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

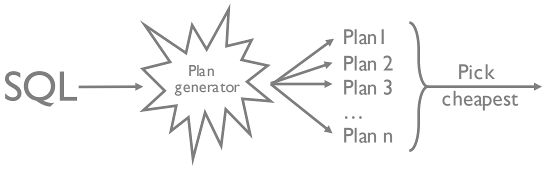
Gritty Details

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

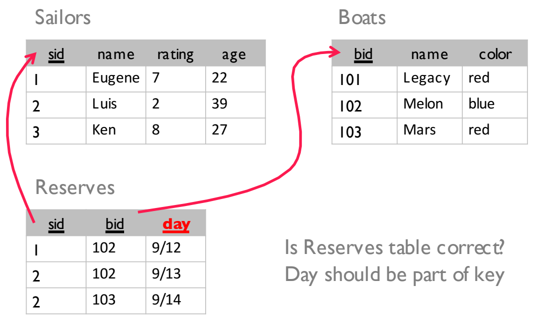
bid	name	color
101	Legacy	red
102	Melon	blue
103	Mars	red

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
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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
```

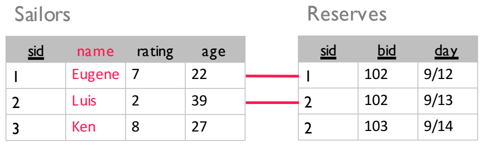
$\sigma_{age<30}(\text{Sailors})$

```
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

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

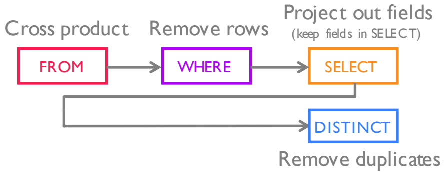
Semantics

```
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
```


Cross product
Remove rows
Project out fields (keep fields in SELECT)
FROM
WHERE
SELECT
DISTINCT
Remove duplicates

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

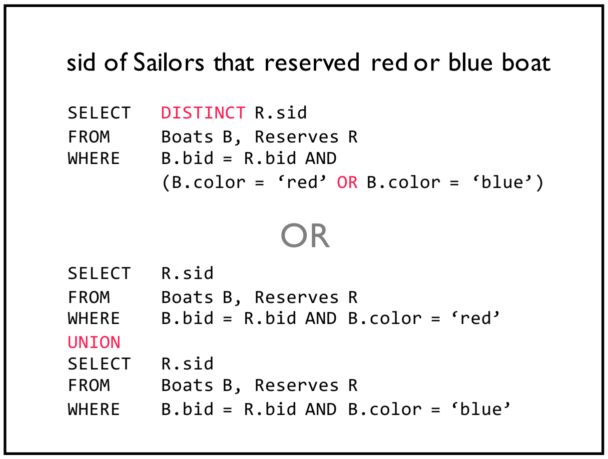
Constant	1
Col reference	Sailors.name
Arithmetic	Sailors.sid * 10
Unary operators	NOT, EXISTS
Binary operators	AND, OR, IN
Function calls	abs(), sqrt(), ...
Casting	1.7::int, '10-12-2015'::date

