Week 6: Embedded SQL

Impedance Mismatch
Statement-Level vs Call-Level Interfaces
Static SQL
Transactions and Cursors
Dynamic SQL
JDBC

Interactive vs. Non-Interactive SQL

→ **Non-interactive SQL**: Statements are included in an application program written in a host language — such as C, Java, COBOL

→ **Interactive SQL**: Statements input from terminal; DBMS outputs to screen

Interactive SQL is inadequate for most uses:
- It may be necessary to process the data before output;
- Amount of data returned not known in advance;
Embedded SQL

- Traditional applications often need to embed SQL statements inside the instructions of a procedural programming language (C, COBOL, etc.)

- There is a severe mismatch between the computational model of a programming language (PL) and that of a DBMS:
  - A PL is Turing-complete, SQL is not;
  - The variables of a PL take as values single records, those of SQL whole tables;
  - PL computations are generally on a single data structure, SQL ones on bulk data structures.

Basic Elements of Embedded SQL

- Programs with embedded SQL use a pre-compiler to manage SQL statements. Embedded statements are preceded by `$` or `EXEC SQL`.

- Program variables may be used as parameters in the SQL statements (preceded by `:`).

- `select` statements producing a single row and update statements can be embedded easily; but not `select` statements producing sets of rows.

- The SQL environment offers a predefined variable `sqlstate` which describes the execution status of a statement ("00000" if executed successfully).
Application Program

- **Host language**: A conventional programming language (e.g., C, Java) that supplies control structures, computational capabilities, interaction with physical devices, … .
- **SQL**: supplies ability to interact with database.
- **Using the facilities of both**: the application program can act as an intermediary between the user at a terminal and the DBMS.

Preparation

- Before any SQL statement is executed, it must be prepared by the DBMS:
  - What indices can be used?
  - In what order should tables be accessed?
  - What constraints should be checked?
- Decisions are based on schema, table size, etc.
- Result is a query execution plan.
- Preparation is a complex activity, usually done at run time, justified by the complexity of query processing.
Introducing SQL to an Application

SQL statements can be incorporated into an application program in two different ways.

- **Statement Level Interface (SLI):** Application program is a mixture of host language statements and SQL statements and directives.

- **Call Level Interface (CLI):** Application program is written entirely in host language; SQL statements are values of string variables that are passed as arguments to host language (library) procedures.

Statement Level Interface

- SQL statements and directives in the application have a *special syntax* that sets them off from host language constructs.
  - e.g.,

- Pre-compiler scans program and translates SQL statements into calls to host language library procedures that communicate with DBMS.

- then compiles program.
Statement Level Interface

→ SQL constructs in an application take two forms:

  ✓ Useful when SQL portion of program is known at compile time.

  ✓ Useful when SQL portion of program not known at compile time; Application constructs SQL statements at run time as values of host language variables that are manipulated by directives.

→ Pre-compiler translates statements and directives into arguments of calls to library procedures.

Call Level Interface

→ Application program written entirely in host language (no precompiler)
  Examples: JDBC, ODBC

→ SQL statements are values of string variables constructed using host language — similar to dynamic SQL

→ Application uses string variables as arguments of library routines that communicate with DBMS

  e.g. executeQuery("SQL query statement")
Static SQL

```sql
EXEC SQL BEGIN DECLARE SECTION;
  unsigned long num_enrolled;
  char crs_code;
  char SQLSTATE[5];
EXEC SQL END DECLARE SECTION;

EXEC SQL SELECT C.NumEnrolled
  INTO :num_enrolled
FROM Course C
WHERE C.CrsCode = :crs_code;
```

→ Declaration section for host/SQL communication.
→ Colon convention for value (WHERE) and result (INTO) parameters.

