Embedded SQL

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with examples from Ullman and Widom

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Problems with using interactive SQL

- Standard SQL is not "Turing-complete".
  - E.g., Two profs are "colleagues" if they've co-taught a course or share a colleague.
  - We can't write a query to find all colleagues of a given professor because we have no loops or recursion.
- You can't control the format of its output.
- And most users shouldn't be writing SQL queries!
  - You want to run queries that are *based on* user input, not have users writing actual queries.

SQL + a conventional language

- If we can combine SQL with code in a conventional language, we can solve these problems.
- But we have another problem:
  - SQL is based on relations, and conventional languages have no such type.
- It is solved by
  - feeding tuples from SQL to the other language one at a time, and
  - feeding each attribute value into a particular variable.

Approaches

- Three approaches for combining SQL and a general-purpose language:
  - Stored Procedures
  - Statement-level Interface
  - Call-level interface

Three Approaches

1. Stored Procedures

- The SQL standard includes a language for defining "stored procedures", which can
  - have parameters and a return value,
  - use local variables, ifs, loops, etc.,
  - execute SQL queries.
- Stored procedures can be used in these ways:
  - called from the interpreter,
  - called from SQL queries,
  - called from another stored procedure,
  - be the action that a trigger performs.

Example (just to give you an idea)

- A boolean function `BandW(y INT, s CHAR(15))` that returns true iff
  - movie studio s produced no movies in year y, or
  - produced at least one comedy.
- (Yes, that's an odd name for this function.)

- Reference: Ullman and Widom textbook, chapter 9

Reference: textbook figure 9.1.3

```
CREATE FUNCTION BandW(y INT, s CHAR(15)) RETURNS BOOLEAN
IF NOT EXISTS
   (SELECT *
    FROM Movies
    WHERE year = y AND studioName = s)
THEN RETURN TRUE;
ELSIF 1 <=
   (SELECT COUNT(*)
    FROM Movies
    WHERE year = y AND studioName = s AND
          genre = 'comedy')
THEN RETURN TRUE;
ELSE RETURN FALSE;
END IF;
```

Calling it

- Now we can say things like this:

```
SELECT StudioName
FROM Studios
WHERE BandW(2010, StudioName);
```

Not very standard

- The language is called SQL/PSM (Persistent Stored Modules).
    - It came into the SQL standard in SQL3, 1999.
    - Reference: textbook, section 9.4
- By then, commercial DBMSs had defined their own proprietary languages for stored procedures
    - They have generally stuck to them.
- PostgreSQL has defined PL/pgSQL.
    - It supports some, but not all, of SQL/PSM.
    - Reference: Chapter 39 of the PostgreSQL documentation.

