SQL: Programming

Introduction to Databases

CompSci 316 Fall 2019

DUKE
COMPUTER SCIENCE

Announcements (Mon., Sep. 30)

- Please fill out the RATest survey (1 free pt on midterm)
- Gradiance SQL Recursion exercise assigned
- Homework 2 + Gradiance SQL Constraints due tonight!
- Wednesday
  - Midterm in class
    - Open-book, open-notes
    - Same format as sample midterm (posted in Sakai)
  - Gradiance SQL Triggers/Views due
- After fall break
  - Project milestone 1 due; remember `members.txt`
  - Gradiance SQL Recursion due

Motivation

- Pros and cons of SQL
  - Very high-level, possible to optimize
  - Not intended for general-purpose computation
- Solutions
  - Augment SQL with constructs from general-purpose programming languages
    - E.g.: SQL/PSM
  - Use SQL together with general-purpose programming languages: many possibilities
    - Through an API, e.g., Python `psycopg2`
    - Embedded SQL, e.g., in C
    - Automatic object-relational mapping, e.g.: Python SQLAlchemy
    - Extending programming languages with SQL-like constructs, e.g.: LINQ

An "impedance mismatch"

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

☞Solution: cursor

- Open (a result table): position the cursor before the first row
- Get next: move the cursor to the next row and return that row; raise a flag if there is no such row
- Close: clean up and release DBMS resources

☞Found in virtually every database language/API

- With slightly different syntaxes

☞Some support more positioning and movement options, modification at the current position, etc.

Augmenting SQL: SQL/PSM

- PSM = Persistent Stored Modules
- `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*`);`

SQL/PSM example

```
CREATE FUNCTION SetMaxPop(IN newMaxPop FLOAT)
  RETURNS INT
  -- Enforce newMaxPop; return # rows modified.
BEGIN
  DECLARE rowsUpdated INT DEFAULT 0;
  DECLARE thisPop FLOAT;
  -- A cursor to range over all users:
  DECLARE userCursor CURSOR FOR
      SELECT pop FROM User
  FOR UPDATE;
  -- Set a flag upon "not found" exception:
  DECLARE noMoreRows INT DEFAULT 0;
  DECLARE CONTINUE HANDLER FOR NOT FOUND
      SET noMoreRows = 1;
  ... (see next slide) ...
  RETURN rowsUpdated;
END
```

SQL/PSM example continued

```
-- Fetch the first result row:
OPEN userCursor;
FETCH FROM userCursor INTO thisPop;
-- Loop over all result rows:
WHILE noMoreRows <> 1 DO
    IF thisPop > newMaxPop THEN
        -- Enforce newMaxPop:
        UPDATE User SET pop = newMaxPop
        WHERE CURRENT OF userCursor;
        -- Update count:
        SET rowsUpdated = rowsUpdated + 1;
    END IF;
    -- Fetch the next result row:
    FETCH FROM userCursor INTO thisPop;
END WHILE;
CLOSE userCursor;
```

Other SQL/PSM features

- Assignment using scalar query results
  - `SELECT INTO`
- Other loop constructs
  - `FOR`, `REPEAT UNTIL`, `LOOP`
- Flow control
  - `GOTO`
- Exceptions
  - `SIGNAL`, `RESIGNAL`

…

- For more PostgreSQL-specific information, look for "PL/pgSQL" in PostgreSQL documentation
  - Link available from course website (under Help: PostgreSQL Tips)

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(dbname='beers')
cur = conn.cursor()
# list all drinkers:
cur.execute('SELECT * FROM Drinker')
for drinker, address in cur:
    print(drinker + ' lives at ' + address)
# print menu for bars whose name contains "a":
cur.execute('SELECT * FROM Serves WHERE bar LIKE %s', ('%a%',))
for bar, beer, price in cur:
    print('{} serves {} at ${:,.2f}'.format(bar, beer, price))
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

(note that the trailing "," is needed when the tuple contains only one value)