Status

```sql
EXEC SQL SELECT C.NumEnrolled
  INTO :num_enrolled
FROM Course C
WHERE C.CrsCode = :crs_code;
if ( !strcmp (SQLSTATE, "00000") ) {
  printf ( "statement failed" )
};
```
Connections

To connect to an SQL database, use a connect statement

```
CONNECT TO database_name AS
  connection_name USING user_id
```

Transactions

No explicit statement is needed to begin a transaction: A transaction is initiated when the first SQL statement that accesses the database is executed.

The mode of transaction execution can be set with

```
SET TRANSACTION READ ONLY
  ISOLATION LEVEL SERIALIZABLE
```

Transactions are terminated with `COMMIT` or `ROLLBACK` statements.
Example: Course Deregistration

```sql
EXEC SQL CONNECT TO :dbserver;
if ( ! strcmp (SQLSTATE, "00000") ) exit (1);
...
EXEC SQL DELETE FROM Transcript T
   WHERE T.StudId = :studid AND T.Semester = 'S2000'
       AND T.CrsCode = :crscode;
if ( ! strcmp (SQLSTATE, "00000") ) EXEC SQL ROLLBACK;
else {
   EXEC SQL UPDATE Course C
      SET C.Numenrolled = C.Numenrolled - 1
      WHERE C.CrsCode = :crscode;
   if ( ! strcmp (SQLSTATE, "00000") ) EXEC SQL ROLLBACK;
   else EXEC SQL COMMIT;
}
```

Impedance Mismatch Problem

- **Fundamental problem** with database technology: traditional programming languages process records one-at-a-time (tuple-oriented); SQL processes tuple sets (set-oriented).
- **Cursors** solve this problem: A cursor returns tuples from a result set, to be processed one-by-one.
- **Syntax of cursor definition:**

  ```sql
declare CursorName [ scroll ]
cursor for SelectSQL
   [ for < read only | update [ of Attribute {, Attribute} ] ]
  ```
Operations on Cursors

- **Result set** – rows returned by a `SELECT` statement

  - To execute the query associated with a cursor:
    - `open CursorName`

  - To extract one tuple from the query result:
    - `fetch [Position] from CursorName into FetchList`

  - To free the cursor, discarding the query result:
    - `close CursorName`

  - To access the current tuple (when a cursor reads a relation, in order to update it):
    - `current of CursorName`

How Cursors Work

- Application
  - Cursor
  - `SELECT`
  - Result set (or pointers to it)
  - Base table
Example of Cursor Use

```sql
EXEC SQL DECLARE GetEnroll INSENSITIVE CURSOR FOR
SELECT T.StudId, T.Grade  /* cursor is not a schema element */
FROM Transcript T
WHERE T.CrsCode = :crscode AND T.Semester = 'S2000';

EXEC SQL OPEN GetEnroll;
if (!strcmp (SQLSTATE, "00000")) {... fail exit... };

EXEC SQL FETCH GetEnroll INTO :studid, :grade;
while (SQLSTATE = "00000") {
    ... process the returned row...
    EXEC SQL FETCH GetEnroll INTO :studid, :grade;
} if (!strcmp (SQLSTATE, "02000")) {... fail exit... };

EXEC SQL CLOSE GetEnroll;
```

Cursor Types

- **Insensitive cursors**: Result set (effectively) computed and stored in separate table at `OPEN` time
  - Changes made to base table subsequent to `OPEN` (by any transaction) do not affect result set
  - Cursor is read-only

- **Cursors that are not insensitive**: Specification not part of SQL standard
  - Changes made to base table subsequent to `OPEN` (by any transaction) can affect result set
  - Cursor is updatable
Insensitive Cursor

Changes made after opening cursor not seen by the cursor

Keyset-Driven Cursor

- Example of a cursor that is not insensitive.
- Primary key of each row in result set is computed at open time.
- `UPDATE` or `DELETE` of a row in base table by a concurrent transaction between `OPEN` and `FETCH` might be seen through cursor.
- `INSERT` into base table, however, not seen through cursor.
- Cursor is updatable.
Keyset-Driven Cursor

- Tuples added after cursor is open are not seen, but updates to key1, key3, key4 are seen by the cursor.

