L5
SQL SQL SQL SQL SQL SQL SQL

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Didn't Lecture 3 Go Over SQL?

Two sublanguages

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

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

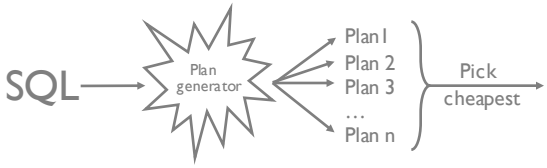
Gritty Details

DDL
- NULL, Views

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

Didn't Lecture 3 Go Over SQL?

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



Didn't Lecture 3 Go Over SQL?

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

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

Today's Database

Sailors

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

Boats

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

Reserves

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

Is Reserves table correct?

Today's Database

Sailors

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

Boats

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

Reserves

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

Is Reserves table correct?
Day should be part of key

Follow along at home!

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

or

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

<30 year old sailors

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

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

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

name	age
Eugene	22
Ken	27

<30 year old sailors

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

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

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

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

Multiple Relations

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

Sailors

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

Reserves

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

Multiple Relations

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

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

Structure of a SQL Query

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

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

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

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

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

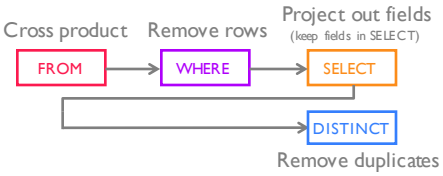
Semantics

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

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

Conceptual Query Evaluation

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



Not how actually executed! Above is likely very slow

DISTINCT (vol.1)

Reserves

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

```
SELECT   bid
FROM     Reserves
```

bid
102
102
103

```
SELECT   DISTINCT bid
FROM     Reserves
```

bid
102
103

Sailors that reserved 1+ boats

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

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

Range Variables

Disambiguate relations
same table used multiple times (self join)

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

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

Range Variables

Disambiguate relations

same table used multiple times (self join)

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

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

Expressions (Math)

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

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

Expressions (Strings)

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

'_' any one character (. in regex)

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

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

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

Expressions (Date/Time)

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

TIMESTAMP, DATE, TIME types

now() returns timestamp at start of transaction

DBMSes provide rich time manipulation support

exact support may vary by vender

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

Expressions

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

sid of Sailors that reserved red or blue boat

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

OR

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

sid of Sailors that reserved red or blue boat

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

OR

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

sid of Sailors that reserved red and blue boat

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

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

sid of Sailors that reserved red and blue boat

Can use self-join instead

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

         B1.color = 'red'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

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

         B1.color = 'red'
```

sid of Sailors that reserved red and blue boat

Can use self-join instead

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

sid of Sailors that reserved red and blue boat

Can use self-join instead

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

sids of sailors that haven't reserved a boat

```
SELECT   S.sid
FROM     Sailors S

EXCEPT

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

Can we write EXCEPT using more basic functionality?

SET Comparison Operators

UNION, INTERSECT, EXCEPT

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

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

Many of these rely on Nested Query Support

Nested Queries

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

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

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

Nested Correlated Queries

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

Outer table referenced in nested query

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

Nested Correlated Queries

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

UNIQUE checks that there are no duplicates

What does this do?

Nested Correlated Queries

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

UNIQUE checks that there are no duplicates

What does this do?

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

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

What about this?

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

Rewrite INTERSECT using IN

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

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

Similar trick for EXCEPT → NOT IN

What if want *names* instead of sids?

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

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

    (SELECT    B.bid  FROM    Boats  B)

    EXCEPT

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

HW1 bugs

Conflicting CHECK constraints

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

conflicting

HW1 bugs

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

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

Wrong

HW1 bugs

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

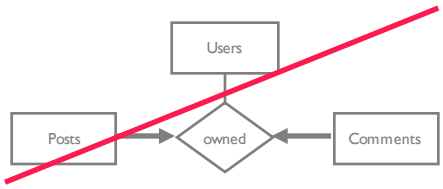
```
CREATE TABLE Offers (
   deptid text,
   courseid text,
   semester text,
   year int,
   . . .
   PRIMARY KEY(deptid, courseid, semester, year)
);
```

HW1 bugs

Reddit:

Comments owned by one user

Posts owned by one user



HW1 bugs

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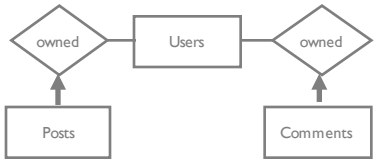


Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

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

Sailors S such that

There's no boat without

A reservation by S

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

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

Sailors S such that

There's no boat without

A reservation by S

Sailors that reserved all boats (Division)

Hint: double negation

reserved all boats == no boat w/out reservation

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

Sailors S such that

There's no boat without

A reservation by S

NULL

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

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

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

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

NULL

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

Some truth tables

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

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

JOINS

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

INNER is default
Difference in how to deal with NULL values

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

Inner/Natural Join

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

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

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

All Equivalent!

