

L5 SQL SQL SQL SQL SQL SQL SQL

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Fall 2015

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

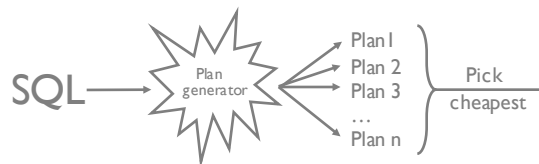
Gritty Details

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

<u>sid</u>	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Boats

<u>bid</u>	name	color
101	Legacy	red
102	Melon	blue
103	Mars	red

Reserves

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

Is Reserves table correct?

Today's Database

Sailors

<u>sid</u>	name	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Boats

<u>bid</u>	name	color
101	Legacy	red
102	Melon	blue
103	Mars	red

Reserves

<u>sid</u>	<u>bid</u>	<u>day</u>
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
```

<u>sid</u>	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
```

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

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

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

Multiple Relations

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

Sailors

<u>sid</u>	<u>name</u>	rating	age
1	Eugene	7	22
2	Luis	2	39
3	Ken	8	27

Reserves

<u>sid</u>	<u>bid</u>	<u>day</u>
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
```

$\pi_{name}(\sigma_{bid=102}(\text{Sailors} \bowtie_{sid} \text{Reserves}))$

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
attr₁ op const
attr₁ op attr₂
op is =, <, >, !=, etc

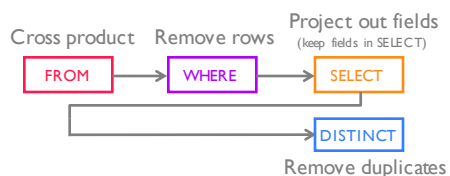
Semantics

```
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.I)

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 Sailsors, Sailsors
WHERE age > age
```

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

Expressions (Math)

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

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

Expressions (Strings)

```
SELECT S.name
FROM Sailsors 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 vendor

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
 $op \in \{<, >, =, \leq, \geq, \neq, \dots\}$

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)

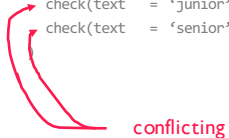
Hint: double negation
reserved all boats == no boat w/out reservation

```
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)
)
```

HWI 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

HWI 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

HWI bugs

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

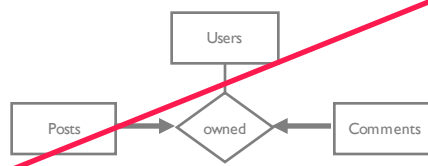
```
CREATE TABLE Offers (
  deptid text,
  courseid text,
  semester text,
  year int,
  . . .
  PRIMARY KEY(deptid, courseid, semester, year)
);
```

HWI bugs

Reddit:

Comments owned by one user

Posts owned by one user

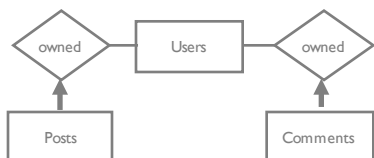


HWI bugs

Reddit:

Comments owned by one user

Posts owned by one user



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
```

All
Equivalent!

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

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
```

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

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

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
```

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

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

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

Can Left Outer Join be expressed with Cross-Product?

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

sid	bid	day
-----	-----	-----

Sailors x Reserves

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

sid	name	bid
-----	------	-----

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

Can Left Outer Join be expressed with Cross-Product?

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

sid	bid	day
-----	-----	-----

Sailors \bowtie Reserves

U

(Sailors - (Sailors \bowtie 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
COUNT([DISTINCT] A)

SELECT AVG(S.age)
FROM Sailors S
WHERE S.rating = 10
SUM([DISTINCT] A)

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

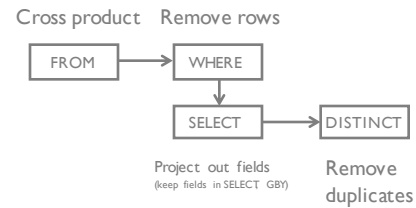
$attribute-names \subseteq grouping-list$
aggregation expressions

Conceptual Query Evaluation

