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?

Rewrite INTERSECT using IN

```
SELECT S2.name
FROM Sailors S2, (
    SELECT S.sid
    FROM   Sailors S
    WHERE  S.rating > 2

    INTERSECT

    SELECT R.sid
    FROM   Reserves R
    ) as tmp
WHERE tmp.sid = S2.sid
```

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

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)
)
```

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == ∄ boat ∄ 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 == ∄ boat ∄ 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 == ∄ boat ∄ 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
                                          AND R.bid = B.bid ))
```

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
```

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

Result

sid	name	bid

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?

Joins as For Loops

```
for s in Sailors:

    for r in Reserves:
        if s.sid = r.sid:
            yield s, r
```

Inner Join

Joins as For Loops

```
for s in Sailors:
    bmatched = False
    for r in Reserves:
        if s.sid = r.sid:
            yield s, r
            bmatched = True

    if not bmatched:
        yield s, null
```

Left Outer Join

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?

Functions as Joins

What is f(x) = x * 2?

What is f(8)?

x
8

f

x	y
1	1*2 = 2
2	2*2 = 4
3	3*2 = 6
...	...

How big is this relation?

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 minimum age *per rating level*?

We don't even know how many rating levels exist!

If we did, could write (awkward):

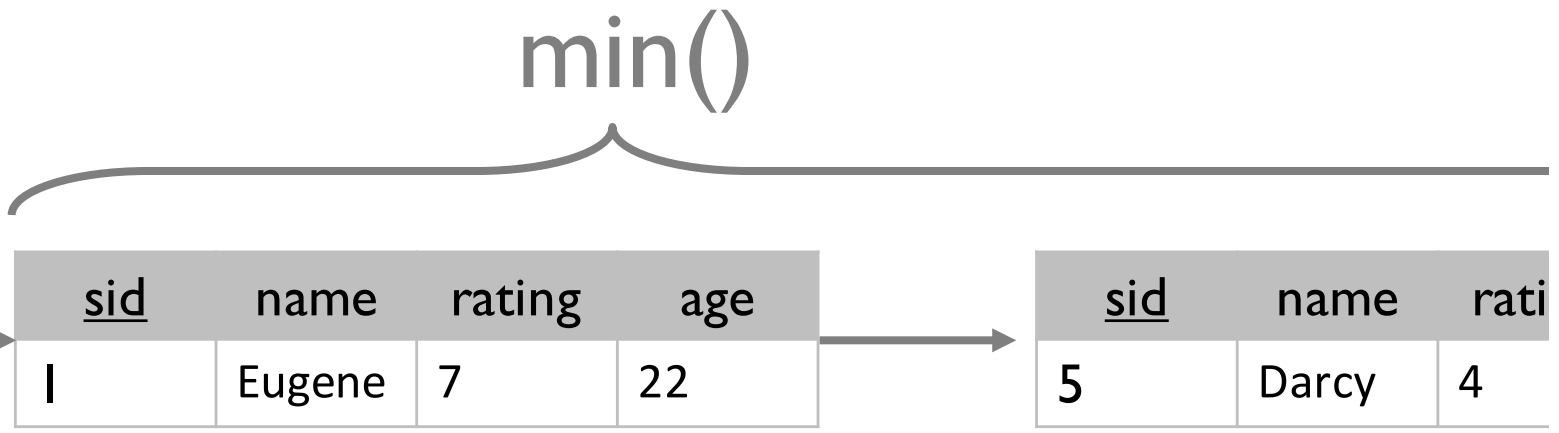
```
for rating in [0…10]
    SELECT min(s.age)
    FROM   Sailors s
    WHERE  s.rating = <rating>
```

In relational terms, what is this??

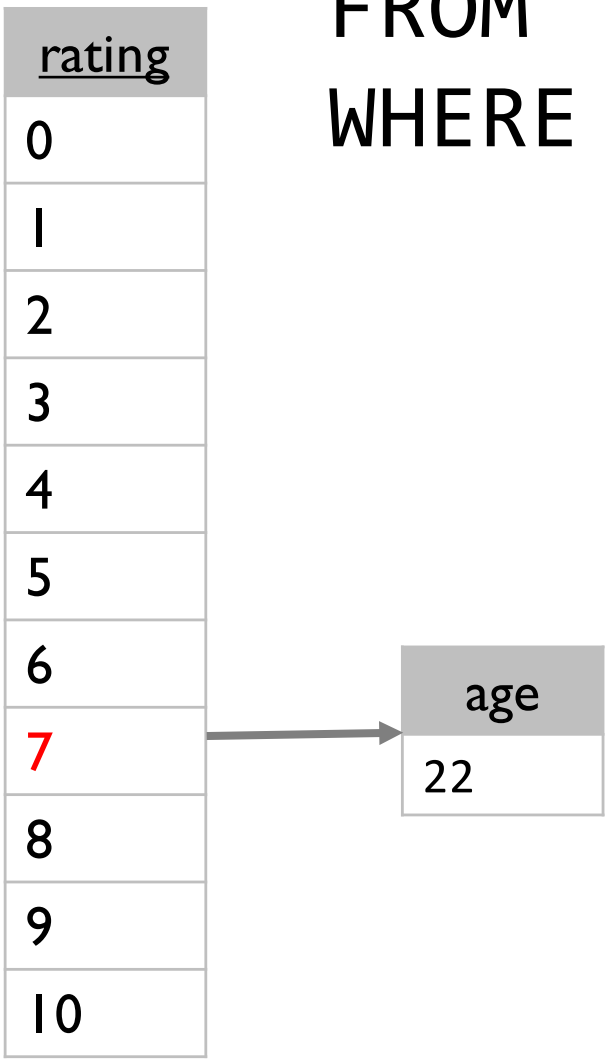
```
for rating in [0...10]
   SELECT min(s.age)
   FROM  Sailors s
   WHERE s.rating = <rating>
```

