Real SQL
Application Programming

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Reference:
A First Course in Database Systems,
3rd edition, Chapter 9

Important Notices

- Midterm and Midterm Answers are on Piazza.
  - Answers were reviewed in class on Wed, Feb 15.
  - Midterm grades (uncurved) were posted on Canvas.
  - Curve: 0.9 * X + 12
  - Exam returned on Friday, Feb 24 and Monday, Feb 27.
- Lab3 Solution was posted on Monday, Feb 27.
- Lab4 assignment was posted on Monday, Feb 27.
  - Due by Sunday, March 12, 11:59pm (2 weeks).
  - Lab4 focusses on material in this Application Programming lecture (JDBC, Stored Procedures).
  - If you don't attend Lectures and Labs, you probably will find Lab4 difficult.
- Gradiance Assignment #4 is due by Tuesday, March 7, 11:59pm.

SQL in Real Programs

- We have seen only how SQL is used at a generic query interface --- an environment where we sit at a terminal and ask queries of (or modify) a database.
- Reality is almost always different!
  - Conventional programs written in C or Java, (or other languages) that interact with database using SQL.
  - Why?

Approaches

1. Code in a specialized language is stored in the database itself (e.g., **Stored Procedure** languages such as PSM and PL/SQL).
2. SQL statements are **embedded in a host language** (e.g., C).
3. **Connection tools/libraries** are used to allow a **conventional language** to access a database (e.g., CLI, JDBC).

Approach 1: Stored Procedures

- PSM, or "*persistent stored modules*," allows us to store procedures as database schema elements.
- PSM = a mixture of conventional statements (if, while, etc.) and SQL.
- Lets us do things we cannot do in SQL alone.

Basic PSM Form

CREATE PROCEDURE <name> (

<parameter list>)

<optional local declarations>

<body>;

Basic PSM Form

CREATE FUNCTION <name> (

<parameter list>) RETURNS <type>

<optional local declarations>

<body>;

Parameters in PSM

- Unlike the usual name-type pairs in languages like C, PSM uses mode-name-type triples, where the *mode* can be:
  - IN = procedure uses value, does not change value.
  - OUT = procedure changes, does not use.
  - INOUT = both.
- Function parameters must be of mode IN. Functions returns value, but must have no side-effects on parameters.

Example: Stored Procedure

- Let's write a procedure that takes two arguments *b* and *p*, and adds a tuple to Sells(bar, beer, price) that has bar = 'Joe''s Bar', beer = *b*, and price = *p*.
  - Used by Joe to add to his menu more easily.

The Procedure

```
CREATE PROCEDURE JoeMenu (
    IN    b    CHAR(20),
    IN    p    REAL
)
    INSERT INTO Sells
    VALUES('Joe''s Bar', b, p);
```

Parameters are both read-only, not changed

The body --- a single insertion

Invoking Procedures

- Use SQL/PSM statement CALL, with the name of the desired procedure and arguments.
- Example:

```
CALL JoeMenu('Moosedrool', 5.00);
```

- Functions may be used in SQL expressions wherever a value of their return type is appropriate.

Kinds of PSM statements – (1)

- RETURN <expression> sets the return value of a function.
  - Unlike C, etc., RETURN *does not* terminate function execution.
- DECLARE <name> <type> used to declare local variables.
- BEGIN . . . END for groups of statements.
  - Separate statements by semicolons.

Kinds of PSM Statements – (2)

- Assignment statements:

  SET <variable> = <expression>;

  - Example: `SET b = 'Bud';`

- Statement labels: give a statement a label by prefixing a name and a colon.

IF Statements

- Simplest form:
  IF <condition> THEN
  <statements(s)>
  END IF;

- Add ELSE <statement(s)> if desired, as
  IF . . . THEN . . . ELSE . . . END IF;

- Add additional cases by ELSEIF <statements(s)>:
  IF … THEN … ELSEIF … THEN … ELSEIF …
  THEN … ELSE … END IF;

Example: IF

- Let's rate bars by how many customers they have, based on Frequents(drinker,bar).
  - < 100 customers: 'unpopular'.
  - 100-199 customers: 'average'.
  - >= 200 customers: 'popular'.
- Function Rate(b) rates bar b.