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'
```

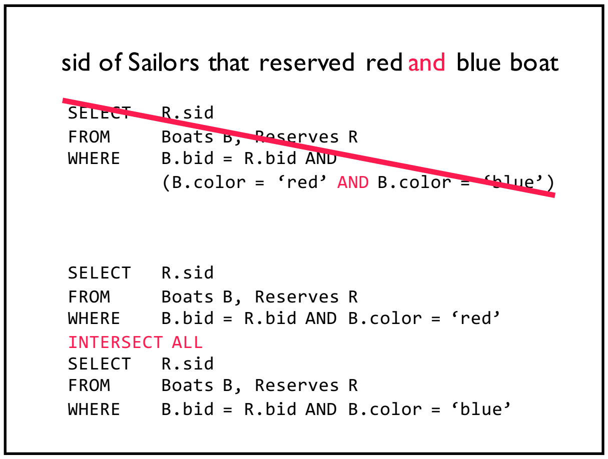


sid of Sailors that reserved red or blue boat

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

OR

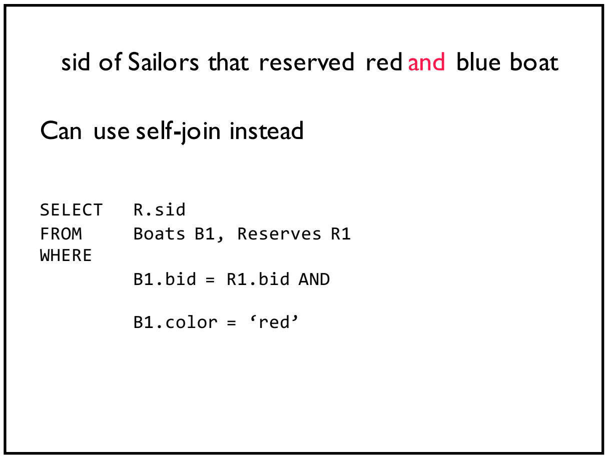
```
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'red'
UNION
SELECT   R.sid
FROM     Boats B, Reserves R
WHERE    B.bid = R.bid AND B.color = 'blue'
```



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'
```



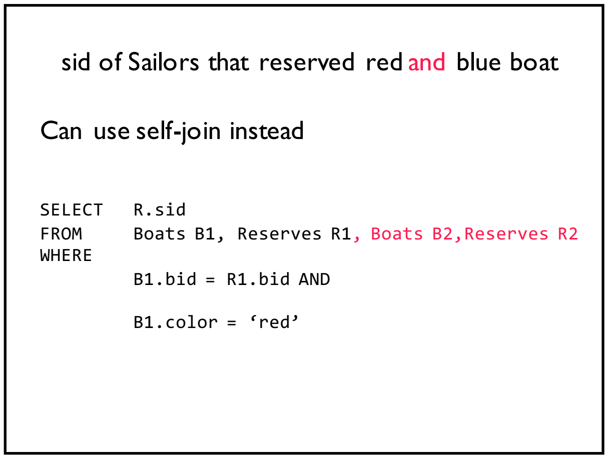
sid of Sailors that reserved red and blue boat

Can use self-join instead

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

         B1.bid = R1.bid AND

         B1.color = 'red'
```



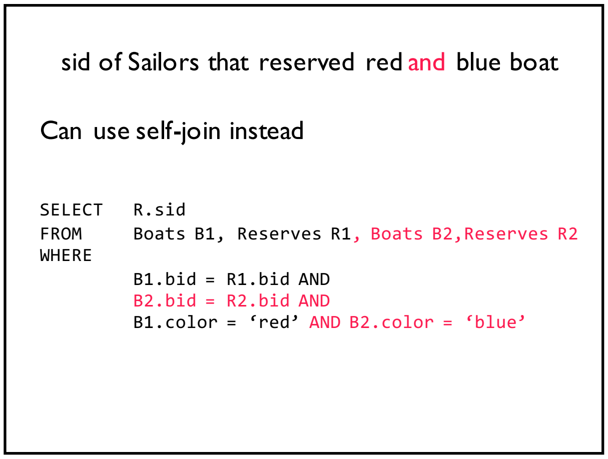
sid of Sailors that reserved red and blue boat

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'
```