```

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

```

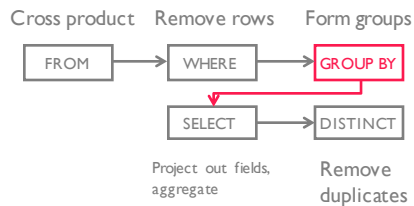


Conceptual Query Evaluation

```

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

```

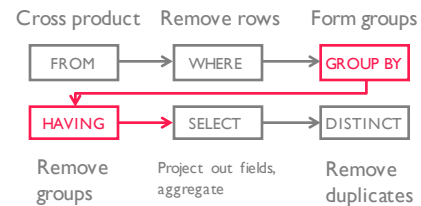


Conceptual Query Evaluation

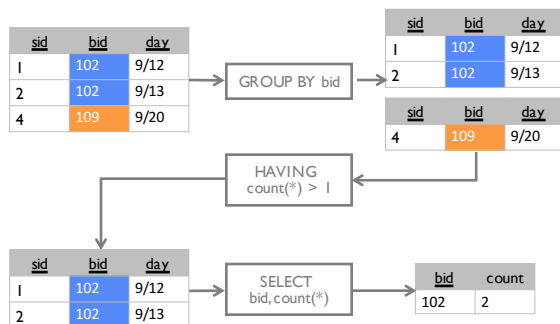
```

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

```



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 I Part 2

Users assigned to schemas (namespaces).

Notion 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

username
vx3948
et1827
etu4938

```
SELECT username
FROM pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT schemaname
FROM pg_tables;
```

Setting up Proj I Part 2

```
FROM (SELECT username FROM pg_user) AS U
      (SELECT schemaname FROM pg_tables) AS S
```

username
vx3948
et1827
etu4938

```
SELECT username
FROM pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT schemaname
FROM pg_tables;
```

Setting up Proj I Part 2

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

username
vx3948
et1827
etu4938

```
SELECT username
FROM pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT schemaname
FROM pg_tables;
```

Setting up Proj I Part 2

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

username
vx3948
et1827
etu4938

```
SELECT username
FROM pg_user;
```

schemaname
et2039
sa2037
kt6765

```
SELECT schemaname
FROM pg_tables;
```

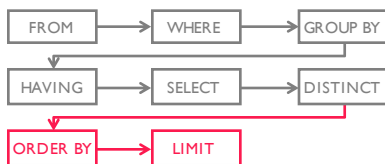
Setting up Proj I Part 2

```
SELECT count(*)
FROM (
  SELECT U.username, S.schemaname
  FROM (SELECT username FROM pg_user) AS U
        LEFT 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' NOT IN (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?

Only runs if Sailors has rows (ignores Boats)

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/func-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/func-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/func-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/9.4/static/func-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 $$
import requests
resp = requests.get('http://google.com/search?q=%s' % v)
return resp.content.decode('unicode-escape')
$$ 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

Disable inserts into Sailors table (logical)

```
CREATE TRIGGER disableNewSailor
BEFORE INSERT ON SAILORS
FOR EACH STATEMENT
NULL
```

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?

╰(ˊˋ)╯

```
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 vs Constraints

Constraint

Statement about state of database

Upheld by the database for *any* modifications

Doesn't modify the database state

Triggers

Operational: X should happen when Y

Specific to statements

Very flexible

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_stillwrong() 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_stillwrong BEFORE INSERT ON a
FOR EACH ROW
EXECUTE PROCEDURE addme_stillwrong();
```

<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

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
```

```
WITH tablename(attr1, ...) AS (select_query)
[,tablename(attr1, ...) AS (select_query)]
main_select_query
```

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

Names of popular boats

```
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
```

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

Names of popular boats

Rewritten expanded query

CREATE TABLE

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

Guess the schema:

```
CREATE TABLE used_boats1 AS      CREATE TABLE used_boats2 AS
  SELECT r.bid                    SELECT r.bid as foo
  FROM   Sailors s,              FROM   Sailors s,
        Reservations r          Reservations r
  WHERE  s.sid = r.sid           WHERE  s.sid = r.sid
used_boats1(bid int)             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