Example: IF (continued)

```
CREATE FUNCTION Rate (IN b CHAR(20) )
        RETURNS CHAR(10)
        DECLARE cust INTEGER;
    BEGIN
        SET cust = (SELECT COUNT(*) FROM Frequents
                    WHERE bar = b);
        IF cust < 100 THEN RETURN 'unpopular'
        ELSEIF cust < 200 THEN RETURN 'average'
        ELSE RETURN 'popular'
        END IF;
    END;
```

Number of customers of bar b

Nested IF statement

Return occurs here, not at one of the RETURN statements

Loops

- Basic form:

  <loop name>: LOOP

  <statements>

  END LOOP;

- Exit from a loop by:

  LEAVE <loop name>;

Example: Exiting a Loop

```
loop1: LOOP
        . . .
        LEAVE loop1;
        . . .
END LOOP;
```

If this statement is executed . . .

Control winds up here

Other Loop Forms

- WHILE <condition>
  DO <statements>
  END WHILE;

- REPEAT <statements>
  UNTIL <condition>
  END REPEAT;

Queries

- General SELECT-FROM-WHERE queries are *not* permitted in PSM.
- There are three ways to get the effect of a query:
  1. Queries producing one value can be the expression in an assignment.
  2. Single-row SELECT . . . INTO …
  3. Cursors

Example: Assignment/Query

- Using local variable *p* and Sells(bar, beer, price), we can get the price Joe charges for Bud by:

```
SET p = (SELECT price FROM Sells
 WHERE bar = 'Joe''s Bar'
   AND beer = 'Bud');
```

SELECT . . . INTO …

- Another way to get the value of a query that returns one tuple is by placing INTO <variable> after the SELECT clause.
- Example:

```
SELECT price INTO p
FROM Sells
WHERE bar = 'Joe''s Bar'
  AND beer = 'Bud';
```

Cursors

- A *cursor* is essentially a tuple-variable that ranges over all tuples in the result of some query.

- Declare a cursor *c* by:

  DECLARE c CURSOR FOR <query>;

Opening and Closing Cursors

- To use cursor *c*, we must issue the command:

  OPEN c;

  - The query of *c* is evaluated, and *c* is set to point to the first tuple of the result.

- When finished with *c*, issue command:

  CLOSE c;

Fetching Tuples From a Cursor

- To get the next tuple from cursor c, issue command:

  FETCH FROM c INTO x1, x2,…, x*n* ;

- The *x*'s are a list of variables, one for each component of the tuples referred to by *c*.

- c is moved automatically to the next tuple.

Breaking Cursor Loops – (1)

- The usual way to use a cursor is to create a loop with a FETCH statement, and do something with each tuple fetched.

- A tricky point is how we get out of the loop when the cursor has no more tuples to deliver.

Breaking Cursor Loops – (2)

- Each SQL operation returns a *status*, which is a 5-digit character string.
  - For example:
    - '00000' means "Everything OK,"
    - '02000' means "Failed to find a tuple."
- In PSM, we can get the value of the status in a variable called SQLSTATE.

Breaking Cursor Loops – (3)

- We may declare a *condition*, which is a boolean variable that is true if and only if SQLSTATE has a particular value.

- Example: We can declare condition `NotFound` to represent 02000 by:

```
DECLARE NotFound CONDITION FOR
    SQLSTATE '02000';
```

Breaking Cursor Loops – (4)

- The structure of a cursor loop is thus:

```
cursorLoop: LOOP
  …
  FETCH c INTO … ;
  IF NotFound THEN LEAVE cursorLoop;
  END IF;
  …
END LOOP;
```

Example: Cursor

- Let's write a procedure that examines Sells(bar, beer, price), and raises by one dollar the price of all beers at Joe's Bar that are under three dollars.
  - Yes, we could write this as a simple UPDATE, but the details are instructive anyway.