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)
#  ...
bar = input('Enter the bar to update: ').strip()
beer = input('Enter the beer to update: ').strip()
price = float(input('Enter the new price: '))
try:
    cur.execute('''
UPDATE Serves
SET price = %s
WHERE bar = %s AND beer = %s''', (price, bar, beer))
    if cur.rowcount != 1:
        print('{} row(s) updated: correct bar/beer?'\
              .format(cur.rowcount))
except Exception as e:
    print(e)
```

# of tuples modified

Exceptions can be thrown
(e.g., if positive-price constraint is violated)

Prepared statements: motivation

```
while True:
    # Input bar, beer, price...
    cur.execute('''
UPDATE Serves
SET price = %s
WHERE bar = %s AND beer = %s''', (price, bar, beer))
    # Check result...
```

- Every time we send an SQL string to the DBMS, it must perform parsing, semantic analysis, optimization, compilation, and finally execution
- A typical application issues many queries with a small number of patterns (with different parameter values)
- Can we reduce this overhead?

Prepared statements: example

See `/opt/dbcourse/examples/psycopg2/` on your VM for a complete code example

```
cur.execute('''
PREPARE update_price AS
UPDATE Serves
SET price = $1
WHERE bar = $2 AND beer = $3''')
```

```
# Prepare once (in SQL).
# Name the prepared plan,

# and note the $1, $2, … notation for
# parameter placeholders.
```

```
while True:
    # Input bar, beer, price…
    cur.execute('EXECUTE update_price(%s, %s, %s)',\
                (price, bar, beer))
```

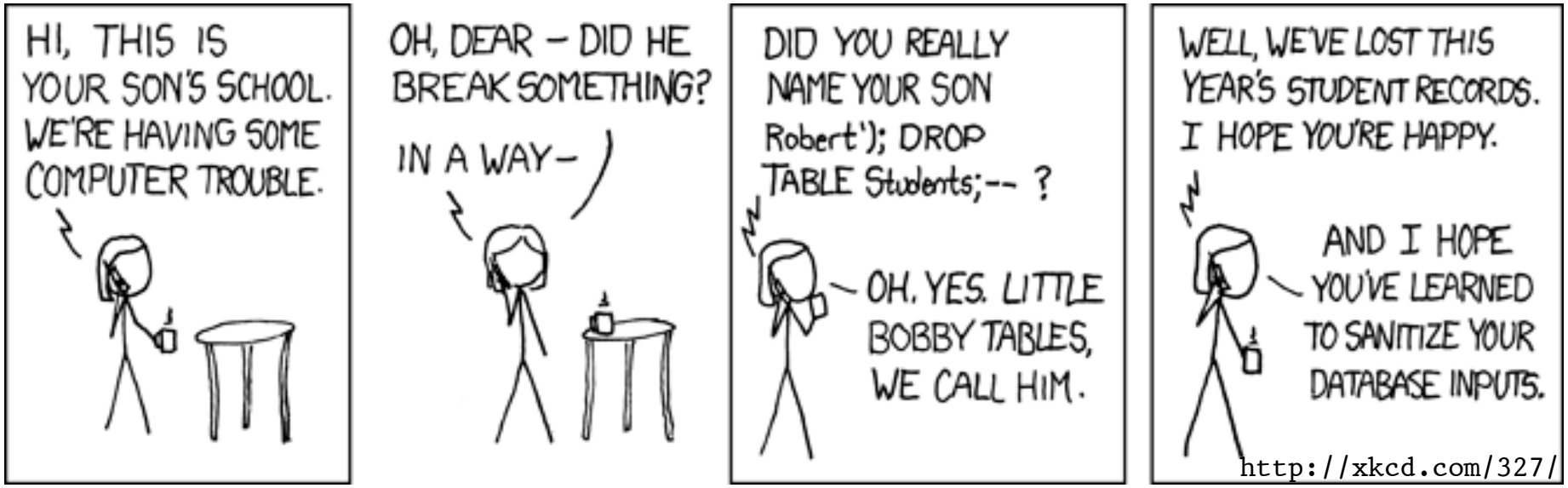
```
# Execute many times.

