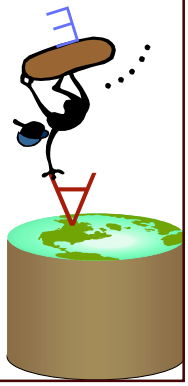
Relational Calculus

CS 186, Fall 2005
R&G, Chapter 4

We will occasionally use this arrow notation unless there is danger of no confusion.

Ronald Graham
Elements of Ramsey Theory



Relational Calculus

- **Comes in two flavors: *Tuple relational calculus* (TRC) and *Domain relational calculus* (DRC).**
- **Calculus has *variables, constants, comparison ops, logical connectives* and *quantifiers*.**
  - *TRC*: Variables range over (i.e., get bound to) *tuples*.
    - Like SQL.
  - *DRC*: Variables range over *domain elements* (= field values).
    - Like Query-By-Example (QBE)
  - Both TRC and DRC are simple subsets of first-order logic.
    - We'll focus on TRC here
- **Expressions in the calculus are called *formulas*.**
- **Answer tuple is an assignment of constants to variables that make the formula evaluate to *true*.**

Tuple Relational Calculus

- ***Query* has the form: $\{T \mid p(T)\}$**
  - ***p(T)*** denotes a formula in which tuple variable ***T*** appears.
- ***Answer* is the set of all tuples *T* for which the *formula p(T)* evaluates to *true*.**
- ***Formula* is recursively defined:**
  - ❖start with simple *atomic formulas* (get tuples from relations or make comparisons of values)
  - ❖build bigger and better formulas using the *logical connectives*.

TRC Formulas

- ***An Atomic formula is one of the following:***
  - $R \in Rel$
  - $R.a\ op\ S.b$
  - $R.a\ op\ constant$
  - *op* is one of $<, >, =, \leq, \geq, \neq$
- **A *formula* can be:**
  - an atomic formula
  - $\neg p, p \wedge q, p \vee q$ where p and q are formulas
  - $\exists R(p(R))$ where variable R is a tuple variable
  - $\forall R(p(R))$ where variable R is a tuple variable

Free and Bound Variables

- **The use of quantifiers $\exists X$ and $\forall X$ in a formula is said to *bind* X in the formula.**
  - A variable that is not bound is free.
- **Let us revisit the definition of a query:**
  - $\{T \mid p(T)\}$
- **There is an important restriction**
  - the variable T that appears to the left of `|' must be the *only* free variable in the formula $p(T)$.
  - in other words, all other tuple variables must be bound using a quantifier.

Selection and Projection

- **Find all sailors with rating above 7**

$$\{S \mid S \in Sailors \wedge S.rating > 7\}$$

  - Modify this query to answer: Find sailors who are older than 18 or have a rating under 9, and are called 'Bob'.
- **Find names and ages of sailors with rating above 7.**

$$\{S \mid \exists S1 \in Sailors(S1.rating > 7 \wedge S.sname = S1.sname \wedge S.age = S1.age)\}$$

  - Note: S is a tuple variable of 2 fields (i.e. {S} is a projection of *Sailors*)
    - only 2 fields are ever mentioned and *S* is never used to range over any relations in the query.

Joins

Find sailors rated > 7 who've reserved boat #103

$$\{S \mid S \in Sailors \wedge S.rating > 7 \wedge \exists R(R \in Reserves \wedge R.sid = S.sid \wedge R.bid = 103)\}$$

Note the use of ∃ to find a tuple in Reserves that `joins with' the Sailors tuple under consideration.

Joins (continued)

$$\{S \mid S \in Sailors \wedge S.rating > 7 \wedge \exists R(R \in Reserves \wedge R.sid = S.sid \wedge \exists B(B \in Boats \wedge B.bid = R.bid \wedge B.color = \text{'red'}))\}$$

Find sailors rated > 7 who've reserved a red boat

- **Observe how the parentheses control the scope of each quantifier's binding.**
- **This may look cumbersome, but it's not so different from SQL!**

Division (makes more sense here???)

