# Database Application Development

# Overview

Concepts covered in this lecture:

- SQL in application code
- Embedded SQL
- Cursors
- Dynamic SQL
- JDBC
- SQLJ
- ODBC
- Stored procedures

# Justification for access to databases via programming languages :

- SQL is a direct query language; as such, it has limitations.
- via programming languages :
  - Complex computational processing of the data.
  - ·Specialized user interfaces.
  - Access to more than one database at a time.

# SQL in Application Code

- SQL commands can be called from within a host language (e.g., C++ or Java) program.
  - SQL statements can refer to host variables (including special variables used to return status).
  - Must include a statement to *connect* to the right database.

# SQL in Application Code (Contd.)

Impedance mismatch:

- SQL relations are (multi-) sets of records, with no *a priori* bound on the number of records. No such data structure exist traditionally in procedural programming languages such as C++. (Though now: STL)
  - SQL supports a mechanism called a *cursor* to handle this.

# Desirable features of such systems:

- Ease of use.

- Conformance to standards for existing programming languages, database query languages, and development environments.

- Interoperability: the ability to use a common interface to diverse database systems on different operating systems

# Vendor specific solutions

- Oracle PL/SQL: A proprietary PL/1-like language which supports the execution of SQL queries:
- Advantages:
  - Many Oracle-specific features, not common to other systems, are supported.
  - Performance may be optimized to Oraclebased systems.
- Disadvantages:
  - Ties the applications to a specific DBMS.
  - The application programmer must depend upon the vendor for the application development environment.
  - It may not beavailable for all platforms.

# Vendor Independent solutions based on SQL

There are three basic strategies which may be considered:

- Embed SQL in the host language (Embedded SQL, SQLJ)
- SQL modules
- SQL call level interfaces

# Embedded SQL

- Approach: Embed SQL in the host language.
  - A preprocessor converts the SQL statements into special API calls.
  - Then a regular compiler is used to compile the code.
- Language constructs:
  - Connecting to a database:
    EXEC SQL CONNECT
  - Declaring variables:
    EXEC SQL BEGIN (END) DECLARE SECTION
  - Statements:
    EXEC SQL Statement;

# Embedded SQL: Variables

```
EXEC SQL BEGIN DECLARE SECTION
char c_sname[20];
long c_sid;
short c_rating;
float c_age;
EXEC SQL END DECLARE SECTION
```

- Two special “error” variables:
  - SQLCODE (long, is negative if an error has occurred)
  - SQLSTATE (char[6], predefined codes for common errors)

# Cursors

- Can declare a cursor on a relation or query statement (which generates a relation).
- Can *open* a cursor, and repeatedly *fetch* a tuple then *move* the cursor, until all tuples have been retrieved.
  - Can use a special clause, called ORDER BY, in queries that are accessed through a cursor, to control the order in which tuples are returned.
    - Fields in ORDER BY clause must also appear in SELECT clause.
  - The ORDER BY clause, which orders answer tuples, is *only* allowed in the context of a cursor.
- Can also modify/delete tuple pointed to by a cursor.

# Cursor that gets names of sailors who've reserved a red boat, in alphabetical order

```
EXEC SQL DECLARE sinfo CURSOR FOR
        SELECT  S.sname
        FROM  Sailors S, Boats B, Reserves R
        WHERE  S.sid=R.sid AND R.bid=B.bid AND B.color='red'
        ORDER BY  S.sname
```

- Note that it is illegal to replace *S.sname* by, say, *S.sid* in the ORDER BY clause! (Why?)
- Can we add *S.sid* to the SELECT clause and replace *S.sname* by *S.sid* in the ORDER BY clause?