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

Sailor names and their reserved boat ids

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

Sailors

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

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Sailor names and their reserved boat ids

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

Sailors

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

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Prefer INNER JOIN over NATURAL JOIN. Why?

Sailor names and their reserved boat ids

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

Sailors

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

Reserves

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

Result

sid	name	bid
1	Eugene	102
2	Luis	102

Notice: No result for Ken!

Left Outer Join (or No Results for Ken)

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

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

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

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

Left Outer Join

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

Sailors

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

Reserves

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

Result

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

Can Left Outer Join be expressed with Cross-Product?

Sailors

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

Reserves

sid	bid	day

Sailors x Reserves

Result

sid	name	bid

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

Result

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

Can Left Outer Join be expressed with Cross-Product?

Sailors

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

Reserves

sid	bid	day

Sailors ⋈ Reserves

U

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

How to compute this with a query?

Right Outer Join

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

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

FULL OUTER JOIN

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

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

FULL OUTER JOIN

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

Sailors

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

Reserves

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

Result

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

Why is sid NULL?

Serious people can count: Aggregation

```
SELECT  COUNT(*)
FROM    Sailors S

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

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

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

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

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

Name and age of oldest sailor(s)

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

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

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

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

← When does this not work?

GROUP BY

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

Minimum age among all sailors

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

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

GROUP BY

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

Total number of reservations

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

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

GROUP BY

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

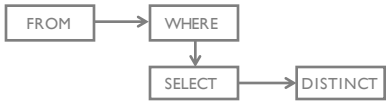
grouping-list is a list of expressions that defines groups
- set of tuples w/ same value for all attributes in grouping-list

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

Conceptual Query Evaluation

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

Cross product Remove rows

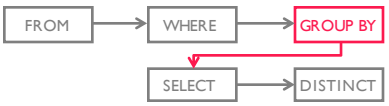


Project out fields (keep fields in SELECT GBY) Remove duplicates

Conceptual Query Evaluation

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

Cross product Remove rows Form groups



Project out fields, aggregate Remove duplicates

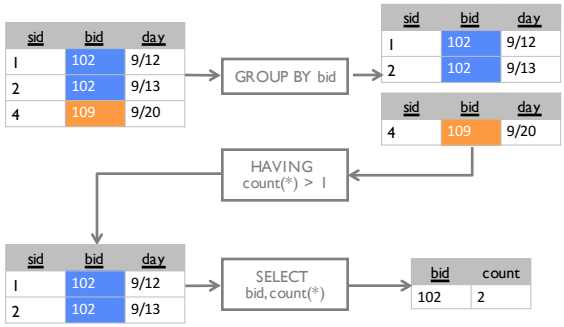
Conceptual Query Evaluation

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

Cross product Remove rows Form groups

Remove groups Project out fields, aggregate Remove duplicates

Conceptual Evaluation



GROUP BY

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

Minimum age for each rating

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

Minimum age for each boat with more than 1 reservation

HAVING

group-qualification used to remove groups
similar to WHERE clause

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

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

AVG age of sailors reserving red boats, by rating

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

AVG age of sailors reserving red boats, by rating

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

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

Ratings where the avg age is min over all ratings

✗

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

✔

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

Ratings where the avg age is min over all ratings

✗

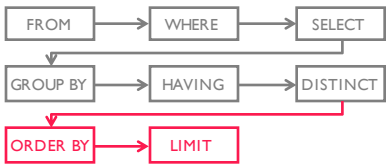
```
SELECT S.rating
FROM   Sailors S
WHERE  S.age = (
           SELECT MIN(AVG(S2.age))
           FROM Sailors S2
       )
```

✔

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

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.age  / (S.rating   + 1)  ASC,
            S.rating   DESC
```

List of *order-list* expressions dictates ordering precedence
- Sorted in ascending by age/rating ratio
- If ties, sorted high to low rating

LIMIT

```
SELECT      S.name
FROM        Sailors  S
ORDER  BY   S.age  / (S.rating   + 1)  ASC,
            S.rating   DESC
LIMIT       5
```

Only the first 5 results

LIMIT

```
SELECT      S.name
FROM        Sailors  S
ORDER  BY   S.age  / (S.rating   + 1)  ASC,
            S.rating   DESC
LIMIT       (SELECT  count(S2.*)  / 2
             FROM  Sailors  AS  S2)
```

Can have expressions instead of constants

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;
```

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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