Find sailors who've reserved all boats
(hint, use ∀)

$$\{S \mid S \in Sailors \wedge \forall B \in Boats\ (\exists R \in Reserves\ (S.sid = R.sid \wedge B.bid = R.bid))\}$$

- **Find all sailors *S* such that for all tuples *B* in Boats there is a tuple in Reserves showing that sailor *S* has reserved *B*.**

Division – a trickier example…

Find sailors who've reserved all Red boats

$$\{S \mid S \in Sailors \wedge \forall B \in Boats\ (B.color = \text{'red'} \Rightarrow \exists R(R \in Reserves \wedge S.sid = R.sid \wedge B.bid = R.bid))\}$$

Alternatively…

$$\{S \mid S \in Sailors \wedge \forall B \in Boats\ (B.color \neq \text{'red'} \vee \exists R(R \in Reserves \wedge S.sid = R.sid \wedge B.bid = R.bid))\}$$

$a \Rightarrow b$ is the same as $\neg a \vee b$

a \ b	T	F
T	T	F
F	T	T

- **If a is true, b must be true!**
  - If a is true and b is false, the implication evaluates to false.
- **If a is not true, we don't care about b**
  - The expression is always true.

Unsafe Queries, Expressive Power

- **∃ syntactically correct calculus queries that have an infinite number of answers! *Unsafe* queries.**
  - e.g., $\{S \mid \neg(S \in Sailors)\}$
  - Solution???? Don't do that!
- **Expressive Power (Theorem due to Codd):**
  - every query that can be expressed in relational algebra can be expressed as a *safe* query in DRC / TRC; the converse is also true.
- ***Relational Completeness*: Query language (e.g., SQL) can express every query that is expressible in relational algebra/calculus. (actually, SQL is more powerful, as we will see…)**

Summary

- **The relational model has rigorously defined query languages — simple and powerful.**
- **Relational algebra is more operational**
  - useful as internal representation for query evaluation plans.
- **Relational calculus is non-operational**
  - users define queries in terms of what they want, not in terms of how to compute it. (*Declarative*)
- **Several ways of expressing a given query**
  - a *query optimizer* should choose the most efficient version.
- **Algebra and safe calculus have same *expressive power***
  - leads to the notion of *relational completeness*.

Addendum: Use of ∀

- ∀x (P(x)) - is only true if P(x) is true for *every* x in the universe
- Usually:

  ∀x ((x ∈ Boats) ⇒ (x.color = "Red")
- ⇒ logical implication,

  a ⇒ b means that if a is true, b must be true

  a ⇒ b is the same as ¬a ∨ b

Find sailors who've reserved all boats

{S | S∈Sailors ∧
∀B((B∈Boats) ⇒
∃R(R∈Reserves ∧ S.sid = R.sid
∧ B.bid = R.bid))}

- **Find all sailors *S* such that for each tuple *B* either it is not a tuple in Boats or there is a tuple in Reserves showing that sailor *S* has reserved it.**

{S | S∈Sailors ∧
∀B(¬(B∈Boats) ∨
∃R(R∈Reserves ∧ S.sid = R.sid
∧ B.bid = R.bid))}

... reserved all red boats

{S | S∈Sailors ∧
∀B((B∈Boats ∧ B.color = "red") ⇒
∃R(R∈Reserves ∧ S.sid = R.sid
∧ B.bid = R.bid))}

- **Find all sailors *S* such that for each tuple *B* either it is not a tuple in Boats or there is a tuple in Reserves showing that sailor *S* has reserved it.**

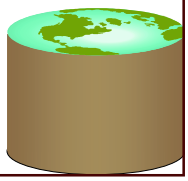
{S | S∈Sailors ∧
∀B(¬(B∈Boats) ∨ (B.color ≠ "red") ∨
∃R(R∈Reserves ∧ S.sid = R.sid
∧ B.bid = R.bid))}

SQL: The Query Language Part 1

CS186, Fall 2005
R&G, Chapter 5

Life is just a bowl of queries.

