Using SQL in an Application

CSE 532, Theory of Database Systems

Stony Brook University

http://www.cs.stonybrook.edu/~cse532

Interactive vs. Non-Interactive SQL

- *Interactive SQL*: SQL statements input from terminal; DBMS outputs to screen
  - Inadequate for most uses
    - It may be necessary to process the data before output
    - Amount of data returned not known in advance
    - SQL has very limited expressive power (not Turing-complete)
- *Non-interactive SQL*: SQL statements are included in an application program written in a host language, like C, Java, COBOL

Application Program

- *Host language*: A conventional 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 an 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*
- *Precompiler* 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
- Precompiler 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 SECTION;
  unsigned long num_enrolled;
  char crs_code;
  char SQLSTATE [6];
EXEC SQL END DECLARE SECTION;
      ……….
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                      Out parameter
    FROM Course C
    WHERE C.CrsCode = :crs_code;               In parameter
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

```
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;
}
```

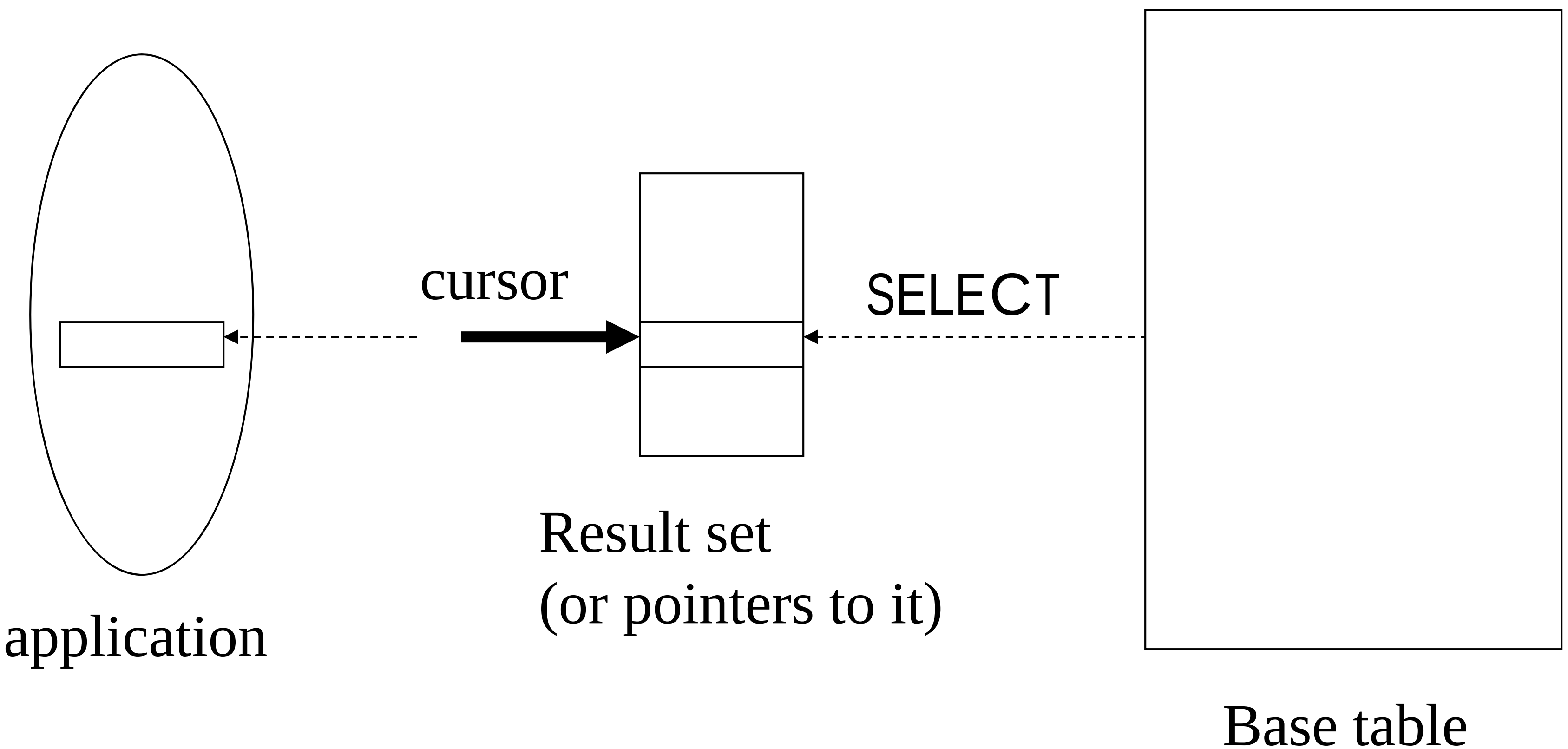
Buffer Mismatch Problem

- **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)



