SQL: Programming

CompSci 316

Introduction to Database Systems

Announcements (Thu. Oct. 3)

- Homework #2 due tonight
- Data+Journalism talk by Derek Willis on Monday
  - RSVP before space runs out!
- Midterm next Thursday, in class
  - Open-book, open-notes
  - No communication devices
  - Will cover all materials through next Tuesday
  - Solution to sample midterm to be posted this weekend
- Project milestone #1 due the following Thursday
  - Right after fall break

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
    - E.g.: JDBC, embedded SQL
  - Extend general-purpose programming languages with SQL-like constructs
    - E.g.: LINQ (Language Integrated Query for .NET), HQL (Hibernate Query Language)

Impedance mismatch and a solution

- SQL operates on a set of records at a time
- Typical low-level general-purpose programming languages operates on one record at a time
- ☞ 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* `(` *parameter_declarations* `)`
  local_declarations
  procedure_body`;`
- `CREATE FUNCTION` *func_name* `(` *parameter_declarations* `)`
  `RETURNS` *return_type*
  local_declarations
  procedure_body`;`
- `CALL` *proc_name* `(` *parameters* `);`
- Inside procedure body:
  `SET` *variable* `=` `CALL` *func_name* `(` *parameters* `);`

SQL/PSM example


```
CREATE FUNCTION SetMaxGPA(IN newMaxGPA FLOAT)
  RETURNS INT
  -- Enforce newMaxGPA; return number of rows modified.
BEGIN
  DECLARE rowsUpdated INT DEFAULT 0;
  DECLARE thisGPA FLOAT;
  -- A cursor to range over all students:
  DECLARE studentCursor CURSOR FOR
      SELECT GPA FROM Student
  FOR UPDATE;
  -- Set a flag whenever there is a "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

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```
-- Fetch the first result row:
OPEN studentCursor;
FETCH FROM studentCursor INTO thisGPA;
-- Loop over all result rows:
WHILE noMoreRows <> 1 DO
    IF thisGPA > newMaxGPA THEN
        -- Enforce newMaxGPA:
        UPDATE Student SET Student.GPA = newMaxGPA
        WHERE CURRENT OF studentCursor;
        -- Update count:
        SET rowsUpdated = rowsUpdated + 1;
    END IF;
    -- Fetch the next result row:
    FETCH FROM studentCursor INTO thisGPA;
END WHILE;
CLOSE studentCursor;
```

Other SQL/PSM features

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- 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 Programming Notes: PostgreSQL Notes)

Interfacing SQL with another language

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- API approach
  - SQL commands are sent to the DBMS at runtime
  - Examples: JDBC, ODBC (C/C++/VB), Python DB API
  - These API's are all based on the SQL/CLI (Call-Level Interface) standard
- Embedded SQL approach
  - SQL commands are embedded in application code
  - A precompiler checks these commands at compile-time and converts them into DBMS-specific API calls
  - Examples: embedded SQL for C/C++, SQLJ (for Java)

Example API: JDBC

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- JDBC (Java DataBase Connectivity) is an API that allows a Java program to access databases

```
// Use the JDBC package:
import java.sql.*;
…
public class … {
    …
    static {
        // Load the JDBC driver:
        try {
            Class.forName("org.postgresql.Driver");
        } catch (ClassNotFoundException e) {
            …
        }
    }
    …
}
```

- Not very nice since it ties your code to a particular DBMS
- Best if you load it from a properties file
- Or, for web apps, use a JNDI `DataSource` (see course website: Programming Notes: Tomcat Notes)

Connections

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```
// Connection URL is a DBMS-specific string:
String url =
  "jdbc:postgresql:azureuser";
// Making a connection:
Properties props = new Properties();
props.setProperty("user", "azureuser");
props.setProperty("password", "mypassword");
Connection con =
  DriverManager.getConnection(url, props);
…
// Closing a connection:
con.close();
```

name of the database connecting to

- For clarity we are ignoring exception handling here
- Again, in practice you should avoid hard-coding DBMS-specific things (see previous slide)

Statements

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```
// Create an object for sending SQL statements:
Statement stmt = con.createStatement();
// Execute a query and get its results:
ResultSet rs =
    stmt.executeQuery("SELECT SID, name FROM Student");
// Work on the results:
…
// Execute a modification (returns the number of rows affected):
int rowsUpdated =
    stmt.executeUpdate
    ("UPDATE Student SET name = 'Barney' WHERE SID = 142");
// Close the statement:
stmt.close();
```

Query results


```
// Execute a query and get its results:
ResultSet rs =
    stmt.executeQuery("SELECT SID, name FROM Student");
// Loop through all result rows:
while (rs.next()) {
    // Get column values:
    int sid = rs.getInt(1);
    String name = rs.getString(2);
    // Work on sid and name:
    …
}
// Close the ResultSet:
rs.close();
```

Other `ResultSet` features

- Move the cursor (pointing to the current row) backwards and forwards, or position it anywhere within the `ResultSet`
- Update/delete the database row corresponding to the current result row, or insert a row into the database
  - Possible only when there is a clear 1-1 correspondence between the change and a row in the underlying table
  - Analogous to the view update problem
    - Covered in the lecture on SQL views
- Obtain metadata: `rs.getMetaData()` returns a `ResultSetMetaData` object describing the output table schema (number, order, names, types of columns, etc.)

