SQL: Programming & Recursion

CS348 Spring 2023

Instructor: Sujaya Maiyya

Sections: **002 & 004 only**

Announcements

- Assignment 1 due by 11:59PM tonight!
  - Submit via CrowdMark

SQL

- Basic SQL (queries, modifications, and constraints)

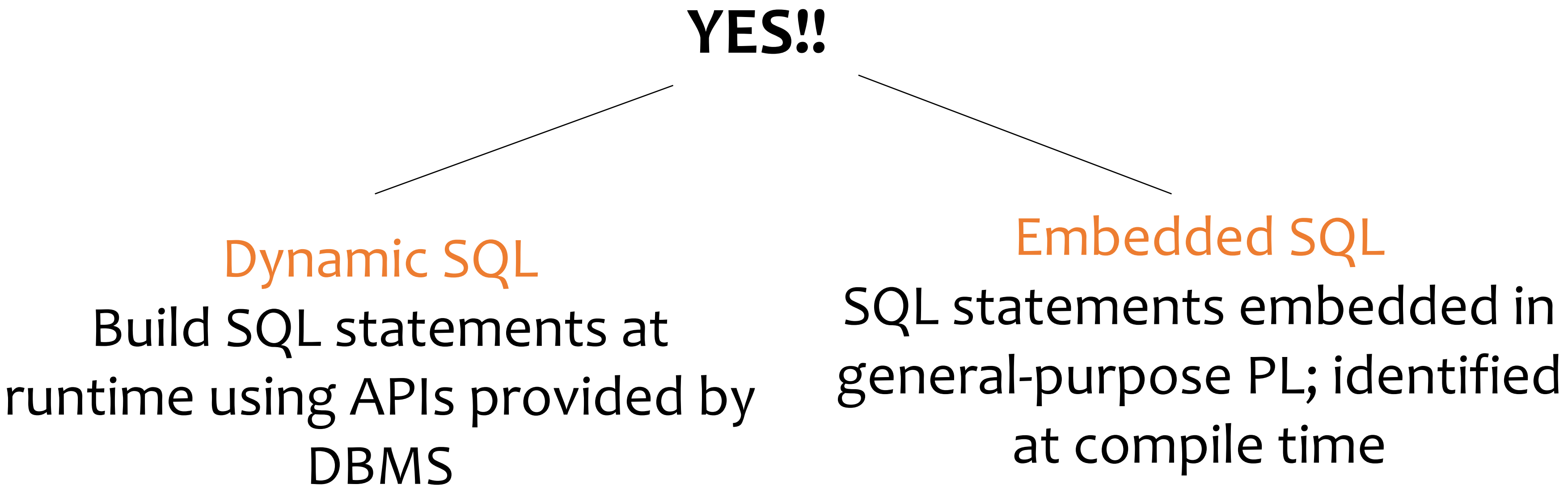
- Intermediate SQL
  - Triggers
  - Views
  - Indexes

- Advanced SQL
  - Programming
  - Recursion

Motivation

- Pros and cons of SQL
  - Very high-level, possible to optimize
  - Not intended for general-purpose computation

- Can SQL and general-purpose programming languages (PL) interact with each other?



YES!!

Dynamic SQL

Build SQL statements at runtime using APIs provided by DBMS

Embedded SQL

SQL statements embedded in general-purpose PL; identified at compile time

A mismatch b/w SQL and PLs

- SQL operates on a set of records at a time
- Typical low-level general-purpose programming languages operate on one record at a time