Cursors (cont'd)

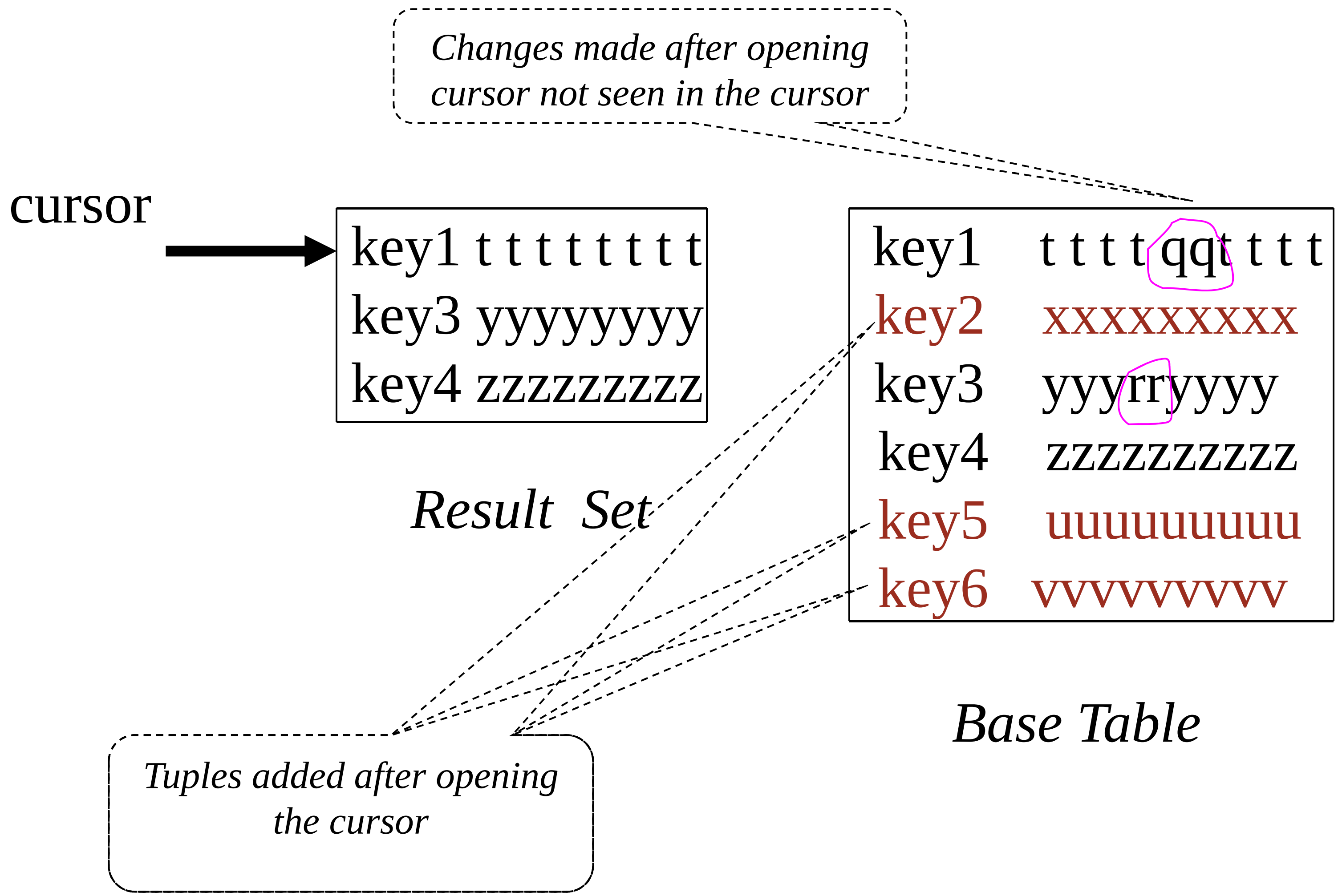
```
EXEC SQL DECLARE  GetEnroll INSENSITIVE  CURSOR FOR
    SELECT  T.StudId, T.Grade        --cursor is not a schema element
    FROM Transcript T
    WHERE  T.CrsCode = :crscode  AND T.Semester = 'S2000';
