.name, r.bid
FROM    Sailors s Full OUTER JOIN Reserves r
ON      s.sid = r.sid
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
4	109	9/20

Result

sid	name	bid
1	Eugene	102
2	Luis	102
3	Ken	NULL
NULL	NULL	109

Why is sid NULL?

Serious people can count: Aggregation

```
SELECT  COUNT(*)
FROM    Sailors S

SELECT  AVG(S.age)
FROM    Sailors S
WHERE   S.rating = 10

SELECT  COUNT(DISTINCT S.name)
FROM    Sailors S
WHERE   S.name LIKE 'D%'

SELECT  S.name
FROM    Sailors
WHERE   S.rating = (SELECT MAX(S2.rating)
                    FROM   Sailors S2)
```

COUNT([DISTINCT] A)
SUM([DISTINCT] A)
AVG([DISTINCT] A)
MAX/MIN(A)
STDDEV(A)
CORR(A,B)

PostgreSQL documentation
http://www.postgresql.org/docs/9.4/static/functions-aggregate.html

Name and age of oldest sailor(s)

```
SELECT  S.name, MAX(S.age)
FROM    Sailors S

SELECT  S.name, S.age
FROM    Sailors S
WHERE   S.age >= ALL (SELECT  S2.age
                      FROM    Sailors S2)

SELECT  S.name, S.age
FROM    Sailors S
WHERE   S.age = (SELECT    MAX(S2.age)
                 FROM      Sailors S2)

SELECT  S.name, S.age
FROM    Sailors S
ORDER BY   S.age DESC
LIMIT 1
```

← When does this not work?

GROUP BY

```
SELECT  min(s.age)
FROM    Sailors  s
```

Minimum age among all sailors

What if want min age *per rating level*?
We don't even know how many rating levels exist!
If we did, could write (awkward):

```
for rating in [0…10]
    SELECT  min(s.age)
    FROM    Sailors  s
    WHERE   s.rating  = <rating>
```

GROUP BY

```
SELECT  count(*)
FROM    Reserves  R
```

Total number of reservations

What if want reservations per boat?
May not even know all our boats (depends on data)!
If we did, could write (awkward):

```
for boat in [0…10]
    SELECT  count(*)
    FROM    Reserves  R
    WHERE   R.bid  = <boat>
```

GROUP BY

```
SELECT      [DISTINCT]   target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
```

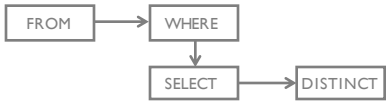
grouping-list is a list of expressions that defines groups
- set of tuples w/ same value for all attributes in grouping-list

target-list contains
- *attribute-names* ⊆ *grouping-list*
- *aggregation expressions*

Conceptual Query Evaluation

```
SELECT      [DISTINCT]   target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
```

Cross product Remove rows

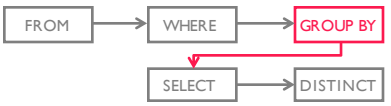


Project out fields (keep fields in SELECT GBY) Remove duplicates

Conceptual Query Evaluation

```
SELECT      [DISTINCT]   target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
```

Cross product Remove rows Form groups



Project out fields, aggregate Remove duplicates

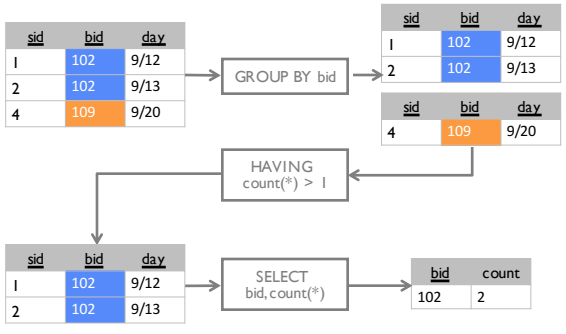
Conceptual Query Evaluation

```
SELECT      [DISTINCT]   target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
```