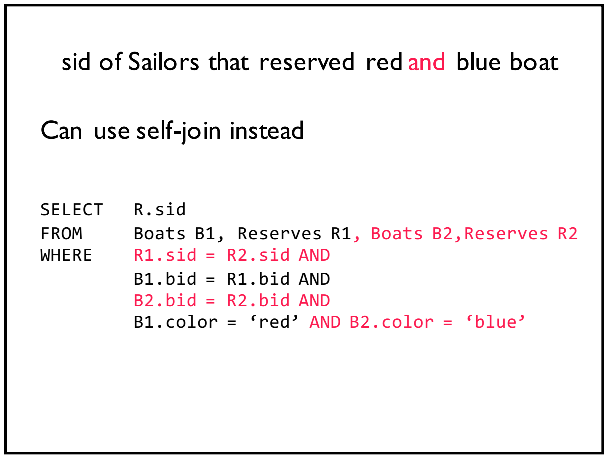


sid of Sailors that reserved red and blue boat

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

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

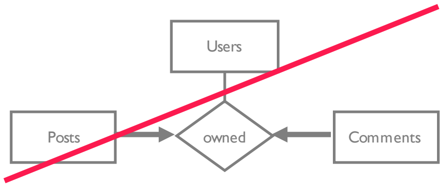
```
CREATE TABLE Offers (
    deptid text,
    courseid text,
    semester text,
    year int,
    . . .
    PRIMARY KEY(deptid, courseid, semester, year)
);
```

HW1 bugs

Reddit:

Comments owned by one user

Posts owned by one user



HW1 bugs

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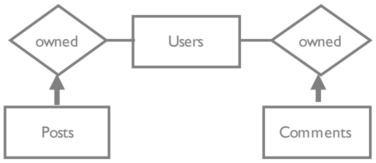


Sailors that reserved all boats (Division)

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

$$\text{Sailors} \bowtie \text{Reserves}$$

$$\cup$$

$$(\text{Sailors} - (\text{Sailors} \bowtie \text{Reserves})) \times \{(\text{null}, \ldots)\}$$

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    Sailors s RIGHT OUTER JOIN Reserves r
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
```

Target-list contains

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

grouping-list is a list of expressions that defines groups

- set of tuples w/ same value for all attributes in grouping-list

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

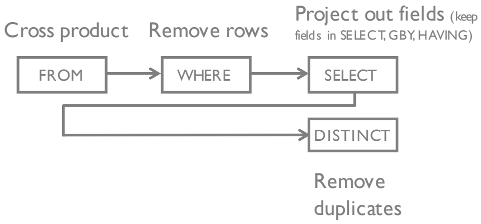
Expressions must have *one value per group*. Either

- An aggregation function or
- In *grouping-list*

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

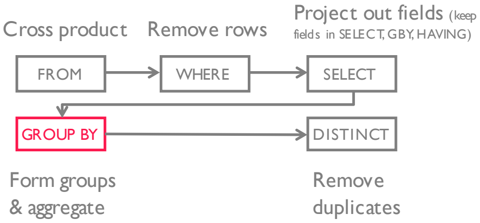
Conceptual Query Evaluation

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*
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WHERE *qualification*
GROUP BY *grouping-list*
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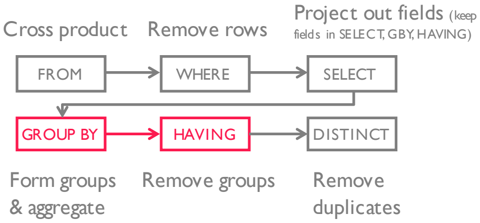
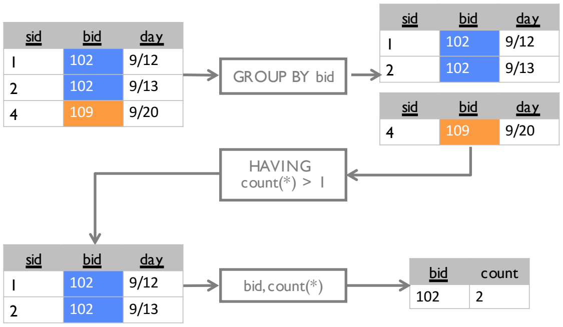


Conceptual Evaluation



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

GROUP BY bid

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

sid	bid	day
4	109	9/20

HAVING count(*) > 1

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

bid, count(*)

bid	count
102	2

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(tmp.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
)
```