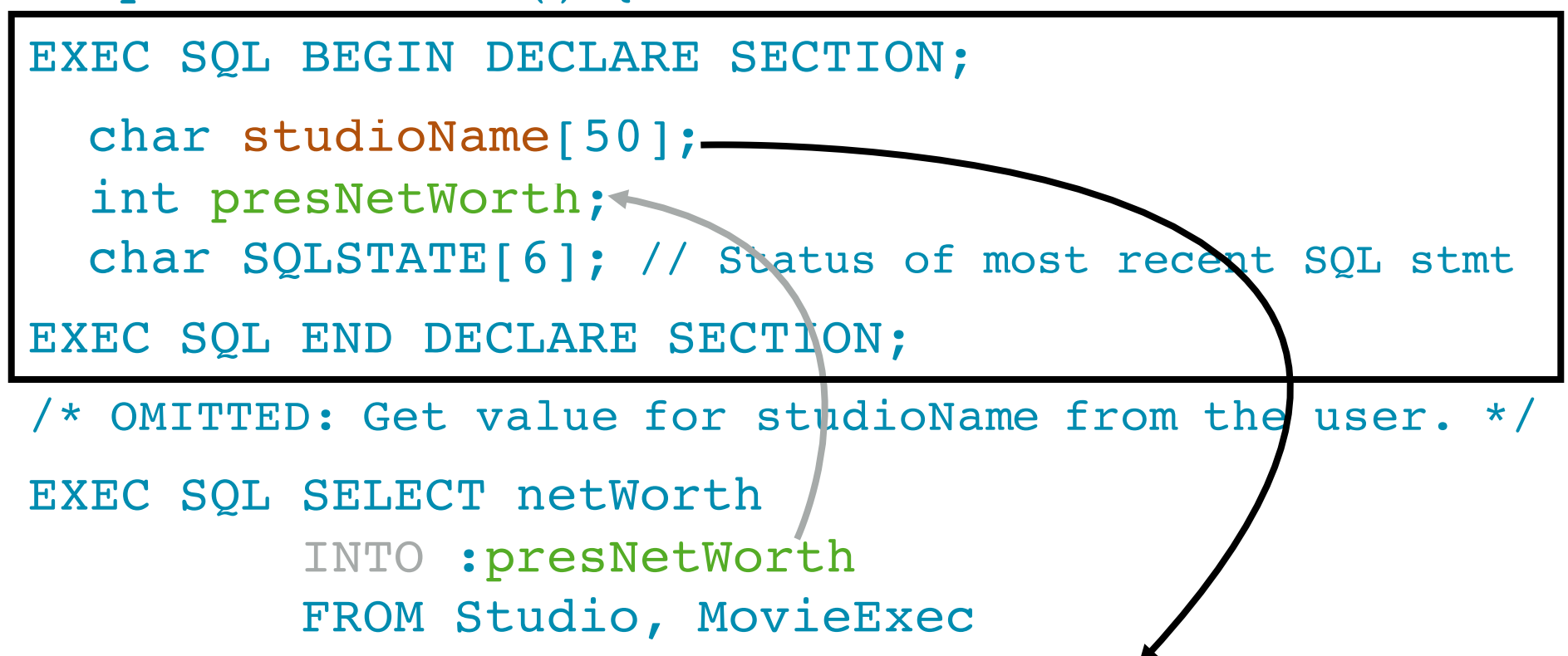
2. Statement-level interface (SLI)

- Embed SQL statements into code in a conventional language like C or Java.
- Use a preprocessor to replace the SQL with calls written in the host language to functions defined in an SQL library.
- Special syntax indicates which bits of code the preprocessor needs to convert.

