SQL in the Real World

Interactive vs. Non-Interactive SQL

- *Interactive SQL*: SQL statements input from terminal; DBMS outputs to screen
  - Inadequate for most applications
    - 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 an unsophisticated user at a terminal and the DBMS

Preparation

- Before an SQL statement is executed, it must be ***prepared***:
  - What indices can be used?
  - In what order should tables be accessed?
  - What constraints should be checked?
- Decisions 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

- 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 COMMIT or ROLLBACK statements

Example: Course Deregistration

```
EXEC SQL CONNECT TO :dbserver;
if ( ! strcmp (SQLSTATE, "000000") ) exit (1);
   …..
EXEC SQL DELETE FROM Transcript T
  WHERE T.StudId = :studid AND T.Semester = 'S2000'
                  AND T.CrsCode = :crscode;
if (! strcmp (SQLSTATE, "000000") ) EXEC SQL ROLLBACK;
else {
  EXEC SQL UPDATE Course C
         SET C.Numenrolled = C.Numenrolled - 1
         WHERE C.CrsCode = :crscode;
   if (! strcmp (SQLSTATE, "000000") ) EXEC SQL ROLLBACK;
   else EXEC SQL COMMIT;
}
```

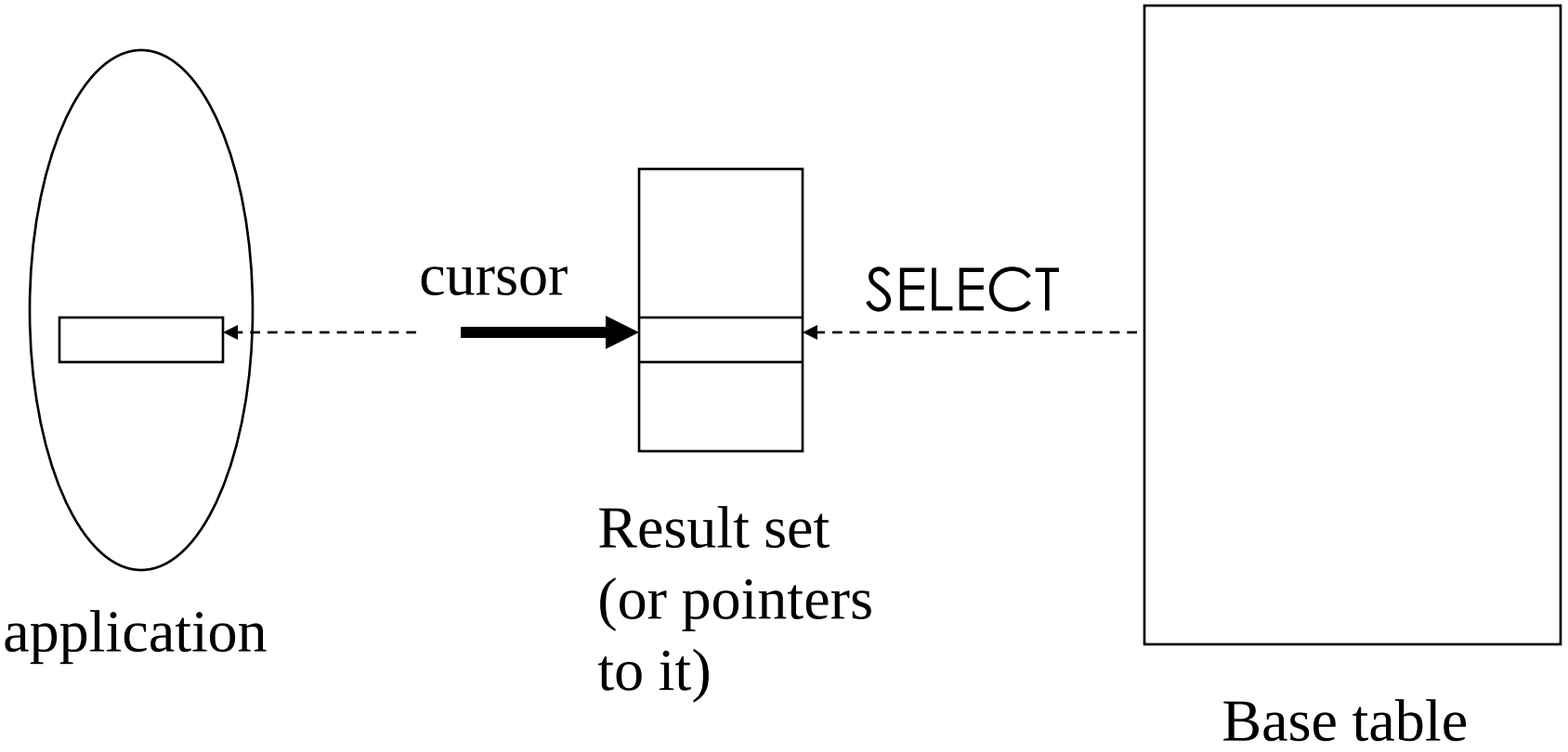
Buffer Mismatch

- **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

Cursor Overview

- ***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

Cursor


cursor
SELECT
application
Result set
(or pointers
to it)
Base table

Cursor

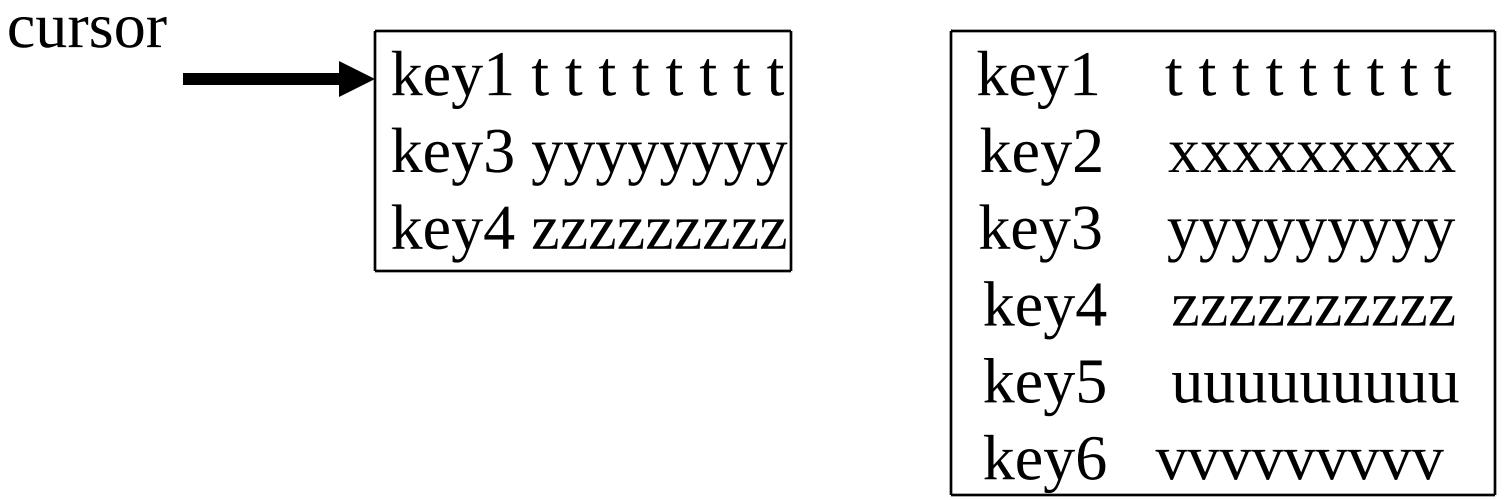
```
