SQL: The Query Language

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The important thing is not to stop questioning.

Albert Einstein

Review

- Relational Algebra (Operational Semantics操作语义)
  - Given a query, how to mix and match the relational algebra operators to answer it
  - Used for query optimization用于查询优化
- Relational Calculus (Declarative Semantics说明性语义)
  - 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有相同的表达力
- SQL can express every query that is expressible in relational algebra/calculus. (and more)

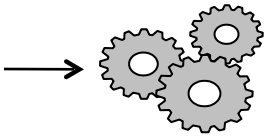
RA → SQL

- SQL SELECT → RA Projection Π
- SQL WHERE → RA Selection σ
- SQL FROM → RA Join/cross
  - Comma-separated list…
- SQL renaming → RA rho ρ

- More ops later
- *Keep RA in the back of your mind…*

Relational Query Languages

SQL Query



查询分析

Rel. Algebra
Query 1

Rel. Algebra
Query 2

.
.
.

Rel. Algebra
Query n

Pick the
cheapest one

Relational Query Languages

- Two sublanguages:
  - DDL – Data Definition定义 Language
    - Define and modify schema (at all 3 levels)
  - DML – Data Manipulation操作 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" 成本模型

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

FOREIGN KEY 外键

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:

$\sigma_{age=18}(Sailors)$

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

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

$\pi_{sname, rating}(\sigma_{age=18}(Sailors))$

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

Querying Multiple Relations

Cross Product

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

Natural Join

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*.

SQL Query Semantics

```
SELECT a1, a2, …, ak
FROM   R1 AS x1, R2 AS x2, …, Rn AS xn
WHERE  Conditions
```

Parallel assignment – all tuples

```
Answer = {}
for all assignments x1 in R1, …, xn in Rn do
   if Conditions then
      Answer = Answer ∪ {(a1,…,ak)}
return Answer
```

Doesn't impose any order

SQL Query Semantics

```
SELECT a1, a2, …, ak
FROM   R1 AS x1, R2 AS x2, …, Rn AS xn
WHERE  Conditions
```

Nested loops:

```
Answer = {}
for x1 in R1 do
   for x2 in R2 do
      …..
         for xn in Rn do
            if Conditions then
               Answer = Answer ∪ {(a1,…,ak)}
return 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 x

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

Sailors y

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

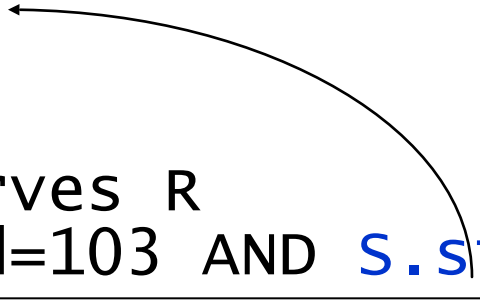
*Names of sailors who've **not** reserved boat #103:*