# Embedding SQL in C: An Example

```
char SQLSTATE[6];
EXEC SQL BEGIN DECLARE SECTION
char c_sname[20]; short c_minrating; float c_age;
EXEC SQL END DECLARE SECTION
c_minrating = random();
EXEC SQL DECLARE sinfo CURSOR FOR
    SELECT S.sname, S.age        FROM Sailors S
    WHERE S.rating > :c_minrating
    ORDER BY S.sname;
do {
    EXEC SQL FETCH sinfo INTO :c_sname, :c_age;
    printf("%s is %d years old\n", c_sname, c_age);
} while (SQLSTATE != '02000');
EXEC SQL CLOSE sinfo;
```

# Dynamic SQL

- SQL query strings are not always known at compile time (e.g., spreadsheet, graphical DBMS frontend): Allow construction of SQL statements on-the-fly

- Example:

```
char c_sqlstring[]=
    {“DELETE FROM Sailors WHERE rating>5”};
EXEC SQL PREPARE readytogo FROM :c_sqlstring;
EXEC SQL EXECUTE readytogo;
```

# Disadvantages:

- It is a real pain to debug preprocessed programs.
- The use of a program-development environment is compromised substantially.
- The preprocessor must be vendor and platform specific.

# SQL Modules

- In the module approach, invocations to SQL are made via libraries of procedures , rather than via preprocessing
- Special standardized interface: procedures/objects
- Pass SQL strings from language, presents result sets in a language-friendly way
- Supposedly DBMS-neutral
  - a “driver” traps the calls and translates them into DBMS-specific code
  - database can be across a network

# Example module based

- Sun's *JDBC:* Java API
- Part of the java.sql package

- Advantages over embedded SQL:
  - Clean separation of SQL from the host programming language.
  - Debugging is much more straightforward, since no preprocessor is involved.

- Disadvantages:
  - The module libraries are specific to the programming language and environment. Thus, portability is compromised greatly.

# JDBC: Architecture

- Four architectural components:
  - Application (initiates and terminates connections, submits SQL statements)
  - Driver manager (load JDBC driver)
  - Driver (connects to data source, transmits requests and returns/translates results and error codes)
  - Data source (processes SQL statements)

# JDBC Architecture (Contd.)

Four types of drivers:

Bridge:

- Translates SQL commands into non-native API.
  Example: JDBC-ODBC bridge. Code for ODBC and JDBC driver needs to be available on each client.

Direct translation to native API, non-Java driver:

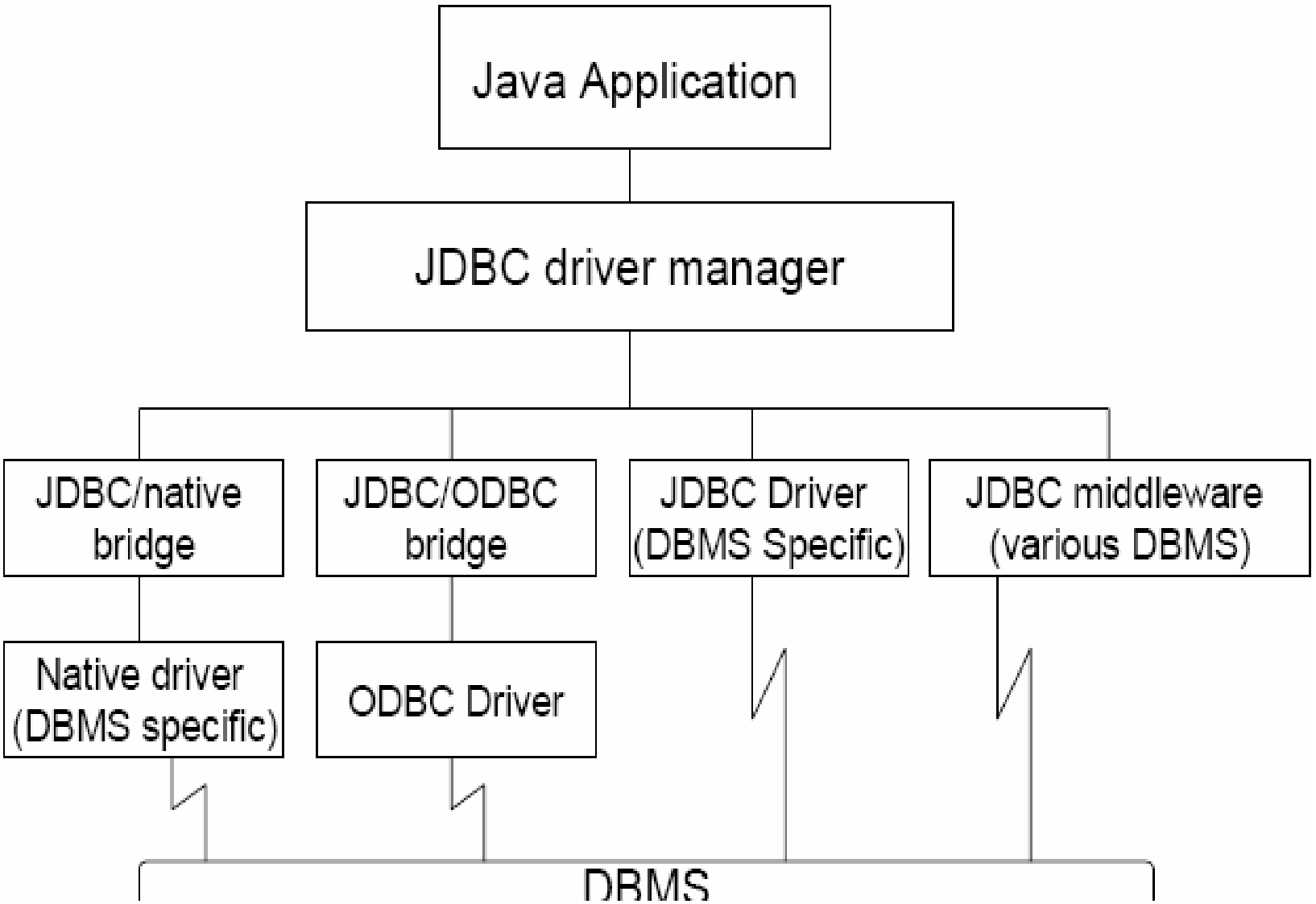
- Translates SQL commands to native API of data source. Need OS-specific binary on each client.