☞Solution: cursor

  - Open (a result table), Get next, Close

  ☞Found in virtually every database language/API

    - With slightly different syntaxes

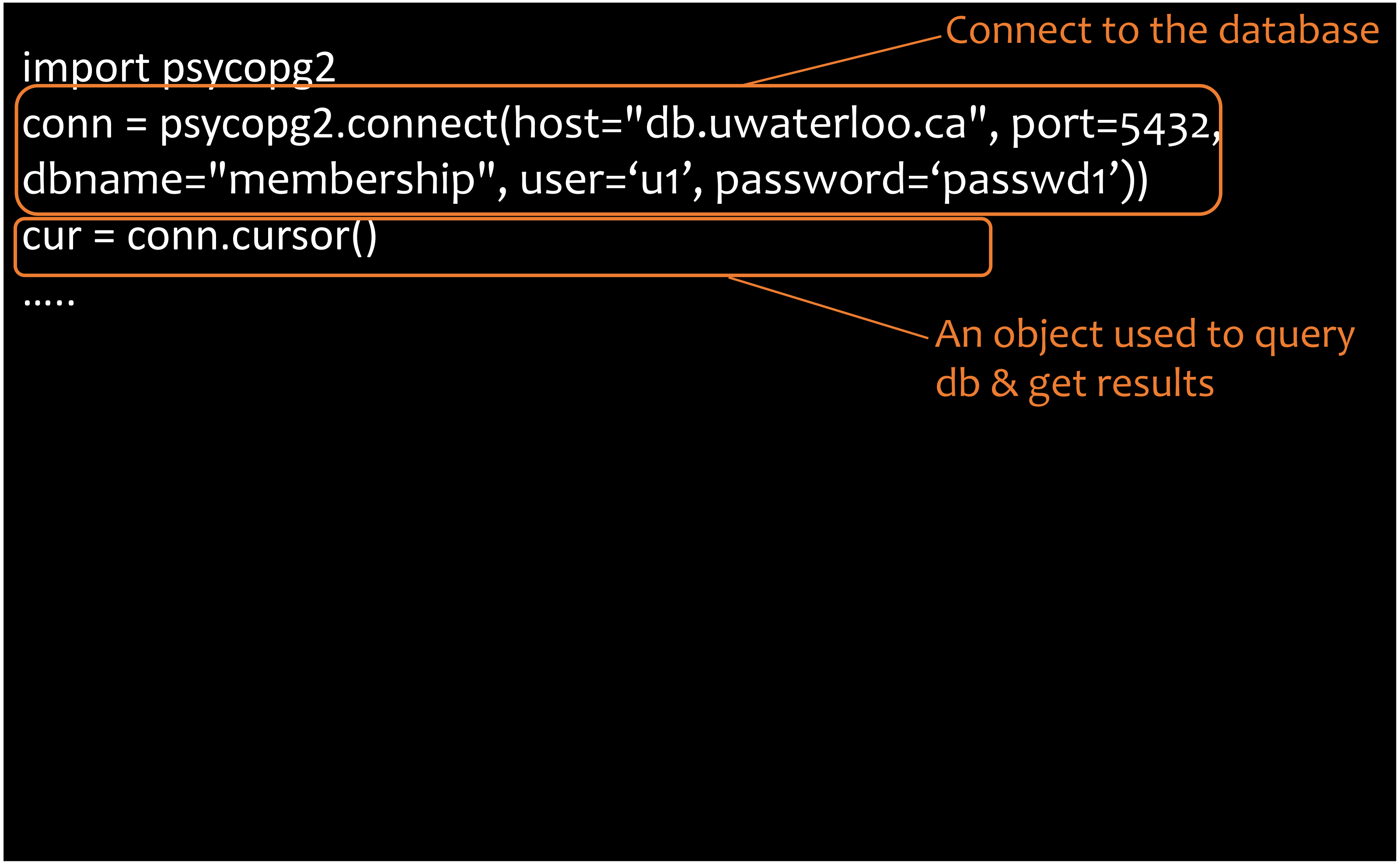
Dynamic SQL: Working with SQL through an API

- E.g.: Python psycopg2, JDBC, ODBC (C/C^{++}/VB)
  - All based on the SQL/CLI (Call-Level Interface) standard

- The application program sends SQL commands to the DBMS at runtime

- Responses/results are converted to objects in the application program

Example API: Python psycopg2



```
import psycopg2
conn = psycopg2.connect(host="db.uwaterloo.ca", port=5432,
dbname="membership", user=‘u1’, password=‘passwd1’))
cur = conn.cursor()
.....
```