```
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

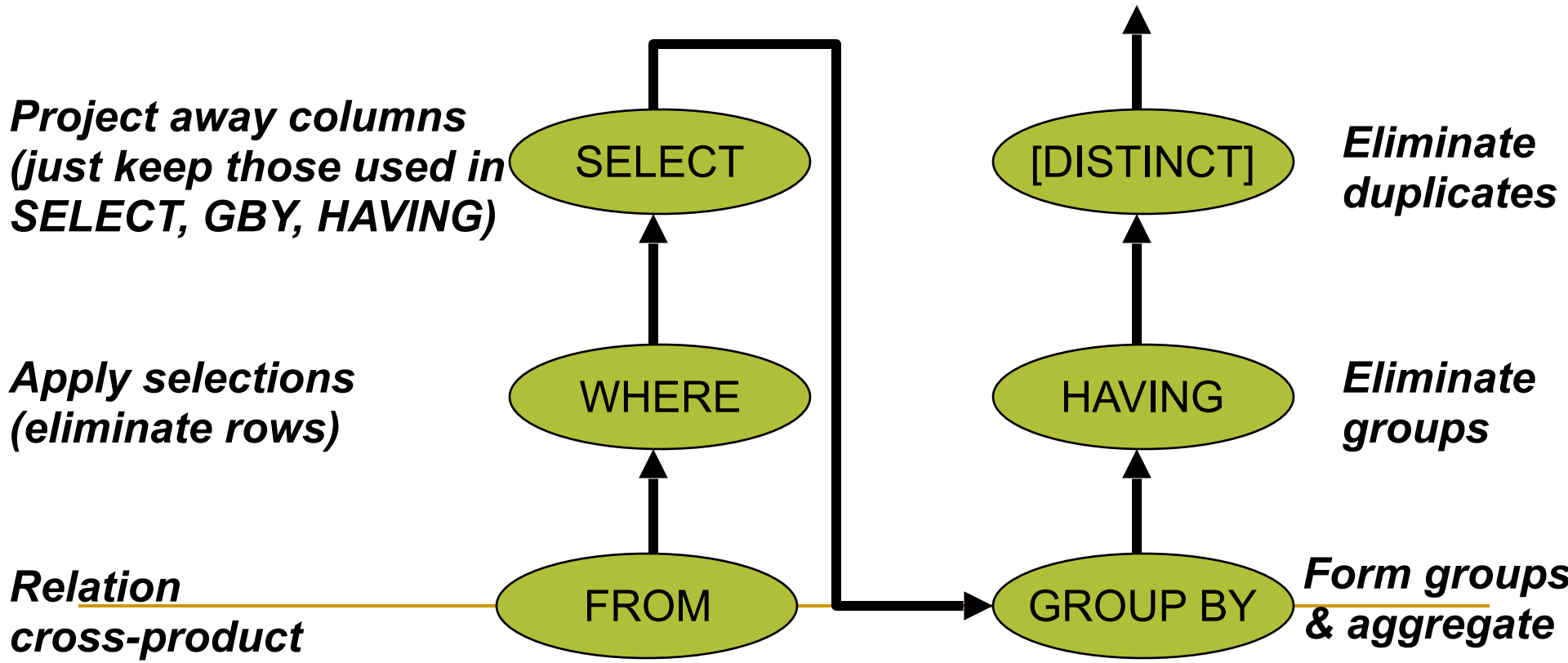
More on Set-Comparison Operators

- 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')
```

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*).

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.

```
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
```

```
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
```

```
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
```

```
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
```

bid	scount
102	1

Reds

```
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)

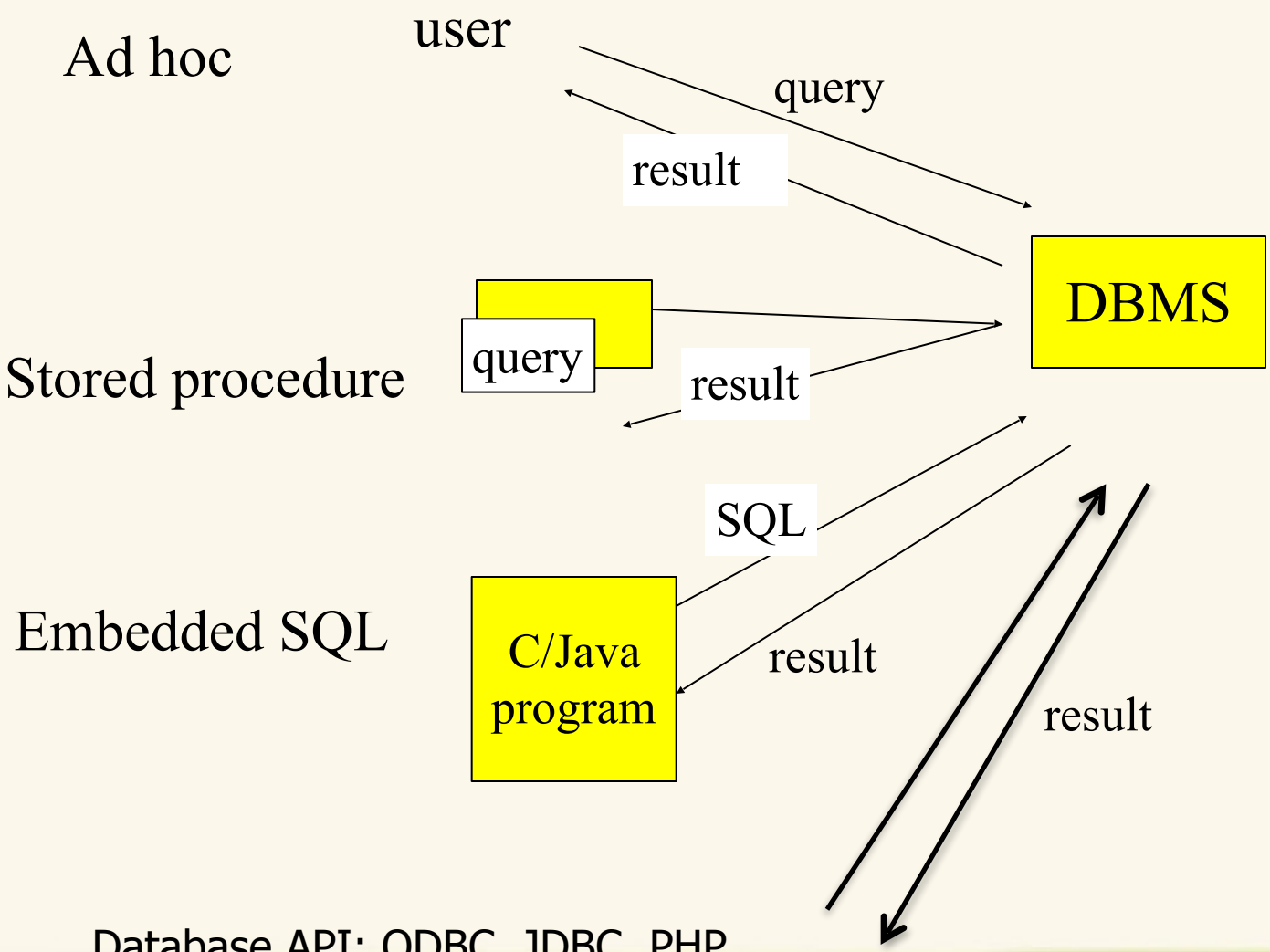
- An IC describes conditions that every *legal instance* of a relation must satisfy.
  - Inserts/deletes/updates that violate IC's are disallowed.
  - Can ensure application semantics (e.g., *sid* is a key), or prevent inconsistencies (e.g., *sname* has to be a string, *age* must be < 200)
- *Types of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