Network bridge:

- Send commands over the network to a middleware server that talks to the data source. Needs only small JDBC driver at each client.

Direction translation to native API via Java driver:

- Converts JDBC calls directly to network protocol used by DBMS. Needs DBMS-specific Java driver at each client.


Java Application
JDBC driver manager
JDBC/native bridge
JDBC/ODBC bridge
JDBC Driver (DBMS Specific)
JDBC middleware (various DBMS)
Native driver (DBMS specific)
ODBC Driver
DBMS

# JDBC Classes and Interfaces

Steps to submit a database query:

- Load the JDBC driver
- Connect to the data source
- Execute SQL statements

# JDBC Driver Management

- All drivers are managed by the DriverManager class
- Loading a JDBC driver:
  - In the Java code:
    Class.forName("oracle/jdbc.driver.Oracledrive r");
  - When starting the Java application:
    -Djdbc.drivers=oracle/jdbc.driver

# Connections in JDBC

We interact with a data source through sessions. Each connection identifies a logical session.

- JDBC URL: jdbc:<subprotocol>:<otherParameters>

Example:

```
String url="jdbc:oracle:www.bookstore.com:3083";
Connection con;
try{
    con = DriverManager.getConnection(url,usedId,password);
} catch SQLException excpt { …}
```

# Connection Class Interface

- public int getTransactionIsolation() and
  void setTransactionIsolation(int level)
  Gets/Sets isolation level for the current connection.

- public boolean getReadOnly() and
  void setReadOnly(boolean b)
  Specifies if transactions in this connection are read-only

- public boolean getAutoCommit() and
  void setAutoCommit(boolean b)
  If autocommit is set, then each SQL statement is considered its own transaction. Otherwise, a transaction is committed using commit(), or aborted using rollback().

- public boolean isClosed()
  Checks whether connection is still open.

# Executing SQL Statements

- Three different ways of executing SQL statements:
  - Statement (both static and dynamic SQL statements)
  - PreparedStatement (semi-static SQL statements)
  - CallableStatment (stored procedures)

- PreparedStatement class: Precompiled, parametrized SQL statements:
  - Structure is fixed
  - Values of parameters are determined at run-time

# Executing SQL Statements (Contd.)

```
String sql="INSERT INTO Sailors VALUES(?,?,?,?)";
PreparedStatment pstmt=con.prepareStatement(sql);
pstmt.clearParameters();
pstmt.setInt(1,sid);
pstmt.setString(2,sname);
pstmt.setInt(3, rating);
pstmt.setFloat(4,age);

// we know that no rows are returned, thus we use
    executeUpdate()
int numRows = pstmt.executeUpdate();
```