Connect to the database

An object used to query db & get results

Example API: Python psycopg2

```
import psycopg2
conn = psycopg2.connect(host="db.uwaterloo.ca", port=5432,
dbname="membership", user=‘u1’, password=‘passwd1’)
cur = conn.cursor()
# list all groups:
cur.execute('SELECT * FROM Group')
for gid, name in cur:
   print(‘Group ’ + gid + ‘ has name ’ + name)
# print users whose name contains “a”:
cur.execute('SELECT name, pop FROM User WHERE name LIKE %s', ('a%'))
for name, pop  in cur:
   print(‘{} has a popularity of {}'.format(gid, name))
cur.close()
conn.close()
```

You can iterate over cur one tuple at a time

Placeholder for query parameter

Tuple of parameter values, one for each %s

More psycopg2 examples

```
# “commit” each change immediately—need to set this option just once at
the start of the session
conn.set_session(autocommit=True)
# …
uid = input('Enter the user id to update: ').strip()
name = input('Enter the name to update: ').strip()
pop = float(input('Enter new pop: '))
try:
   cur.execute(“
            UPDATE User
            SET pop = %s
            WHERE uid = %s AND name = %s”, (pop, uid, name))
   print('{} row(s) updated'.format(cur.rowcount))
except Exception as e:
   print(e)
```

Perform parsing, semantic analysis, optimization, compilation, and finally execution

More psycopg2 examples

```
….
while true:
# Input uid, name, pop…
    cur.execute('”
        UPDATE User
        SET pop = %s
        WHERE uid = %s AND name = %s'”, (pop, uid, name))
    ….
    # Check result...
```

Perform parsing, semantic analysis, optimization, compilation, and finally execution

Execute many times

Can we reduce this overhead?

Prepared statements: example

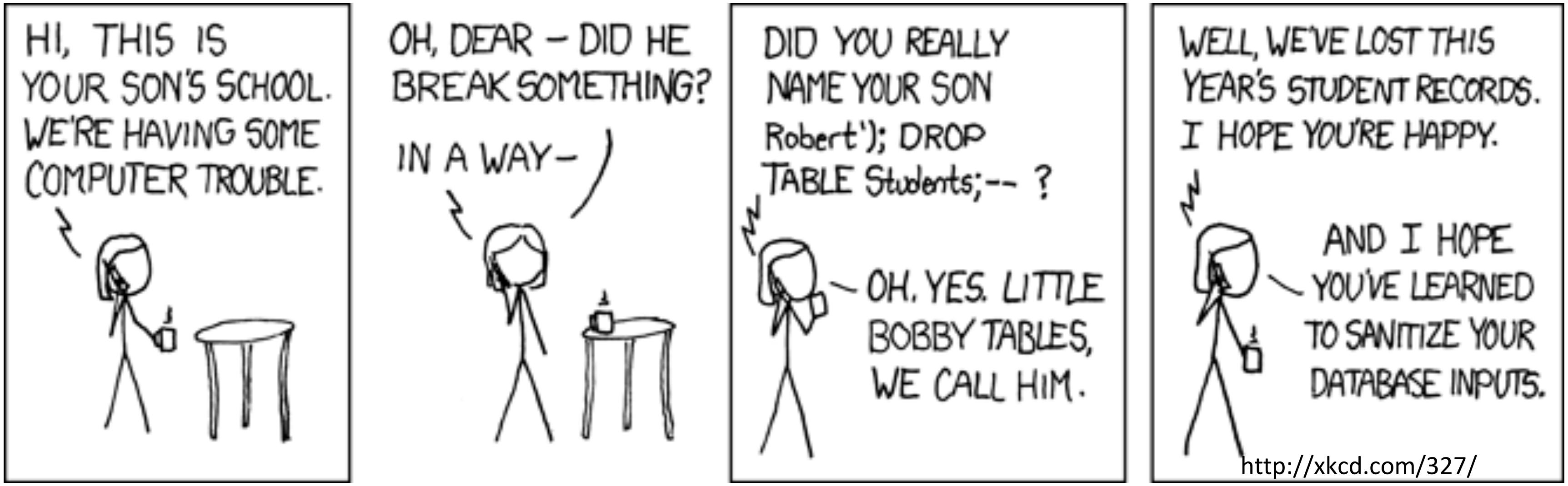
```
cur.execute('''              # Prepare once (in SQL).    Prepare only once
         PREPARE update_pop AS        # Name the prepared plan,
         UPDATE User
         SET pop = $1                 # and note the $1, $2, … notation for
         WHERE uid = $2 AND name = $3''') # parameter placeholders.
while true:
# Input uid, name, pop
    cur.execute('
         EXECUTE update_pop(%s, %s, %s)',\ # Execute many times.
              (pop, uid, name))....
    # Check result...
```