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)))
```



Database API: ODBC, JDBC, PHP

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

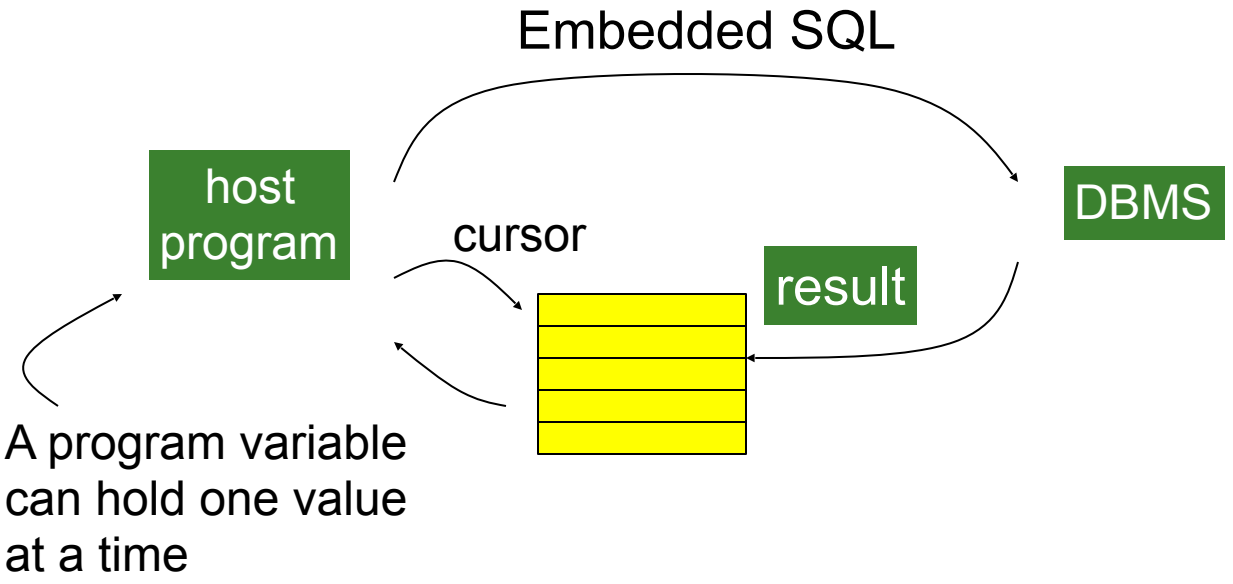
Allow SQL to be embedded in regular programming languages.

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.

Why is cursor needed?



Cursor bridges the gap between value-oriented host program and set-oriented DBMS

Example Embedded SQL

From within a host language, find the names and account numbers of customers with more than the variable *amount* dollars in some account.

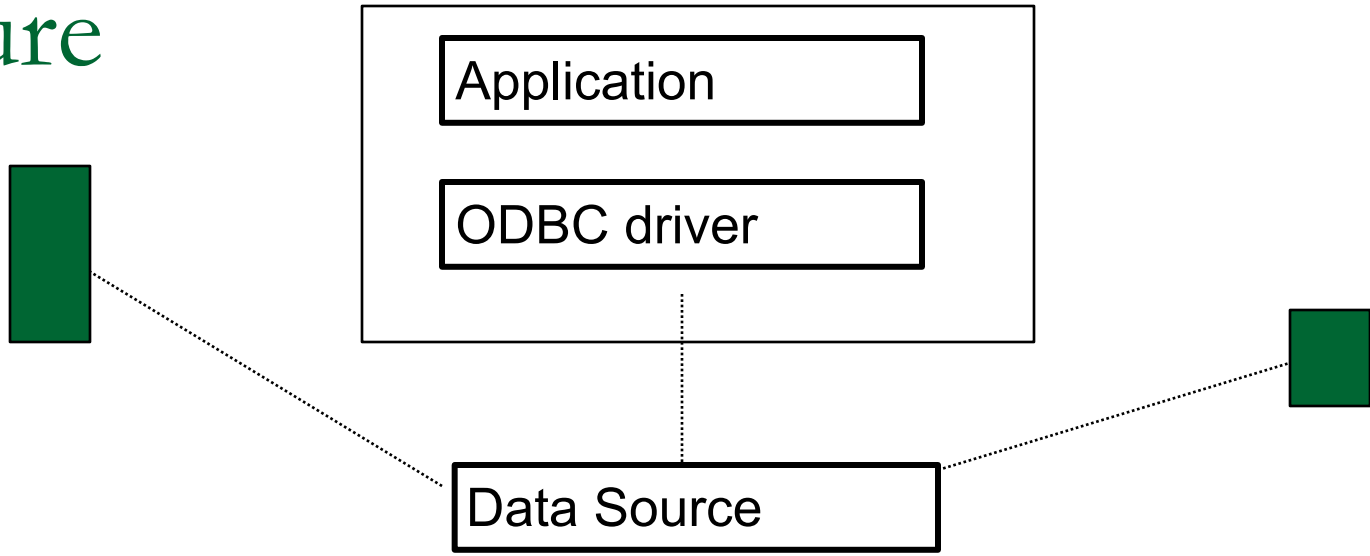
- Specify the query in SQL and declare a *cursor* for it