    .........
EXEC SQL OPEN GetEnroll;
if ( !strcmp ( SQLSTATE, "00000")) {... fail exit... };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

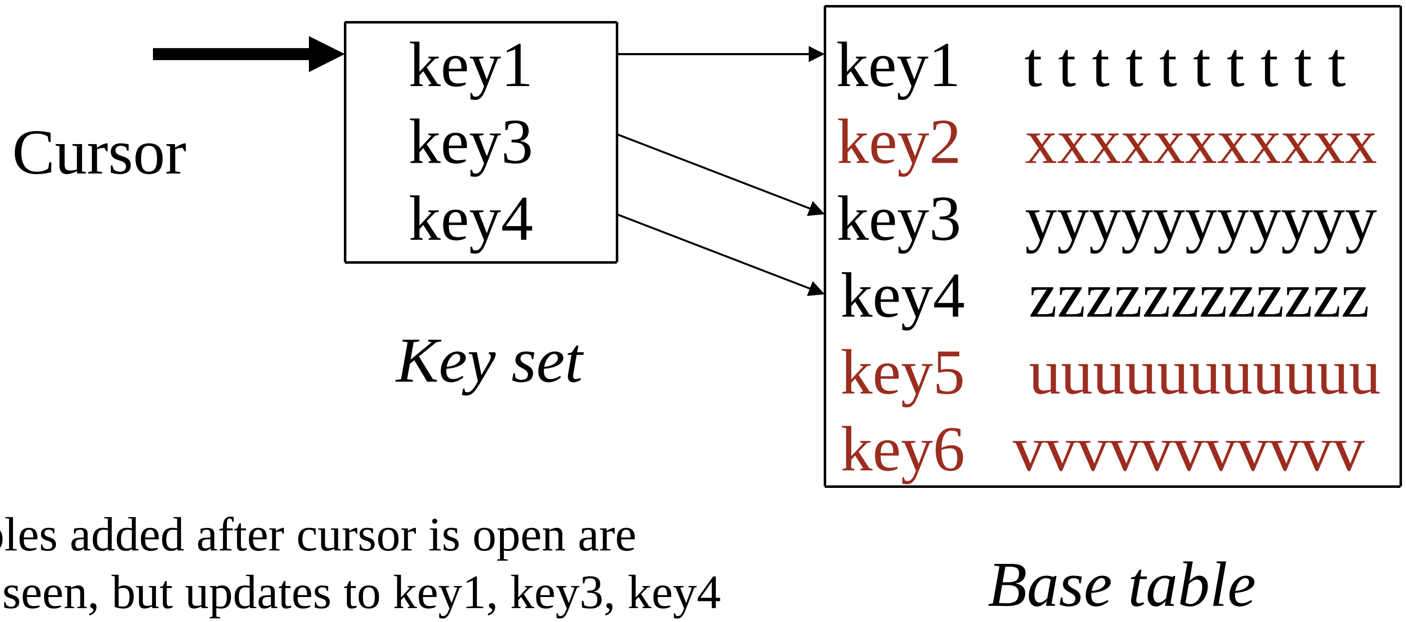
Insensitive Cursor



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 can be