Announcements (Tue. Sep. 23)

- Homework #2 due next Thursday
  - Please start early—you can do all of it now!
- Homework #1 sample solution available
  - Only in hardcopies; see me if you did not get one in class
- Project milestone #1 due in 3½ weeks

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 (analogous to view update), 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

```sql
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 studentsCursor 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

```sql
OPEN studentCursor;
FETCH FROM studentCursor INTO thisGPA;
WHILE noMoreRows <> 1 DO
  IF thisGPA > newMaxGPA THEN
    UPDATE Student SET Student.GPA = newMaxGPA
    WHERE CURRENT OF studentCursor;
    UPDATE count;
    SET rowsUpdated = rowsUpdated + 1;
  END IF;
  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 DB2-specific information, search for “SQL routines” in DB2 v9.5 Information Center
  - Link available from course website (under Programming Notes: DB2 SQL 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 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

- JDBC (Java Database Connectivity) is an API that allows a Java program to access databases
  
  ```java
  public class ...
  {
      static {
          // Load the JDBC driver:
          try {
              Class.forName("com.ibm.db2.jcc.DB2Driver");
          } 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

- Connection URL is a DBMS-specific string:
  
  ```java
  String url = "jdbc:db2://cps116.cod.cs.duke.edu:50000/dbcourse";
  ```

Statements

- Create an object for sending SQL statements:
  
  ```java
  Statement stmt = con.createStatement();
  ```

- Execute a query and get its results:
  
  ```java
  ResultSet rs = stmt.executeQuery("SELECT SID, name FROM Student");
  ```

- Execute a modification (returns the number of rows affected):
  
  ```java
  int rowsUpdated = stmt.executeUpdate("UPDATE Student SET name = 'Barney' WHERE SID = 142");
  ```
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 result:
    ...
}  // 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:
}
```

- 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.

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.

A note on JDBC drivers

- Type I (bridge): translates JDBC calls to standard API not native to DBMS:
  - E.g.: JDBC-ODBC bridge.
  - Driver is easy to build using existing standard APIs.
  - Extra layer of API adds overhead.
- Type II (native API, partly Java): translates JDBC calls to DBMS-specific client API:
  - DBMS-specific non-Java client library needs to be installed on each client.
  - Good performance.
- Type III (network bridge): sends JDBC requests to a middleware server which in turn communicates with a database:
  - Client JDBC driver is completely Java, easy to build, and does not need to be DBMS-specific.
  - Middleware adds translation overhead.
- Type IV (native protocol, full Java): converts JDBC requests directly to native network protocol of the DBMS:
  - Client JDBC driver is completely Java but is also DBMS-specific.
  - Good performance.
  - Supported by, e.g., com.ibm.db2.jcc.DB2Driver.
Embedded C example

...  
/* 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 CPS116Student CURSOR FOR
SELECT SID, GPA FROM Student
WHERE SID IN
(SELECT SID FROM Enroll WHERE CID = 'CPS116')
FOR UPDATE;
...

Embedded C example continued

/* Open the cursor: */
EXEC SQL OPEN CPS116Student;
/* 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 CPS116Student INTO :thisSID, :thisGPA;
    /* Update GPA: */
    printf("Enter new GPA: ");
    scanf("%f", &thisGPA);
    EXEC SQL UPDATE Student SET GPA = :thisGPA
    WHERE CURRENT OF CPS116Student;
}
/* Close the cursor: */
EXEC SQL CLOSE CPS116Student;

Pros and cons of embedded SQL

- 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
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**

Making a language SQL-like?

- E.g.: LINQ (for C#), HQL (for Java/Hibernate)
- Example LINQ code (from Wiki)
  ```csharp
  int someValue = 5;
  var results = from c in someCollection
  let x = someValue * 2
  where c.SameProperty < x
  select new {c.SomeProperty, c.OtherProperty};
  foreach (var result in results) {
    Console.WriteLine(result);
  }
  ```
- Automatic data mapping and query translation
- Fad or way of the future?