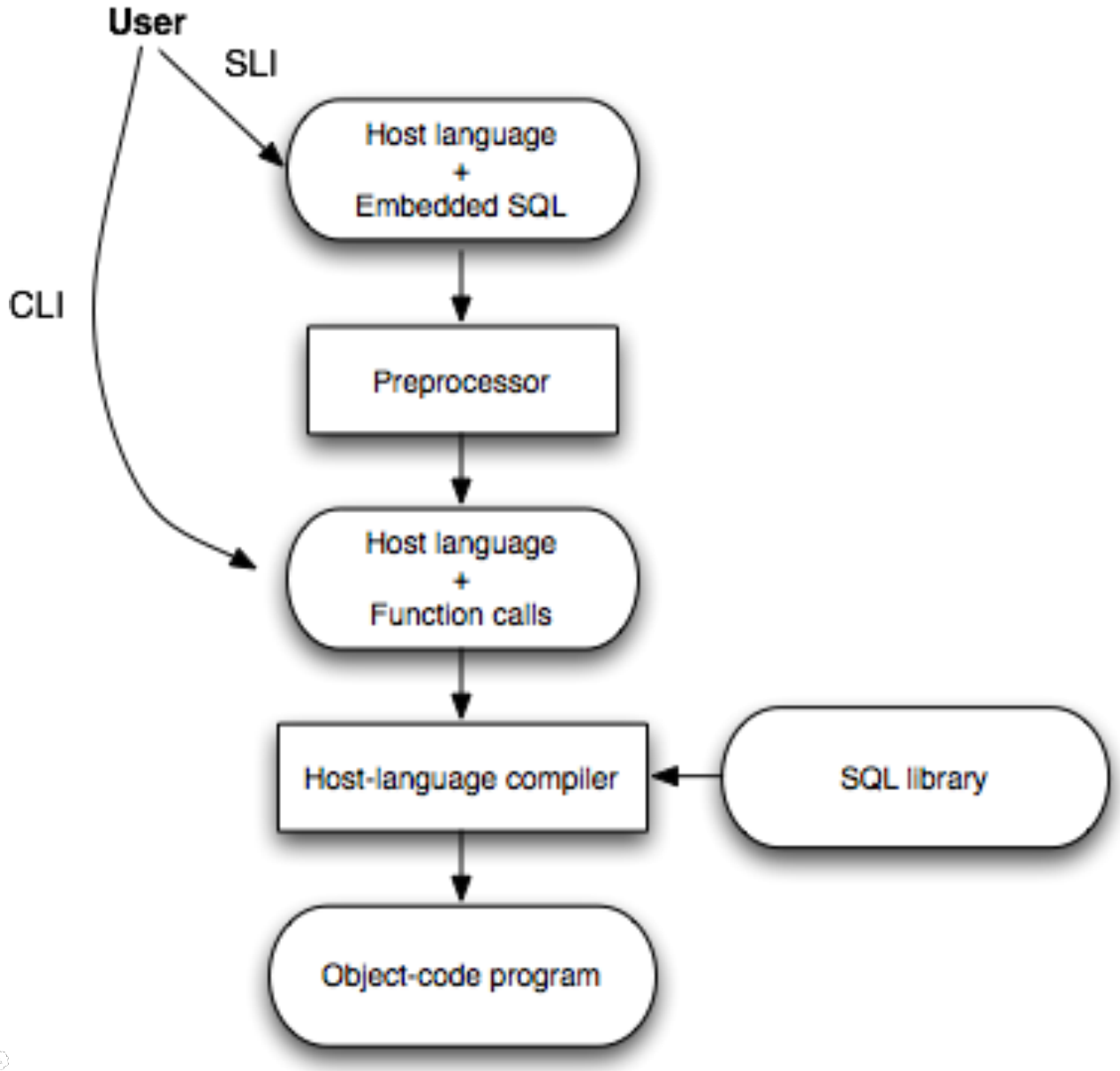
Example, in C (just to give you an idea)

Reference: textbook example 9.7

```
void printNetWorth() {
  EXEC SQL BEGIN DECLARE SECTION;
    char studioName[50];
    int presNetWorth;
    char SQLSTATE[6]; // Status of most recent SQL stmt
  EXEC SQL END DECLARE SECTION;
  /* OMITTED: Get value for studioName from the user. */
  EXEC SQL SELECT netWorth
           INTO :presNetWorth
           FROM Studio, MovieExec
           WHERE Studio.name = :studioName;
  /* OMITTED: Report back to the user */
}
```



Big picture (figure 9.5)



3. Call-level interface (CLI)

- Instead of using a pre-processor to replace embedded SQL with calls to library functions, write those calls yourself.
- Eliminates need to preprocess.
- Each language has its own set of library functions for this.
    - for C, it's called SQL/CLI
    - for Java, it's called JDBC
    - for PHP, it's called PEAR DB
- We'll look at just one: JDBC.

JDBC

JDBC Example (see section 9.6)

Do this once in your program:

```
/* Get ready to execute queries. */
import java.sql.*;
/* A static method of the Class class. It loads the
   specified driver */
Class.forName("org.postgresql.jdbc.Driver");
Connection conn = DriverManager.getConnection(
   jdbc:postgresql://localhost:5432/csc343h-dianeh,
   dianeh,
   "");
/* Continued ... */
```

The arguments to getConnection

- `jdbc:postgresql`
  We'll use this, but it could be, e.g., `jdbc:mysql`
- `localhost:5432`
  You must use exactly this for the CS Teaching Labs.
- `csc343h-dianeh` and `dianeh`
  Substitute your userid on the CS Teaching Labs.
- `""`
  Password (unrelated to your password).
  Literally use the empty string.