Syntax for Cursors

```
DECLARE cursor-name [INSENSITIVE] [SCROLL] CURSOR FOR table-expr
[ ORDER BY column-list ]
[ FOR {READ ONLY | UPDATE [ OF column-list ] } ]
```

For updatable (not insensitive, not read-only) cursors

```
UPDATE table-name — base table
SET assignment
WHERE CURRENT OF cursor-name
DELETE FROM table-name — base table
WHERE CURRENT OF cursor-name
```

Restriction – `table-expr` must satisfy restrictions of updatable views
Scrolling

➔ If `SCROLL` option not specified in cursor declaration, `FETCH` always moves cursor forward one position

➔ If `SCROLL` option is included in `DECLARE CURSOR` section, cursor can be moved in arbitrary ways around result set:

```sql
FETCH PRIOR FROM GetEnroll INTO :studid, :grade;
```

• Also: `FIRST, LAST, ABSOLUTE n, RELATIVE n`

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Stored Procedures

➔ *(Stored) Procedure* – written in a PL, included as schema element (stored in DBMS), invoked by the application.

➔ For example,

```sql
procedure AssignCity
  (:Dep char(20), :City char(20))
update Department
set City = :City
where Name = :Dep
```

➔ SQL-2 does not support the definition of complex procedures

➔ Most systems offer SQL extensions that support complex procedures (e.g., Oracle PL/SQL).

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Procedure in Oracle PL/SQL

Procedure Debit(ClientAcct char(5), Withdr int) is
    OldAmount integer; NewAmount integer;
    Threshold integer;
begin
    select Amount, Overdraft into OldAmount, Threshold
    from BankAcct where AcctNo = ClientAcct
    for update of Amount;
    NewAmount := OldAmount - WithDr;
    if NewAmount > Threshold
    then update BankAcct
        set Amount = NewAmount
        where AcctNo = ClientAcct;
    else insert into OverDraftExceeded
        values(ClientAcct, Withdr, sysdate);
    end if;
end Debit;

Advantages of Stored Procedures

Æ Intermediate data need not be communicated to application (time and cost savings)
Æ Procedure’s SQL statements prepared in advance
Æ Authorization can be done at procedure level
Æ Added security since procedure resides in server
Æ Applications that call the procedure need not know the details of database schema – all database access is encapsulated within the procedure
Dynamic SQL

- When applications do not know at compile-time the statement to execute, they need dynamic SQL.
- Major problem: managing the transfer of parameters between program and SQL environment.
- For direct execution:
  - `execute immediate SQLStatement`
- For execution preceded by the analysis of the statement:
  - `prepare CommandName from SQLStatement`
  - followed by:
  - `execute CommandName [into TargetList] [using ParameterList]`

Example of Dynamic SQL

```c
strcpy (tmp, "SELECT C.NumEnrolled FROM Course C
WHERE C.CrsCode = ?") ;
EXEC SQL PREPARE st FROM :tmp;
EXEC SQL EXECUTE st INTO :num_enrolled USING :crs_code;
```

- `st` is an SQL variable; names the SQL statement
- `tmp`, `crs_code`, `num_enrolled` are host language variables (note colon notation)
- `crs_code` is an in parameter; supplies value for placeholder (?)
- `num_enrolled` is an out parameter; receives value from `C.NumEnrolled`
Parameters for Static SQL

For Static SQL:
- Names of (host language) parameters are contained in SQL statement and available to pre-compiler.
- Address and type information in symbol table.
- Routines for fetching and storing argument values can be generated.
- Complete statement (with parameter values) sent to DBMS when statement is executed.

```sql
EXEC SQL SELECT C.NumEnrolled INTO :num_enrolled
FROM Course C
WHERE C.CrsCode = :crs_code;
```