```
for rating in ratings
   SELECT min(s.age)
   FROM   Sailors s
   WHERE  s.rating = <rating>
```

rating
0
1
2
3
4
5
6
7
8
9
10



```
for rating in ratings
   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 [100…131]
    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

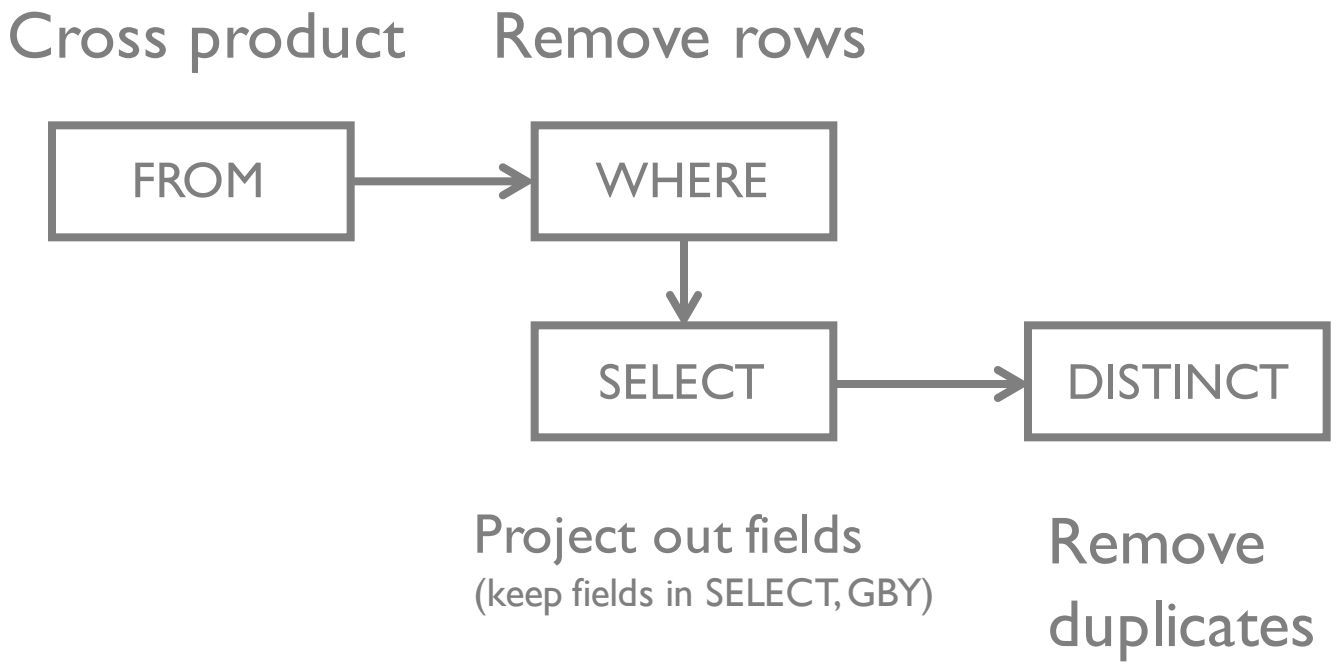
target-list contains

attribute-names $\subseteq$ *grouping-list*

