SQL: The Query Language

R & G - Chapter 5

SQL: "Intergalactic Dataspeak"

- Developed @IBM Research in the 1970s
  - System R project
  - Vs. Berkeley's Quel language (Ingres project)
- Commercialized/Popularized in the 1980s
  - IBM beaten to market by a startup called Oracle
- Questioned repeatedly
  - 90's: OO-DBMS (OQL, etc.)
  - 2000's: XML (Xquery, Xpath, XSLT)
  - 2010's: NoSQL & MapReduce
- SQL keeps re-emerging as the standard
  - Even Hadoop, Spark etc. see lots of SQL
  - May not be perfect, but it is useful

SQL Pros and Cons

- Declarative!
  - Say *what* you want, not *how* to get it
- Implemented widely
  - With varying levels of efficiency, completeness
- Constrained
  - Not a Turing-complete language
- General-purpose and feature-rich
  - many years of added features
  - extensible: callouts to other languages, data sources

Relational Terminology

- *Database*: Set of Relations
- *Relation* (*Table*):
  - *Schema* (description)
  - *Instance* (data satisfying the schema)
- *Attribute* (*Column*)
- *Tuple* (*Record, Row*)

- Also: schema of database is set of schemas of its relations

Relational Tables

- *Schema* is fixed:
  - attribute names, *atomic* types
  - `students(name text, gpa float, dept text)`
- *Instance* can change
  - a *multi*set of "rows" ("tuples")
    - `{('Bob Snob', 3.3,'CS'), ('Bob Snob', 3.3,'CS'), ('Mary Contrary', 3.8, 'CS')}`

SQL Language

- Two sublanguages:
  - DDL – Data Definition Language
    - Define and modify schema
  - DML – Data Manipulation Language
    - Queries can be written intuitively.
- RDBMS responsible for efficient evaluation.
  - Choose and run algorithms for declarative queries
    - Choice of algorithm must not affect query answer.

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	9/12/2015
2	102	9/13/2015

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 27-year-old sailors:

```
SELECT *
  FROM  Sailors AS S
WHERE S.age=27;
```

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

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

SQL DML 1: Basic Single-Table Queries

```
• SELECT [DISTINCT] <column expression list>
    FROM <single table>
  [WHERE <predicate>]
  [GROUP BY <column list>
   [HAVING <predicate>] ]
  [ORDER BY <column list>];
```

Basic Single-Table Queries

```
• SELECT [DISTINCT] <column expression list>
    FROM <single table>
  [WHERE <predicate>]
  [GROUP BY <column list>
   [HAVING <predicate>] ]
  [ORDER BY <column list>] ;
```

- Simplest version is straightforward
  - Produce all tuples in the table that satisfy the predicate
  - Output the expressions in the SELECT list
  - Expression can be a column reference, or an arithmetic expression over column refs

Basic Single-Table Queries

```
• SELECT          S.name, S.gpa
    FROM students S
   WHERE S.dept = 'CS'
  [GROUP BY <column list>
   [HAVING <predicate>] ]
  [ORDER BY <column list>] ;
```

- Simplest version is straightforward
  - Produce all tuples in the table that satisfy the predicate
  - Output the expressions in the SELECT list
  - Expression can be a column reference, or an arithmetic expression over column refs

SELECT DISTINCT

```
SELECT DISTINCT S.name, S.gpa
  FROM students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
[ORDER BY <column list>] ;
```

- DISTINCT flag specifies removal of duplicates before output

ORDER BY

```
SELECT  DISTINCT  S.name, S.gpa, S.age*2 AS a2
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
 ORDER BY S.gpa, S.name, a2;
```

- ORDER BY clause specifies output to be sorted
  - ***Lexicographic*** ordering
- Obviously must refer to columns in the output
  - Note the AS clause for naming output columns!