The Needed Declarations

```
CREATE PROCEDURE JoeGouge( )
    DECLARE theBeer CHAR(20);
    DECLARE thePrice REAL;
    DECLARE NotFound CONDITION FOR
     SQLSTATE '02000';
    DECLARE c CURSOR FOR
     (SELECT beer, price FROM Sells
      WHERE bar = 'Joe''s Bar');
```

Used to hold beer-price pairs when fetching through cursor c

Returns Joe's menu

The Procedure Body

```
BEGIN
    OPEN c;
    menuLoop: LOOP
        FETCH c INTO theBeer, thePrice;
        IF NotFound THEN LEAVE menuLoop END IF;
        IF thePrice < 3.00 THEN
            UPDATE Sells SET price = thePrice + 1.00
            WHERE bar = 'Joe''s Bar' AND beer = theBeer;
        END IF;
    END LOOP;
    CLOSE c;
END;
```

Check if the recent FETCH failed to get a tuple

If Joe charges less than $3 for the beer, raise its price at Joe's Bar by $1.

The Procedure Body:

Using CURRENT OF Cursor

```
BEGIN
    OPEN c;
    menuLoop: LOOP
        FETCH c INTO theBeer, thePrice;
        IF NotFound THEN LEAVE menuLoop END IF;
        IF thePrice < 3.00 THEN
            UPDATE Sells SET price = thePrice + 1.00
            WHERE CURRENT OF c;
        END IF;
    END LOOP;
    CLOSE c;
END;
```

Check if the recent FETCH failed to get a tuple

If Joe charges less than $3 for the beer, raise its price at Joe's Bar by $1.

PL/SQL

- Oracle uses PL/SQL, a variation of SQL/PSM that helped inspire PSM.
- PL/SQL not only allows you to create and store procedures or functions, but it also can be run from Oracle's *generic query interface (SQL*Plus)*, just like any SQL statement.

- PostgreSQL: PL/pgSQL **(needed for Lab4)**
- IBM DB2: SQL PL
- MS SQL Server and Sybase: Transact-SQL (T-SQL)

Triggers and Stored Procedures

Trigger

- *Event* : typically a type of database modification, e.g., "insert on Sells"
- *Condition* : Any SQL boolean-valued expression
- *Action* : Any SQL statements

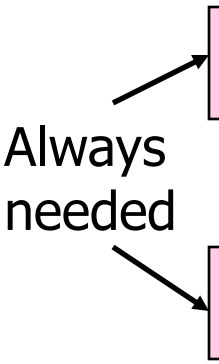
- Triggers may invoke Stored Procedures.
- A typical trigger body (actions) may itself be thought of as an unnamed Stored Procedure.
  - In some systems, the trigger body may include many of the kinds of statements that can be in a Stored Procedure.

Approach 2: Embedded SQL

- Key idea: A pre-processor turns SQL statements into procedure calls that fit with the surrounding host-language code.
- All embedded SQL statements begin with EXEC SQL, so the pre-processor can find them easily.

Shared Variables

- To connect SQL and the host-language program, the two parts must share some variables.
- Declarations of shared variables are bracketed by:



EXEC SQL BEGIN DECLARE SECTION;

<host-language declarations>

EXEC SQL END DECLARE SECTION;

Use of Shared Variables

- In SQL, the shared variables must be preceded by a colon.
  - They may be used as if they were constants provided by the host-language program.
  - They may get values from SQL statements and pass those values to the host-language program.
- In the host language, shared variables behave like any other variable.

Example: Looking Up Prices

- We'll use C with embedded SQL to sketch the important parts of a function that obtains a beer and a bar, and looks up the price of that beer at that bar.
- Assumes database has the Sells(bar, beer, price) relation.

Example: C with SQL

```
EXEC SQL BEGIN DECLARE SECTION;
    char theBar[21], theBeer[21];
    float thePrice;
EXEC SQL END DECLARE SECTION;
  /* obtain values for theBar and theBeer */
EXEC SQL SELECT price INTO :thePrice
    FROM Sells
    WHERE bar = :theBar AND beer = :theBeer;
  /* do something with thePrice */
```

Note 21-char arrays needed for 20 chars + endmarker

SELECT-INTO as in PSM

Embedded Queries

- Embedded SQL has the same limitations as PSM regarding queries:
  - SELECT-INTO for a query guaranteed to produce a single tuple.
  - Otherwise, you have to use a cursor.
    - Small syntactic differences, but the key ideas are the same.