moved in arbitrary ways around result set:

Get previous tuple

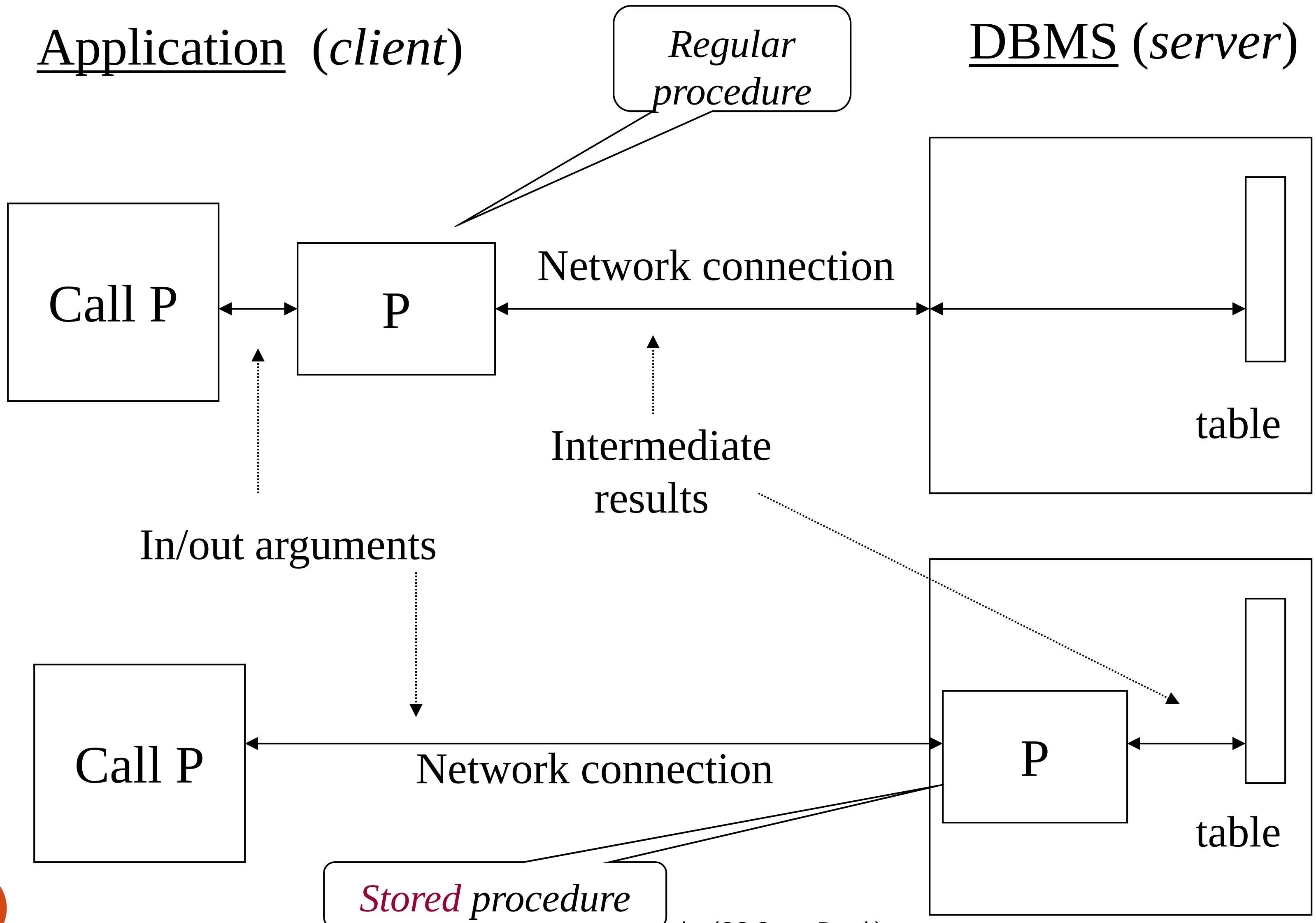
```
FETCH PRIOR FROM GetEnroll INTO :studid, :grade;
```

- 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

Stored Procedures



Stored Procedures

Schema:

```
CREATE PROCEDURE Register (char :par1, char :par2)
  AS BEGIN
        EXEC SQL SELECT ....... ;
          IF ( ......) THEN ......      -- SQL embedded in
                       ELSE ....        -- Persistent Stored Modules
                                        -- (PSM) language
     END
```

Application:

```
EXEC SQL EXECUTE PROCEDURE Register ( :crscode, :studid);
```

Integrity Constraint Checking

- Transaction moves database from an initial to a final state, both of which satisfy all integrity constraints but …
  - Constraints might not be true of intermediate states hence …
  - Constraint checks at statement boundaries might be inappropriate
- SQL (optionally) allows checking to be deferred to transaction COMMIT

Deferred Constraint Checking

Schema:

```
CREATE ASSERTION NumberEnrolled
  CHECK ( .......)
  DEFERRABLE;
```

Application:

```
SET CONSTRAINT NumberEnrolled DEFERRED;
```

Transaction is aborted if constraint is false at commit time

Dynamic SQL

- **Problem**: Application might not know in advance:
  - The SQL statement to be executed
  - The database schema to which the statement is directed
- **Example**: User inputs database name and SQL statement interactively from terminal
- In general, application constructs (as the value of a host language string variable) the SQL statement at run time
- Preparation (necessarily) done at run time

Dynamic SQL

- SQL-92 defines syntax for embedding directives into application for constructing, preparing, and executing an SQL statement
