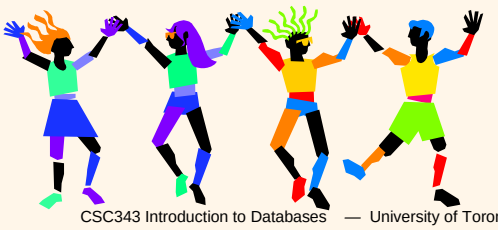
Week 6: Embedded SQL

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 [ ] 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 [ ] to manage SQL statements. Embedded statements are preceded by ‘[ ]
- 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 [ ] 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 [ ].
- 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.

- Application program is a mixture of host language statements and SQL statements and directives.
- 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.,
- 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

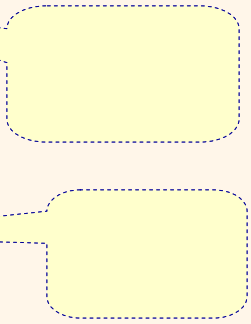
→SQL statements are values of string variables constructed using host language — similar to dynamic SQL

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

e.g.

Static SQL

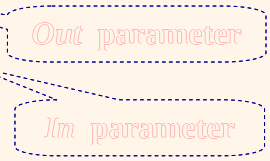
```
EXEC SQL BEGIN DECLARE S;
  unsigned long num_enrolled;
  char crs_code;
  char SQLSTATE [5];
EXEC SQL END DECLARE SE;
      …….
EXEC SQL SELECT C.NumEnrolled
    INTO :num_enrolled
    FROM Course C
    WHERE C.CrsCode = :crs_code;
```



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

Status

```
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 _____ or _____ statements.

Example: Course Deregistration

```
EXEC SQL                    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                ;
else {
  EXEC SQL UPDATE Course C
        SET C.Numenrolled = C.Numenrolled – 1
        WHERE C.CrsCode = :crscode;
   if (! strcmp (SQLSTATE, "00000") ) EXEC SQL
   else EXEC SQL
}
```


Impedance Mismatch Problem

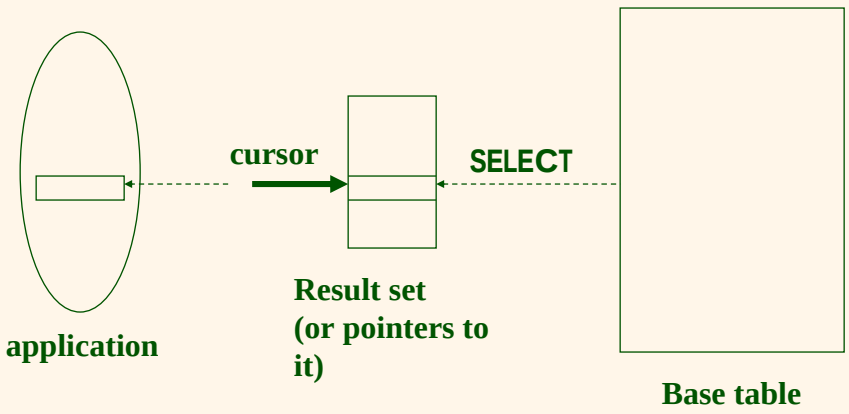
- Fundamental problem with database technology: — traditional programming languages process records one-at-a-time (tuple-oriented); SQL processes tuple sets (set-oriented).
- solve this problem: A cursor returns tuples from a result set, to be process one-by-one.
- Syntax of cursor definition:

```
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:
- To extract one tuple from the query result:
- To free the cursor, discarding the query result:
- To access the current tuple (when a cursor reads a relation, in order to update it):

How Cursors Work



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

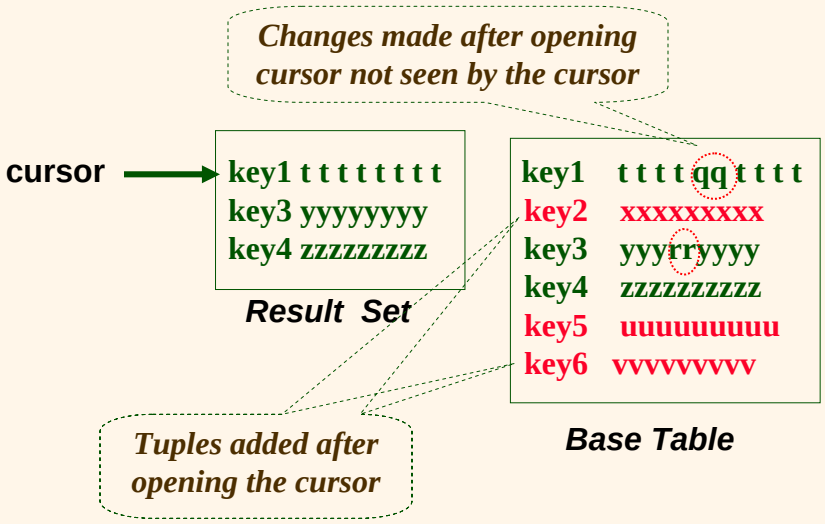
→ : Result set (effectively) computed and stored in separate table at **OPEN** time