aggregation expressions

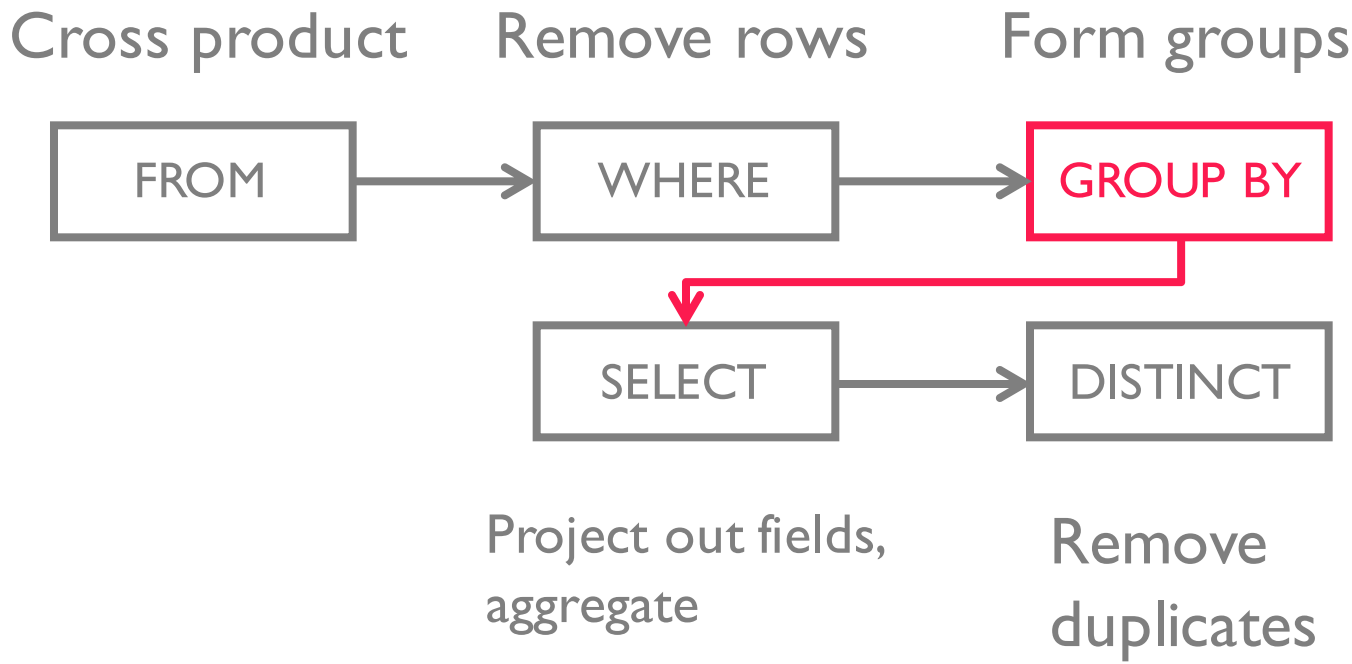
Conceptual Query Evaluation

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



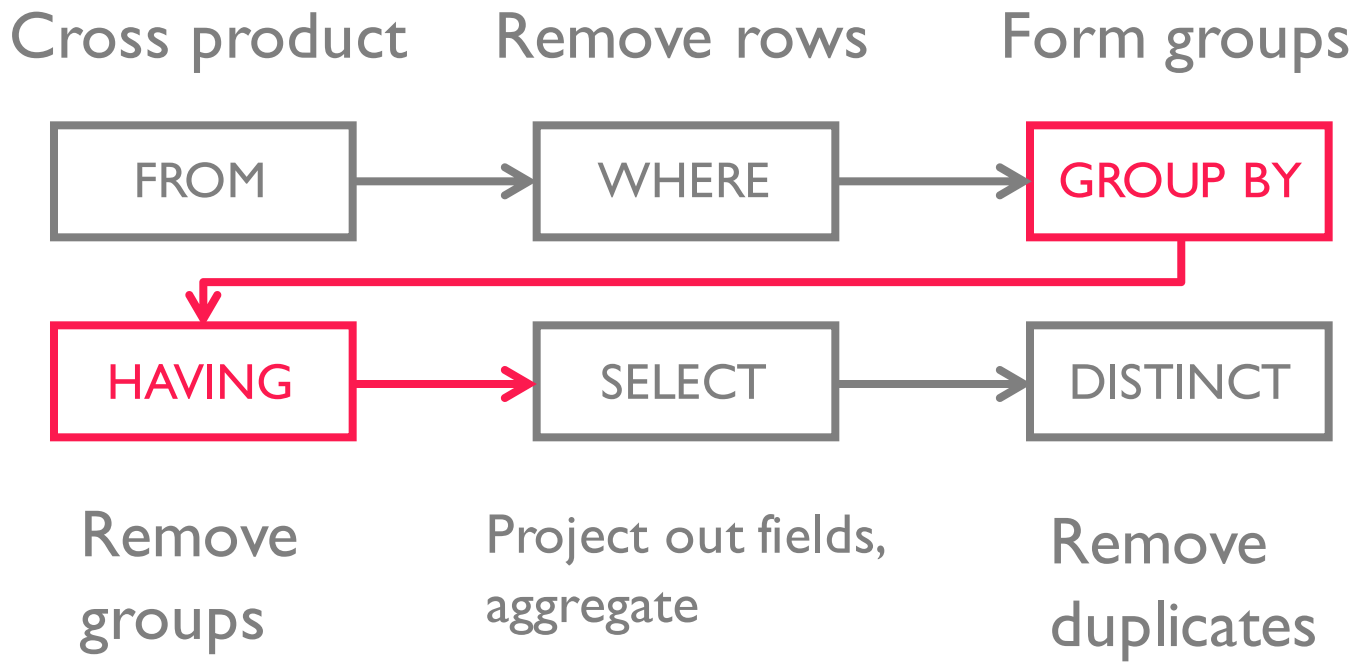
Conceptual Query Evaluation

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

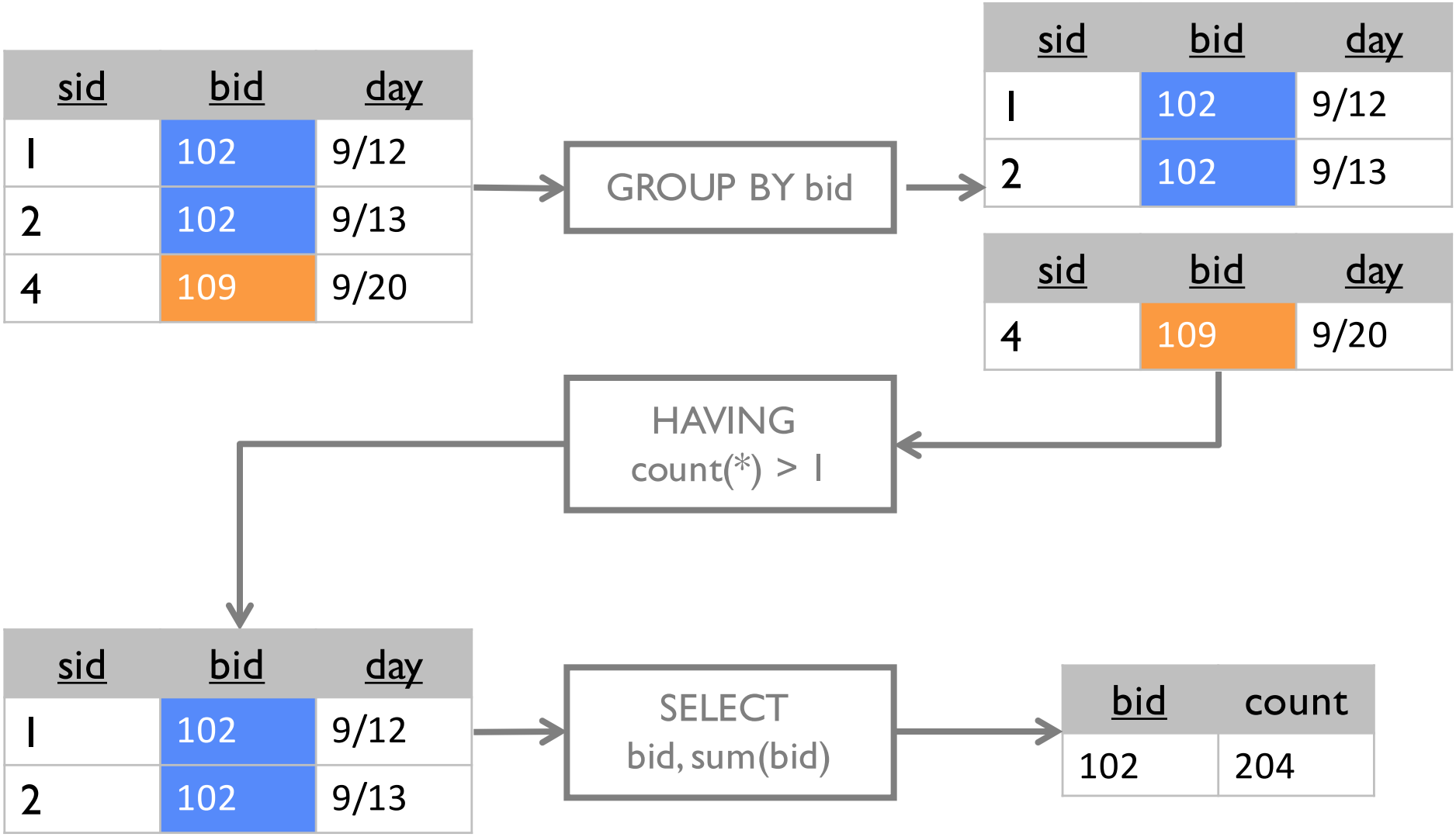


Conceptual Query Evaluation

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



Conceptual Evaluation



GROUP BY

```
SELECT    rating, min(age)
FROM      Sailors
GROUP BY  rating
```

Minimum age for each rating

```
SELECT    min(age)
FROM      Reserves R, Sailors S
WHERE     S.sid = R.sid
GROUP BY  bid
HAVING    count(*) > 1
```

Minimum sailor 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?