ORDER BY

```
SELECT  DISTINCT  S.name, S.gpa
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
 ORDER BY S.gpa DESC, S.name ASC;
```

- Ascending order by default, but can be overriden
  - DESC flag for descending, ASC for ascending
  - Can mix and match, lexicographically

Aggregates

```
SELECT [DISTINCT] AVG(S.gpa)
  FROM Students S
 WHERE S.dept = 'CS'
[GROUP BY <column list>
 [HAVING <predicate>] ]
[ORDER BY <column list>] ;
```

- Before producing output, compute a summary (a.k.a. an *aggregate*) of some arithmetic expression
- Produces 1 row of output
  - with one column in this case
- Other aggregates: SUM, COUNT, MAX, MIN
- Note: can use DISTINCT *inside* the agg function
  - SELECT COUNT(DISTINCT S.name) FROM Students S
  - vs. SELECT DISTINCT COUNT (S.name) FROM Students S;

GROUP BY

```
SELECT [DISTINCT] AVG(S.gpa), S.dept
  FROM Students S
[WHERE <predicate>]
 GROUP BY S.dept
 [HAVING <predicate>]
[ORDER BY <column list>] ;
```

- Partition table into groups with same GROUP BY column values
  - Can group by a list of columns
- Produce an aggregate result per group
  - Cardinality of output = # of distinct group values
- Note: can put grouping columns in SELECT list
  - For aggregate queries, SELECT list can contain aggs and GROUP BY columns only!
  - What would it mean if we said SELECT S.name, AVG(S.gpa) above??

HAVING

```
SELECT [DISTINCT] AVG(S.gpa), S.dept
  FROM Students S
[WHERE <predicate>]
 GROUP BY S.dept
  HAVING COUNT(*) > 5
[ORDER BY <column list>] ;
```

- The HAVING predicate is applied *after* grouping and aggregation
  - Hence can contain anything that could go in the SELECT list
  - I.e. aggs or GROUP BY columns
- HAVING can only be used in aggregate queries
- It's an optional clause

Putting it all together

```
· SELECT S.dept, AVG(S.gpa), COUNT(*)
    FROM Students S
   WHERE S.gender = 'F'
   GROUP BY S.dept
  HAVING COUNT(*) > 2
   ORDER BY S.dept;
```

Try It Yourself

```
vagrant@precise64:~$ sudo su - postgres
postgres@precise64:~$ createdb testdb
postgres@precise64:~$ psql testdb
psql (9.3.5)
Type "help" for help.
testdb=# create table students(name text, gpa float, age integer, dept
text, gender char);
CREATE TABLE
testdb=# insert into students values
 ('Sergey Brin', 4.0, 40, 'CS', 'M'),
  ('Danah Boyd', 4.0, 35, 'CS', 'F'),
  ('Bill Gates', 1.0, 60, 'CS', 'M'),
  ('Hillary Mason', 4.0, 35, 'DATASCI', 'F'),
  ('Mike Olson', 4.0, 50, 'CS', 'M'),
  ('Mark Zuckerberg', 4.0, 30, 'CS', 'M'),
  ('Cheryl Sandberg', 4.0, 47, 'BUSINESS', 'F'),
  ('Susan Wojcicki', 4.0, 46, 'BUSINESS', 'F'),
  ('Marissa Meyer', 4.0, 45, 'BUSINESS', 'F');
INSERT 0 9
testdb=# SELECT S.name, S.gpa  FROM students S WHERE S.dept = 'CS';
 name | gpa
------+-----
```

Querying Multiple Relations

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

Sailors

sid	sname	rating	age
1	Popeye	10	22
2	OliveOyl	11	39
3	Garfield	1	27
4	Bob	5	19

Reserves

sid	bid	day
1	102	9/12
2	102	9/13
1	101	10/01

Join Queries

```
· SELECT [DISTINCT] <column expression list>
    FROM <table1 [AS t1], ... , tableN [AS tn]>
   [WHERE <predicate>]
   [GROUP BY <column list>
    [HAVING <predicate>] ]
   [ORDER BY <column list>];
```

Query Semantics

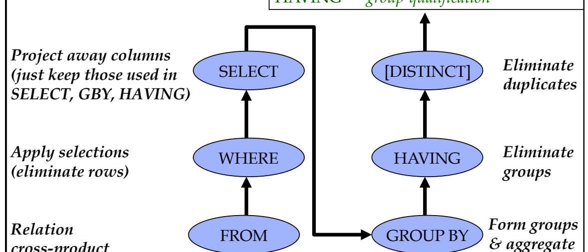
SELECT [DISTINCT] *target-list*
FROM *relation-list*
WHERE *qualification*

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

- Note: likely a terribly inefficient strategy!
  - Query optimizer will find more efficient plans.

Conceptual SQL Evaluation

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



Find sailors who've reserved at least one boat

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

- Would DISTINCT make a difference here?