Cross product Remove rows Form groups

Remove groups Project out fields, aggregate Remove duplicates

Conceptual Evaluation



GROUP BY

```
SELECT      bid,  count(*)
FROM        Reserves   R
GROUP  BY   bid
```

Minimum age for each rating

```
SELECT      bid,  count(*)
FROM        Reserves   R
GROUP  BY   bid
HAVING      count(*)   > 1
```

Minimum age for each boat with more than 1 reservation

HAVING

group-qualification used to remove groups
similar to WHERE clause

Expressions must have *one value per group*. Either
An aggregation function or
In *grouping-list*

```
SELECT    bid,  count(*)
FROM      Reserves  R
GROUP BY  bid
HAVING    color = 'red'
```

AVG age of sailors reserving red boats, by rating

```
SELECT
FROM      Sailors S, Boats B, Reserves R
WHERE     S.sid = R.sid AND
          R.bid = B.bid AND
          B.color = 'red'
```

AVG age of sailors reserving red boats, by rating

```
SELECT    S.rating,  avg(S.age)  AS age
FROM      Sailors S, Boats B, Reserves R
WHERE     S.sid = R.sid AND
          R.bid = B.bid AND
          B.color = 'red'
GROUP BY  S.rating
```

What if move B.color='red' to HAVING clause?

Ratings where the avg age is min over all ratings

✗

```
SELECT S.rating
FROM   Sailors S
WHERE  S.age = (
           SELECT MIN(AVG(S2.age))
           FROM Sailors S2
       )
```

✔

```
SELECT S.rating
FROM   (SELECT S.rating, AVG(S.age) as avgage
          FROM Sailors S
       GROUP BY S.rating) AS tmp
WHERE  tmp.avgage = (
    SELECT MIN(tmp2.avgage) FROM (
       SELECT  S.rating, AVG(S.age) as avgage
         FROM  Sailors S
      GROUP BY  S.rating
    ) AS tmp2
)
```

Ratings where the avg age is min over all ratings

✗

```
SELECT S.rating
FROM   Sailors S
WHERE  S.age = (
           SELECT MIN(AVG(S2.age))
           FROM Sailors S2
       )
```

✔

```
SELECT S.rating
FROM   (SELECT S.rating, AVG(S.age) as avgage
          FROM Sailors S
       GROUP BY S.rating) AS tmp
WHERE  tmp.avgage <= ALL (
    SELECT tmp2.avgage FROM (
       SELECT  S.rating, AVG(S.age) as avgage
         FROM  Sailors S
      GROUP BY  S.rating
    ) AS tmp2
)
```

Setting up Proj 1 Part 2

Users assigned to schemas (namespaces).
Noticed user didn't have an assigned schema
User created their tables under Public schema.
Uh oh! Did I miss anyone else

Students without a schema

usename
vx3948
et1827
etu4938

```
SELECT  usename
FROM  pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT  schemaname
FROM  pg_tables;
```

Setting up Proj 1 Part 2

```
FROM    (SELECT usename FROM pg_user) AS U

        (SELECT schemaname FROM pg_tables) AS S
```

usename
vx3948
et1827
etu4938

```
SELECT  usename
FROM  pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT  schemaname
FROM  pg_tables;
```

Setting up Proj 1 Part 2

```
FROM    (SELECT usename FROM pg_user) AS U
        RIGHT OUTER JOIN
        (SELECT schemaname FROM pg_tables) AS S
        ON U.username = S.schemaname
```

usename
vx3948
et1827
etu4938

```
SELECT  usename
FROM  pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT  schemaname
FROM  pg_tables;
```

Setting up Proj 1 Part 2

```
SELECT U.username, S.schemaname
FROM    (SELECT usename FROM pg_user) AS U
        RIGHT OUTER JOIN
        (SELECT schemaname FROM pg_tables) AS S
        ON U.username = S.schemaname
WHERE   S.schemaname is null;
```

usename
vx3948
et1827
etu4938

```
SELECT  usename
FROM  pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT  schemaname
FROM  pg_tables;
```