EXEC SQL DECLARE  GetEnroll INSENSITIVE  CURSOR FOR
    SELECT  T.StudId, T.Grade          --cursor is not a schema element
     FROM Transcript T
     WHERE  T.CrsCode = :crscode  AND T.Semester = 'S2000';
    ……
EXEC SQL OPEN GetEnroll;
if ( !strcmp ( SQLSTATE, "00000")) {... fail exit... };
 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

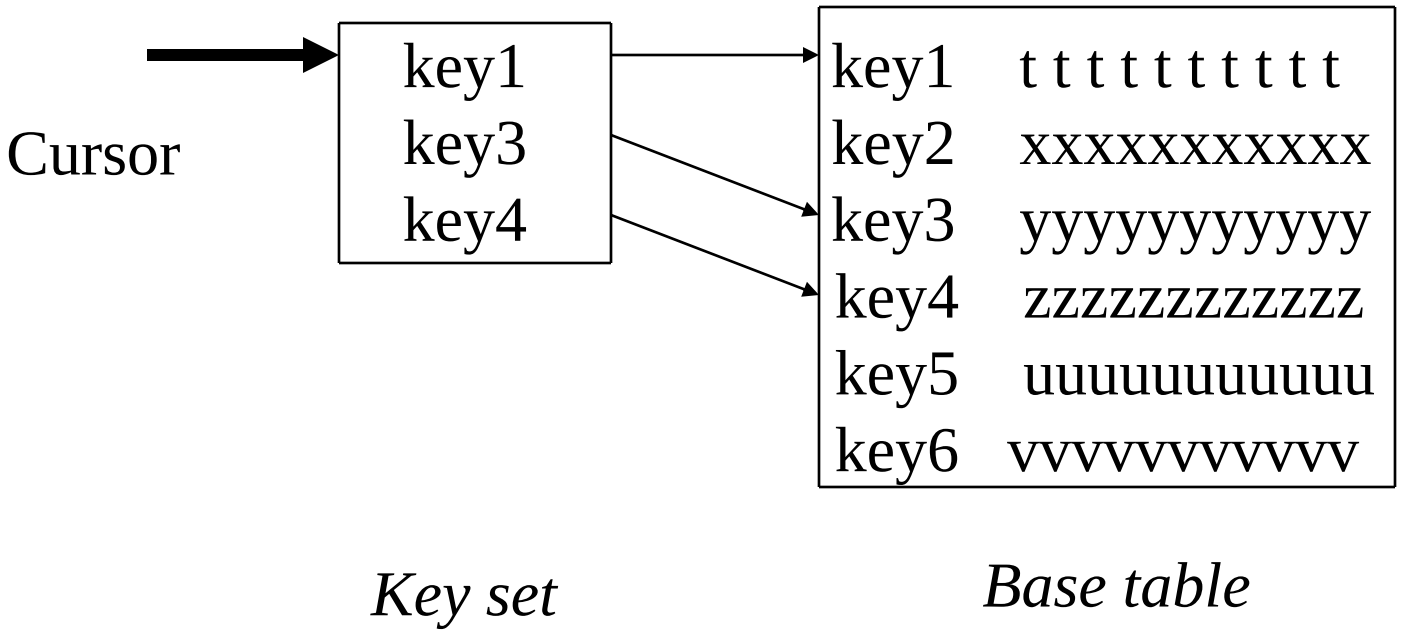
Insensitive Cursor



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



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

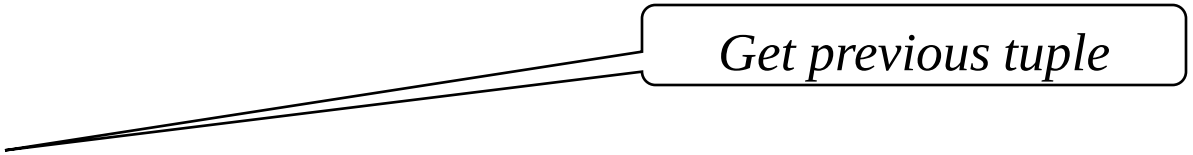
UPDATE *table-name* --*base table*
SET *assignment*
WHERE CURRENT OF *cursor-name*

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:



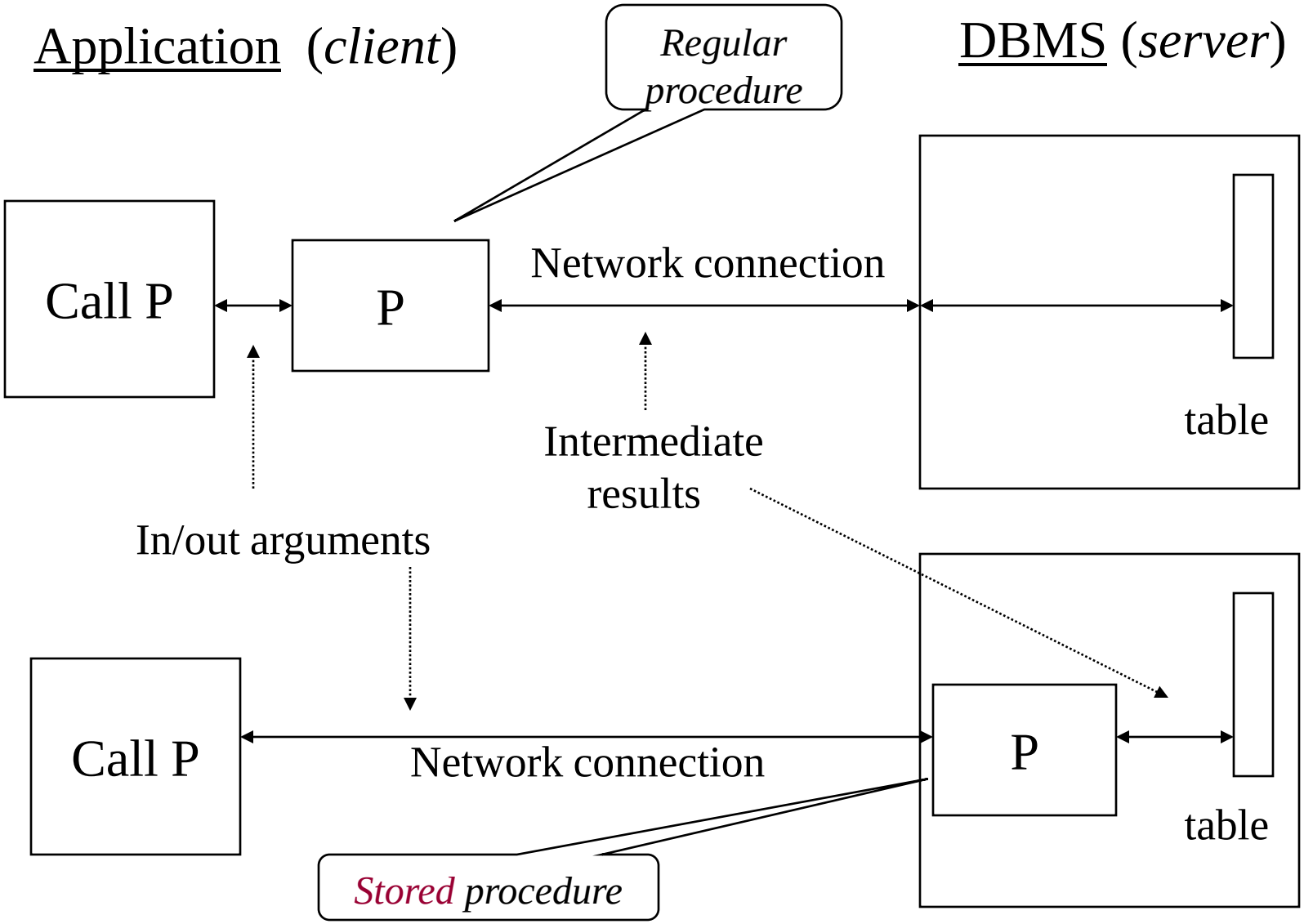