Cursor Statements

- Declare a cursor *c* with:

EXEC SQL DECLARE *c* CURSOR FOR <query>;

- Open and close cursor c with:

EXEC SQL OPEN CURSOR c;

EXEC SQL CLOSE CURSOR c;

- Fetch from *c* by:

EXEC SQL FETCH c INTO <variable(s)>;

  - You can write a macro NOT_FOUND that is true if and only if the FETCH fails to find a tuple.
- If c is a cursor, you may use … WHERE CURRENT OF c, just as in Stored Procedures.

Example: Print Joe's Menu

- Let's write C + SQL to print Joe's menu – the list of beer-price pairs that we find in Sells(bar, beer, price) with bar = Joe's Bar.

- A cursor will visit each Sells tuple that has bar = Joe's Bar.

Example: Declarations

```
EXEC SQL BEGIN DECLARE SECTION;
    char theBeer[21]; float thePrice;
EXEC SQL END DECLARE SECTION;
EXEC SQL DECLARE c CURSOR FOR
    SELECT beer, price FROM Sells
    WHERE bar = 'Joe''s Bar';
```

The cursor declaration goes outside the declare-section

Example: Executable Part

```
EXEC SQL OPEN CURSOR c;
while(1) {
    EXEC SQL FETCH c
        INTO :theBeer, :thePrice;
    if (NOT_FOUND) break;
    /* format and print theBeer and thePrice */
}
EXEC SQL CLOSE CURSOR c;
```

The C style of breaking loops

Need for Dynamic SQL

- Most applications use specific queries and modification statements to interact with the database.
  - The DBMS compiles EXEC SQL … statements into specific procedure calls and produces an ordinary host-language program that uses a library.

Dynamic SQL

- Preparing a query:

  EXEC SQL PREPARE <query-name>

  FROM <text of the query>;

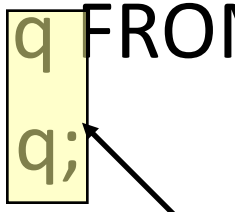
- Executing a query:

  EXEC SQL EXECUTE <query-name>;

- “Prepare” means optimize query.
- Prepare once, Execute many times.

Example: A Generic Interface

```
EXEC SQL BEGIN DECLARE SECTION;
   char query[MAX_LENGTH];
EXEC SQL END DECLARE SECTION;
while(1) {
   /* issue SQL> prompt */
   /* read user's query into array query */
   EXEC SQL PREPARE q FROM :query;
   EXEC SQL EXECUTE q;
}
```



q is an SQL "query variable" representing the optimized form of whatever statement is typed into :query

Execute-Immediate

- If we are only going to execute the query once, we can combine the PREPARE and EXECUTE steps into one.

- Use:

    EXEC SQL EXECUTE IMMEDIATE <text>;

Example: Generic Interface Again

```
EXEC SQL BEGIN DECLARE SECTION;
  char query[MAX_LENGTH];
EXEC SQL END DECLARE SECTION;

while(1) {
  /* issue SQL> prompt */
  /* read user's query into array query
  */
  EXEC SQL EXECUTE IMMEDIATE :query;
}
```

Approach 3: Host Language/SQL Interfaces via Libraries

- The third approach to connecting databases to conventional languages is to use library calls.
  1. C + CLI
  2. Java + JDBC
  3. PHP + PEAR/DB

Three-Tier Architecture

- A common environment for using a database has three tiers of processors:
  1. *Web servers* --- talk to the user.
  2. Application servers --- execute business logic.
     - Often not used—logic in web tier
  3. *Database servers* --- get what the app servers (or web servers) need from the database.

