Week 5: Embedded SQL

Update Statements

Embedded SQL

- Traditional applications often need to "**embed**" SQL statements inside the instructions of a procedural programming language (C, COBOL, etc.)
- 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.
- The SQL environment offers a predefined variable `sqlcode` which describes the execution status of an SQL statement (=0 if it executed successfully).

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;**
  - ✓ **SQL has limited expressive power — *note: not Turing-complete.***

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 sizes, 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 Into the 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., EXEC SQL *SQL_statement*

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

Statement Level Interface

- SQL constructs in an application take two forms:
  - ✓Standard SQL statements (***static*** or ***embedded*** SQL): Useful when SQL portion of program is known at ***compile time***
  - ✓Directives (***dynamic*** SQL): 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 *at run time* 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

```
EXEC SQL BEGIN DECLARE S;
 unsigned long num_enrolled;
 char crs_code;
 char SQLSTATE [6];
EXEC SQL END DECLARE SE;
     ……
EXEC SQL SELECT C.NumEnrolled
   INTO :num_enrolled
   FROM Course C
   WHERE C.CrsCode = :crs_code;
```

Variables shared by host and SQL

":" used to set off host variables

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

Status

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

Out parameter

In parameter

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

```
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;
}
```

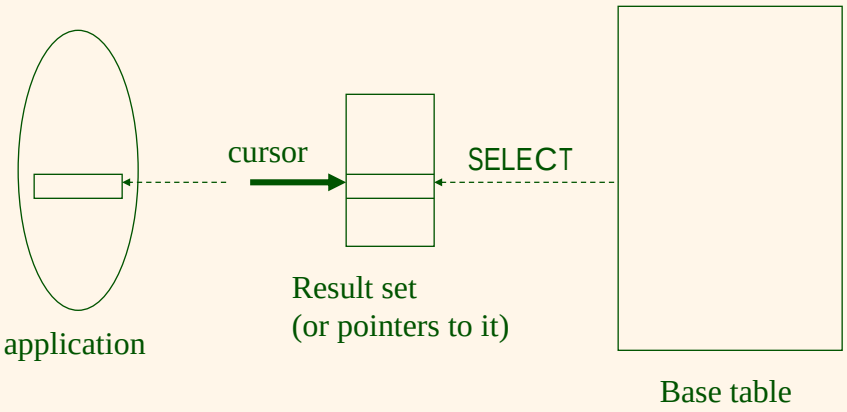
Buffer Mismatch Problem

- **Problem**: SQL deals with tables (of arbitrary size); host language program deals with fixed size buffers
  - ✓ How is the application to allocate storage for the result of a SELECT statement?
- **Solution**: Fetch a single row at a time
  - ✓ Space for a single row (number and type of *out* parameters) can be determined from schema and allocated in application

Cursors

- ***Result set*** – set of rows produced by a SELECT statement
- ***Cursor*** – pointer to a row in the result set.
- Cursor operations:
  - ✓ ***Declaration***
  - ✓ ***Open*** – execute SELECT to determine result set and initialize pointer
  - ✓ ***Fetch*** – advance pointer and retrieve next row
  - ✓ ***Close*** – deallocate cursor

Cursors (cont'd)



Example of Cursor Use

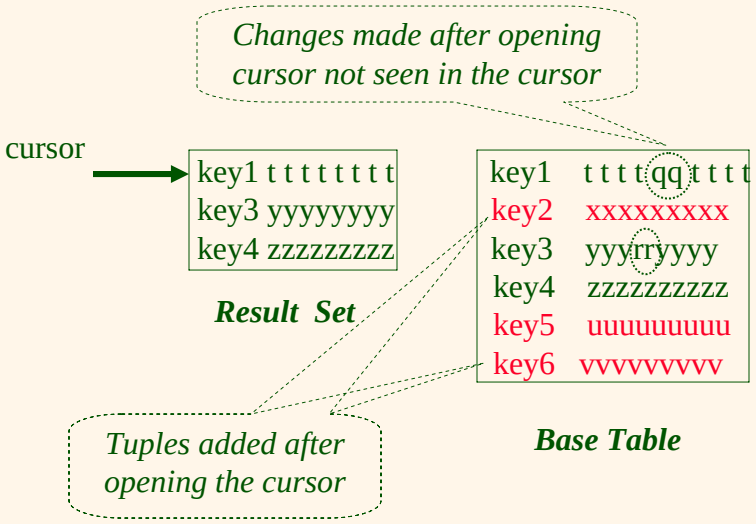
```
EXEC SQL DECLARE GetEnroll INSENSITIVE CURSOR FOR
   SELECT T.StudId, T.Grade        — cursor is not a schema element
   FROM Transcript T
   WHERE T.CrsCode = :crscode AND T.Semester = 'S2000';
   ……..
EXEC SQL OPEN GetEnroll;
if ( !strcmp ( SQLSTATE, "00000")) {... fail exit... };
   ……..
EXEC 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;
```