Prepared statements: example (JDBC)

Specific API provided by the driver

```
PreparedStatement pStmt = conn.prepareStatement(
          "insert into user values(?,?,?,?)");
pStmt.setInt(1, 678);
pStmt.setString(2, ”Bart");
pStmt.setFloat(3, 0.6);
pStmt.setInt(4, 10);
pStmt.executeUpdate();
```

“Exploits of a mom”


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

http://xkcd.com/327/

- The school probably had something like:

```
SELECT * FROM Students
WHERE (name =‘Bart’)
```

```
cur.execute("SELECT * FROM Students " + \
        "WHERE (name = ‘" + name +" ’)")
```

where name is a string input by user

- Called an SQL injection attack

Guarding against SQL injection

- Escape certain characters in a user input string, to ensure that it remains a single string

- Luckily, most API’s provide ways to “sanitize” input automatically when using prepared statements (%s)
  - E.g., user input for name= " Robert’);Drop table students; ”
    - SELECT * FROM Students WHERE (name =‘Robert\’;Drop table students;’)
    - Returns empty relation

- Some systems limit only one SQL query per API call

So far in programming

- Dynamic SQL

- Augmented SQL

- Embedded SQL

Augmenting SQL: functions & procedures

- Procedures and functions allow business logic to be stored in db and executed from SQL statements
- CREATE PROCEDURE *proc_name*(*param_decls*)