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 AS x, Sailors AS y
WHERE   x.age > y.age
```

Sailors

sid	sname	rating	age
1	Popeye	10	22
2	OliveOyl	11	39
3	Garfield	1	27
4	Bob	5	19

Arithmetic Expressions

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

```
SELECT S1.sname AS name1, S2.sname AS name2
FROM   Sailors AS S1, Sailors AS 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.

Most DBMSs now support standard regex as well (incl. PostgreSQL)

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 ALL
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 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 #102:

```
SELECT S.sname
FROM   Sailors S
WHERE  S.sid IN
    (SELECT  R.sid
     FROM    Reserves R
     WHERE  R.bid=102)
```

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 #102:

```
SELECT  S.sname
FROM    Sailors S
WHERE EXISTS
      (SELECT  *
       FROM  Reserves R
       WHERE R.bid=102 AND S.sid=R.sid)
```

- 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 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 Fred:

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

A Tough One

Find sailors who've reserved all boats.
(relational division: no "counterexample boats")

```
SELECT  S.sname                                  Sailors S such that ...
FROM  Sailors S
WHERE  NOT EXISTS ( SELECT  B.bid               there is no boat B that...
                    FROM  Boats B
                    WHERE  NOT EXISTS ( SELECT  R.bid
                                        FROM  Reserves R
  ...is missing a Reserves tuple         WHERE  R.bid=B.bid
  showing S reserved B                   AND R.sid=S.sid ))
```

ARGMAX?

- The sailor with the highest rating
  - what about ties for highest?!

```
SELECT MAX(S.rating)
  FROM Sailors S; -- OK

SELECT S.*, MAX(S.rating)
FROM   Sailors S; -- Not OK
```

ARGMAX?

- The sailor with the highest rating
  - what about ties for highest?!

```
SELECT *
FROM   Sailors S
WHERE  S.rating >= ALL
   (SELECT  S2.rating
    FROM  Sailors S2)
```

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

```
SELECT *
FROM   Sailors S
ORDER BY rating DESC
LIMIT 1;
```

Null Values

- Field values are sometimes unknown or inapplicable
  - SQL provides a special value null for such situations.
- The presence of null complicates many issues. E.g.:
  - Special syntax "IS NULL" and "IS NOT NULL"
  - Assume rating IS NULL. Consider predicate "rating>8".
    - True? False?
    - What about AND, OR and NOT connectives?
    - SUM?
  - 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 ...

- INNER is default

Inner/Natural Joins

SELECT s.sid, s.sname, r.bid
FROM Sailors s, Reserves r
WHERE s.sid = r.sid

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

SELECT s.sid, s.sname, r.bid
FROM Sailors s **NATURAL JOIN** Reserves r

all 3 are equivalent!

- "NATURAL" means equi-join for each pair of attributes with the same name
  - Note SELECT * : removes duplicate attributes in output!

SELECT s.sid, s.sname, r.bid
FROM Sailors2 s INNER JOIN Reserves2 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.sname	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.sname, r.bid
FROM Sailors2 s LEFT OUTER JOIN Reserves2 r
ON s.sid = r.sid;

Returns all sailors & bid for boat in any of their reservations
Note: no match for s.sid? r.bid IS NULL!

SELECT s.sid, s.sname, r.bid
FROM Sailors2 s LEFT OUTER JOIN Reserves2 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.bname
FROM Reserves2 r RIGHT OUTER JOIN Boats2 b
ON r.bid = b.bid;

- Returns all boats & information on which ones are reserved.
- No match for b.bid? r.sid IS NULL!

SELECT r.sid, b.bid, b.bname
FROM Reserves2 r RIGHT OUTER JOIN Boats2 b
ON r.bid = b.bid;

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

bid	name	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 Reserves2 r FULL OUTER JOIN Boats2 b
ON r.bid = b.bid

- Returns all boats & all information on reservations
- No match for r.bid?
  - b.bid IS NULL AND b.bname IS NULL!
- No match for b.bid?
  - r.sid IS NULL!