Reference resolved at compile time, Value substituted at OPEN *time*

Cursor Types

- → ***Insensitive cursor***: **Result set (effectively) computed and stored in a 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**

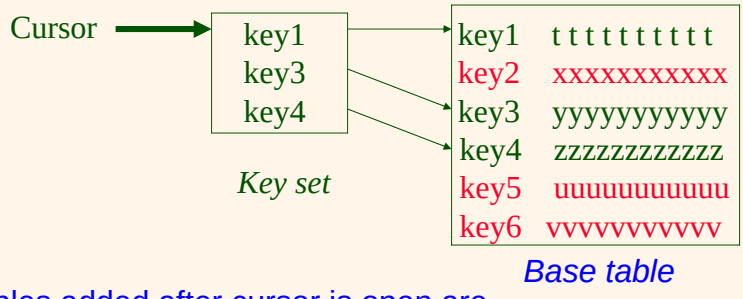
Insensitive Cursor



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 in the cursor.

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 view

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 c… arbitrary ways around result set:**

Get previous tuple

FETCH PRIOR FROM GetEnroll INTO :studid, :grade;

- Also: FIRST, LAST, ABSOLUTE n, RELATIVE n

Stored Procedures

- **Procedure – written in a conventional algorithmic language**
  - ✓ **Included as schema element (stored in DBMS)**
  - ✓ **Invoked by the application**
- **Advantages:**
  - ✓ **Intermediate data need not be communicated to application (time and cost savings)**
  - ✓ **Procedure's SQL statements prepared in advance**
  - ✓ **Authorization can be done at procedure level**
  - ✓ **Added security since procedure resides in server**
  - ✓ **Applications that call the procedure need not know the details of database schema – all database access is encapsulated within the procedure**

Dynamic SQL

```
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 :crscode;
```

placeholder

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

Dynamic SQL

- → **PREPARE** names SQL statement **st** and sends it to DBMS for preparation
- → **EXECUTE** causes the statement named **st** to be executed

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.

```
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**
- **Case 1: Parameters *are* known at compile time**

```
strcpy (tmp, "SELECT C.NumEnrolled FROM Course C \
              WHERE C.CrsCode = ?" ) ;
EXEC SQL PREPARE st FROM :tmp;
```

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

```
EXEC SQL EXECUTE st INTO :num_enrolled USING :crs_code;
```

- ✓ **EXECUTE statement is compiled using symbol table**
  - ***fetch()* and *store()* routines generated**

Parameters for Dynamic SQL (Case 1: parameters known at compile time)

- ✓ **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**

Parameters in Dynamic SQL
(parameters supplied at runtime)

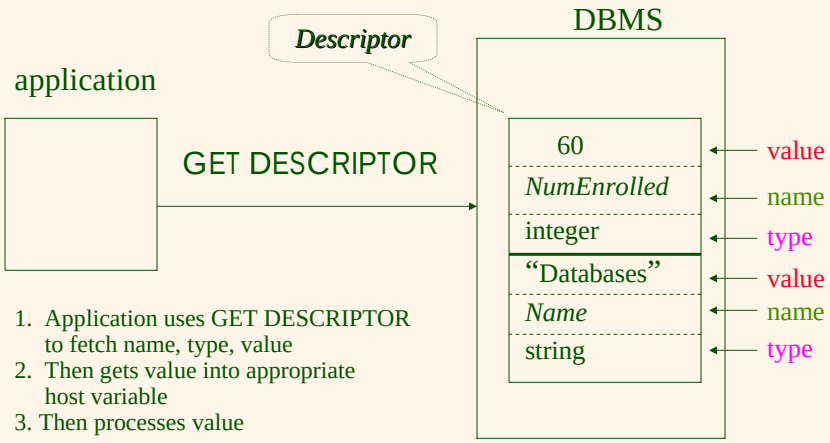
- → **Case 2: Parameters *not* known at compile time**
- → ***Example*: Statement input from terminal**
  - ✓ **Application cannot parse statement and might not know schema, so it does not have any parameter information**
- → **EXECUTE statement cannot name parameters in INTO and USING clauses**

Parameters in Dynamic SQL
(Case 2: parameters supplied at runtime)

- ✓ **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 when Descriptors are Used