# ResultSets

- PreparedStatement.executeUpdate only returns the number of affected records
- PreparedStatement.executeQuery returns data, encapsulated in a ResultSet object (a cursor)

```
ResultSet rs=pstmt.executeQuery(sql);
// rs is now a cursor
While (rs.next()) {
  // process the data
}
```

# ResultSets (Contd.)

A ResultSet is a very powerful cursor:

- previous(): moves one row back
- absolute(int num): moves to the row with the specified number
- relative (int num): moves forward or backward
- first() and last()

# Matching Java and SQL Data Types

| SQL Type | Java class | ResultSet get method |
|---|---|---|
| BIT | Boolean | getBoolean() |
| CHAR | String | getString() |
| VARCHAR | String | getString() |
| DOUBLE | Double | getDouble() |
| FLOAT | Double | getDouble() |
| INTEGER | Integer | getInt() |
| REAL | Double | getFloat() |
| DATE | java.sql.Date | getDate() |
| TIME | java.sql.Time | getTime() |
| TIMESTAMP | java.sql.TimeStamp | getTimestamp() |

# Examining Database Metadata

DatabaseMetaData object gives information about the database system and the catalog.

```
DatabaseMetaData md = con.getMetaData();
// print information about the driver:
System.out.println(
   “Name:” + md.getDriverName() +
   “version: ” + md.getDriverVersion());
```

# Database Metadata (Contd.)

```
DatabaseMetaData md=con.getMetaData();
ResultSet trs=md.getTables(null,null,null,null);
String tableName;
While(trs.next()) {
    tableName = trs.getString(“TABLE_NAME”);
    System.out.println(“Table: “ + tableName);
    //print all attributes
    ResultSet crs = md.getColumns(null,null,tableName, null);
    while (crs.next()) {
        System.out.println(crs.getString(“COLUMN_NAME” + “, “);
    }
}
```

# A (Semi-)Complete Example

```
import java.sql.*;

/**
 * This is a sample program with jdbc odbc  Driver
*/
public class localdemo {

  public static void main(String[] args) {
    try {

      // Register JDBC/ODBC Driver in jdbc DriverManager
      // On some platforms with some java VMs, newInstance() is necessary...
      Class.forName("sun.jdbc.odbc.JdbcOdbcDriver").newInstance();

      // Test with MS Access database (sailors ODBC data source)
      String url = "jdbc:odbc:mysailors";

      java.sql.Connection c = DriverManager.getConnection(url);
```

# A (Semi-)Complete Example cont

```
java.sql.Statement st = c.createStatement();
    java.sql.ResultSet rs = st.executeQuery("select * from Sailors");

    java.sql.ResultSetMetaData md = rs.getMetaData();
    while(rs.next()) {
      System.out.print("\nTUPLE: | ");
      for(int i=1; i<= md.getColumnCount(); i++) {
        System.out.print(rs.getString(i) + " | ");
      }
    }
    rs.close();
  } catch(Exception e) {
    e.printStackTrace();
  }
 }
};
```

# SQLJ

Complements JDBC with a (semi-)static query model:
Compiler can perform syntax checks, strong type checks, consistency of the query with the schema

- All arguments always bound to the same variable:

```
#sql x = {
   SELECT name, rating INTO :name, :rating
   FROM Books WHERE sid = :sid;
```

- Compare to JDBC:

```
sid=rs.getInt(1);
if (sid==1) {sname=rs.getString(2);}
else { sname2=rs.getString(2);}
```

- SQLJ (part of the SQL standard) versus embedded SQL (vendor-specific)

# SQLJ Code

```
Int sid; String name; Int rating;
// named iterator
#sql iterator Sailors(Int sid, String name, Int rating);
Sailors sailors;
// assume that the application sets rating
#sailors = {
    SELECT sid, sname INTO :sid, :name
     FROM Sailors WHERE rating = :rating
};
// retrieve results
while (sailors.next()) {
    System.out.println(sailors.sid + " " + sailors.sname));
}
sailors.close();
```

# SQLJ Iterators

Two types of iterators ("cursors"):