```
EXEC SQL
        declare c cursor for
        select customer-name, account-number
        from depositor, account
        where depositor.account-number = account.account-number and
account.balance > :amount
END-EXEC
```

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 *client*s 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/

hello.php

- http://pages.stern.nyu.edu/~mjohnson/dbms/php/hello.php

```
<html>
<head><title>Hello from PHP</title>
</head>
<body>
Here comes the PHP part:<BR><BR>
<?php print "Hello, World!<br>\n"; ?>
<br>That's it!
</body></html>
```

- Q: What the difference between
 and \n?

PHP vars

- Names always start with $
  - http://pages.stern.nyu.edu/~mjohnson/dbms/php/math.php

```
<?
   $num1 = 58;
   $num2 = 67;
   print "First number " . $num1 . "<br>";
   print "Second number " . $num2 . "<br>";
   $total = $num1 + $num2;
   print "The sum is " . $total . "<br>";
?>
```

Combining PHP and HTML

- http://pages.stern.nyu.edu/~mjohnson/dbms/php/combine.php

```
<?php
  for($z=0;$z<=5;$z++) {
?>
     Iteration number <? = $z ?><br>
<?
  }
?>
```

PHP & MySQL

1. Open a connection and open our DB:

```
$db = mysql_connect(“localhost",      user, pass);
mysql_select_db("test", $db);
```

2. Run query:

```
$result = mysql_query($query,$db);
```

PHP & MySQL

3. Extract next row of data from the results:

```
$myrow = mysql_fetch_row($result)
```

- What this means: myrow is an array that can then be accessed
- Other options, see code

- In general, to scroll through results, do:

```
while ($myrow = mysql_fetch_row($result))
        # print row's data
```

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.

Review

- Examples from sqlzoo.net

```
SELECT  L
FROM    R1, …, Rn
WHERE   C
```

$$\Pi_L(\sigma_C(R_1 \times \ldots R_n))$$

Another complex example

- People(ssn, name, street, city, state, state)
- Q: Who lives on George's street?

- A: First, generate pairs of (renamed) people:
  - ρ_{p1}(People) x ρ_{p2}(People)

- Then pick out pairs with George:
  - $\sigma_{p1.name='George'}(\rho_{p1}(People) \times \rho_{p2}(People))$

- And refine to rows with George and someone else:
  - $\sigma_{p1.name='George' \text{ AND } p1.name<>p2.name}(\rho_{p1}(People) \times \rho_{p2}(People))$

- Finally, project out the names:
  - $\Pi_{p2.name}(\sigma_{p1.name='George' \text{ AND } p1.name<>p2.name}(\rho_{p1}(People) \times \rho_{p2}(People))$

Live examples

- Q: produce a list of employees and their bosses
  - What if no boss? Or no subordinate?

- Joins on emp, emp man:
  - Comma-based
  - Inner
  - Natural
  - Cross
  - Outer – left, right, full

More live examples

- Inner joins require an ON clause
  - Like a where clause
  - Arbitrary boolean expression
  - If always true (1=1), reduces to cross join
- New compar op: BETWEEN
  - a between 5 and 10 ⇔ a >= 5 and a <= 10
- Q: produce a list of employees with their salary grades
  - emp, salgrade