Parameters for Dynamic SQL

- **Dynamic SQL**: SQL statement constructed at run time when symbol table is no longer present.
- Two cases to deal with:
  - Case I: Parameters *are* known at compile time;
  - Case II: Parameters not known at compile time.
Case I

- Parameters are named in `EXECUTE` statement: `in` parameters in `USING`; `out` parameters in `INTO` clauses

```c
strcpy(tmp, "SELECT C.NumEnrolled FROM Course C \n      WHERE C.CrsCode = ?" );
EXEC SQL PREPARE st FROM :tmp;
EXEC SQL EXECUTE st INTO :num_enrolled USING :crs_code;
```

- `EXECUTE` statement is compiled using symbol table; `fetch()` and `store()` routines generated.

Dealing with Case I

- Fetch and store routines are executed at client when `EXECUTE` is executed to communicate argument values with DBMS
- `EXECUTE` can be invoked multiple times with different values of `in` parameters
  - Each invocation uses same query execution plan
- Values substituted for placeholders by DBMS (in order) at invocation time and statement is executed
Case II

- Parameters *not* known at compile time
- *Example*: Statement input from terminal
  - Application cannot parse statement and might not know schema, so it does not have any parameter information
  - EXECUTE statement cannot name parameters in INTO and USING clauses

Dealing with Case II

- DBMS determines number and type of parameters after preparing the statement
- Information stored by DBMS in a descriptor – a data structure inside the DBMS, which records the name, type, and value of each parameter
- Dynamic SQL provides directive GET DESCRIPTOR to get information about parameters (e.g., number, name, type) from DBMS and to fetch value of out parameters
- Dynamic SQL provides directive SET DESCRIPTOR to supply value to in parameters
Descriptors

temp = "SELECT C.NumEnrolled, C.Name FROM Course C  
WHERE C.CrsCode = 'CS305' "

1. Application uses GET DESCRIPTOR to fetch name, type, value
2. Then gets value into appropriate host variable
3. Then processes value

Dynamic SQL Calls with Descriptors

… … construct SQL statement in temp … …
EXEC SQL PREPARE st FROM :temp; // prepare statement

EXEC SQL ALLOCATE DESCRIPTOR ‘desc’; // create descriptor
EXEC SQL DESCRIBE OUTPUT st USING
    SQL DESCRIPTOR ‘desc’; // populate desc with info
    // about out parameters

EXEC SQL EXECUTE st INTO
    SQL DESCRIPTOR AREA ‘desc’; // store out values in desc

EXEC SQL GET DESCRIPTOR ‘desc’ …; // get out values

… … similar strategy is used for in parameters … …
Example: Nothing Known at Compile Time

```c
sprintf(my_sql_stmt,
    "SELECT * FROM %s WHERE COUNT(*) = 1",
    table); // table – host var; even the table is known only at run time!
EXEC SQL PREPARE st FROM :my_sql_stmt;
EXEC SQL ALLOCATE DESCRIPTOR 'st_output';
EXEC SQL DESCRIBE OUTPUT st USING SQL DESCRIPTOR 'st_output'
    ✓ The SQL statement to execute is known only at run time
    ✓ At this point DBMS knows what the exact statement is
      (including the table name, the number of out parameters, their types)
    ✓ The above statement asks to create descriptors in st_output for
      all the (now known) out parameters
EXEC SQL EXECUTE st INTO SQL DESCRIPTOR 'st_output';
```

Example: Getting Meta-Information from a Descriptor

```c
// Host var colcount gets the number of out parameters in
// the SQL statement described by st_output
EXEC SQL GET DESCRIPTOR 'st_output' :colcount = COUNT;

// Set host vars coltype, collength, colname with the type,
// length, and name of the colnumber's out parameter in
// the SQL statement described by st_output
EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber;
    :coltype = TYPE, // predefined integer constants,
        // such as SQL_CHAR, SQL_FLOAT,
    :collength = LENGTH,
    :colname = NAME;
```
Example: Using Meta-Information to Extract Attribute Value

```c
char strdata[1024];
int intdata;
... ...
switch (coltype) {
case SQL_CHAR:
    EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber
        strdata=DATA;
    break;
case SQL_INT:
    EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber
        :intdata=DATA;
    break;
case SQL_FLOAT:
    ... ...
}
```