Setting up Proj 1 Part 2

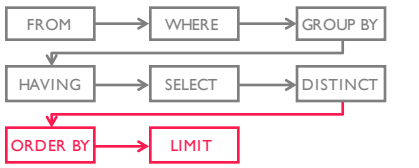
```
SELECT count(*)
FROM (
    SELECT U.username, S.schemaname
    FROM    (SELECT usename FROM pg_user) AS U
            RIGHT OUTER JOIN
            (SELECT schemaname FROM pg_tables) AS S
            ON U.username = S.schemaname
    WHERE   S.schemaname is null;
) AS nestedquery
```

124

but 190 users!

ORDER BY, LIMIT

```
SELECT      [DISTINCT]  target-list
FROM        relation-list
WHERE       qualification
GROUP BY    grouping-list
HAVING      group-qualification
ORDER BY    order-list
LIMIT       limit-expr  [OFFSET  offset-expr]
```



ORDER BY

```
SELECT      S.name
FROM        Sailors  S
ORDER BY    (S.rating/2)::int  ASC,
            S.age  DESC
```

List of *order-list* expressions dictates ordering precedence

- Sorted in ascending by age/rating ratio
- If ties, sorted high to low rating

ORDER BY

```
SELECT    S.name,  (S.rating/2)::int,  S.age
FROM      Sailors  S
ORDER BY  (S.rating/2)::int  ASC,
          S.age  DESC
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

name	int4	age
Luis	1	39
Ken	4	27
Eugene	4	22

ORDER BY

```
SELECT    S.name,  (S.rating/2)::int,  S.age
FROM      Sailors  S
ORDER BY  (S.rating/2)::int  ASC,
          S.age  ASC
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

name	int4	age
Luis	1	39
Eugene	4	22
Ken	4	27

LIMIT

```
SELECT    S.name,  (S.rating/2)::int,  S.age
FROM      Sailors  S
ORDER BY  (S.rating/2)::int  ASC,
          S.age  DESC
LIMIT     2
```

Only the first 2 results

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

name	int4	age
Luis	1	39
Ken	4	27

LIMIT

```
SELECT    S.name,  (S.rating/2)::int,  S.age
FROM      Sailors  S
ORDER BY  (S.rating/2)::int  ASC,
          S.age  DESC
LIMIT     2 OFFSET  1
```

Only the first 2 results

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

name	int4	age
Ken	4	27
Eugene	4	22

LIMIT

```
SELECT    S.name,  (S.rating/2)::int,  S.age
FROM      Sailors  S
ORDER BY  (S.rating/2)::int  ASC,
          S.age  DESC
LIMIT     (SELECT  count(S2.*)  / 2
           FROM  Sailors  AS  S2)
```

Can have expressions instead of constants

Result

name	int4	age
Luis	1	39

Integrity Constraints

Conditions that every legal instance must satisfy
- Inserts/Deletes/Updates that violate ICs rejected
- Helps ensure app semantics or prevent inconsistencies

We've discussed
- domain/type constraints, primary/foreign key
- general constraints ←

Beyond Keys: Table Constraints

Runs when table is not empty

```
CREATE TABLE Sailors(
    sid int,
    …
    PRIMARY KEY (sid),
    CHECK (rating >= 1 AND rating <= 10)

CREATE TABLE Reserves(
    sid int,
    bid int,
    day date,
    PRIMARY KEY (bid, day),
    CONSTRAINT no_red_reservations
    CHECK ('red' <> (SELECT B.color
                     FROM Boats B
                     WHERE B.bid = bid))
```

Nested subqueries
Named constraints

Multi-Relation Constraints

of sailors + # of boats should be less than 100

```
CREATE TABLE Sailors (
    sid int,
    bid int,
    day date,
    PRIMARY KEY (bid, day),
    CHECK (
        (SELECT COUNT(S.sid) FROM Sailors S)
        +
        (SELECT COUNT(B.bid) FROM Boats B)
        < 100
    )
```

What if Sailors is empty?