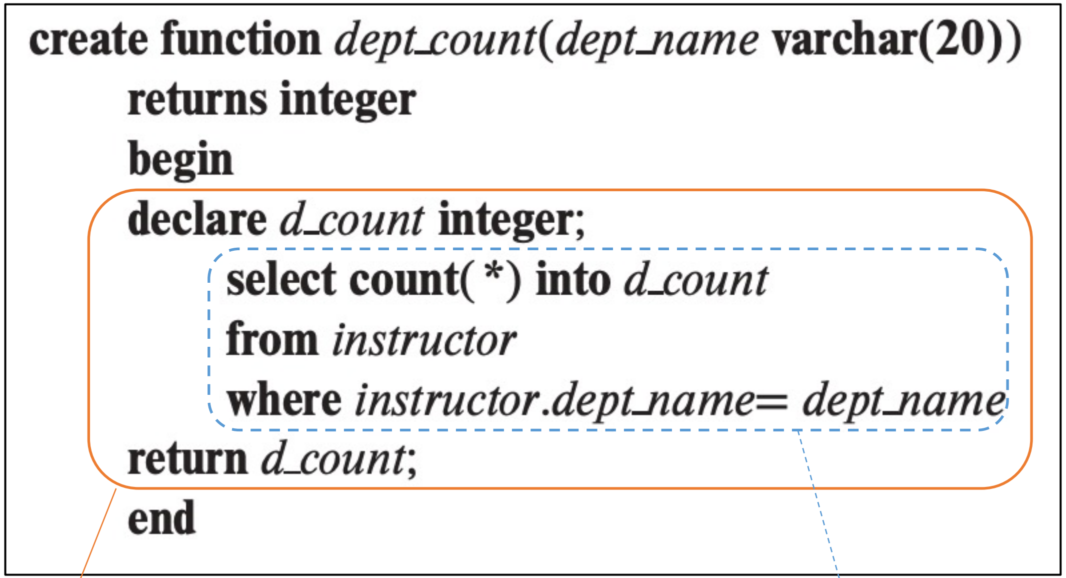
  local_decls

  proc_body;
- CREATE FUNCTION *func_name*(*param_decls*) RETURNS *return_type*

  local_decls

  func_body;
- CALL *proc_name*(*params*);
- Inside procedure body: SET *variable* = CALL *func_name*(*params*);

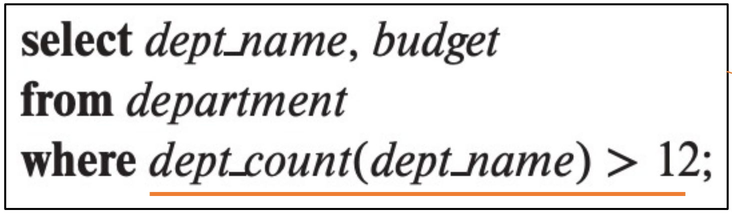
Creating function in SQL



```
create function dept_count(dept_name varchar(20))
        returns integer
        begin
        declare d_count integer;
                select count( *) into d_count
                from instructor
                where instructor.dept_name= dept_name
        return d_count;
        end
```

Declaring variables and defining the function

Writing an SQL query to get desired results

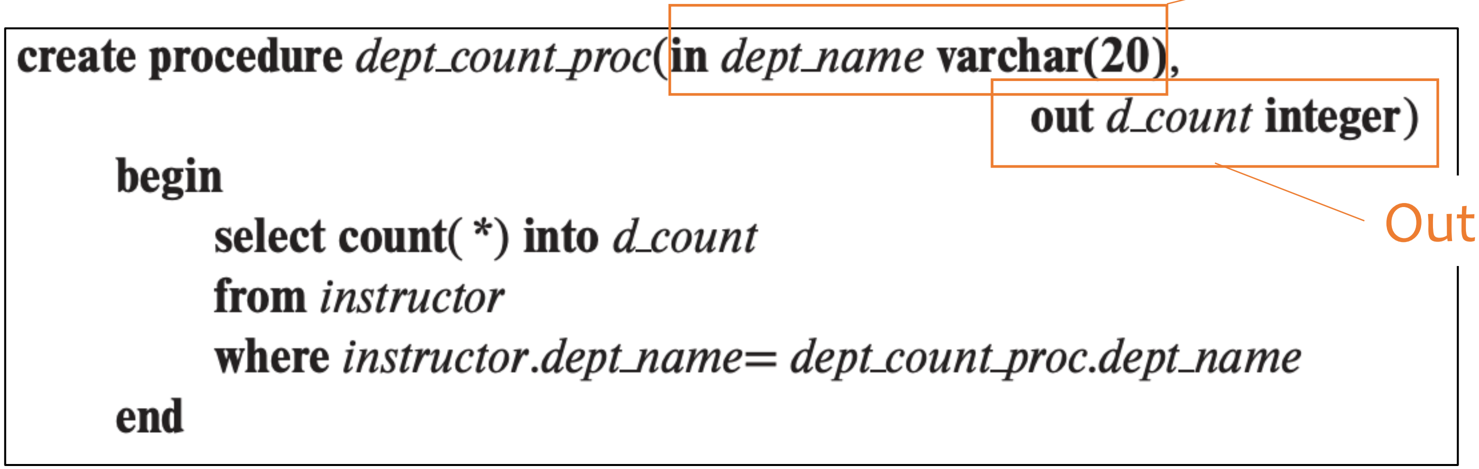


```
select dept_name, budget
from department
where dept_count(dept_name) > 12;
```

Invoking the function: returns dept. names & budgets for all depts with > 12 instructors