Put the value of attribute colnumber into the variable strdata

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JDBC

- for executing SQL from a Java program
- SQL statement is constructed at run time as the value of a Java variable (as in dynamic SQL)
- JDBC passes SQL statements to the underlying DBMS. Can be interfaced to any DBMS that has a JDBC driver
- Part of SQL:2003
Executing a Query

```java
import java.sql.*;  // import all classes in package java.sql

Class.forName (driver name);  // static method of Class
    // loads specified driver

Connection con = DriverManager.getConnection(Url, Id, Passwd);
    // Static method of class DriverManager; attempts
to connect to DBMS
    // If successful, creates a connection object, con,
for managing the connection

Statement stat = con.createStatement ();
    // Creates a statement object stat
    // Statements have executeQuery() method
```
Executing a Query (cont’d)

String query = “SELECT T.StudId FROM Transcript T” +
“WHERE T.CrsCode = ‘cse305’ ” +
“AND T.Semester = ‘S2000’ ”;

ResultSet res = stat.executeQuery(query);

- Creates a result set object, res.
- Prepares and executes the query.
- Stores the result set produced by execution in res (analogous to opening a cursor).
- The query string can be constructed at run time (as above).
- The input parameters are plugged into the query when the string is formed (as above).

Preparing and Executing a Query

String query = “SELECT T.StudId FROM Transcript T” +
“WHERE T.CrsCode = ? AND T.Semester = ?”;  

placeholders

PreparedStatement ps = con.prepareStatement(query);

- Prepares the statement
- Creates a prepared statement object, ps, containing the prepared statement
- Placeholders (?) mark positions of in parameters; special API is provided to plug the actual values in positions indicated by the ?’s
Executing a Query

String crs_code, semester;

........
ps.setString(1, crs_code); // set value of 1st in parameter
ps.setString(2, semester); // set value of 2nd in parameter

ResultSet res = ps.executeQuery();
- Creates a result set object, res
-Executes the query
- Stores the result set produced by execution in res

while (res.next()) {
    j = res.getInt("StudId"); // fetch output int-value
    ...process output value...
}

Result Sets and Cursors

Three types of result sets in JDBC:

- Forward-only: not scrollable
- Scroll-insensitive: scrollable; changes made to underlying tables after the creation of the result set are not visible through that result set
- Scroll-sensitive: scrollable; updates and deletes made to tuples in the underlying tables after the creation of the result set are visible through the set
Result Set

Statement stat = con.createStatement (ResultSet.TYPE_SCROLL_SENSITIVE, ResultSet.CONCUR_UPDATABLE);

- Any result set type can be declared read-only or updatable – CONCUR_UPDATABLE (assuming SQL query satisfies the conditions for updatable views)

- **Updatable**: Current row of an updatable result set can be changed or deleted, or a new row can be inserted. Any such change causes changes to the underlying database table

  res.updateString ("Name", "John");  // change the attribute "Name" of current row in the row buffer.
  res.updateRow ( );  // install changes to the current row buffer
  // in the underlying database table

Handling Exceptions

```java
try {
    ...
    Java/JDBC code...
} catch (SQLException ex) {
    ....exception handling code...
}
```

- try/catch is the basic structure within which an SQL statement should be embedded
- If an exception is thrown, an exception object, ex, is created and the catch clause is executed
- The exception object has methods to print an error message, return SQLSTATE, etc.
Transactions in JDBC