- Named iterator
  - Need both variable type and name, and then allows retrieval of columns by name.
  - See example on previous slide.
- Positional iterator
  - Need only variable type, and then uses FETCH .. INTO construct:

```
#sql iterator Sailors(Int, String, Int);
Sailors sailors;
#sailors = …
while (true) {
    #sql {FETCH :sailors INTO :sid, :name} ;
    if (sailors.endFetch()) { break; }
    // process the sailor
}
```

# SQL call level interfaces

- A call-level interface provides a library of functions for access to DBMS's.
- The DBMS drivers are stored separately; thus the library used by the programming language is DBMS independent.
- The programming language functions provided only an interface to the DBMS drivers.

# SQL call level interfaces

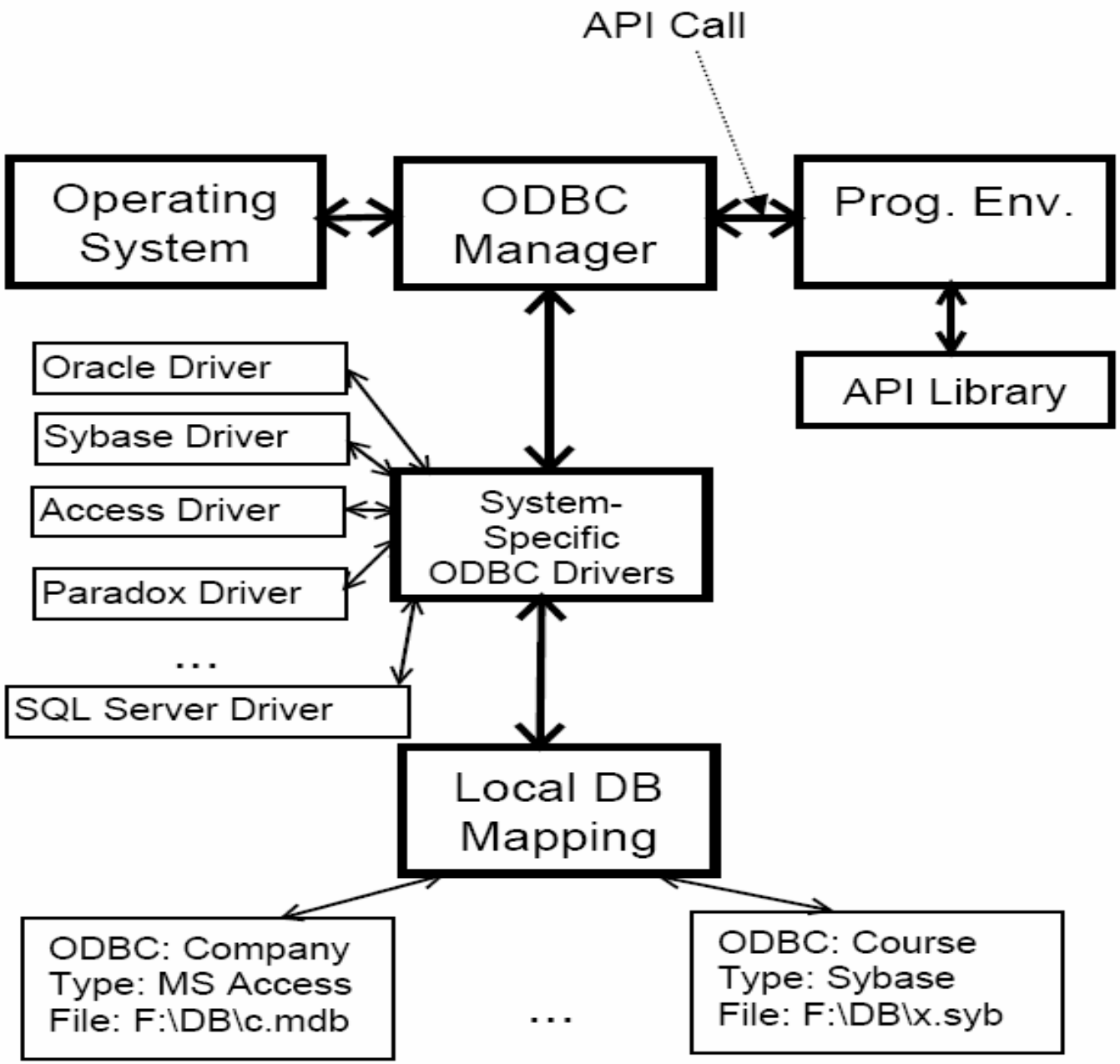
- Advantages:
  - The development environment is not tied to a particular DBMS, operating sytem, or even a particular development environment.
- Disadvantages:
  - Some low-level optimization may be more difficult or impossible to achieve.