-Anon
(not Forrest Gump)



Relational Query Languages

- **A major strength of the relational model: supports simple, powerful *querying* of data.**
- **Two sublanguages:**
- **DDL – Data Definition Language**
  - define and modify schema (at all 3 levels)
- **DML – Data Manipulation Language**
  - Queries can be written intuitively.
- **The DBMS is responsible for efficient evaluation.**
  - The key: precise semantics for relational queries.
  - Allows the optimizer to re-order/change operations, and *ensure that the answer does not change*.
  - Internal cost model drives use of indexes and choice of access paths and physical operators.

The SQL Query Language

- The most widely used relational query language.
  - Current standard is SQL-1999
    - Not fully supported yet
    - Introduced "Object-Relational" concepts (and lots more)
      - Many of which were pioneered in Postgres here at Berkeley!
  - SQL-200x is in draft
  - SQL-92 is a basic subset
    - Most systems support a medium
  - PostgreSQL has some "unique" aspects
    - as do most systems.
  - XML support/integration is the next challenge for SQL (more on this in a later class).

DDL – Create Table

- **CREATE TABLE *table_name***
  ({ *column_name data_type* [DEFAULT *default_expr*] [*column_constraint* [, ...]] | *table_constraint* } [, ...])

- **Data Types (PostgreSQL) include:**
  character(n) – fixed-length character string
  character varying(n) – variable-length character string
  smallint, integer, bigint, numeric, real, double precision
  date, time, timestamp, …
  serial - unique ID for indexing and cross reference
  …
- **PostgreSQL also allows OIDs, arrays, inheritance, rules…**
  conformance to the SQL-1999 standard is variable so we won't use these in the project.

Create Table (w/column constraints)

- **CREATE TABLE *table_name***
  ({ *column_name data_type* [DEFAULT *default_expr*] [*column_constraint* [, ...]] | *table_constraint* } [, ...])

Column Constraints:

- **[CONSTRAINT *constraint_name*]**
  { NOT NULL | NULL | UNIQUE | PRIMARY KEY | CHECK (*expression*) |
  REFERENCES *reftable* [(*refcolumn*)] [ON DELETE *action*] [ON UPDATE *action*] }

***action* is one of:**
NO ACTION, CASCADE, SET NULL, SET DEFAULT

***expression* for column constraint must produce a boolean result and reference the related column's value only.**

Create Table (w/table constraints)

- **CREATE TABLE *table_name***
  ({ *column_name data_type* [DEFAULT *default_expr*] [*column_constraint* [, ...]] | *table_constraint* } [, ...])

Table Constraints:

- **[CONSTRAINT *constraint_name*]**
  { UNIQUE (*column_name* [, ...]) |
  PRIMARY KEY (*column_name* [, ...]) |
  CHECK (*expression*) |
  FOREIGN KEY (*column_name* [, ...]) REFERENCES *reftable* [(*refcolumn* [, ...])] [ON DELETE *action*] [ON UPDATE *action*] }

Here, *expressions, keys, etc can include multiple columns*

Create Table (Examples)

```
CREATE TABLE films (
    code          CHAR(5) PRIMARY KEY,
    title         VARCHAR(40),
    did           DECIMAL(3),
    date_prod     DATE,
    kind          VARCHAR(10),
CONSTRAINT production UNIQUE(date_prod)
FOREIGN KEY did REFERENCES distributors
   ON DELETE NO ACTION
);
CREATE TABLE distributors (
    did     DECIMAL(3) PRIMARY KEY,
    name    VARCHAR(40)
    CONSTRAINT con1 CHECK (did > 100 AND name <> ' ')
);
```

The SQL DML

- Single-table queries are straightforward.
- To find all 18 year old students, we can write:

```
SELECT *
  FROM Students S
 WHERE S.age=18
```

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2

- To find just names and logins, replace the first line:

```
SELECT S.name, S.login
```

Querying Multiple Relations

- Can specify a join over two tables as follows:

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid AND E.grade='B'
```

sid	cid	grade
53831	Carnatic101	C
53831	Reggae203	B
53650	Topology112	A
53666	History105	B

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@ee	18	3.2

result =

S.name	E.cid
Jones	History105

Note: obviously no referential integrity constraints have been used here.

Basic SQL Query

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

- *relation-list* : A list of relation names
  - possibly with a *range-variable* after each name
- *target-list* : A list of attributes of tables in *relation-list*
- *qualification* : Comparisons combined using AND, OR and NOT.
  - Comparisons are Attr *op* const or Attr1 *op* Attr2, where *op* is one of $<, >, =, \leq, \geq, \neq$
- *DISTINCT*: optional keyword indicating that the answer should not contain duplicates.
  - In SQL SELECT, the default is that duplicates are *not* eliminated! (Result is called a "multiset")

Query Semantics

- Semantics of an SQL query are defined in terms of the following conceptual evaluation strategy:
  1. do FROM clause: compute *cross-product* of tables (e.g., Students and Enrolled).
  2. do WHERE clause: Check conditions, discard tuples that fail. (called "selection").
  3. do SELECT clause: Delete unwanted fields. (called "projection").
  4. If DISTINCT specified, eliminate duplicate rows.
- Probably the least efficient way to compute a query!
  - An optimizer will find more efficient strategies to get the *same answer*.

Step 1 – Cross Product

S.sid	S.name	S.login	S.age	S.gpa	E.sid	E.cid	E.grade
53666	Jones	jones@cs	18	3.4	53831	Carnatic101	C
53666	Jones	jones@cs	18	3.4	53832	Reggae203	B
53666	Jones	jones@cs	18	3.4	53650	Topology112	A
53666	Jones	jones@cs	18	3.4	53666	History105	B
53688	Smith	smith@ee	18	3.2	53831	Carnatic101	C
53688	Smith	smith@ee	18	3.2	53831	Reggae203	B
53688	Smith	smith@ee	18	3.2	53650	Topology112	A
53688	Smith	smith@ee	18	3.2	53666	History105	B

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid AND E.grade='B'
```

Step 2) Discard tuples that fail predicate

S.sid	S.name	S.login	S.age	S.gpa	E.sid	E.cid	E.grade
53666	Jones	jones@cs	18	3.4	53831	Carnatic101	C
53666	Jones	jones@cs	18	3.4	53832	Reggae203	B
53666	Jones	jones@cs	18	3.4	53650	Topology112	A
53666	Jones	jones@cs	18	3.4	53666	History105	B
53688	Smith	smith@ee	18	3.2	53831	Carnatic101	C
53688	Smith	smith@ee	18	3.2	53831	Reggae203	B
53688	Smith	smith@ee	18	3.2	53650	Topology112	A
53688	Smith	smith@ee	18	3.2	53666	History105	B

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid AND E.grade='B'
```

Step 3) Discard Unwanted Columns

S.sid	S.name	S.login	S.age	S.gpa	E.sid	E.cid	E.grade
53666	Jones	jones@cs	18	3.4	53831	Carnatic101	C
53666	Jones	jones@cs	18	3.4	53832	Reggae203	B
53666	Jones	jones@cs	18	3.4	53650	Topology112	A
53666	Jones	jones@cs	18	3.4	53666	History105	B
53688	Smith	smith@ee	18	3.2	53831	Carnatic101	C
53688	Smith	smith@ee	18	3.2	53831	Reggae203	B
53688	Smith	smith@ee	18	3.2	53650	Topology112	A
53688	Smith	smith@ee	18	3.2	53666	History105	B

```
SELECT S.name, E.cid
 FROM Students S, Enrolled E
 WHERE S.sid=E.sid AND E.grade='B'
```

Now the Details

We will use these instances of relations in our examples.

(Question: If the key for the Reserves relation contained only the attributes *sid* and *bid*, how would the semantics differ?)

Reserves

sid	bid	day
22	101	10/10/96
95	103	11/12/96

Sailors

sid	sname	rating	age
22	Dustin	7	45.0
31	Lubber	8	55.5
95	Bob	3	63.5

Boats

bid	bname	color
101	Interlake	blue
102	Interlake	red
103	Clipper	green
104	Marine	red

Example Schemas

