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' or some distinguished token
- 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;
}
```

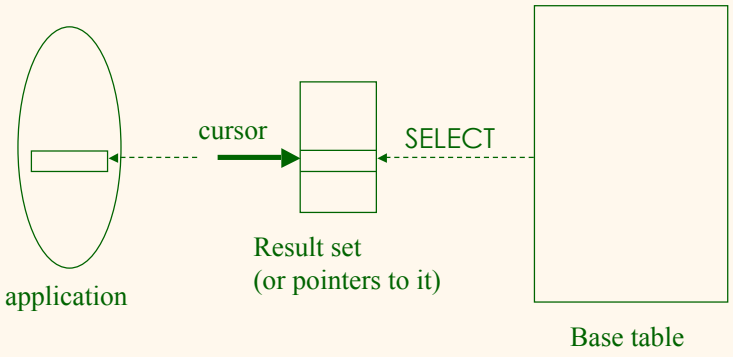
Buffer Mismatch Problem

- **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

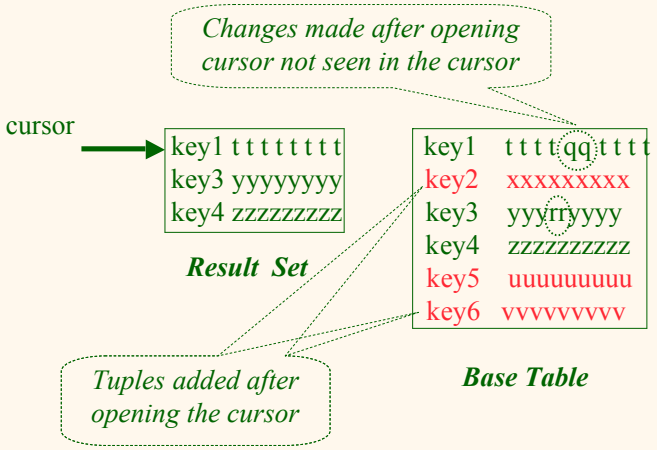
```
EXEC SQL DECLARE GetEnroll INSENSITIVE CURSOR FOR
   SELECT T.StudId, T.Grade        — cursor is not a schema element
    FROM Transcript T
    WHERE T.CrsCode = :crscode AND T.Semester = 'S2000';
   ……
EXEC SQL OPEN GetEnroll;
if ( !strcmp ( SQLSTATE, "00000")) {... fail exit... };
   ……
EXEC SQL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

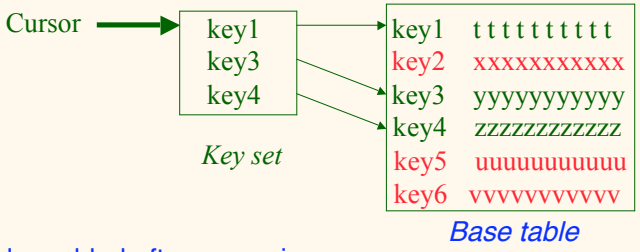
Insensitive Cursor



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 ca… 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)

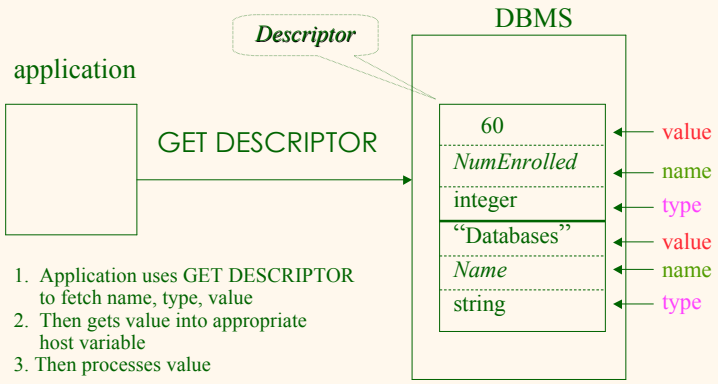
- → Case 2: Parameters ***not*** known at compile time
- → *Example*: Statement input from terminal
  - ✓ Application cannot parse statement and might not know schema, so it does not have any parameter information
- → EXECUTE statement cannot name parameters in INTO and USING clauses

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

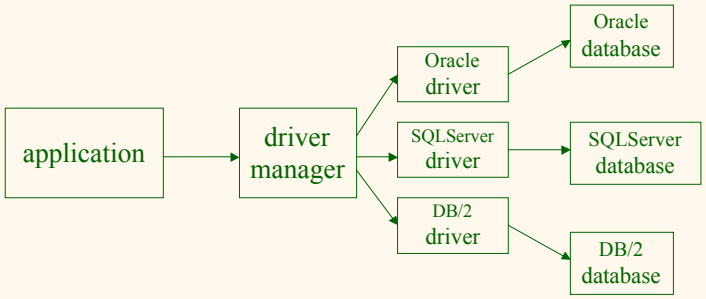
```
char strdata[1024];
int intdata;
… … …
switch (coltype) {
case SQL_CHAR:
 EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber strdata=DATA
 break;
case SQL_INT:
 EXEC SQL GET DESCRIPTOR 'st_output'  VALUE   :colnumber
   :intdata=DATA;
 break;
case SQL_FLOAT:
   … … …
}
```

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 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 {
    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*** {, ***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):
  `current of` ***CursorName***
  (in a `where` clause)

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);
$   fetch DeptEmp into :FirstName, :Surname,
:Salary; }
$ close DeptEmp;      }
```

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:

  `execute` *CommandName* [`into` *TargetList*]
  [`using` *ParameterList*]

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 support complex procedures (e.g., Oracle PL/SQL).

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;
        else insert into OverDraftExceeded
          values(ClientAcct,Withdr,sysdate);
    end if;
  end Debit;
```