# Key example:

- The SQL CLI (X/Open CLI)
- Microsoft ODBC (Open Database Connectivity)
- · The two are closely aligned.

# **O**pen **D**ata**B**ase **C**onnectivity

- Shorten to ODBC, a standard database access method
- The goal:  make it possible to access any data from any application, regardless of which (DBMS).
- ODBC manages this by inserting a middle layer, called a database *driver ,* between an application and the DBMS.
- The purpose of this layer is to translate the application's data queries into commands that the DBMS understands.
- For this to work, both the application and the DBMS must be ODBC-compliant -- that is, the application must be capable of issuing ODBC commands and the DBMS must be capable of responding to them.


API Call
Operating System
ODBC Manager
Prog. Env.
API Library
Oracle Driver
Sybase Driver
Access Driver
Paradox Driver
...
SQL Server Driver
System-Specific ODBC Drivers
Local DB Mapping
ODBC: Company
Type: MS Access
File: F:\DB\c.mdb
...
ODBC: Course
Type: Sybase
File: F:\DB\x.syb

# Configuring a datasource (Access) under Windows

- Open the ODBC menu in the control panel.
- Click on the User DSN tab.
  - click on Add.
- From the menu in the new window,
  - select Microsoft Access Driver (sailors.mdb),
  - click on Finish.
- From the menu in the new window,
  - type in a data source name (mysailors), and optionally, a description.
  - Then click on either Select or Create, depending upon whether you want to link to an existing database, or create a new blank one.
- In the new window, give the path to the database.
- "OK" away the pile of subwindows; the new database should appear under the top-level ODBC User DSN tab.

```
// program connects to an ODBC data source called “mysailors“ then executes SQL
     statement “SELECT *  FROM Sailors';"
#include <windows.h>
#include <sqlext.h>
#include <stdio.h>

int main(void)
{
     HENV   hEnv = NULL;                                   // Env Handle from SQLAllocEnv()
     HDBC   hDBC = NULL;                                   // Connection handle
     HSTMT          hStmt = NULL;                                  // Statement handle
     UCHAR          szDSN[SQL_MAX_DSN_LENGTH] = “mysailors";// Data Source Name
     buffer
     UCHAR*         szUID = NULL;                                  // User ID buffer
     UCHAR*         szPasswd = NULL;                               // Password buffer
     UCHAR          szname[255];                                   //  buffer
     SDWORD         cbname;                                        // bytes recieved
     UCHAR          szSqlStr[] = "Select * From Sailors”;          // SQL string
     RETCODE        retcode;                                       // Return code

// Allocate memory for ODBC Environment handle
SQLAllocEnv (&hEnv);

// Allocate memory for the connection handle
SQLAllocConnect (hEnv, &hDBC);
```

```
// Connect to the data source “mysailors" using userid and password.
retcode = SQLConnect (hDBC, szDSN, SQL_NTS, szUID, SQL_NTS, szPasswd, SQL_NTS);

if (retcode == SQL_SUCCESS || retcode == SQL_SUCCESS_WITH_INFO)
    {
     // Allocate memory for the statement handle
     retcode = SQLAllocStmt (hDBC, &hStmt);

     // Prepare the SQL statement by assigning it to the statement handle
     retcode = SQLPrepare (hStmt, szSqlStr, sizeof (szSqlStr));

     // Execute the SQL statement handle
     retcode = SQLExecute (hStmt);

     // Project only column 2 which is the name
     SQLBindCol (hStmt, 2, SQL_C_CHAR, szname, sizeof(szname), &cbModel);

     // Get row of data from the result set defined above in the statement
     retcode = SQLFetch (hStmt);
```

```
while (retcode == SQL_SUCCESS || retcode == SQL_SUCCESS_WITH_INFO)
      {       printf ("\t%s\n", szname);            // Print row (sname)
              retcode = SQLFetch (hStmt);       // Fetch next row from result set
      }

      // Free the allocated statement handle
      SQLFreeStmt (hStmt, SQL_DROP);

      // Disconnect from datasource
      SQLDisconnect (hDBC);
     }

     // Free the allocated connection handle
     SQLFreeConnect (hDBC);

     // Free the allocated ODBC environment handle
     SQLFreeEnv (hEnv);
     return 0;
}
```