ASSERTIONS: Multi-Relation Constraints

```
CREATE ASSERTION small_club
CHECK (
    (SELECT COUNT(*) FROM Sailors S)
    +
    (SELECT COUNT(*) FROM Boats B)
    < 100
)
```

ASSERTIONs are not associated with any table

WHAT!

So many things we can't express or don't work!

Assertions

Nested queries in CHECK constraints

Advanced Stuff

User defined functions

Triggers

WITH

Views

User Defined Functions (UDFs)

Custom functions that can be called in database

Many languages: SQL, python, C, perl, etc

```
CREATE FUNCTION function_name(p1 type, p2 type, …)
RETURNS type
```

User Defined Functions (UDFs)

Custom functions that can be called in database
Many languages: SQL, python, C, perl, etc

```
CREATE FUNCTION function_name(p1 type, p2 type, …)
RETURNS type
AS $$

-- logic

$$ LANGUAGE language_name;
```

User Defined Functions (UDFs)

Custom functions that can be called in database
Many languages: SQL, python, C, perl, etc

```
CREATE FUNCTION function_name(p1 type, p2 type, …)
RETURNS type
AS $$

-- logic

$$ LANGUAGE language_name;
```

A simple UDF (lang = SQL)

```
CREATE FUNCTION mult1(v int) RETURNS int
AS $$
SELECT v * 100;
$$ LANGUAGE SQL;
```

Last statement is returned

```
CREATE FUNCTION function_name(p1 type, p2 type, …)
RETURNS type
AS $$

-- logic

$$ LANGUAGE language_name;
```

A simple UDF (lang = SQL)

```
CREATE FUNCTION mult1(v int) RETURNS int
AS $$
SELECT v * 100;
$$ LANGUAGE SQL;

SELECT mult1(S.age)
FROM sailors AS S
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

int4
220
390
270

http://www.postgresql.org/docs/9.1/static/xfunc-sql.html

A simple UDF (lang = SQL)

```
CREATE FUNCTION mult1(v int) RETURNS int
AS $$
SELECT $1 * 100;
$$ LANGUAGE SQL;

SELECT mult1(S.age)
FROM sailors AS S
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

int4
220
390
270

http://www.postgresql.org/docs/9.1/static/xfunc-sql.html

Process a Record (lang = SQL)

```
CREATE FUNCTION mult2(x sailors) RETURNS int
AS $$
SELECT (x.sid + x.age) / x.rating;
$$ LANGUAGE SQL;

SELECT mult2(S.*)
FROM sailors AS S
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

int4
3.285
20.5
3.75

http://www.postgresql.org/docs/9.1/static/xfunc-sql.html

Process a Record (lang = SQL)

```
CREATE FUNCTION mult2(sailors) RETURNS int
AS $$
SELECT ($1.sid + $1.age) / $1.rating;
$$ LANGUAGE SQL;

SELECT mult2(S.*)
FROM sailors AS S
```

Sailors

sid	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Result

int4
3.285
20.5
3.75

http://www.postgresql.org/docs/9.1/static/xfunc-sql.html

Procedural Language/SQL (lang = plsql)

```
CREATE FUNCTION proc(v int) RETURNS int
AS $$
DECLARE
    -- define variables
BEGIN
    -- PL/SQL code
END;
$$ LANGUAGE plpgsql;
```

Boilerplate

http://www.postgresql.org/docs/9.4/static/plpgsql.html

Procedural Language/SQL (lang = plsql)

```
CREATE FUNCTION proc(v int) RETURNS int
AS $$
DECLARE
    -- define variables.  VAR TYPE [= value]
    qty int = 10;
BEGIN
    qty = qty * v;
    INSERT INTO blah VALUES(qty);
    RETURN qty + 2;
END;
$$ LANGUAGE plpgsql;
```

http://www.postgresql.org/docs/9.4/static/plpgsql.html

Procedural Code (lang = plpython2u)

