Example Instances

We will use these instances of the Sailors and Reserves relations in our examples.

If the key for the Reserves relation contained only the attributes sid and bid, how would the semantics differ?
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 relations in relation-list.
- **qualification** Comparisons (Attr op const or Attr1 op Attr2, where op is one of <, >, =, ≤, ≥, ≠ ) combined using AND, OR and NOT.
- **DISTINCT** is an optional keyword indicating that the answer should not contain duplicates. Default is that duplicates are not eliminated!

Conceptual Evaluation Strategy

- Semantics of an SQL query defined in terms of the following conceptual evaluation strategy:
  - Compute the cross-product of relation-list.
  - Discard resulting tuples if they fail qualifications.
  - Delete attributes that are not in target-list.
  - If DISTINCT is specified, eliminate duplicate rows.
- This strategy is probably the least efficient way to compute a query! An optimizer will find more efficient strategies to compute the same answers.
Example of Conceptual Evaluation

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

<table>
<thead>
<tr>
<th>(sid)</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
<th>(sid)</th>
<th>bid</th>
<th>day</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
<td>22</td>
<td>101</td>
<td>10/10/96</td>
</tr>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
<td>58</td>
<td>103</td>
<td>10/10/96</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
<td>22</td>
<td>101</td>
<td>10/10/96</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
<td>58</td>
<td>103</td>
<td>11/12/96</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
<td>22</td>
<td>101</td>
<td>10/10/96</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
<td>58</td>
<td>103</td>
<td>11/12/96</td>
</tr>
</tbody>
</table>

A Note on Range Variables

- Really needed only if the same relation appears twice in the FROM clause. The previous query can also be written as:

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

It is good style, however, to use range variables always!

```sql
OR
SELECT sname
FROM   Sailors, Reserves
WHERE  Sailors.sid=Reserves.sid
       AND bid=103
```
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 and Strings

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

- Illustrates use of arithmetic expressions and string pattern matching: Find triples (of ages of sailors and two fields defined by expressions) for sailors whose names begin and end with B and contain at least three characters.
- AS and = are two ways to name fields in result.
- LIKE is used for string matching. `_` 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).
- If we replace OR by AND in the first version, what do we get?
- Also available: **EXCEPT** (What do we get if we replace UNION by EXCEPT?)

```sql
SELECT S.sid
FROM Sailors S, Boats B, Reserves R
AND (B.color='red' OR B.color='green')
```

```sql
SELECT S.sid
FROM Sailors S, Boats B, Reserves R
AND B.color='red'
UNION
SELECT S.sid
FROM Sailors S, Boats B, Reserves R
AND B.color='green'
```

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

- **INTERSECT**: Can be used to compute the intersection of any two union-compatible sets of tuples.
- Included in the SQL/92 standard, but some systems don’t support it.
- Contrast symmetry of the UNION and INTERSECT queries with how much the other versions differ.

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

```sql
SELECT S.sid
FROM Sailors S, Boats B, Reserves R
AND B.color='red'
INTERSECT
SELECT S.sid
FROM Sailors S, Boats B, Reserves R
AND B.color='green'
```
Nested Queries

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

\[
\text{SELECT S.sname}
\text{FROM Sailors S}
\text{WHERE S.sid IN (SELECT R.sid}
\text{FROM Reserves R}
\text{WHERE R.bid=103)}
\]

- A very powerful feature of SQL: a WHERE clause can itself contain an SQL query! (Actually, so can FROM and HAVING clauses.)
- 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:

\[
\text{SELECT S.sname}
\text{FROM Sailors S}
\text{WHERE EXISTS (SELECT *}
\text{FROM Reserves R}
\text{WHERE R.bid=103 AND S.sid=R.sid)}
\]

- EXISTS is another set comparison operator, like IN.
- 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; * denotes all attributes. Why do we have to replace * by R.bid?)
- Illustrates why, in general, subquery must be re-computed for each Sailors tuple.
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, op IN >, <, =, >=, <=, ≠
- Find sailors whose rating is greater than that of some sailor called Horatio:

  ```sql
  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:

  ```sql
  SELECT S.sid
  FROM Sailors S, Boats B, Reserves R
  WHERE S.sid=R.sid AND R.bid=B.bid AND B.color='red'
  AND S.sid IN (SELECT S2.sid
    FROM Sailors S2, Boats B2, Reserves R2
    WHERE S2.sid=R2.sid AND R2.bid=B2.bid
    AND B2.color='green')
  ```

- Similarly, EXCEPT queries re-written using NOT IN.
- To find names (not sid’s) of Sailors who’ve reserved both red and green boats, just replace S.sid by S.sname in SELECT clause. (What about INTERSECT query?)
Division in SQL

Find sailors who’ve reserved all boats.

- Let’s do it the hard way, without EXCEPT:

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

(2) 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

Aggregate Operators

- Significant extension of relational algebra.

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'

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 illegal! (We'll look into the reason a bit later, when we discuss GROUP BY.)
- The third query is equivalent to the second query, and is allowed in the SQL/92 standard, but is not supported in some systems.

```sql
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
```

Motivation for Grouping

- 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 (!):

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

For i = 1, 2, ..., 10:
Queries With GROUP BY and HAVING

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

- The target-list contains (i) attribute names (ii) terms with aggregate operations (e.g., MIN (S.age)).
  - The attribute list (i) must be a subset of grouping-list. Intuitively, each answer tuple corresponds to a group, and these attributes must have a single value per group. (A group is a set of tuples that have the same value for all attributes in grouping-list.)

Conceptual Evaluation

- The cross-product of relation-list is computed, tuples that fail qualification are discarded, ‘unnecessary’ fields are deleted, and the remaining tuples are partitioned into groups by the value of attributes in grouping-list.
- The group-qualification is then applied to eliminate some groups. Expressions in group-qualification must have a single value per group!
  - In effect, an attribute in group-qualification that is not an argument of an aggregate op also appears in grouping-list.
- One answer tuple is generated per qualifying group.
Find age of the youngest sailor with age \( \geq 18 \), for each rating with at least 2 such sailors.

```
SELECT S.rating, MIN (S.age) AS minage
FROM Sailors S
WHERE S.age \( \geq 18 \)
GROUP BY S.rating
HAVING COUNT (*) > 1
```

<table>
<thead>
<tr>
<th>sid</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>29</td>
<td>brutus</td>
<td>1</td>
<td>33.0</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>32</td>
<td>andy</td>
<td>8</td>
<td>25.5</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
<tr>
<td>64</td>
<td>horatio</td>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td>71</td>
<td>zorba</td>
<td>10</td>
<td>16.0</td>
</tr>
<tr>
<td>74</td>
<td>horatio</td>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>85</td>
<td>art</td>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>95</td>
<td>bob</td>
<td>3</td>
<td>63.5</td>
</tr>
<tr>
<td>96</td>
<td>frodo</td>
<td>3</td>
<td>25.5</td>
</tr>
</tbody>
</table>

Answer relation:

```
rating | minage
--------|------
3       | 25.5
7       | 35.0
8       | 25.5
```

Find age of the youngest sailor with age \( \geq 18 \), for each rating with at least 2 such sailors.

```
<table>
<thead>
<tr>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>1</td>
<td>33.0</td>
</tr>
<tr>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>8</td>
<td>25.5</td>
</tr>
<tr>
<td>10</td>
<td>35.0</td>
</tr>
<tr>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td>10</td>
<td>16.0</td>
</tr>
<tr>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>3</td>
<td>63.5</td>
</tr>
<tr>
<td>3</td>
<td>25.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>33.0</td>
</tr>
<tr>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>3</td>
<td>63.5</td>
</tr>
<tr>
<td>10</td>
<td>35.0</td>
</tr>
</tbody>
</table>
```

Sailors instance:

```
<table>
<thead>
<tr>
<th>sid</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>29</td>
<td>brutus</td>
<td>1</td>
<td>33.0</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>32</td>
<td>andy</td>
<td>8</td>
<td>25.5</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
<tr>
<td>64</td>
<td>horatio</td>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td>71</td>
<td>zorba</td>
<td>10</td>
<td>16.0</td>
</tr>
<tr>
<td>74</td>
<td>horatio</td>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>85</td>
<td>art</td>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>95</td>
<td>bob</td>
<td>3</td>
<td>63.5</td>
</tr>
<tr>
<td>96</td>
<td>frodo</td>
<td>3</td>
<td>25.5</td>
</tr>
</tbody>
</table>
```

Answer relation:

```
rating | minage
--------|------
3       | 25.5
7       | 35.0
8       | 25.5
```
Find age of the youngest sailor with age ≥18, for each rating with at least 2 such sailors and with every sailor under 60.

**HAVING COUNT(*) > 1 AND EVERY (S.age <= 60)**

What is the result of changing EVERY to ANY?

---

Find age of the youngest sailor with age ≥18, for each rating with at least 2 sailors between 18 and 60.

**SELECT S.rating, MIN(S.age) AS minage**

**FROM Sailors S**

**WHERE S.age >= 18 AND S.age <= 60**

**GROUP BY S.rating**

**HAVING COUNT(*) > 1**

**Answer relation:**

<table>
<thead>
<tr>
<th>rating</th>
<th>minage</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td>8</td>
<td>25.5</td>
</tr>
</tbody>
</table>

---

**Sailors instance:**

<table>
<thead>
<tr>
<th>sid</th>
<th>sname</th>
<th>rating</th>
<th>age</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td>dustin</td>
<td>7</td>
<td>45.0</td>
</tr>
<tr>
<td>29</td>
<td>brutus</td>
<td>1</td>
<td>33.0</td>
</tr>
<tr>
<td>31</td>
<td>lubber</td>
<td>8</td>
<td>55.5</td>
</tr>
<tr>
<td>32</td>
<td>andy</td>
<td>8</td>
<td>25.5</td>
</tr>
<tr>
<td>58</td>
<td>rusty</td>
<td>10</td>
<td>35.0</td>
</tr>
<tr>
<td>64</td>
<td>horatio</td>
<td>7</td>
<td>35.0</td>
</tr>
<tr>
<td>71</td>
<td>zorba</td>
<td>10</td>
<td>16.0</td>
</tr>
<tr>
<td>74</td>
<td>horatio</td>
<td>9</td>
<td>35.0</td>
</tr>
<tr>
<td>85</td>
<td>art</td>
<td>3</td>
<td>25.5</td>
</tr>
<tr>
<td>95</td>
<td>bob</td>
<td>3</td>
<td>63.5</td>
</tr>
<tr>
<td>96</td>
<td>frodo</td>
<td>3</td>
<td>25.5</td>
</tr>
</tbody>
</table>
For each red boat, find the number of reservations for this boat

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

- Grouping over a join of three relations.
- What do we get if we remove `B.color='red'` from the WHERE clause and add a HAVING clause with this condition?
- What if we drop Sailors and the condition involving `S.sid`?

---

Find age of the youngest sailor with age > 18, for each rating with at least 2 sailors (of any age)

```
SELECT S.rating, MIN(S.age)
FROM Sailors S
WHERE S.age > 18
GROUP BY S.rating
HAVING 1 < (SELECT COUNT(*)
            FROM Sailors S2
            WHERE S.rating=S2.rating)
```

- Shows HAVING clause can also contain a subquery.
- Compare this with the query where we considered only ratings with 2 sailors over 18!
- What if HAVING clause is replaced by:
  - `HAVING COUNT(*) >1`
Find those ratings for which the average age is the minimum over all ratings

- Aggregate operations cannot be nested! **WRONG:**

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

- Correct solution (in SQL/92):

