SQL: The Query Language
Part 1

R &G - Chapter 5

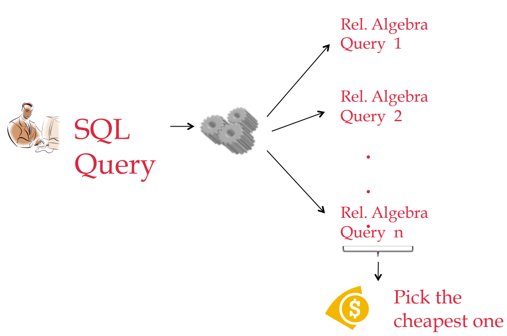
The important thing is not to stop questioning.

Albert Einstein

Review

- Relational Algebra (Operational Semantics)
  - Given a query, how to mix and match the relational algebra operators to answer it
  - Used for query optimization
- Relational Calculus (Declarative Semantics)
  - Given a query, what do I want my answer set to include?
- Algebra and safe calculus are simple and powerful models for query languages for relational model
  - Have same expressive power
- SQL can express every query that is expressible in relational algebra/calculus. (and more)

Relational Query Languages



Relational Query Languages

- **Two sublanguages:**
  - DDL – Data Definition Language
    - Define and modify schema (at all 3 levels)
  - DML – Data Manipulation Language
    - Queries can be written intuitively.
- **DBMS is responsible for efficient evaluation.**
  - The key: precise semantics for relational queries.
  - Optimizer can re-order operations
    - Won't affect query answer.
  - Choices driven by "cost model"

The SQL Query Language

- The most widely used relational query language.
- Standardized

  (although most systems add their own "special sauce" -- including PostgreSQL)
- We will study **SQL92** -- a basic subset

Example Database

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

Boats

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

Reserves

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

The SQL DDL

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

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

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

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

bid	bname	color
101	Nina	red
102	Pinta	blue
103	Santa Maria	red

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

The SQL DML

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

- Find all 18-year-old sailors:

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

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

```
SELECT S.sname, S.rating
```

Querying Multiple Relations

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

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

Reserves

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

Basic SQL Query

DISTINCT: optional. Answer should not contain duplicates.
SQL default: duplicates are *not* eliminated! (Result a "multiset")

target-list : List of expressions over attributes of tables in *relation-list*

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

qualification : Comparisons combined using AND, OR and NOT. Comparisons are Attr *op* const or Attr1 *op* Attr2, where *op* is one of =,<,>,≠, etc.

relation-list : List of relation names, possibly with a *range-variable* after each name

Query Semantics

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

1. FROM : compute *cross product* of tables.
2. WHERE : Check conditions, discard tuples that fail.
3. SELECT : Delete unwanted fields.
4. DISTINCT *(optional)* : eliminate duplicate rows.

Note: Probably the least efficient way to compute a query!

– *Query optimizer* will find more efficient ways to get the *same answer.*

Find sailors who've reserved at least one boat

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

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

About Range Variables

- Needed when ambiguity could arise.
  - e.g., same table used multiple times in FROM ("self-join")

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

Sailors

sid	sname	rating	age
1	Fred	7	22
2	Jim	2	39
3	Nancy	8	27

Arithmetic Expressions

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

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

String Comparisons

```
SELECT S.sname
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

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

... or:

```
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

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

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

```
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'
```

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

- 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')
```

Find sid's of sailors who have not reserved a boat

```
SELECT S.sid
FROM   Sailors S

EXCEPT

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

Nested Queries: IN

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)
```

Nested Queries: NOT IN

*Names of sailors who've **not** reserved boat #103:*

```
SELECT  S.sname
FROM    Sailors S
WHERE   S.sid NOT IN
    (SELECT  R.sid
     FROM    Reserves R
     WHERE  R.bid=103)
```

Nested Queries with Correlation

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)
```

- **Subquery must be recomputed for each Sailors tuple.**
  - Think of subquery as a function call that runs a query
- **Also: NOT EXISTS.**

More on Set-Comparison Operators

- we've seen: **IN, EXISTS**
- can also have: **NOT IN, NOT EXISTS**
- other forms: ***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')
```

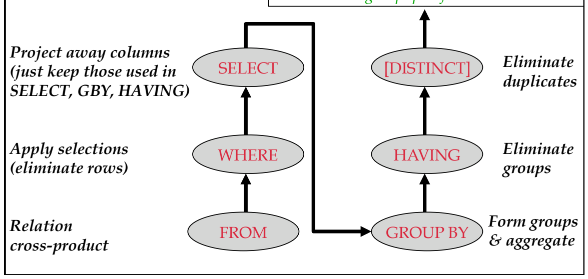
A Tough One

Find sailors who've reserved all boats.