Prepared statements: motivation


```
Statement stmt = con.createStatement();
for (int age=0; age<100; age+=10) {
    ResultSet rs = stmt.executeQuery
        ("SELECT AVG(GPA) FROM Student" +
         " WHERE age >= " + age + " AND age < " + (age+10));
    // Work on the results:
    …
}
```

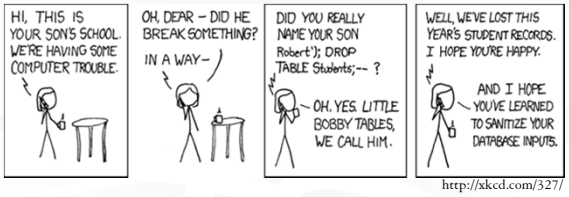
- Every time an SQL string is sent to the DBMS, the DBMS must perform parsing, semantic analysis, optimization, compilation, and then finally execution
- These costs are incurred 10 times in the above example
- A typical application issues many queries with a small number of patterns (with different parameter values)

Prepared statements: syntax


```
// Prepare the statement, using ? as placeholders for actual parameters:
PreparedStatement stmt = con.prepareStatement
    ("SELECT AVG(GPA) FROM Student WHERE age >= ? AND age < ?");
for (int age=0; age<100; age+=10) {
    // Set actual parameter values:
    stmt.setInt(1, age);
    stmt.setInt(2, age+10);
    ResultSet rs = stmt.executeQuery();
    // Work on the results:
    …
}
```

- 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 execution plan

"Exploits of a mom"



http://xkcd.com/327/

- The school probably did something like:
  `stmt.executeQuery("SELECT * FROM Students WHERE (name = '" + name + "')");`
  where `name` is a string input by user
- Called a SQL injection attack
  - Be careful in constructing SQL from user input strings!

Guarding against SQL injection attacks

- Need to escape certain characters in a user input string to ensure that it stays as a single string
  - E.g., `'`, which would terminate a string in SQL, must be replaced by `''` (two single quotes in a row)
- Luckily, most APIs provide ways to "sanitize" input automatically (if you use them properly)
  - E.g., setting parameters in a prepared statement sanitizes input automatically—another reason to use them!

```
PreparedStatement stmt =
    con.prepareStatement("SELECT * FROM Student WHERE name = ?");
stmt.setString(1, name);
stmt.executeQuery();
```

Odds and ends of JDBC

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- Most methods can throw `SQLException`
  - Make sure your code catches them
  - Remember to close `Statement`, `ResultSet`, etc., in `finally` block
  - `getSQLState()` returns the standard SQL error code
  - `getMessage()` returns the error message
- `DataSource` interface for establishing connections
- Methods for examining metadata in databases
- Methods to retrieve the value of a column for all result rows into an array without calling `ResultSet.next()` in a loop
- Methods to construct/execute a batch of SQL statements

…

- For additional information and example code, see course website: Programming Notes: JDBC Notes

Embedded C example

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```
…
/* Declare variables to be "shared" between the application
   and the DBMS: */
EXEC SQL BEGIN DECLARE SECTION;
int thisSID; float thisGPA;
EXEC SQL END DECLARE SECTION;
/* Declare a cursor: */
EXEC SQL DECLARE CPS316Student CURSOR FOR
    SELECT SID, GPA FROM Student
    WHERE SID IN
        (SELECT SID FROM Enroll WHERE CID = 'CPS316')
    FOR UPDATE;
…
```

Embedded C example continued

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```
/* Open the cursor: */
EXEC SQL OPEN CPS316Student;
/* Specify exit condition: */
EXEC SQL WHENEVER NOT FOUND DO break;
/* Loop through result rows: */
while (1) {
    /* Get column values for the current row: */
    EXEC SQL FETCH CPS316Student INTO :thisSID, :thisGPA;
    printf("SID %d: current GPA is %f\n", thisSID, thisGPA);
    /* Update GPA: */
    printf("Enter new GPA: ");
    scanf("%f", &thisGPA);
    EXEC SQL UPDATE Student SET GPA = :thisGPA
        WHERE CURRENT OF CPS316Student;
}
/* Close the cursor: */
EXEC SQL CLOSE CPS316Student;
```

Pros and cons of embedded SQL (vs. API)

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- Pros
  - More compile-time checking (syntax, type, schema, …)
  - Code could be more efficient (if the embedded SQL statements do not need to checked and recompiled at run-time)
- Cons
  - DBMS-specific
    - Vendors have different precompilers which translate code into different native API's
    - Application executable is not portable (although code is)
    - Application cannot talk to different DBMS at the same time

Pros and cons of augmenting SQL

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- Cons
  - Already too many programming languages
  - SQL is already too big
  - General-purpose programming constructs complicate optimization, and make it difficult to tell if code running inside the DBMS is safe
  - At some point, one must recognize that SQL and the DBMS engine are not for everything!
- Pros
  - More sophisticated processing inside DBMS
  - More application logic can be pushed closer to data

Making a language SQL-like?

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- E.g.: LINQ (for C#), HQL (for Java/Hibernate)
- Example LINQ code (from Wiki)

```
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);
}
```

- Automatic data mapping and query translation
- But a different syntax for each host language?