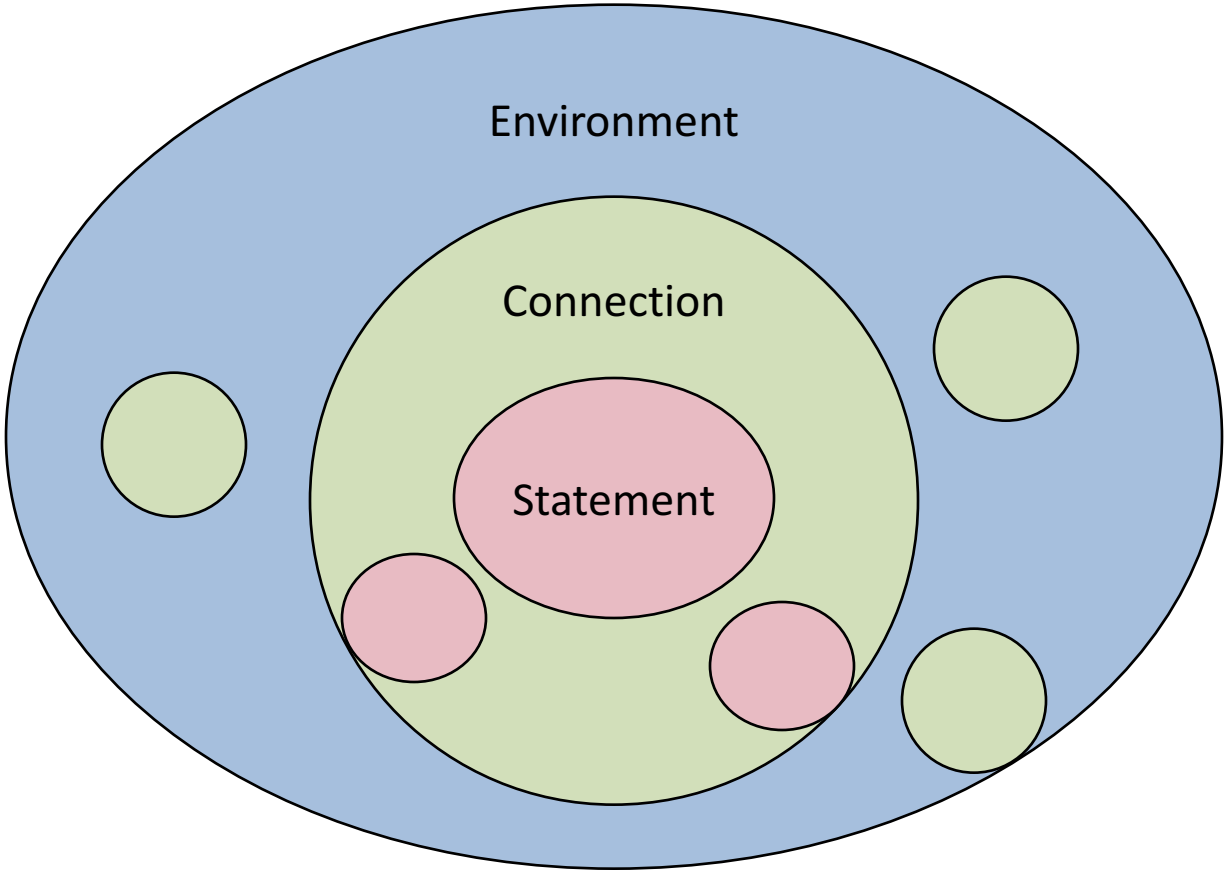
Example: Amazon

- Database holds the information about products, customers, etc.
- Business logic includes things like “What do I do after someone clicks ‘checkout’?”
  - Answer: Show the “How will you pay for this?” screen.
- Presentation layer, handled on web server and web browser, handles preparation and display of web pages

Environments, Connections, Queries

- The database is, in many DB-access languages, an *environment*.
- Database servers maintain some number of *connections*, so app servers can connect to them and ask queries or perform modifications.
- The app server issues *statements* : queries and modifications, usually.

Diagram to Remember



SQL/CLI

- Instead of using a pre-processor (as in embedded SQL), we can use a library of functions.
  - The library for C is called SQL/CLI = "*Call-Level Interface*."
  - Embedded SQL's pre-processor will translate the EXEC SQL … statements into CLI or similar calls, anyway.