```
FETCH PRIOR FROM GetEnroll INTO :studid, :grade;
```

- 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 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 - Dynamic SQL (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)

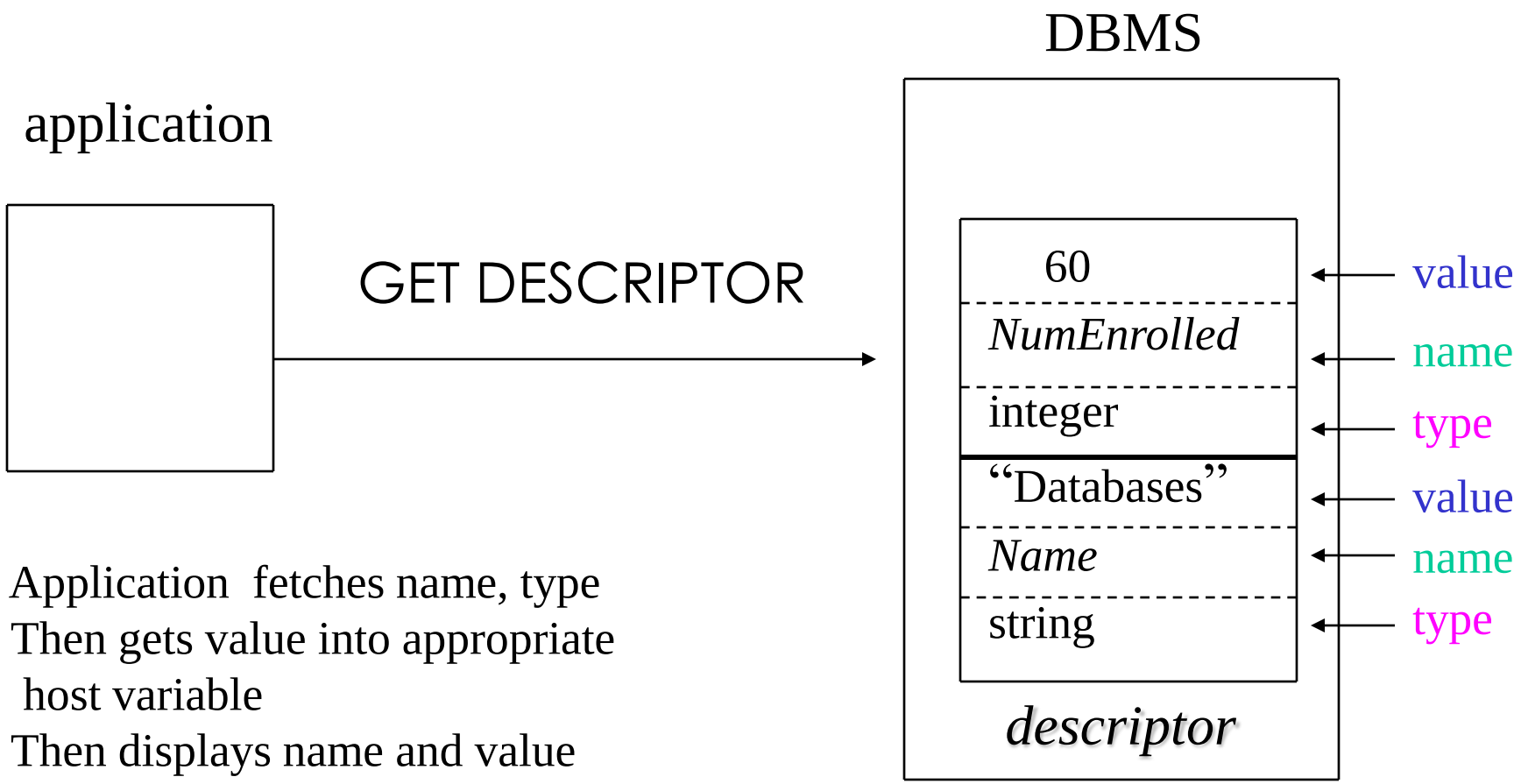
- Case 2: Parameters not known at compile time
- *Example*: Statement input from terminal
  - Application cannot parse statement and might not know schema, so it does not have any parameter information