```
SELECT S.sname                               Sailors S such that ...
FROM Sailors S
WHERE NOT EXISTS ( SELECT B.bid              there is no boat B
                   FROM Boats B              without ...
                   WHERE NOT EXISTS ( SELECT R.bid
                                      FROM Reserves R
a Reserves tuple showing S reserved B WHERE R.bid=B.bid
                                      AND R.sid=S.sid ))
```

Conceptual SQL Evaluation

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



Sorting the Results of a Query

- **ORDER BY *column* [ASC | DESC] [, ...]**

```
SELECT S.rating, S.sname, S.age
     FROM Sailors S, Boats B, Reserves R
     WHERE S.sid=R.sid
          AND R.bid=B.bid AND B.color='red'
     ORDER BY S.rating, S.sname;
```

- **Can order by any column in SELECT list, including expressions or aggs:**

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

Null Values

- **Field values 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.

Joins

```
SELECT (column_list)
FROM  table_name
  [INNER | {LEFT |RIGHT | FULL } OUTER] JOIN table_name
    ON qualification_list
WHERE ...
```

Explicit join semantics needed unless it is an INNER join (INNER is default)

Inner Join

Only rows that match the qualification are returned.

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

Returns only those sailors who have reserved boats. SQL-92 also allows:

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

"NATURAL" means equi-join for each pair of attributes with the same name

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

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

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

s.sid	s.name	r.bid
22	Dustin	101
95	Bob	103

Left Outer Join

Returns all matched rows, plus all unmatched rows from the table on the left of the join clause

(use nulls in fields of non-matching tuples)

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

Returns all sailors & information on whether they have reserved boats

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

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

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

s.sid	s.name	r.bid
22	Dustin	101
95	Bob	103
31	Lubber	

Right Outer Join

Right Outer Join returns all matched rows, plus all unmatched rows from the table on the right of the join clause

SELECT r.sid, b.bid, b.name
FROM Reserves r RIGHT OUTER JOIN Boats b
ON r.bid = b.bid

Returns all boats & information on which ones are reserved.

SELECT r.sid, b.bid, b.name
FROM Reserves r RIGHT OUTER JOIN Boats b
ON r.bid = b.bid

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

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

r.sid	b.bid	b.name
22	101	Interlake
	102	Interlake
95	103	Clipper
	104	Marine

Full Outer Join

Full Outer Join returns all (matched or unmatched) rows from the tables on both sides of the join clause

SELECT r.sid, b.bid, b.name
FROM Reserves r FULL OUTER JOIN Boats b
ON r.bid = b.bid

Returns all boats & all information on reservations

SELECT r.sid, b.bid, b.name
FROM Reserves r FULL OUTER JOIN Boats b
ON r.bid = b.bid

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

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

r.sid	b.bid	b.name
22	101	Interlake
	102	Interlake
95	103	Clipper
	104	Marine

Note: in this case it is the same as the ROJ!
bid is a foreign key in reserves, so all reservations must have a corresponding tuple in boats.

Views: Defining External DB Schemas

CREATE VIEW *view_name*
AS *select_statement*

Makes development simpler
Often used for security
Not "materialized"

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

Views Instead of Relations in Queries

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

Reds

bid	scount
102	1

```
SELECT  bname, scount
    FROM Reds R, Boats B
    WHERE  R.bid=B.bid
        AND scount < 10
```

Discretionary Access Control

GRANT *privileges* ON *object* TO *users*
[WITH GRANT OPTION]

- **Object can be a Table or a View**
- **Privileges can be:**
  - **Select**
  - **Insert**
  - **Delete**
  - **References (cols) – allow to create a foreign key that references the specified column(s)**
  - **All**
- **Can later be REVOKEd**
- **Users can be single users or groups**
- **See Chapter 17 for more details.**

Two more important topics

- **Constraints**
- **SQL embedded in other languages**

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 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.
  – *Primary key and foreign key constraints*: you know them.

General Constraints

- **Useful when more general ICs than keys are involved.**
- **Can use queries to express constraint.**
- **Checked on insert or update.**
- **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

- Awkward and wrong!
- Only checks sailors!
- Only required to hold if the associated table is non-empty.