```
CREATE FUNCTION proc(v int) RETURNS int
AS $$
import random
return random.randint(0, 100) * v
$$ LANGUAGE plpython2u;
```

Very powerful – can do anything so must be careful

run in a python interpreter with no security protection

plpy module provides database access

```
plpy.execute("select 1")
```

http://www.postgresql.org/docs/9.4/static/plpython.html

Procedural Code (lang = plpython2u)

```
CREATE FUNCTION proc(word text) RETURNS text
AS $$
import requests
resp = requests.get('http://google.com/search?q=%s' % v)
return resp.content
$$ LANGUAGE plpython2u;
```

Very powerful – can do anything so must be careful

run in a python interpreter with no security protection

plpy module provides database access

```
plpy.execute("select 1")
```

http://www.postgresql.org/docs/9.4/static/plpython.html

Triggers (logical)

def: procedure that runs automatically if specified changes in DBMS happen

```
CREATE TRIGGER name
```

Event activates the trigger

Condition tests if triggers should run

Action what to do

Triggers (logical)

def: procedure that runs automatically if specified changes in DBMS happen

```
CREATE TRIGGER name
    [BEFORE | AFTER | INSTEAD OF] event_list
    ON table
```

Event activates the trigger
Condition tests if triggers should run
Action what to do

Triggers (logical)

def: procedure that runs automatically if specified changes in DBMS happen

```
CREATE TRIGGER name
    [BEFORE | AFTER | INSTEAD OF] event_list
    ON table

    WHEN trigger_qualifications
```

Event activates the trigger
Condition tests if triggers should run
Action what to do

Triggers (logical)

def: procedure that runs automatically if specified changes in DBMS happen

```
CREATE TRIGGER name
    [BEFORE | AFTER | INSTEAD OF] event_list
    ON table
    [FOR EACH ROW]
    WHEN trigger_qualifications
    procedure
```

Event activates the trigger
Condition tests if triggers should run
Action what to do

Copy new young sailors into special table (logical)

```
CREATE TRIGGER youngSailorUpdate
    AFTER INSERT ON SAILORS
REFERENCING NEW TABLE NewInserts
FOR EACH STATEMENT
    INSERT
        INTO YoungSailors(sid, name, age, rating)
        SELECT sid, name, age, rating
        FROM NewInserts N
        WHERE N.age <= 18
```

Event activates the trigger
Condition tests if triggers should run
Action what to do

Copy new young sailors into special table (logical)

```
CREATE TRIGGER youngSailorUpdate
    AFTER INSERT ON SAILORS
FOR EACH ROW
    WHEN NEW.age <= 18
    INSERT
        INTO YoungSailors (sid, name, age, rating)
        VALUES (NEW.sid, NEW.name, NEW.age, NEW.rating)
```

Event activates the trigger
Condition tests if triggers should run
Action what to do

Triggers (logical)

Can be complicated to reason about
- Triggers may (e.g., insert) cause other triggers to run
- If > 1 trigger match an action, which is run first?

¯_(ツ)_/¯

```
CREATE TRIGGER recursiveTrigger
    AFTER INSERT ON SAILORS
FOR EACH ROW
    INSERT INTO Sailors(sid, name, age, rating)
        SELECT sid, name, age, rating
        FROM Sailors S
```

Triggers (postgres)

```
CREATE TRIGGER name
    [BEFORE | AFTER | INSTEAD OF] event_list
    ON table
    FOR EACH (ROW | STATEMENT)
    WHEN trigger_qualifications
    EXECUTE PROCEDURE user_defined_function();
```

PostgreSQL only runs *trigger* UDFs

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

Trigger Example

```
CREATE FUNCTION copyrecord() RETURNS trigger
AS $$
BEGIN
    INSERT INTO blah VALUES(NEW.a);
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;
```

Signature: no args, return type is trigger
Returns NULL or same record structure as modified row
Special variables: OLD, NEW

```
CREATE TRIGGER t_copyinserts BEFORE INSERT ON a
    FOR EACH ROW
        EXECUTE PROCEDURE copyrecord();
```

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

Total boats and sailors < 100