- EXECUTE statement cannot name parameters in INTO and USING clauses

Parameters in Dynamic SQL (cont'd) (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 fetches name, type
2. Then gets value into appropriate host variable
3. Then displays name and 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

- More details in the book:

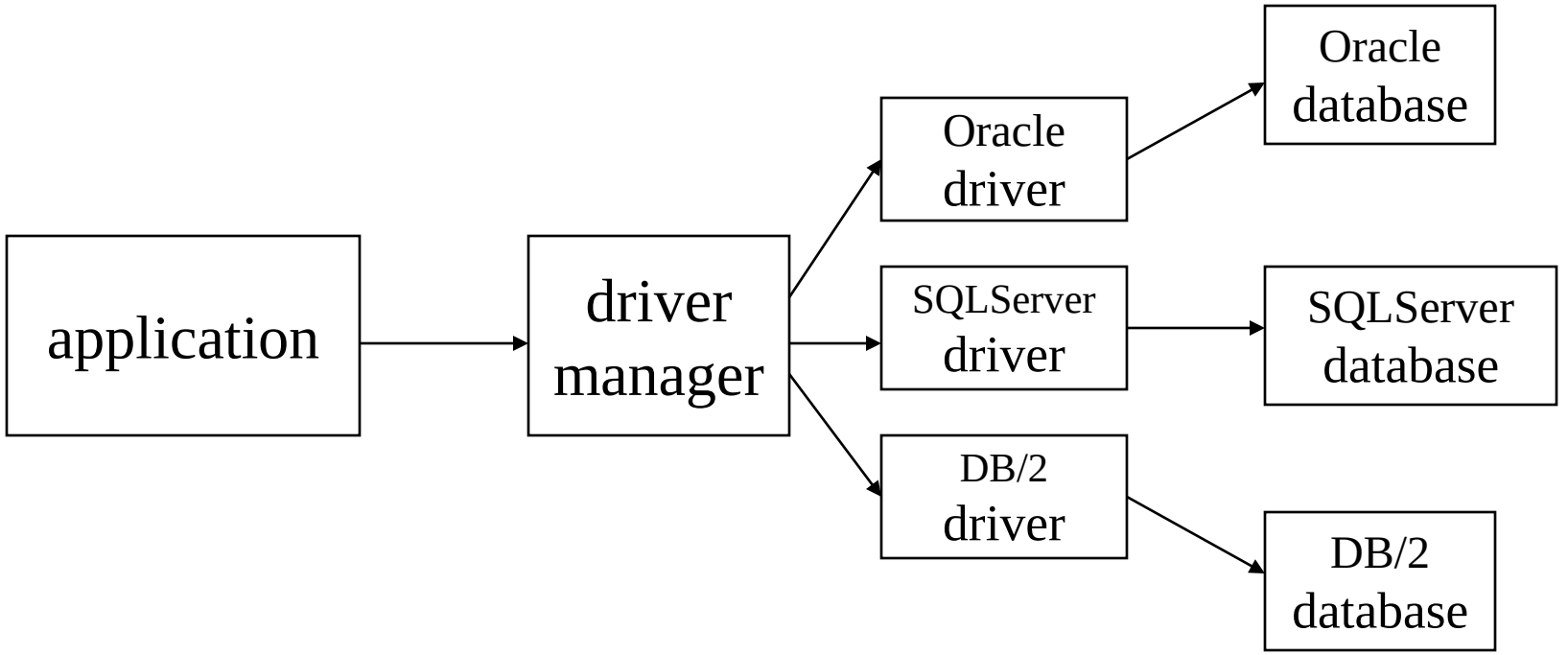
```
// Host var colcount gets the number of out parameters in the SQL statement
// described by st_output
EXEC SQL GET DESCRIPTOR 'st_output' :colcount = COUNT;

