Announcements (Tue. Oct. 2)

- Homework #2 due Thursday
- Midterm next Thursday, in class
  - You should have received a sample midterm via email
- Project milestone #1 due the following Thursday

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 operate 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
BEGIN
  DECLARE rowsUpdated INT DEFAULT 0;
  DECLARE thisGPA FLOAT;
  DECLARE studentCursor CURSOR FOR
    SELECT GPA FROM Student
    FOR UPDATE;
  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 studentCursor;
-- 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

- 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

- **API approach**
  - SQL commands are sent to the DBMS at runtime
  - Examples: JDBC, ODBC (C/C++/VB), Python DB API
  - These APIs 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

```
// 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)
  }

  // Connection URL is a DBMS-specific string:
  String url = "jdbc:postgresql://localhost:ubuntu", connecting to
  // Making a connection:
  Properties props = new Properties();
  props.setProperty("user", "ubuntu");
  props.setProperty("password", "reverse");
  Connection con = DriverManager.getConnection(url, props);
  ...
  // Closing a connection:
  con.close();
  // Again, in practice you should avoid hard-coding DBMS-specific things (see previous slide)

  // 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();
  ...
```

Connections

Statements
Query results

```java
// 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

```java
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:
    ...
} // Close the ResultSet:
rs.close();
```

- 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

```java
// 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:
} // Close the ResultSet:
rs.close();
```

- 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"

- The school probably did something like:
  ```java
  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!
    ```java
    PreparedStatement stmt = con.prepareStatement("SELECT * FROM Student WHERE name = ?");
    stmt.setString(1, name);
    stmt.executeQuery();
    ```
Odds and ends of JDBC

- 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

```c
/* 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;

/* 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);
    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)

- 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

- 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?

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

```c
int sameValue = 5;
var results = from c in someCollection
let x = sameValue * 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?