```
CREATE TABLE Sailors (sid INTEGER PRIMARY KEY,
  sname CHAR(20),rating INTEGER,age REAL)

CREATE TABLE Boats (bid INTEGER PRIMARY KEY,
  bname CHAR (20), color CHAR(10))

 CREATE TABLE Reserves (
  sid INTEGER REFERENCES Sailors,
  bid INTEGER, day DATE,
  PRIMARY KEY (sid, bid, day),
  FOREIGN KEY (bid) REFERENCES Boats)
```

Another Join Query

```
SELECT  sname
FROM    Sailors, Reserves
WHERE   Sailors.sid=Reserves.sid
        AND bid=103
```

(sid)	sname	rating	age	(sid)	bid	day
22	dustin	7	45.0	22	101	10/10/96
22	dustin	7	45.0	95	103	11/12/96
31	lubber	8	55.5	22	101	10/10/96
31	lubber	8	55.5	95	103	11/12/96
95	Bob	3	63.5	22	101	10/10/96
95	Bob	3	63.5	95	103	11/12/96

Some Notes on Range Variables

- Can associate "range variables" with the tables in the FROM clause.
  - saves writing, makes queries easier to understand
- Needed when ambiguity could arise.
  - for example, if same table used multiple times in same FROM (called a "self-join")

```
SELECT sname
FROM Sailors,Reserves
WHERE Sailors.sid=Reserves.sid AND bid=103
```

Can be rewritten using range variables as:

```
SELECT S.sname
FROM Sailors S, Reserves R
WHERE S.sid=R.sid AND bid=103
```

More Notes

- Here's an example where range variables are required (self-join example):

```
SELECT  x.sname, x.age, y.sname, y.age
FROM Sailors x, Sailors y
WHERE  x.age > y.age
```

- Note that target list can be replaced by "*" if you don't want to do a projection:

```
SELECT  *
FROM Sailors x
WHERE  x.age > 20
```

Find sailors who've reserved at least one boat

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

- Would adding DISTINCT to this query make a difference?
- What is the effect of replacing *S.sid* by *S.sname* in the SELECT clause?
  - Would adding DISTINCT to this variant of the query make a difference?

Expressions

- Can use arithmetic expressions in SELECT clause (plus other operations we'll discuss later)
- Use AS to provide column names

```
SELECT S.age, S.age-5 AS age1, 2*S.age AS age2
   FROM  Sailors S
WHERE  S.sname = 'Dustin'
```

- Can also have expressions in WHERE clause:

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

String operations

- SQL also supports some string operations
- "LIKE" is used for string matching.

```
SELECT  S.age, S.age-5 AS age1, 2*S.age AS age2
   FROM  Sailors S
WHERE  S.sname LIKE 'B_%b'
```

`_' stands for any one character and `%' stands for 0 or more arbitrary characters.

Find sid's of sailors who've reserved a red **or** a green boat

- UNION: Can be used to compute the union of any two *union-compatible* sets of tuples (which are themselves the result of SQL queries).

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

Vs.

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

Find sid's of sailors who've reserved a red **and** a green boat

- If we simply replace OR by AND in the previous query, we get the wrong answer. (Why?)
- Instead, could use a self-join:

```
SELECT R1.sid
   FROM Boats B1, Reserves R1,
              Boats B2, Reserves R2
WHERE R1.sid=R2.sid
      AND R1.bid=B1.bid
      AND R2.bid=B2.bid
      AND (B1.color='red' AND B2.color='green')
```

AND Continued…

- **INTERSECT:discussed in book. Can be used to compute the intersection of any two *union-compatible* sets of tuples.**
- **Also in text: EXCEPT (sometimes called MINUS)**
- **Included in the SQL/92 standard, but many systems don't support them.**
  - But PostgreSQL does!

Key field!

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

Nested Queries

- **Powerful feature of SQL: WHERE clause can itself contain an SQL query!**
  - Actually, so can FROM and HAVING clauses.

Names of sailors who've reserved boat #103:

```
SELECT  S.sname
FROM  Sailors S
WHERE  S.sid IN (SELECT R.sid
                 FROM  Reserves R
                 WHERE  R.bid=103)
```

- **To find sailors who've *not* reserved #103, use NOT IN.**
- **To understand semantics of nested queries:**
  - think of a *nested loops* evaluation: *For each Sailors tuple, check the qualification by computing the subquery.*

Nested Queries with Correlation

Find names of sailors who've reserved boat #103:

```
SELECT  S.sname
FROM  Sailors S
WHERE EXISTS (SELECT  *
              FROM  Reserves R
              WHERE R.bid=103 AND S.sid=R.sid)
```

- **EXISTS is another set comparison operator, like IN.**
- **Can also specify NOT EXISTS**
- **If UNIQUE is used, and * is replaced by *R.bid*, finds sailors with at most one reservation for boat #103.**
  - UNIQUE checks for duplicate tuples in a subquery;
- **Subquery must be recomputed for each Sailors tuple.**
  - Think of subquery as a function call that runs a query!

More on Set-Comparison Operators

- **We've already seen IN, EXISTS and UNIQUE. Can also use NOT IN, NOT EXISTS and NOT UNIQUE.**
- **Also available: *op* ANY, *op* ALL**
- **Find sailors whose rating is greater than that of some sailor called Horatio:**

```
SELECT  *
FROM  Sailors S
WHERE  S.rating > ANY (SELECT  S2.rating
                       FROM  Sailors S2
                      WHERE S2.sname='Horatio')
```

Rewriting INTERSECT Queries Using IN

Find sid's of sailors who've reserved both a red and a green boat:

```
SELECT  R.sid
FROM Boats B, Reserves R
WHERE R.bid=B.bid
      AND B.color='red'
      AND R.sid IN (SELECT R2.sid
                    FROM  Boats B2, Reserves R2
                    WHERE  R2.bid=B2.bid
                    AND  B2.color='green')
```

- **Similarly, EXCEPT queries re-written using NOT IN.**
- **How would you change this to find *names* (not *sid*'s) of Sailors who've reserved both red and green boats?**

Division in SQL

Find sailors who've reserved all boats.

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

Sailors S such that ...

there is no boat B without ...

a Reserves tuple showing S reserved B

Basic SQL Queries - Summary

- An advantage of the relational model is its well-defined query semantics.
- SQL provides functionality close to that of the basic relational model.
  - some differences in duplicate handling, null values, set operators, etc.
- Typically, many ways to write a query
  - the system is responsible for figuring a fast way to actually execute a query regardless of how it is written.
- Lots more functionality beyond these basic features. Will be covered in subsequent lectures.

Aggregate Operators

- **Significant extension of relational algebra.**

```
COUNT (*)
COUNT ( [DISTINCT] A)
SUM ( [DISTINCT] A)
AVG ( [DISTINCT] A)
MAX (A)
MIN (A)
```

single column

```
SELECT  COUNT (*)
FROM  Sailors S

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

SELECT  COUNT (DISTINCT S.rating)
FROM  Sailors S
WHERE S.sname='Bob'
```

Aggregate Operators

COUNT (*)
COUNT ([DISTINCT] A)
SUM ([DISTINCT] A)
AVG ([DISTINCT] A)
MAX (A)
MIN (A)

single column

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

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

Find name and age of the oldest sailor(s)

- **The first query is incorrect!**
- **Third query equivalent to second query**
  - allowed in SQL/92 standard, but not supported in some systems.
    - PostgreSQL seems to run it

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

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

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

GROUP BY and HAVING

- **So far, we've applied aggregate operators to all (qualifying) tuples.**
  - Sometimes, we want to apply them to each of several *groups* of tuples.
- **Consider:** ***Find the age of the youngest sailor for each rating level.***
  - In general, we don't know how many rating levels exist, and what the rating values for these levels are!
  - Suppose we know that rating values go from 1 to 10; we can write 10 queries that look like this (!):

For i = 1, 2, ... , 10:

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