// Set host vars coltype, collength, colname with the type, length, and name
// of the 3-d out parameter in the SQL statement described by st_output
EXEC SQL GET DESCRIPTOR 'st_output' VALUE 3;
    :coltype = TYPE,    // predefined integer constants, such as SQL_CHAR, SQL_FLOAT,…
    :collength = LENGTH,
    :colname = NAME;
```

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

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*

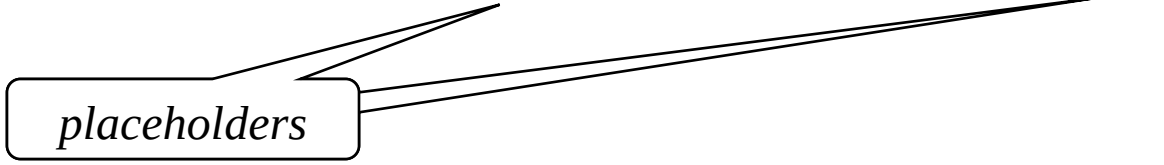
Executing a Query

```
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* = **?**";



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

```
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, changes made to the tuples in a result set after the creation of that 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)
- Current row of an updatable result set can be updated or deleted, and a new row can be inserted, causing changes in base table

```
res.updateString ("Name", "John" );    // update attribute "Name" of
                                       // current row in row buffer.
res.updateRow ( );   // install current row buffer in res and underlying 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

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

```
#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 attrs StudentId, 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)