Do this once per query in your program:

```
/* Execute a query and iterate through the resulting
   tuples. */
PreparedStatement execStat = conn.prepareStatement(
   "SELECT netWorth FROM MovieExec");

ResultSet worths = execStat.executeQuery();
while (worths.next()) {
   int worth = worths.getInt(1);
   /* If the tuple also had a float and another int
      attribute, you'd get them by calling
      worths.getFloat(2) and worths.getInt(3).
      Or you can look up values by attribute name.
      Example: worths.getInt(netWorth)
   */
   /* OMITTED: Process this net worth */
```

The Java details

- For full details on the Java classes and methods used, see the Java API documentation:

  https://docs.oracle.com/javase/8/docs/api/java/sql/package-summary.html

Exceptions can occur

- Any of these calls can generate an exception.
- Therefore, they should be inside try/catch blocks.

```
try {
    /* OMITTED: JDBC code */
} catch (SQLException ex) {
    /* OMITTED: Handle the exception */
}
```

- The class `SQLException` has methods to return the `SQLSTATE`, etc.

What is “preparation”?

- Preparing a statement includes:
  - parsing the SQL
  - compiling
  - optimizing
- The resulting `PreparedStatement` can be executed any number of times without having to repeat these steps.

If the query isn't known until run time

- You may need input and computation to determine exactly what the query should be.
- In that case:
  - Hard-code in the parts you know.
  - Use the character `?` as a placeholder for the values you don't know. (Don't put it in quotes!)
- This is enough to allow a `PreparedStatement` to be constructed.
- Once you know values for the placeholders, use methods `setString`, `setInt`, etc. to fill in those values.

Example (figure 9.22)

```
PreparedStatement studioStat =
    conn.preparedStatement(
        "INSERT INTO Studio(name, address)
         VALUES(?, ?)"
);

/* OMITTED: Get values for studioName and studioAddr */
studioStat.setString(1, studioName);
studioStat.setString(2, studioAddr);
studioStat.executeUpdate();
```

Why not just build the query in a string?

- We constructed an incomplete `preparedStatement` and filled in the missing values using method calls.
- Instead, we could just build up the query in an ordinary string at run time, and ask to execute that.
- There are classes and methods that will do this in JDBC.

Example that builds the query in a string

- We can just use a `Statement`, and give it a String to execute.

```
// stat cannot be compiled & optimized (yet).
Statement stat = conn.createStatement();

String query =
   "SELECT networth
    FROM MovieExec
    WHERE execName like '%Spielberg%';
   "

// executeQuery can now compile and optimize, and run
// the query.
ResultSet worths = stat.executeQuery(query);
```

What could possibly go wrong?

Example: Some vulnerable code

Suppose we want the user to provide the string to compare to

You can do this rather than hard-coding `Spielberg` into the query:

```
Statement stat = conn.createStatement();
String who = /* get a string from the user */
String query =
   "SELECT networth
    FROM MovieExec
    WHERE execName like '%" + who + "%';
   "
ResultSet worths = stat.executeQuery(query);
```

A gentle user does no harm

If a user enters `Milch`, the SQL code we execute is this:

```
SELECT networth
FROM MovieExec
WHERE execName like '%Milch%';
```

Nothing bad happens.

An injection can exploit the vulnerability

What could a malicious user enter?

```
SELECT networth
FROM MovieExec
WHERE execName like '%????????????%';
```

An injection can exploit the vulnerability

But if a malicious user enters

```
Milch%'; drop table Contracts; --
```

the code we execute is this:

```
SELECT networth
FROM MovieExec
WHERE execName like '%Milch%'; DROP TABLE Contracts; --%';
```

In other words:

```
SELECT networth
FROM MovieExec
WHERE execName like '%Milch%';

DROP TABLE Contracts; --%';
```

Ouch!

Always use a `PreparedStatement`

- This was an example of an injection.
- The simple approach of giving a String to a `Statement` is vulnerable to injections.
- Moral of the story:
  Always use a `PreparedStatement` instead.

Queries vs updates in JDBC

- The previous examples used `executeQuery`.
- This method is only for pure queries.
- For SQL statements that change the database (insert, delete or modify tuples, or change the schema), use the analogous method `executeUpdate`.