SELECT r.sid, b.bid, b.bname
FROM Reserves2 r FULL OUTER JOIN Boats2 b
ON r.bid = b.bid

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

bid	name	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: Named Queries

CREATE VIEW *view_name*
AS *select_statement*

Makes development simpler
Often used for security
Not "materialized"

```
CREATE VIEW Redcount
AS SELECT  B.bid,  COUNT (*) AS scount
     FROM Boats2 B, Reserves2 R
     WHERE  R.bid=B.bid AND   B.color='red'
      GROUP BY  B.bid;
```

Views Instead of Relations in Queries

```
CREATE VIEW Redcount
AS SELECT  B.bid,  COUNT (*) AS scount
     FROM Boats2 B, Reserves2 R
     WHERE  R.bid=B.bid AND   B.color='red'
      GROUP BY  B.bid;
```

bid	scount
102	1

Redcount

```
SELECT  bname, scount
     FROM Redcount R, Boats2 B
     WHERE  R.bid=B.bid
         AND scount < 10;
```

Better reserve a red boat!

```
INSERT INTO Reserves2
VALUES (31, 102, '2016-01-26');
```

Subqueries in FROM

Like a "view on the fly"!

```
SELECT  bname, scount
  FROM Boats2 B,
        (SELECT B.bid,  COUNT (*)
          FROM Boats2 B, Reserves2 R
         WHERE  R.bid=B.bid AND   B.color='red'
      GROUP BY  B.bid) AS Reds(bid, scount)
    WHERE  Reds.bid=B.bid
       AND scount < 10
```

WITH (common table expression)

Another "view on the fly" syntax:

```
WITH Reds(bid, scount) AS
(SELECT B.bid,  COUNT (*)
           FROM Boats2 B, Reserves2 R
          WHERE  R.bid=B.bid AND   B.color='red'
       GROUP BY  B.bid)
SELECT  bname, scount
  FROM Boats2 B, Reds
    WHERE  Reds.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

- IC conditions that every legal instance of a relation must satisfy.
  - Inserts/deletes/updates that violate ICs 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: coming right up.

Where do ICs Come From?

- Semantics of the real world!
- Note:
  - We can check IC violation in a DB instance
  - We can NEVER infer that an IC is true by looking at an instance.
    - An IC is a statement about all possible instances!
  - From example, we know name is not a key, but the assertion that sid is a key is given to us.
- Key and foreign key ICs are the most common
- More general ICs supported too.

Keys

- Keys are a way to associate tuples in different relations
- Keys are one form of IC

Enrolled

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

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

FOREIGN Key

PRIMARY Key

Primary Keys

- A set of fields is a superkey if:
  - No two distinct tuples can have same values in all key fields
- A set of fields is a key for a relation if it is *minimal*:
  - It is a superkey
  - No subset of the fields is a superkey
- what if >1 key for a relation?
  - One of the keys is chosen (by DBA) to be the primary key. Other keys are called candidate keys.
- E.g.
  - sid is a key for Students.
  - What about name?
  - The set {sid, gpa} is a superkey.

Primary and Candidate Keys

- Possibly many *candidate keys* (specified using UNIQUE), one of which is chosen as the *primary key*.
- Keys must be used carefully!

```
CREATE TABLE Enrolled1
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY (sid,cid))
```

vs.

```
CREATE TABLE Enrolled2
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade))
```

"For a given student and course, there is a single grade."

Primary and Candidate Keys

```
CREATE TABLE Enrolled1
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY (sid,cid))
```

vs.

```
CREATE TABLE Enrolled2
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade))
```

```
INSERT INTO enrolled1 VALUES ('1234', 'cs186', 'A+');
INSERT INTO enrolled1 VALUES ('1234', 'cs186', 'F');
INSERT INTO enrolled1 VALUES ('1234', 'cs61C', 'A+');
```

```
INSERT INTO enrolled2 VALUES ('1234', 'cs186', 'A+');
INSERT INTO enrolled2 VALUES ('1234', 'cs186', 'F');
INSERT INTO enrolled2 VALUES ('1234', 'cs61C', 'A+');
INSERT INTO enrolled2 VALUES ('4567', 'cs186', 'A+');
```

"For a given student and course, there is a single grade."

Primary and Candidate Keys

```
CREATE TABLE Enrolled1
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY (sid,cid));
```

vs.