```
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 )
```

Number of boats plus number of sailors is < 100

- ASSERTION is the right solution; not associated with either table.
- Unfortunately, not supported in many DBMS.
- *Triggers* are another solution.

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

Serious SQL: Social Nets Example

```
-- An undirected friend graph. Store each link once
CREATE TABLE Friends(
     fromID integer,
     toID integer,
     since date,
     PRIMARY KEY (fromID, toID),
     FOREIGN KEY (fromID) REFERENCES Users,
     FOREIGN KEY (toID) REFERENCES Users,
     CHECK (fromID < toID));

-- Return both directions
CREATE VIEW BothFriends AS
   SELECT * FROM Friends
   UNION ALL
   SELECT F.toID AS fromID, F.fromID AS toID, F.since
   FROM Friends F;
```

6 degrees of friends

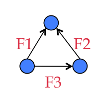
```
SELECT
  FROM

 WHERE
   AND
   AND
   AND
```

Clustering Coefficient of a Node

$$C_i = 2|\{e_{jk}\}| / k_i(k_i-1)$$

- where:
  - k_i is the number of neighbors of node i
  - e_{jk} is an edge between nodes *j* and *k* neighbors of *i*, (*j* < *k*). (A triangle!)
- I.e. Cliquishness: the fraction of your friends that are friends with each other!
- Clustering Coefficient of a graph is the average CC of all nodes.

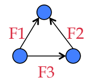
In SQL



$$C_i = 2|\{e_{jk}\}| / k_i(k_i-1)$$

```
CREATE VIEW NEIGHBOR_CNT AS
SELECT
  FROM
 GROUP

CREATE VIEW TRIANGLES AS
SELECT

  FROM
 WHERE
   AND
   AND
   ;
```

In SQL



$C_i = 2|\{e_{jk}\}| / k_i(k_i-1)$

```
CREATE VIEW NEIGHBOR_EDGE_CNT AS
SELECT
 GROUP

CREATE VIEW CC_PER_NODE AS
SELECT

  FROM
 WHERE

SELECT AVG(cc) FROM CC_PER_NODE;
```

Median

- **Given n values in sorted order, the one at position n/2**
  - Assumes an odd # of items
  - For an even #, can take the lower of the middle 2
- **A much more "robust" statistic than average**
  - Q: Suppose you want the mean to be 1,000,000. How many values to you have to corrupt?
  - Q2: Suppose you want the median to be 1,000,000. Same question.

Median in SQL

```
SELECT c AS median FROM T
 WHERE
```

Faster Median in SQL

```
SELECT x.c as median
  FROM T x, T y
 GROUP BY x.c
HAVING
 SUM(CASE WHEN y.c <= x.c THEN 1 ELSE 0 END)
   >= (COUNT(*)+1)/2
AND
 SUM(CASE WHEN y.c >= x.c THEN 1 ELSE 0 END)
   >= (COUNT(*)/2)+1
```

Why faster?
Note: handles even # of items!

Writing Applications with SQL

- **SQL is not a general purpose programming language.**
  + Tailored for data retrieval and manipulation
  + Relatively easy to optimize and parallelize
  - Can't write entire apps in SQL alone

Options:

Make the query language "Turing complete"
Avoids the "impedance mismatch"
but, loses advantages of relational language simplicity

Allow SQL to be embedded in regular programming languages.

Q: What needs to be solved to make the latter approach work?

Embedded SQL

- **DBMS vendors traditionally provided "host language bindings"**
  - E.g. for C or COBOL
  - Allow SQL statements to be called from within a program
  - Typically you preprocess your programs
  - Preprocessor generates calls to a proprietary DB connectivity library
- **General pattern**
  - One call to *connect* to the right database (login, etc.)
  - SQL statements can refer to host variables from the language
- **Typically vendor-specific**
  - We won't look at any in detail, we'll look at standard stuff
- **Problem**
  - SQL relations are (multi-)sets, no *a priori* bound on the number of records. No such data structure in C.
  - SQL supports a mechanism called a *cursor* to handle this.

Just to give you a flavor