```
… …  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               // execute statement and
        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

```
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

```
// 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

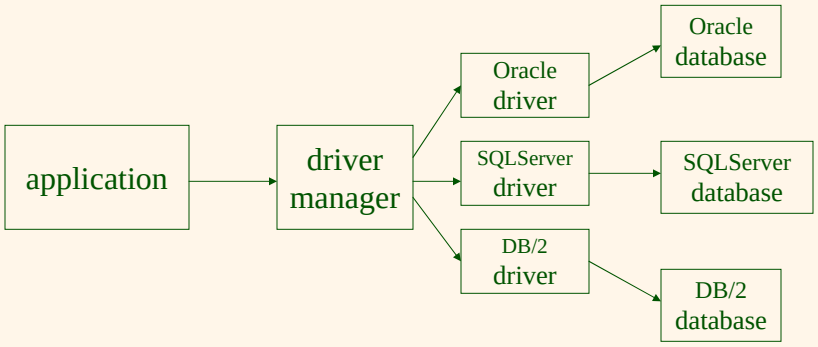
```
char strdata[1024];
int intdata;
… … …
switch (coltype) {
case SQL_CHAR:
 EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber strdata=DATA
 break;
case SQL_INT:
 EXEC SQL GET DESCRIPTOR 'st_output'  VALUE   :colnumber
   :intdata=DATA;
 break;
case SQL_FLOAT:
   … … …
}
```

Put the value of attribute **colnumber** *into the variable* **strdata**

JDBC

- →Call-level interface (CLI) 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

JDBC Run-Time Architecture



Executing a Query

import java.sql.*; -- *import all classes in package* java.sql

Class.forName (*driver name*); // *static method of class* 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*

Preparing and Executing a Query (cont'd)

```
String  crs_code, semester;
……
ps.setString(1, crs_code);     // set value of first in parameter
ps.setString(2, semester);     // set value of second 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 ( ) )  {                    // advance the cursor
      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

```
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

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().

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

SQLJ Example

```
#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  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)

```
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

Sequence of Procedure Calls Needed for ODBC

```
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);
SQLFreeStmt(hstmt);                  // free up statement space
SQLDisconnect(hdbc);
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

```
RETCODE retcode1;
Retcode1 = SQLConnect ( …)
```

- Transactions
  - ✓ Can be committed or aborted with SQLTransact (henv, hdbc, SQL_COMMIT)

Cursors

- Fundamental problem with database technology: *impedance mismatch* — traditional programming languages process records one-at-a-time (tuple-oriented); SQL processes tuple sets (set-oriented).
- Cursors solve this problem: A cursor accesses the result of a query in a set-oriented way, returns tuples for the program to process one-by-one.
- Syntax of cursor definition:

```
declare CursorName [ scroll ]
  cursor for SelectSQL
  [ for < read only | update [ of Attribute
```

Operations on Cursors

- 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)

Example of Embedded SQL

```
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);
```

Dynamic SQL

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

followed by:

Procedures

- SQL-2 allows for the definition of procedures, also known as *stored procedures*.
- Stored procedures are part of the schema

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

- SQL-2 does not support the the definition of complex procedures
- Most systems offer SQL extensions that

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,
  Thresh
      from BankAcct where AcctNo =
  ClientAcct
      for update of Amount;
        NewAmount := OldAmount - WithDr;
        if NewAmount > Thresh
        then update BankAcct
             set Amount = NewAmount
             where AcctNo = ClientAcct;
```