Creating a procedure in SQL

- Functions used to calculate something based on inputs; procedure are precompiled statements to perform some tasks in a specified order

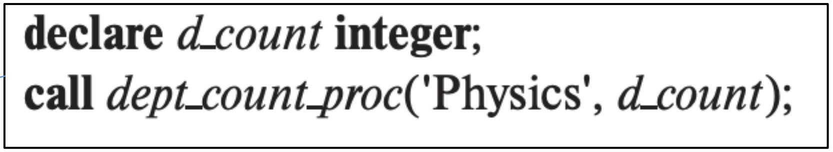


```
create procedure dept_count_proc(in dept_name varchar(20),
                                 out d_count integer)
    begin
        select count( *) into d_count
        from instructor
        where instructor.dept_name= dept_count_proc.dept_name
    end
```

Input param

Output param

Invoking the procedure
(either from another procedure or embedded SQL)



```
declare d_count integer;
call dept_count_proc('Physics', d_count);
```

Other SQL features

- Conditional constructs
  - IF, IF ELSIF ELSE
- Loop constructs
  - FOR, REPEAT UNTIL, LOOP
- Flow control
  - GOTO
- Exceptions
  - SIGNAL, RESIGNAL

…

Read DMBS manual for more details!

Augmenting SQL vs. API

- Pros of augmenting SQL:
  - More processing features for DBMS
  - More application logic can be pushed closer to data

- Cons of augmenting SQL:
  - SQL is already too big
  - Complicate optimization and make it impossible to guarantee safety

- Augmented SQL is not commonly used

Embedded SQL (optional)

- “Embed” SQL in a general-purpose programming language
- A language in which SQl queries are embedded is referred to as a host language
- The SQl structures permitted in the host language constitute embedded SQL
- To identify embedded SQL requests to the preporcessor, we use the “exec SQL” statements.

Embedding SQL in a language

Example in C

```
EXEC SQL BEGIN DECLARE SECTION;
int thisUid; float thisPop;
EXEC SQL END DECLARE SECTION;
EXEC SQL DECLARE ABCMember CURSOR FOR
   SELECT uid, pop FROM User
   WHERE uid IN (SELECT uid FROM Member WHERE gid = 'abc')
EXEC SQL OPEN ABCMember;
EXEC SQL WHENEVER NOT FOUND DO break;
while (1) {
   EXEC SQL FETCH ABCMember INTO :thisUid, :thisPop;
   printf("uid %d: current pop is %f\n", thisUid, thisPop);
                  printf("Enter new popularity: ");
   scanf("%f", &thisPop);
   EXEC SQL UPDATE User SET pop = :thisPop
      WHERE CURRENT OF ABCMember;
}
EXEC SQL CLOSE ABCMember;
```

Declare variables to be “shared” between the application and DBMS

Specify a handler for NOT FOUND exception

Embedded SQL v.s. API

- Pros of embedded SQL:
  - Be processed by a preprocessor prior to compilation → may catch SQL-related errors at preprocessing time
  - API: SQL statements are interpreted at runtime

- Cons of embedded SQL:
  - New host language code → complicate debugging
  - Need a preprocessor s/w

So far

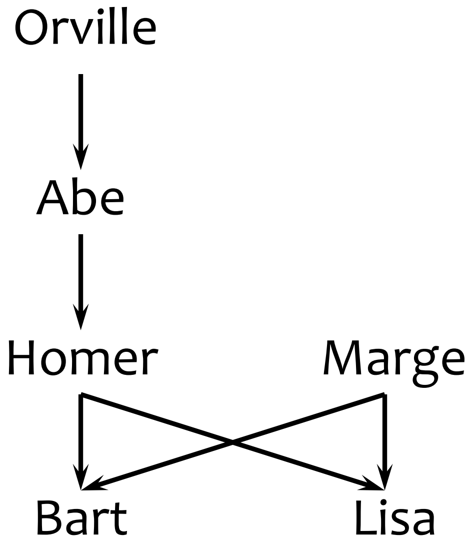
- Basic SQL (queries, modifications, and constraints)
- Intermediate SQL(triggers, views, indexes)
- Programming