Error

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
)
```

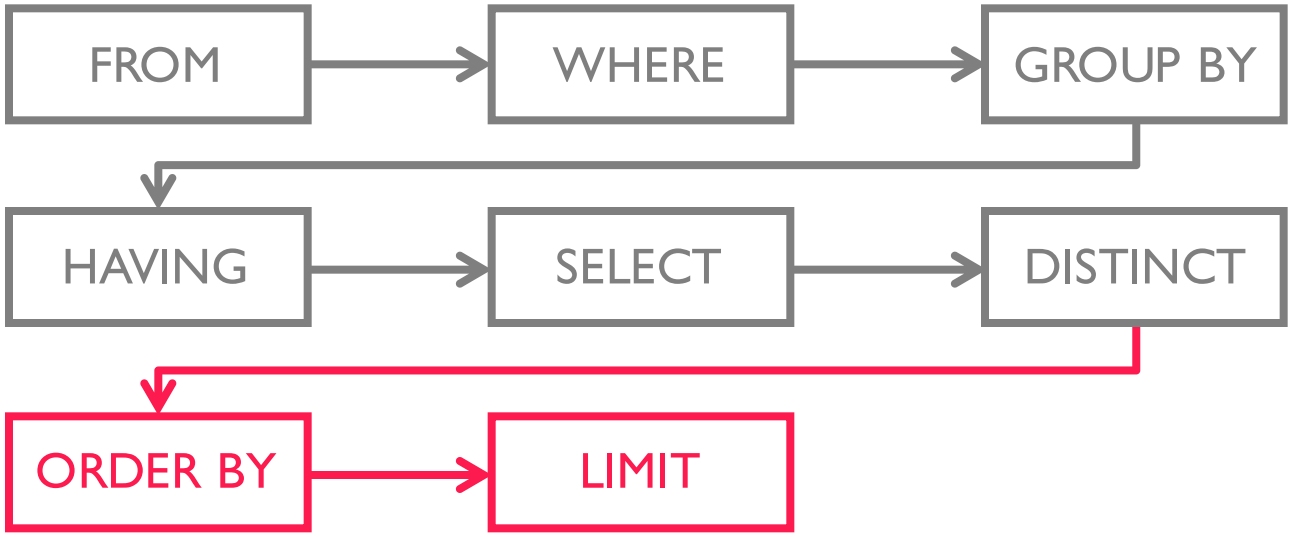
Ratings where the avg age is min over all ratings

```
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
)
```

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
)
```

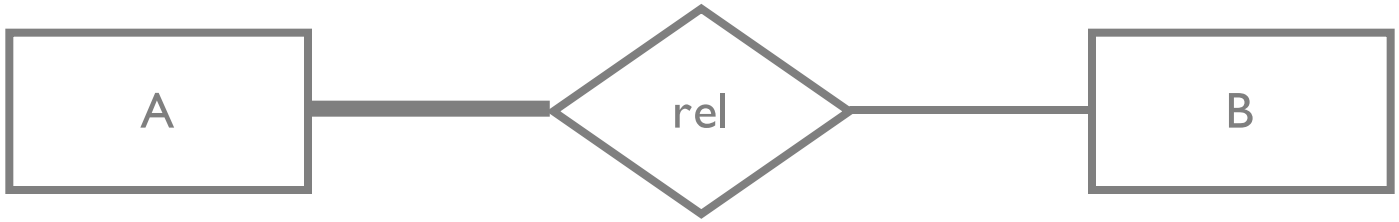
ASSERTIONs are not associated with any table

Total Participation

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

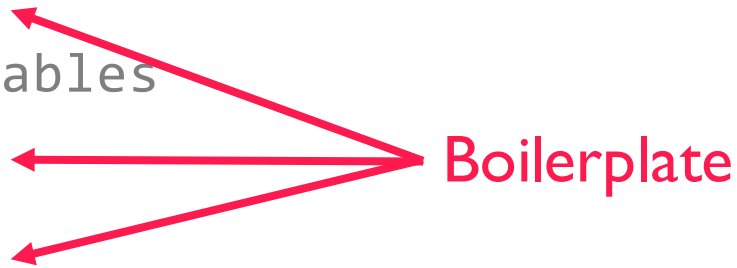
Result

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;
```



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

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 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
```

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