  - Referred to as ***Dynamic SQL***
  - Statement level interface
- Dynamic and static SQL can be mixed in a single application

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, 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: Static vs Dynamic SQL

- *Static SQL*:
  - Names of (host language) parameters are contained in SQL statement and available to precompiler
  - 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: Static vs Dynamic SQL

- *Dynamic SQL*: SQL statement constructed at run time when symbol table is no longer present
- Case 1: Parameters <u>*are*</u> 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 – 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)

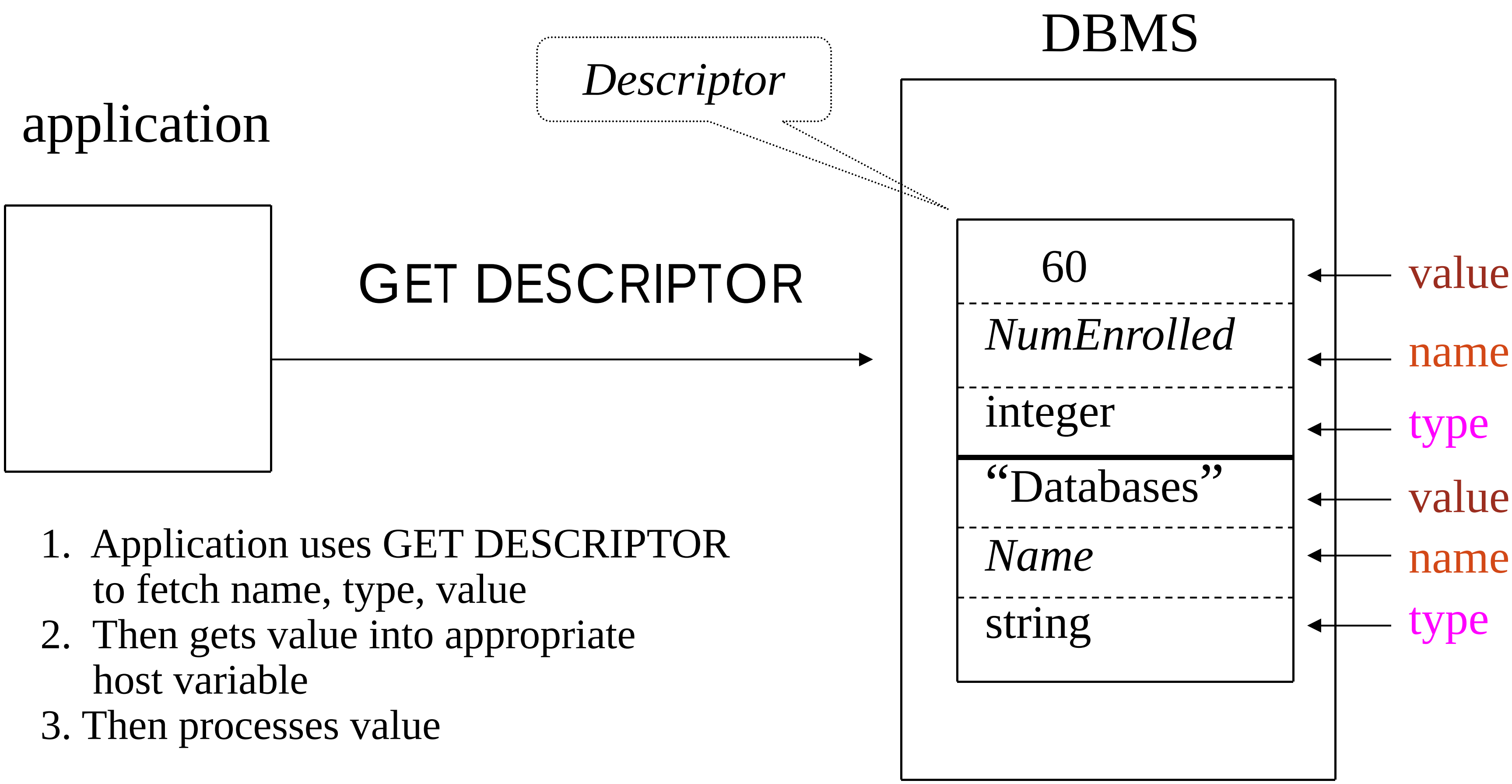
- Case 2: Parameters *not* known at compile time
- *Example*: Statement input from terminal
  - Application cannot parse statement and might not know schema, so it does not have any parameter information
- EXECUTE statement cannot name parameters in INTO and USING clauses

Parameters in Dynamic SQL (cont'd) (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

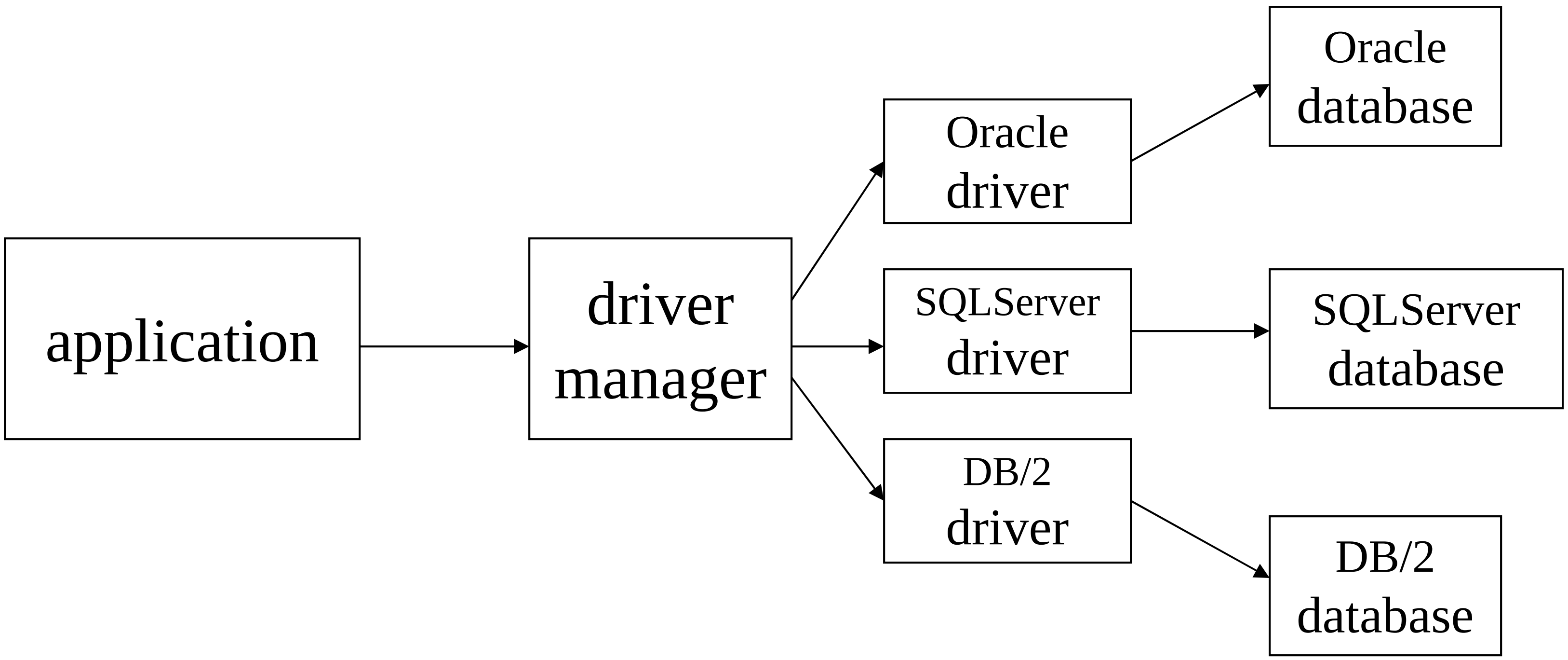
```
char strdata[1024];
int intdata;
… … …
switch (coltype) {
case SQL_CHAR:
    EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber :strdata=DATA;
    break;
case SQL_INT:
    EXEC SQL GET DESCRIPTOR 'st_output' VALUE :colnumber :intdata=DATA;
    break;
case SQL_FLOAT:
    … … …
}
```

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)