- ✓Changes made to base table subsequent to **OPEN** (by any transaction) do not affect result set
- ✓Cursor is read-only

→ : Specification not part of SQL standard

- ✓Changes made to base table subsequent to **OPEN** (by any transaction) can affect result set
- ✓Cursor is updatable

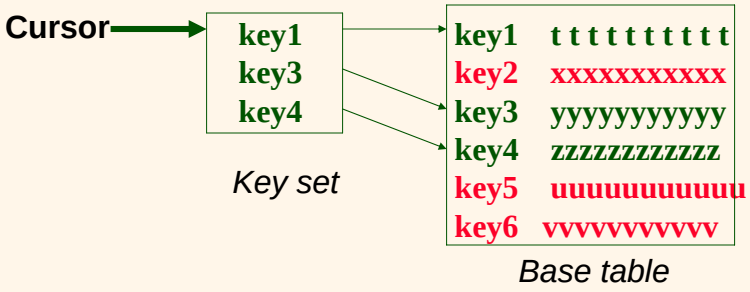
Insensitive Cursor



Keyset-Driven Cursor

- Example of a cursor that is not insensitive.
- [ ] 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:

  FETCH PRIOR FROM GetEnroll INTO :studid, :grade;

  Get previous tuple

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

Stored Procedures

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

```
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).

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

- → 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

- 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

```
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;
```

placeholder

- **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.

```
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

```
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;
```

→**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

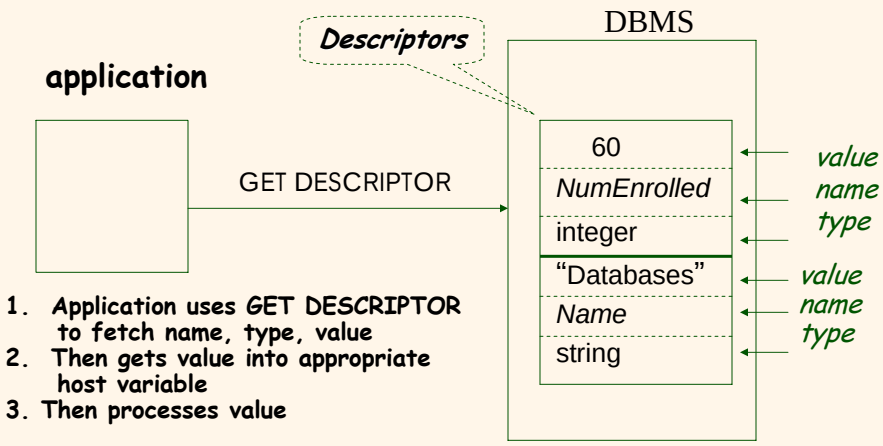
- Parameters ***not*** known at compile time
- *Example*: Statement input from terminal
  - ✓ Application cannot parse statement and might not know schema, so it does not have any parameter information
- **EXECUTE** statement cannot name parameters in **INTO** and **USING** clauses

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' "



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 *// 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

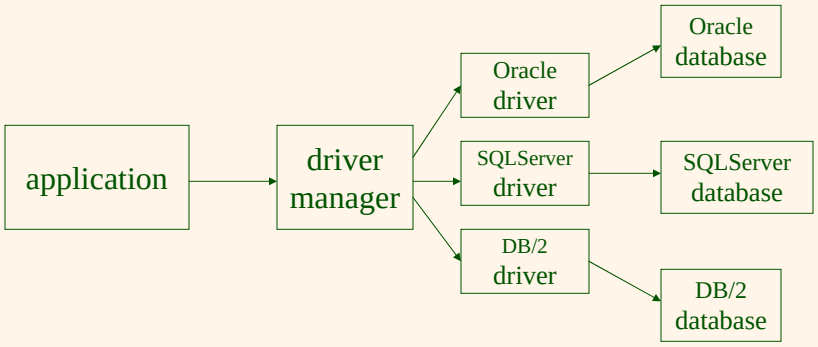
```
char strdata[1024];
int intdata;
… … …
switch (coltype) {
case SQL_CHAR:
 EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber
   strdata=DATA;
 break;
case SQL_INT:
 EXEC SQL GET DESCRIPTOR 'st_output'  VALUE   :colnumber
   :intdata=DATA;
 break;
case SQL_FLOAT:
   … … …
}
```

Put the value of attribute colnumber into the variable strdata

JDBC

- → [ ] 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
// *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 ( ) )  {              // 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:

- ✓ : not scrollable
- ✓ : scrollable; changes made to underlying tables after the creation of the result set are not visible through that result set
- ✓ : 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)

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;      }
```