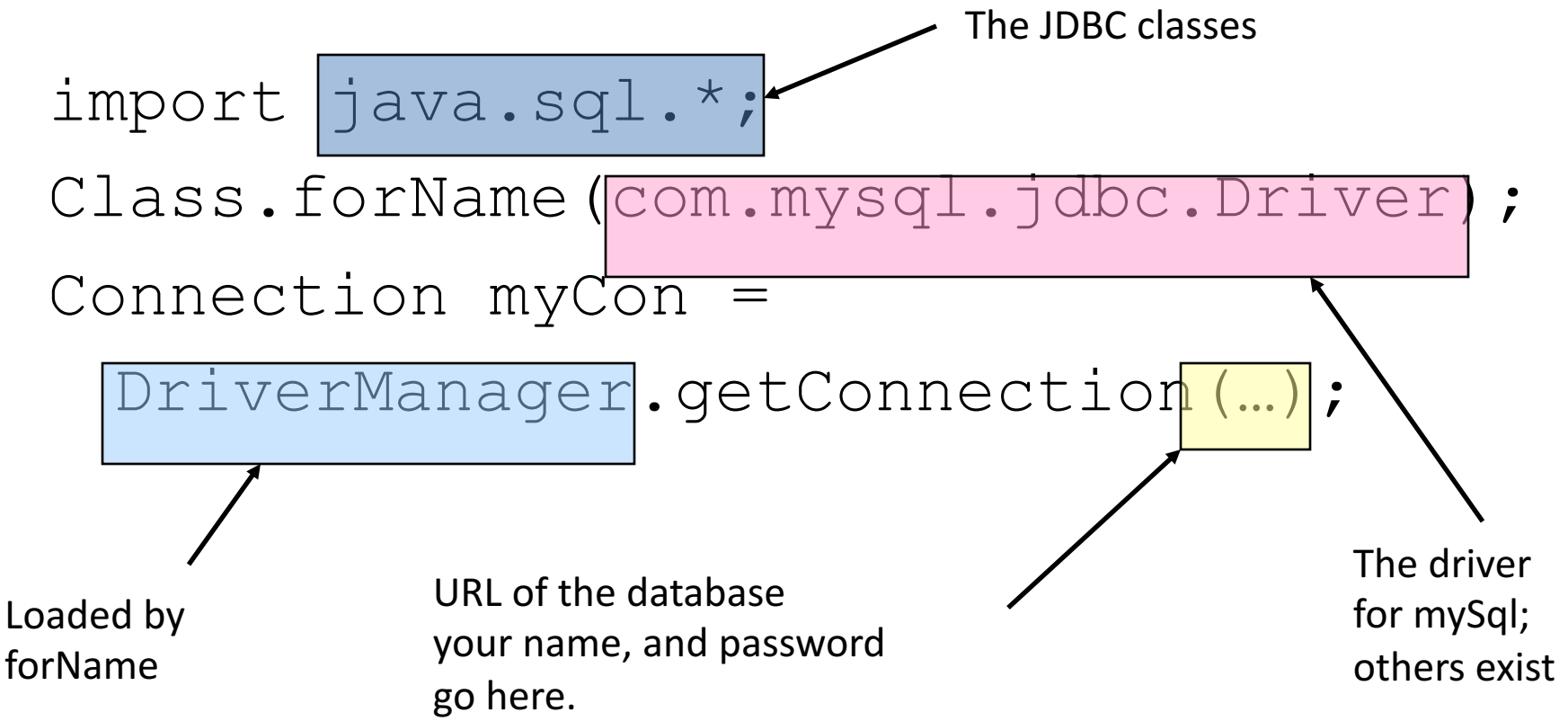
Data Structures

- C connects to the database by structs of the following types:
  1. *Environments* : represent the DBMS installation.
  2. *Connections* : logins to the database.
  3. *Statements* : SQL statements to be passed to a connection.
  4. *Descriptions* : records about tuples from a query, or parameters of a statement.

JDBC

- *Java Database Connectivity* (JDBC) is a library similar to SQL/CLI, but with Java as the host language.
- Like CLI, but with a few differences.

Making a Connection



Statements

- JDBC provides two classes:
  1. *Statement* is an object that can accept a string that is a SQL statement and can execute such a string.
  2. *PreparedStatement* is an object that has an associated SQL statement ready to execute.