```
CREATE TABLE Enrolled2
  (sid CHAR(20),
   cid  CHAR(20),
   grade CHAR(2),
   PRIMARY KEY  (sid),
   UNIQUE (cid, grade));
```

```
INSERT INTO enrolled1 VALUES ('1234', 'cs186', 'A+');
INSERT INTO enrolled1 VALUES ('1234', 'cs186', 'F');
INSERT INTO enrolled1 VALUES ('1234', 'cs61C', 'A+');
```

```
INSERT INTO enrolled2 VALUES ('1234', 'cs186', 'A+');
INSERT INTO enrolled2 VALUES ('1234', 'cs186', 'F');
INSERT INTO enrolled2 VALUES ('1234', 'cs61C', 'A+');
INSERT INTO enrolled2 VALUES ('4567', 'cs186', 'A+');
```

"Students can take only one course, and no two students in a course receive the same grade."

Foreign Keys, Referential Integrity

- *Foreign key*: a "logical pointer"
  - Set of fields in a tuple in one relation that `refer' to a tuple in another relation.
  - Reference to *primary key* of the other relation.
- All foreign key constraints enforced?
  - *referential integrity*!
  - i.e., no dangling references.

Foreign Keys in SQL

- **E.g. Only students listed in the Students relation should be allowed to enroll for courses.**
  - *sid* is a foreign key referring to Students:

```
CREATE TABLE Enrolled
(sid CHAR(20),cid CHAR(20),grade CHAR(2),
 PRIMARY KEY (sid,cid),
 FOREIGN KEY (sid) REFERENCES Students);
```

Enrolled

sid	cid	grade
53666	Carnatic101	C
53666	Reggae203	B
53650	Topology112	A
53666	History105	B
~~11111~~	~~English102~~	~~A~~

Students

sid	name	login	age	gpa
53666	Jones	jones@cs	18	3.4
53688	Smith	smith@eecs	18	3.2
53650	Smith	smith@math	19	3.8

Enforcing Referential Integrity

- *sid* in Enrolled: foreign key referencing Students.
- Scenarios:
  - Insert Enrolled tuple with non-existent student id?
  - Delete a Students tuple?
    - Also delete Enrolled tuples that refer to it? (CASCADE)
    - Disallow if referred to? (NO ACTION)
    - Set sid in referring Enrolled tups to a *default* value? (SET DEFAULT)
    - Set sid in referring Enrolled tuples to *null*, denoting `*unknown*' or `*inapplicable*'. (SET NULL)
- Similar issues arise if primary key of Students tuple is updated.

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

```
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

Constraints Over Multiple Relations

- Awkward and wrong!
  - Only checks sailors!
- ASSERTION is the right solution; not associated with either table.
  - Unfortunately, not supported in many DBMS.
  - *Triggers* are another solution.

```
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

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

Two more important topics

- ~~Constraints~~
- SQL embedded in other languages

Writing Applications with SQL

- SQL is not a general purpose programming language.
  - + Tailored for data retrieval and manipulation
  - + Relatively easy to optimize and parallelize
  - Awkward to write entire apps in SQL
- Options:
  - Make the query language "Turing complete"
    - Avoids the "impedance mismatch"
    - makes "simple" relational language complex
  - Allow SQL to be embedded in regular programming languages.
  - Q: What needs to be solved to make the latter approach work?

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

Database APIs

- 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. in Python there's the "psycopg2" driver
- ODBC/JDBC try to be DBMS-neutral
  - at least try to hide distinctions across different DBMSs
- Object-Relational Mappings (ORMs)
  - Ruby on Rails, Django, Spring, BackboneORM, etc.
    - Automagically map database rows into PL objects
    - Magic can be great; magic can bite you.
  - This year we won't cover ORMs much – see CS169.

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.

Getting Serious

- Two "fancy" queries for different applications
  - Clustering Coefficient for Social Network graphs
  - Medians for "robust" estimates of central value

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 F1.fromID, F5.toID
  FROM BothFriends F1, BothFriends F2, BothFriends F3,
       BothFriends F4, BothFriends F5
 WHERE F1.toID = F2.fromID
   AND F2.toID = F3.fromID
   AND F3.toID = F4.fromID
   AND F4.toID = F5.fromID;
```

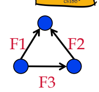
Clustering Coefficient of a Node

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

- 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

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



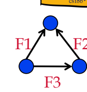

```
CREATE VIEW NEIGHBOR_CNT AS
SELECT
  FROM
 GROUP

CREATE VIEW TRIANGLES AS
SELECT

  FROM
 WHERE
   AND
   AND
  ;
```