```
CREATE FUNCTION checktotal() RETURNS trigger
AS $$
BEGIN
    IF ((SELECT COUNT(*) FROM sailors) +
        (SELECT COUNT(*) FROM boats) < 100) THEN
        RETURN NEW
    ELSE
        RETURN null;
    END IF;
END;
$$ LANGUAGE plpgsql;


CREATE TRIGGER t_checktotal BEFORE INSERT ON sailors
    FOR EACH ROW
        EXECUTE PROCEDURE checktotal();
```

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

You can get into trouble…

```
CREATE FUNCTION addme_bad() RETURNS trigger
AS $$
BEGIN
    INSERT INTO a VALUES (NEW.*);
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;


CREATE TRIGGER t_addme_bad BEFORE INSERT ON a
    FOR EACH ROW
        EXECUTE PROCEDURE addme_bad();
```

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

You can get into trouble…

```
CREATE FUNCTION addme_ok() RETURNS trigger
AS $$
BEGIN
    IF (SELECT COUNT(*) FROM a) < 100 THEN
        INSERT INTO a VALUES (NEW.a + 1);
    END IF;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;


CREATE TRIGGER t_addme_ok BEFORE INSERT ON a
    FOR EACH ROW
        EXECUTE PROCEDURE addme_ok();
```

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

You can get into trouble…

```
CREATE FUNCTION addme_works() RETURNS trigger
AS $$
BEGIN
    IF (SELECT COUNT(*) FROM a) < 100 THEN
        INSERT INTO a VALUES (NEW.a + 1);
    END IF;
    RETURN NEW;
END;
$$ LANGUAGE plpgsql;


CREATE TRIGGER t_addme_works AFTER INSERT ON a
    FOR EACH ROW
        EXECUTE PROCEDURE addme_works();
```

http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html

WITH

```
WITH  RedBoats(bid,   count)  AS
    (SELECT    B.bid,   count(*)
     FROM      Boats  B,  Reserves  R
     WHERE     R.bid  = B.bid  AND  B.color   = 'red'
    GROUP  BY  B.bid)
SELECT      name,  count
FROM        Boats  AS  B,   RedBoats   AS  RB
WHERE       B.bid  = RB.bid   AND  count  < 2
```

Names of unpopular boats

Views

```
CREATE  VIEW  view_name
AS  select_statement
```

"tables" defined as query results rather than inserted base data
- Makes development simpler
- Used for security

Not *materialized*

References to *view_name* replaced with *select_statement*

Similar to WITH, lasts longer than one query

Views

```
CREATE  VIEW  boat_counts
AS  SELECT      bid, count(*)
    FROM        Reserves  R
    GROUP  BY   bid
    HAVING      count(*)  >  10
```

Used like a normal table

```
SELECT  bname
FROM    boat_counts  bc, Boats  B
WHERE   bc.bid = B.bid
```

Names of popular boats

```
SELECT  bname
FROM
    (SELECT bid,  count(*)
     FROM  Reserves  R
     GROUP  BY bid
     HAVING  count(*)  >  10)  bc,
    Boats  B
WHERE   bc.bid = B.bid
```

Rewritten expanded query

CREATE TABLE

```
CREATE  TABLE  <table_name>  AS
   <SELECT  STATEMENT>
```

Guess the schema:

```
CREATE  TABLE  used_boats1  AS
    SELECT  r.bid
    FROM    Sailors  s,
            Reservations  r
    WHERE   s.sid = r.sid
```

used_boats1(bid int)

```
CREATE  TABLE  used_boats2  AS
    SELECT  r.bid  as  foo
    FROM    Sailors  s,
            Reservations  r
    WHERE   s.sid = r.sid
```

used_boats2(foo int)

How is this different than views?
- What if we insert a new record into Reservations?

Summary

SQL is pretty complex
- Superset of Relational Algebra SQL99 turing complete
- Human readable

More than one way to skin a horse
- Many alternatives to write a query
- Optimizer (theoretically) finds most efficient plan