```sql
SELECT Temp.rating, Temp.avgage
FROM (SELECT S.rating, AVG (S.age) AS avgage
      FROM Sailors S
      GROUP BY S.rating) AS Temp
WHERE Temp.avgage = (SELECT MIN (Temp.avgage)
                      FROM Temp)
```

---

**Null Values**

- Field values in a tuple are sometimes unknown (e.g., a rating has not been assigned) or inapplicable (e.g., no spouse's name).
  - SQL provides a special value `null` for such situations.
- The presence of `null` complicates many issues. E.g.:
  - Special operators needed to check if value is/is not null.
  - Is rating>8 true or false when rating is equal to null? What about AND, OR and NOT connectives?
  - We need a 3-valued logic (true, false and unknown).
  - Meaning of constructs must be defined carefully. (e.g., WHERE clause eliminates rows that don't evaluate to true.)
  - New operators (in particular, outer joins) possible/ needed.
Integrity Constraints (Review)

- An IC describes conditions that every legal instance of a relation must satisfy.
  - Inserts/ deletes/ updates that violate IC’s are disallowed.
  - Can be used to ensure application semantics (e.g., sid is a key), or prevent inconsistencies (e.g., sname has to be a string, age must be < 200)

Types of IC’s: Domain constraints, primary key constraints, foreign key constraints, general constraints.
- Domain constraints: Field values must be of right type. Always enforced.

Types of IC’s:
- Domain constraints
- Primary key constraints
- Foreign key constraints
- General constraints

General Constraints

- Useful when more general ICs than keys are involved.
- Can use queries to express constraint.
- Constraints can be named.

CREATE TABLE Sailors
    ( sid INTEGER,
    sname CHAR(10),
    rating INTEGER,
    age REAL,
    PRIMARY KEY  (sid),
    CHECK ( rating >= 1 AND rating <= 10 )
)

CREATE TABLE Reserves
    ( sname CHAR(10),
    bid INTEGER, —
    day DATE,
    PRIMARY KEY (bid,day),
    CONSTRAINT noInterlakeRes
    CHECK (‘Interlake’ <>
        (SELECT B.bname
         FROM Boats B
         WHERE B.bid=bid)))

Constraints Over Multiple Relations

CREATE TABLE Sailors
    ( sid INTEGER,
      sname CHAR(10),
      rating INTEGER,
      age REAL,
      PRIMARY KEY (sid),
      CHECK ((SELECT COUNT(S.sid) FROM Sailors S) + (SELECT COUNT(B.bid) FROM Boats B) < 100)
)

- Awkward and wrong!
- If Sailors is empty, the number of Boats tuples can be anything!
- ASSERTION is the right solution; not associated with either table.

CREATE ASSERTION smallClub
    CHECK ((SELECT COUNT(S.sid) FROM Sailors S) + (SELECT COUNT(B.bid) FROM Boats B) < 100)

Triggers

- Trigger: procedure that starts automatically if specified changes occur to the DBMS
- Three parts:
  - Event (activates the trigger)
  - Condition (tests whether the triggers should run)
  - Action (what happens if the trigger runs)
Triggers: Example (SQL:1999)

```sql
CREATE TRIGGER youngSailorUpdate
    AFTER INSERT ON SAILORS
    REFERENCING NEW TABLE NewSailors
    FOR EACH STATEMENT
    INSERT
        INTO YoungSailors(sid, name, age, rating)
        SELECT sid, name, age, rating
        FROM NewSailors N
        WHERE N.age <= 18
```

Summary

- SQL was an important factor in the early acceptance of the relational model; more natural than earlier, procedural query languages.
- Relationally complete; in fact, significantly more expressive power than relational algebra.
- Even queries that can be expressed in RA can often be expressed more naturally in SQL.
- Many alternative ways to write a query; optimizer should look for most efficient evaluation plan.
  - In practice, users need to be aware of how queries are optimized and evaluated for best results.
Summary (Contd.)

- NULL for unknown field values brings many complications
- SQL allows specification of rich integrity constraints
- Triggers respond to changes in the database