- Default for a connection is
  - Transaction boundaries
    - *Autocommit mode*: each SQL statement is a transaction.
    - To group several statements into a transaction use `con.setAutoCommit(false)`
  - Isolation
    - default isolation level of the underlying DBMS
    - To change isolation level use `con.setTransactionIsolationLevel(TRANSACTION_SERIALIZABLE)`
- With autocommit off:
  - transaction is committed using `con.commit()`.
  - next transaction is automatically initiated (chaining)
- Transactions on each connection committed separately

SQLJ

- A statement-level interface to Java
  - A dialect of embedded SQL designed specifically for Java
  - Translated by precompiler into Java
  - SQL constructs translated into calls to an SQLJ runtime package, which accesses database through calls to a JDBC driver
- Part of SQL:2003
SQLJ

→ Has some of efficiencies of embedded SQL
  ✔ Compile-time syntax and type checking
  ✔ Use of host language variables
  ✔ More elegant than embedded SQL
→ Has some of the advantages of JDBC
  ✔ Can access multiple DBMSs using drivers
  ✔ SQLJ statements and JDBC calls can be included in the same program

SQLJ Example

```sql
#SQL {
  SELECT C.Enrollment
  INTO :numEnrolled
  FROM Class C
  WHERE C.CrsCode = :crsCode
    AND C.Semester = :semester
};
```
Example of SQLJ Iterator

Similar to JDBC’s ResultSet; provides a cursor mechanism

```sql
#SQL iterator GetEnrolledIter (int studentId, String studGrade);
GetEnrolledIter iter1;

#SQL iter1 = {
    SELECT T.StudentId as "studentId",
           T.Grade as "studGrade"
    FROM Transcript T
    WHERE T.CrsCode = :crsCode
         AND T.Semester = :semester
};
```

Method names by which to access the attributes
"StudentId" and "Grade"

Iterator Example (cont’d)

```java
int id;
String grade;
while ( iter1.next() ) {
    id = iter1.studentId();
    grade = iter1.studGrade();
    … process the values in id and grade …
};

iter1.close();
```
**ODBC**

- Call level interface that is database independent
- Related to SQL/CLI, part of SQL:1999
- Software architecture similar to JDBC with driver manager and drivers
- Not object oriented
- Low-level: application must specifically allocate and deallocate storage

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**Sequence of Procedure Calls Needed for ODBC**

```plaintext
SQLAllocEnv(&henv);         // get environment handle
SQLAllocConnect(henv, &hdbc); // get connection handle
SQLConnect(hdbc, db_name, userId, password); // connect
SQLAllocStmt(hdbc, &hstmt); // get statement handle
SQLPrepare(hstmt, SQL statement); // prepare SQL statement
SQLExecute(hstmt);         // free up statement space
SQLDisconnect(hdbc);       // free up environment space
SQLFreeEnv(henv);          // free up environment space
```
ODBC Features

- Cursors — *Statement handle* (for example hstmt) is used as name of cursor
- Status Processing — Each ODBC procedure is actually a function that returns status
  
  ```c
  RETCODE retcode1;
  Retcode1 = SQLConnect ( …)
  ```
- Transactions — Can be committed or aborted with
  
  ```c
  SQLTransact (henv, hdbc, SQL_COMMIT)
  ```

Example of Embedded SQL

```c
void DisplayDepartmentSalaries(char DeptName[])
{
    char FirstName[20], Surname[20];
    long int Salary;
    $ declare DeptEmp cursor for
        select FirstName, Surname, Salary
        from Employee
        where Dept = :DeptName;
    $ open DeptEmp;
    $ fetch DeptEmp into :FirstName, :Surname, :Salary;
    printf("Department %s\n",DeptName);
    while (sqlcode == 0)
    {
        printf("Name: %s %s ",FirstName,Surname);
        printf("Salary: %d\n",Salary);
    
    $ fetch DeptEmp into :FirstName, :Surname, :Salary; }
$ close DeptEmp;    }
```