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: General Constraints

```
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 boats + # of sailors 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

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
AS  $$
BEGIN

--  logic

END;
$$  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  $$
BEGIN

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END;
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```
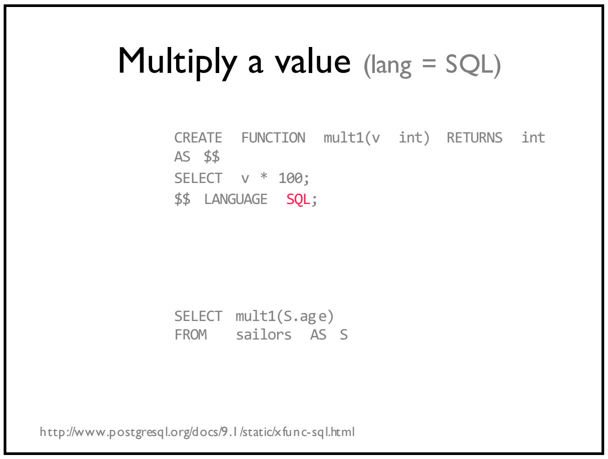
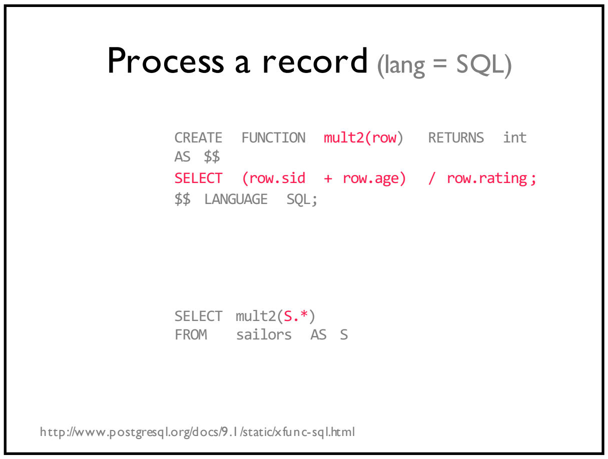



Multiply a value (lang = SQL)

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

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

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

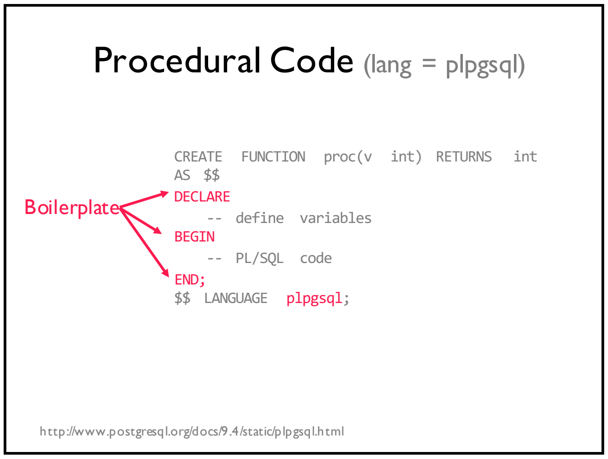


Process a record (lang = SQL)

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

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

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

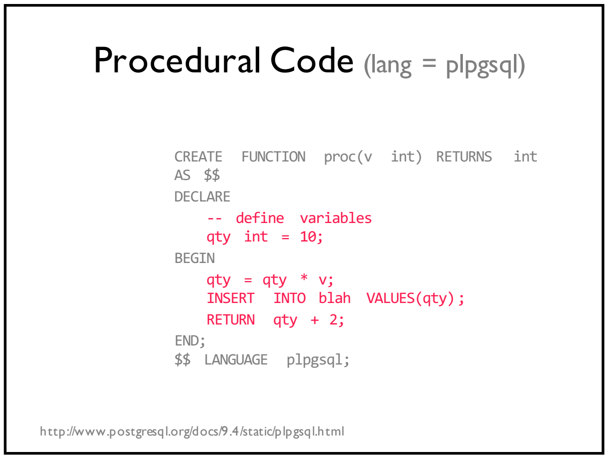


Procedural Code (lang = plpgsql)

Boilerplate

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

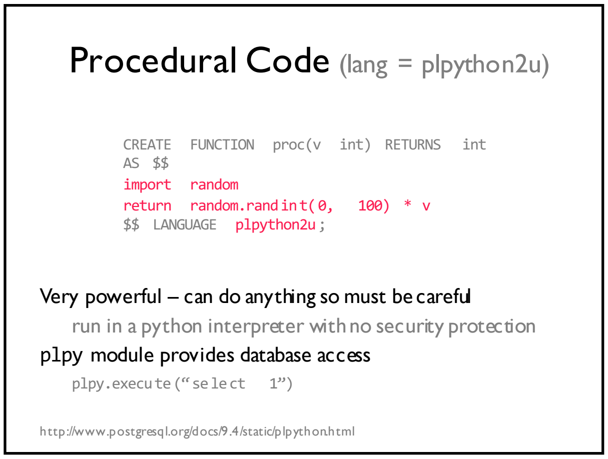
http://www.postgresql.org/docs/9.4/static/plpgsql.html



Procedural Code (lang = plpgsql)