- Recursion

A motivating example

Parent (parent, child)

parent	*child*
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Orville	Abe



Orville

Abe

Homer

Marge

Bart

Lisa

- Example: find Bart’s ancestors
- “Ancestor” has a recursive definition
  - X is Y’s ancestor if
    - X is Y’s parent, or
    - X is Z's ancestor and Z is Y’s ancestor

Recursion in SQL

- SQL2 had no recursion
  - You can find Bart’s parents, grandparents, great grandparents, etc.

```
SELECT p1.parent AS grandparent
FROM Parent p1, Parent p2
WHERE p1.child = p2.parent
      AND p2.child = 'Bart';
```

  - But you cannot find all his ancestors with a single query
- SQL3 introduced recursion
  - WITH RECURSIVE clause
  - Many systems support recursion but limited functionality

Ancestor query in SQL3

```
WITH RECURSIVE
Ancestor(anc, desc) AS
((SELECT parent, child FROM Parent)
 UNION
 (SELECT a1.anc, a2.desc
  FROM Ancestor a1, Ancestor a2
  WHERE a1.desc = a2.anc))
SELECT anc
FROM Ancestor
WHERE desc = 'Bart';
```

base case

a1.anc (X) → a1.desc(Z)
a2.anc (Z) → a2.desc (Y)

recursion step

Define
a relation
recursively

Query using the relation
defined in WITH clause

Finding ancestors

```
WITH RECURSIVE
Ancestor(anc, desc) AS                    base case
((SELECT parent, child FROM Parent)
 UNION
 (SELECT a1.anc, a2.desc
  FROM Ancestor a1, Ancestor a2      recursive
  WHERE a1.desc = a2.anc))           step
…..;
```

parent	child
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Orville	Abe

anc	desc

→

anc	desc
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Orville	Abe

→

anc	desc
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Orville	Abe
Abe	Bart
Abe	Lisa
Orville	Homer

→

anc	desc
Homer	Bart
Homer	Lisa
Marge	Bart
Marge	Lisa
Abe	Homer
Orville	Abe
Abe	Bart
Abe	Lisa
Orville	Homer
Orville	Bart
Orville	Lisa

Fixed point of a function

- If $f: D \rightarrow D$ is a function from a type D to itself, a fixed point of f is a value x such that $f(x) = x$
    - Example: what is the fixed point of f(x) = x/2?
    - Ans: 0, as f(0)=0

- To compute a fixed point of f
    - Start with a "seed": $x \leftarrow x_0$
    - Compute $f(x)$
        - If $f(x) = x$, stop; x is fixed point of f
            - (Similar to base case in recursive prog.)
        - Otherwise, $x \leftarrow f(x)$; repeat

Fixed point of a query

- A query q is just a function that maps an input table to an output table, so a fixed point of q is a table T such that $q(T) = T$

- To compute fixed point of q
  - Start with executing the base query: $T \leftarrow base\ query$
  - Evaluate q over T
    - If the result is identical to T, stop; T is a fixed point
    - Otherwise, let T be the new result; repeat

- *Fixed point: there is no further change in the result of the recursive query evaluation*
- *Fixed point indicates when the evaluation of the recursive query* ***terminates***

Restrictions on recursive queries

Lecture 2

- A recursive query *q* must be monotonic
  - If input changes, old output should still be valid
- If more tuples are added to the recursive relation, *q* must return at least the same set of tuples as before, and possibly return additional tuples

- The following is not allowed in *q:*
  - Aggregation on the recursive relation
  - NOT EXISTS in generating the recursive relation
  - Set difference (EXCEPT) whose right-hand side uses the recursive relation

Summary

- Basic SQL (queries, modifications, and constraints)
- Intermediate SQL(triggers, views, indexes)
- Programming

- Recursion

- Next 2 lectures: DB design (E/R diagrams)