```
EXEC SQL SELECT S.sname, S.age
  INTO :c_sname,:c_age
  FROM Sailors S
  WHERE S.sid = :c_sid
```

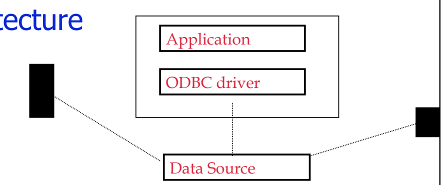
Cursors

- **Can declare a cursor on a relation or query**
- **Can *open* a cursor**
- **Can repeatedly *fetch* a tuple (moving the cursor)**
- **Special return value when all tuples have been retrieved.**
- **ORDER BY allows control over the order tuples are returned.**
  - Fields in ORDER BY clause must also appear in SELECT clause.
- **LIMIT controls the number of rows returned (good fit w/ORDER BY)**
- **Can also modify/delete tuple pointed to by a cursor**
  - A "non-relational" way to get a handle to a particular tuple
- **There's an Embedded SQL syntax for cursors**
  - DECLARE <cursorname> CURSOR FOR <select stmt>
  - FETCH FROM <cursorname> INTO <variable names>
  - But we'll peek at JDBC instead

Database APIs: Alternative to embedding

- **Rather than modify compiler, add a library with database calls (API)**
  - special objects/methods
  - passes SQL strings from language, presents result sets in a language-friendly way
  - *ODBC* a C/C++ standard started on Windows
  - *JDBC* a Java equivalent
  - Most scripting languages have similar things
    - E.g. For Perl there is DBI, "oraPerl", other packages
- **Mostly DBMS-neutral**
  - at least try to hide distinctions across different DBMSs

Architecture



- A lookup service maps "data source names" ("DSNs") to drivers
  - Typically handled by OS
- Based on the DSN used, a "driver" is linked into the app at runtime
- The driver traps calls, translates them into DBMS-specific code
- Database can be across a network
- ODBC is standard, so the same program can be used (in principle) to access multiple database systems
- Data source may not even be an SQL database!

ODBC/JDBC

- **Various vendors provide drivers**
  - MS bundles a bunch into Windows
  - Vendors like DataDirect and OpenLink sell drivers for multiple OSes
- **Drivers for various data sources**
  - Relational DBMSs (Oracle, DB2, SQL Server, etc.)
  - "Desktop" DBMSs (Access, Dbase, Paradox, FoxPro, etc.)
  - Spreadsheets (MS Excel, Lotus 1-2-3, etc.)
  - Delimited text files (.CSV, .TXT, etc.)
- **You can use JDBC/ODBC *clients* over many data sources**
  - E.g. MS Query comes with many versions of MS Office (msqry32.exe)
- **Can write your own Java or C++ programs against xDBC**

JDBC

- **Part of Java, easy to use**
- **Java comes with a JDBC-to-ODBC bridge**
  - So JDBC code can talk to any ODBC data source
  - E.g. look in your Windows Control Panel or MacOS Utilities folder for JDBC/ODBC drivers!
- **JDBC tutorial online**
  - http://developer.java.sun.com/developer/Books/JDBCTutorial/

Ruby on Rails

- **Rails' find method gives a simple rowset interface**
  - Just an array of records
  - Unfortunately slurps entire result set into memory.
- **Rails' ORM (Object Relational Mapping) goes beyond queries and cursors**
  - Data modeling and implicit query construction
  - The ActiveRecord.find method sometimes generates key/foreign-key joins, for example
- **Can also do:**
  - find_by_sql
  - ActiveRecord::Base.connection.execute(

API Summary

APIs are needed to interface DBMSs to programming languages

- Embedded SQL uses "native drivers" and is usually faster but less standard
- ODBC (used to be Microsoft-specific) for C/C++
- JDBC the standard for Java
- Scripting languages (PHP, Perl, JSP) are becoming the preferred technique for web-based systems

Summary

- Relational model has well-defined query semantics
- SQL provides functionality close to basic relational model

  (some differences in duplicate handling, null values, set operators, …)
- Typically, many ways to write a query
  - DBMS figures out a fast way to execute a query, regardless of how it is written.