```
CREATE FUNCTION proc(v int) RETURNS int
AS $$
DECLARE
    -- define variables
    qty int = 10;
BEGIN
    qty = qty * v;
    INSERT INTO blah VALUES(qty);
    RETURN qty + 2;
END;
$$ 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;
```

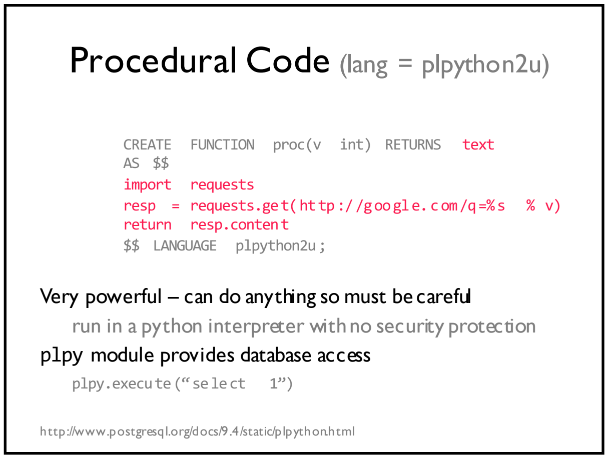
Very powerful – can do anything so must be careful

- 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(v int) RETURNS text
AS $$
import requests
resp = requests.get(http://google.com/q=%s % v)
return resp.content
$$ 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
```

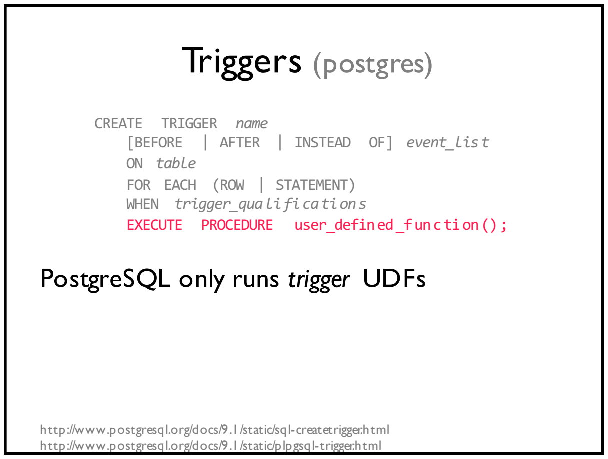
Event activates the trigger
Condition tests if triggers should run
Action what to do

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
```

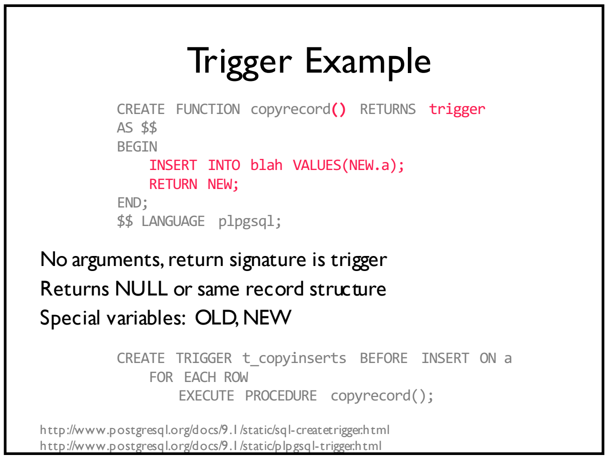


Triggers (postgres)