# Note the switch back to %s for parameter placeholders.
```

```
    # Check result...
```

- The DBMS performs parsing, semantic analysis, optimization, and compilation only once, when it "prepares" the statement
- At execution time, the DBMS only needs to check parameter types and validate the compiled plan
- Most other API's have better support for prepared statements than `psycopg2`
  - E.g., they would provide a `cur.prepare()` method

"Exploits of a mom"



- The school probably had something like:

```
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
  - E.g., `'`, which would terminate a string in SQL, must be replaced by `''` (two single quotes in a row) within the input string
- Luckily, most API's provide ways to "sanitize" input automatically (if you use them properly)
  - E.g., pass parameter values in `psycopg2` through `%s`'s

If one fails to learn the lesson…

… P.S. To Ashley Madison's Development Team: You should be embarrased [sic] for your train wreck of a database (and obviously security), not sanitizing your phone numbers to your database is completely amateur, it's as if the entire site was made by Comp Sci 1XX students.

— Creators of `CheckAshleyMadison.com`

http://www.washingtonpost.com/news/the-intersect/wp/2015/08/19/how-to-see-if-you-or-your-spouse-appear-in-the-ashley-madison-leak/

Augmenting SQL vs. API

- Pros of augmenting SQL:
  - More processing features for DBMS
  - More application logic can be pushed closer to data
    - Less data "shipping," more optimization opportunities ⇒ more efficient
    - Less code ⇒ easier to maintain multiple applications
- Cons of augmenting SQL:
  - SQL is already too big—at some point one must recognize that SQL/DBMS are not for everything!
  - General-purpose programming constructs complicate optimization and make it impossible to guarantee safety

A brief look at other approaches

- "Embed" SQL in a general-purpose programming language
  - E.g.: embedded SQL
- Support database features through an object-oriented programming language
  - By automatically storing objects in tables and translating methods to SQL
  - E.g., object-relational mappers (ORM) like Python SQLAlchemy
- Extend a general-purpose programming language with SQL-like constructs
  - E.g.: LINQ (Language Integrated Query for .NET)

Embedding SQL in a language

Example in C

```
EXEC SQL BEGIN DECLARE SECTION;
int thisUid; float thisPop;
EXEC SQL END DECLARE SECTION;
```

Declare variables to be "shared" between the application and DBMS

```
EXEC SQL DECLARE ABCMember CURSOR FOR
    SELECT uid, pop FROM User
    WHERE uid IN (SELECT uid FROM Member WHERE gid = 'abc')
    FOR UPDATE;

EXEC SQL OPEN ABCMember;
EXEC SQL WHENEVER NOT FOUND DO break;
```

Specify a handler for NOT FOUND exception

```
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;
```

Object-relational mapping

- Example: Python SQLAlchemy

```
class User(Base):
   __tablename__ = 'users'
   id = Column(Integer, primary_key=True)
   name = Column(String)
   password = Column(String)
```

```
class Address(Base):
   __tablename__ = 'addresses'
   id = Column(Integer, primary_key=True)
   email_address = Column(String, nullable=False)
   user_id = Column(Integer, ForeignKey('users.id'))
```

```
Address.user = relationship("User", back_populates="addresses")
User.addresses = relationship("Address", order_by=Address.id, back_populates="user")

jack = User(name='jack', password='gjffdd')
jack.addresses = [Address(email_address='jack@google.com'),
                  Address(email_address='j25@yahoo.com')]
session.add(jack)
session.commit()

session.query(User).join(Address).filter(Address.email_address=='jack@google.com').all()
```

- Automatic data mapping and query translation
- But syntax may vary for different host languages
- Very convenient for simple structures/queries, but quickly get complicated and less intuitive for more complex situations

Deeper language integration

- Example: LINQ (Language Integrated Query) for Microsoft .NET languages (e.g., C#)

```
int someValue = 5;
var results = from c in someCollection
              let x = someValue * 2
              where c.SomeProperty < x
              select new {c.SomeProperty, c.OtherProperty};
foreach (var result in results) {
  Console.WriteLine(result);
}
```

- Again, automatic data mapping and query translation
- Much cleaner syntax, but it still may vary for different host languages