Creating Statements

- The Connection class has methods to create Statements and PreparedStatements.

```
Statement stat1 = myCon.createStatement();

PreparedStatement stat2 =
    myCon.prepareStatement(
        ”SELECT beer, price FROM Sells ” +
        ”WHERE bar = ’Joe’ ’s Bar’ ”
         );
```

Executing SQL Statements

- JDBC distinguishes queries from modifications, which it calls "updates."
- Statement and PreparedStatement each have methods executeQuery and executeUpdate.
  - For Statement: one argument: the query or modification to be executed.
  - For PreparedStatement: no argument.

Example: Update

- stat1 is a Statement.
- We can use it to insert a tuple:

```
stat1.executeUpdate(
  ”INSERT INTO Sells ” +
  ”VALUES(’Brass Rail’,’Bud’,3.00)”
);
```

Example: Query

- stat2 is a PreparedStatement holding the query ”SELECT beer, price FROM Sells WHERE bar = ’Joe’’s Bar’ ”.

- executeQuery returns an object of class ResultSet; we’ll examine that soon.

- The query:

```
ResultSet Menu = stat2.executeQuery();
```

Accessing the ResultSet

- An object of type ResultSet is a lot like a cursor.
- Method next() advances the "cursor" to the next tuple.
  - The first time next() is applied, it gets the first tuple.
  - If there are no more tuples, next() returns the value false.

Reminder of Example: Query

- stat2 is a PreparedStatement holding the query ”SELECT beer, price FROM Sells WHERE bar = ’Joe’’s Bar’ ”.

- executeQuery returns an object of class ResultSet; we’ll examine that soon.

- The query:

```
ResultSet Menu = stat2.executeQuery();
```

Accessing Components of Tuples

- When a ResultSet refers to a tuple, we can get the components of that tuple by applying certain methods to the ResultSet.
- Method get*X* (*i*), where *X* is some type, and *i* is the component number, returns the value of that component.
  - The value must have type *X*.

Example: Accessing Components

- Menu is the ResultSet for query "SELECT beer, price FROM Sells WHERE bar = 'Joe' 's Bar' ".

- Access beer and price from each tuple by:

```
while ( Menu.next() ) {
  theBeer = Menu.getString(1);
  thePrice = Menu.getFloat(2);
   /* do something with theBeer and
  thePrice */
}
```

ExecuteQuery, ExecuteUpdate and Execute

- executeQuery(): Executes a SQL SELECT statement, and returns a ResultSet object.
- executeUpdate(): Executes a SQL UPDATE, INSERT or DELETE statement, and returns the number of affected rows.
  - May also be used with DDL, e.g., CREATE, DROP
- execute(): Executes either query or modification, and returns TRUE if query and FALSE if modification
  - stat.getResultSet for query result
  - stat.getUpdateCount for modification
- All methods may throw Exceptions

Executing a Stored Procedure GoodBeers

Assume GoodBeers somehow finds all the good beers that are sold at a specific bar (theBar) that sell for under a particular price (thePrice).

- We won't tell you the secret of how GoodBeers procedure works.

```
PreparedStatement stmt = mycon.prepareStatement(
     "SELECT * FROM GoodBeers(?, ?)");
stmt.setString(1,theBar);        /* first parameter */
stmt.setFloat(2,thePrice);      /* second parameter */
 ResultSet result = stmt.executeQuery();
 while(result.next())     {
    theBeer= result.getString(1);
    /* do something with theBeer */
 }
```

Executing a Stored Function

- Executing a Stored Function is similar to executing a Stored Procedure, except that what's returned is the result of the Stored Function.
  - Can be a scalar value (as in Lab4) or a table.
  - If it's a scalar value, that can be treat that as a table with one row.
- There is another way to execute Stored Procedures and Stored Functions, using the CallableStatement class (instead of Statement or PreparedStatement).
- This is not described well in the PostgreSQL documentation, but it's a good approach, and you may use it if you can figure it out.

Approaches

When/Why do you use each?

1. **Stored Procedure** languages such as PSM and PL/SQL)
2. SQL statements **embedded in a host language** (e.g., C)
3. **Connection tools/libraries** such as, CLI, and JDBC