```
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;
```

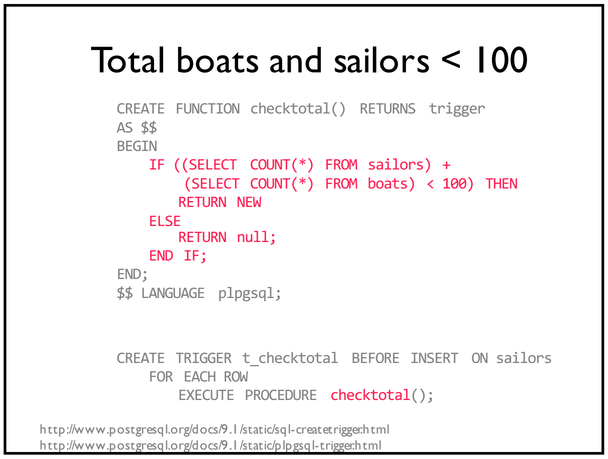
No arguments, return signature is trigger

Returns NULL or same record structure

Special variables: OLD, NEW

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

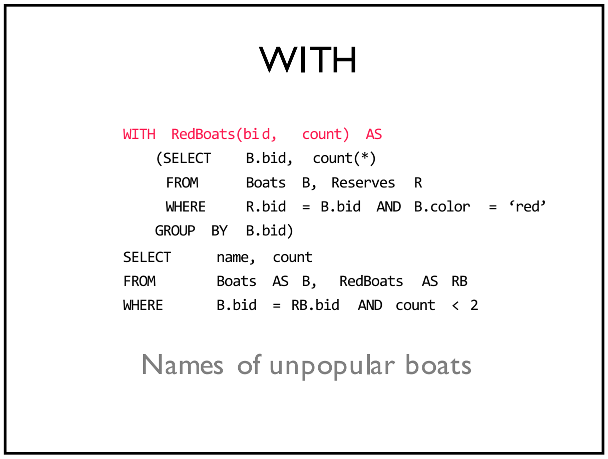
http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html



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();
```

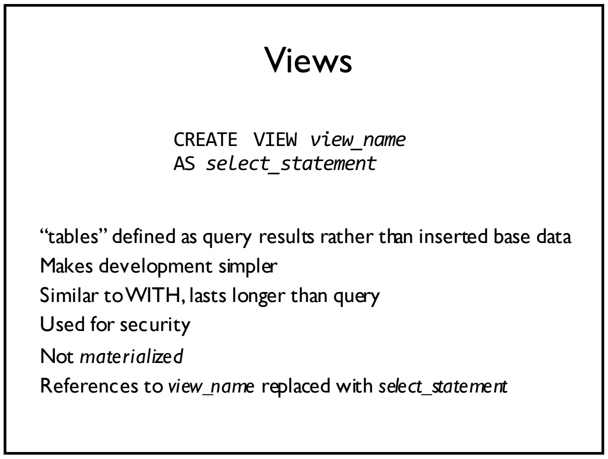
http://www.postgresql.org/docs/9.1/static/sql-createtrigger.html
http://www.postgresql.org/docs/9.1/static/plpgsql-trigger.html



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

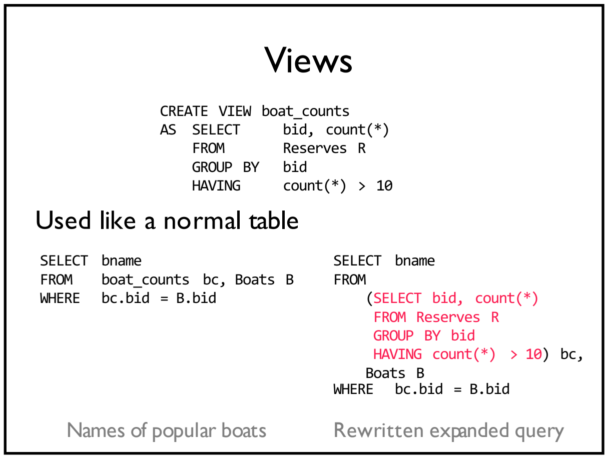
Makes development simpler

Similar to WITH, lasts longer than query

Used for security

Not *materialized*

References to *view_name* replaced with *select_statement*



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