# Stored Procedures

- What is a stored procedure:
  - Program executed through a single SQL statement
  - Executed in the process space of the server
- Advantages:
  - Can encapsulate application logic while staying "close" to the data
  - Reuse of application logic by different users
  - Avoid tuple-at-a-time return of records through cursors

# Stored Procedures: Examples

```
CREATE PROCEDURE ShowNumReservations
    SELECT S.sid, S.sname, COUNT(*)
    FROM Sailors S, Reserves R
    WHERE S.sid = R.sid
    GROUP BY S.sid, S.sname
```

Stored procedures can have parameters:

- Three different modes: IN, OUT, INOUT

```
CREATE PROCEDURE IncreaseRating(
    IN sailor_sid INTEGER, IN increase INTEGER)
UPDATE Sailors
    SET rating = rating + increase
    WHERE sid = sailor_sid
```

# Stored Procedures: Examples (Contd.)

Stored procedure do not have to be written in SQL:

```
CREATE PROCEDURE TopSailors(
    IN num INTEGER)
LANGUAGE JAVA
EXTERNAL NAME “file:///c:/storedProcs/rank.jar”
```

# Calling Stored Procedures

```
EXEC SQL BEGIN DECLARE SECTION
Int sid;
Int rating;
EXEC SQL END DECLARE SECTION

// now increase the rating of this sailor
EXEC CALL IncreaseRating(:sid,:rating);
```

# Calling Stored Procedures (Contd.)

JDBC:

```
CallableStatement cstmt=
    con.prepareCall("{call
    ShowSailors});
ResultSet rs =
    cstmt.executeQuery();
while (rs.next()) {
   …
}
```

SQLJ:

```
#sql iterator
    ShowSailors(…);
ShowSailors showsailors;
#sql showsailors={CALL
    ShowSailors};
while (showsailors.next()) {
    …
}
```

# SQL/PSM

Most DBMSs allow users to write stored procedures in a simple, general-purpose language (close to SQL) → SQL/PSM standard is a representative

**Declare a stored procedure:**

CREATE PROCEDURE name(p1, p2, …, pn)

local variable declarations

procedure code;

**Declare a function:**

CREATE FUNCTION name (p1, …, pn) RETURNS sqlDataType
local variable declarations

function code;

# Main SQL/PSM Constructs

```
CREATE FUNCTION rate Sailor
        (IN sailorId INTEGER)
        RETURNS INTEGER
DECLARE rating INTEGER
DECLARE numRes INTEGER
SET numRes = (SELECT COUNT(*)
                      FROM Reserves R
                       WHERE R.sid = sailorId)
IF (numRes > 10) THEN rating =1;
ELSE rating = 0;
END IF;
RETURN rating;
```

# Main SQL/PSM Constructs (Contd.)

- Local variables (DECLARE)
- RETURN values for FUNCTION
- Assign variables with SET
- Branches and loops:
  - IF (condition) THEN statements;
    ELSEIF (condition) statements;
    … ELSE statements; END IF;
  - LOOP statements; END LOOP
- Queries can be parts of expressions
- Can use cursors naturally without “EXEC SQL”

# Summary

- Embedded SQL allows execution of parametrized static queries within a host language
- Dynamic SQL allows execution of completely ad-hoc queries within a host language
- Cursor mechanism allows retrieval of one record at a time and bridges impedance mismatch between host language and SQL
- APIs such as JDBC introduce a layer of abstraction between application and DBMS

# Summary (Contd.)

- SQLJ: Static model, queries checked a compile-time.
- Stored procedures execute application logic directly at the server
- SQL/PSM standard for writing stored procedures