In SQL

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



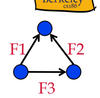

```
CREATE VIEW NEIGHBOR_CNT AS
SELECT fromID AS nodeID, count(*) AS friend_cnt
  FROM BothFriends
 GROUP BY nodeID;

CREATE VIEW TRIANGLES AS
SELECT

  FROM
 WHERE
   AND
   AND
  ;
```

In SQL

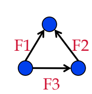
$$C_i = 2|\{e_{jk}\}| / k_i(k_i-1)$$




```
CREATE VIEW NEIGHBOR_CNT AS
SELECT fromID AS nodeID, count(*) AS friend_cnt
  FROM BothFriends
 GROUP BY nodeID;

CREATE VIEW TRIANGLES AS
SELECT F1.toID as root, F1.fromID AS friend1,
       F2.fromID AS friend2
  FROM BothFriends F1, BothFriends F2, Friends F3
 WHERE F1.toID = F2.toID      /* Both point to root */
   AND F1.fromID = F3.fromID /* Same origin as F1  */
   AND F3.toID = F2.fromID    /* points to origin of F2 */
  ;
```

In SQL



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

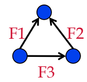
```
CREATE VIEW NEIGHBOR_EDGE_CNT AS
SELECT
 GROUP

CREATE VIEW CC_PER_NODE AS
SELECT

  FROM
 WHERE

SELECT AVG(cc) FROM CC_PER_NODE;
```

In SQL



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

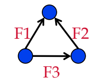
```
CREATE VIEW NEIGHBOR_EDGE_CNT AS
SELECT root, COUNT(*) as cnt FROM TRIANGLES
 GROUP BY root;

CREATE VIEW CC_PER_NODE AS
SELECT [redacted]

  FROM
 WHERE

SELECT AVG(cc) FROM CC_PER_NODE;
```

In SQL



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

```
CREATE VIEW NEIGHBOR_TRI_CNT AS
SELECT root, COUNT(*) as cnt FROM TRIANGLES
 GROUP BY root;

CREATE VIEW CC_PER_NODE AS
SELECT NE.root, 2.0*NE.cnt /
                 (N.friend_cnt*(N.friend_cnt-1)) AS CC
  FROM NEIGHBOR_TRI_CNT NE, NEIGHBOR_CNT N
 WHERE NE.root = N.nodeID;

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. What fraction of values do you have to corrupt?
  - Q2: Suppose you want the median to be 1,000,000. Same question.
  - This is called the *breakdown point* of a statistic.
  - Important for dealing with data *outliers*
    - E.g. dirty data
    - Even with real data: “overfitting”

Median in SQL

```
SELECT c AS median FROM T
 WHERE
[redacted]
```

Median in SQL

```
SELECT c AS median FROM T
 WHERE
[redacted]
 =
[redacted]
```

Median in SQL

```
SELECT c AS median FROM T
 WHERE
 (SELECT COUNT(*) from T AS T1
   WHERE T1.c <= T.c)
 =
[redacted]
```

Median in SQL (odd cardinality)

```
SELECT c AS median FROM T
 WHERE
 (SELECT COUNT(*) from T AS T1
   WHERE T1.c <= T.c)
 =
 (SELECT COUNT(*) from T AS T2
   WHERE T2.c >= T.c);
```

Faster Median in SQL (odd cardinality)

```
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 -- ceiling(N/2)
AND
 SUM(CASE WHEN y.c >= x.c THEN 1 ELSE 0 END)
  >= (COUNT(*)/2)+1 -- floor(N/2) +1
```

Why faster?
Note: handles even # of items!

Using "Window Functions"

Window functions: an SQL idiom to compute with order.
http://www.postgresql.org/docs/9.3/static/tutorial-window.html

```
CREATE VIEW twocounters AS
(SELECT c,
        ROW_NUMBER() OVER (ORDER BY c ASC) AS RowAsc,
        ROW_NUMBER() OVER (ORDER BY c DESC) AS RowDesc
   FROM T
);

SELECT MIN(c)
FROM twocounters
WHERE RowAsc IN (RowDesc, RowDesc - 1, RowDesc + 1);
```

O(n logn!)
Note: handles even # of items.

Notes for Studying

FIX ME

- You'll be resp
  constructs w
  - Window func
  - Programmin
- In HW2 you may write queries using:
  - Any PostgreSQL features you like
  - Except for callouts to user-defined code (C, Java, Python, R, etc.)