Database Application Programming

Agenda

- Database Application Programming Overview

- Introduction to JDBC Technology
  - JDBC drivers
  - Seven basic steps in using JDBC
  - Retrieving data from a ResultSet
  - Using prepared and callable statements
  - Handling SQL exceptions
  - Submitting multiple statements as a transaction

Database Application Architecture

- Client-Server Architectures:
  - 2-Tier: Client and Data-Server
  - 3-Tier:
    - Tier 1: Client
      - User interface : responsible for user interaction and data presentation
    - Tier 2: Application-Server/Middleware
      - Middleware : protects the data from direct access by the clients
    - Tier 3: Data-Server
      - DB server : responsible for data storage

- Clear separation of user-interface-control and data presentation from application-logic.
- Boundaries between tiers are logical. It is quite easily possible to run all three tiers on the same (physical) machine.

3-Tier Architecture

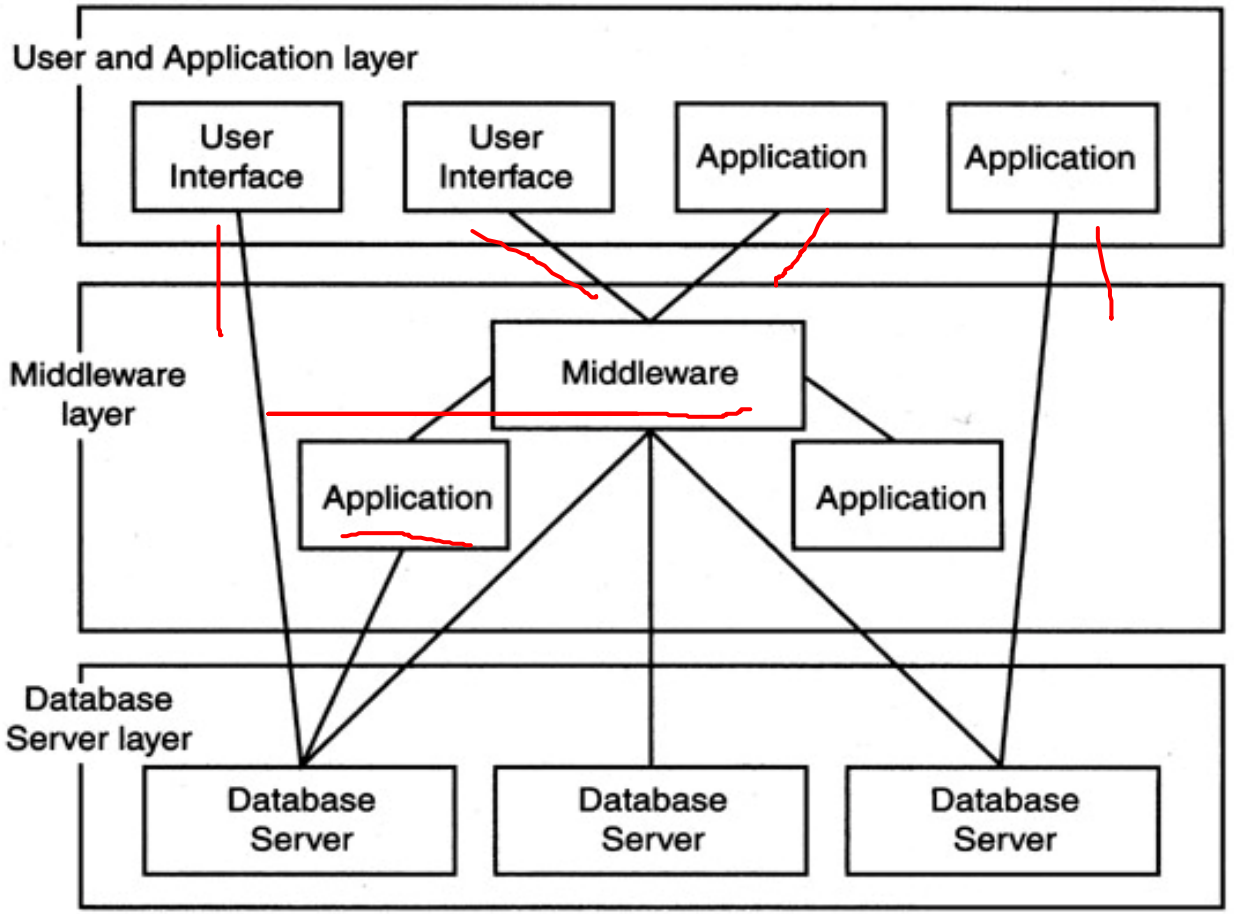


FIGURE 8.1
A variety of client-server architectures for information systems

3-Tier Architecture: Example

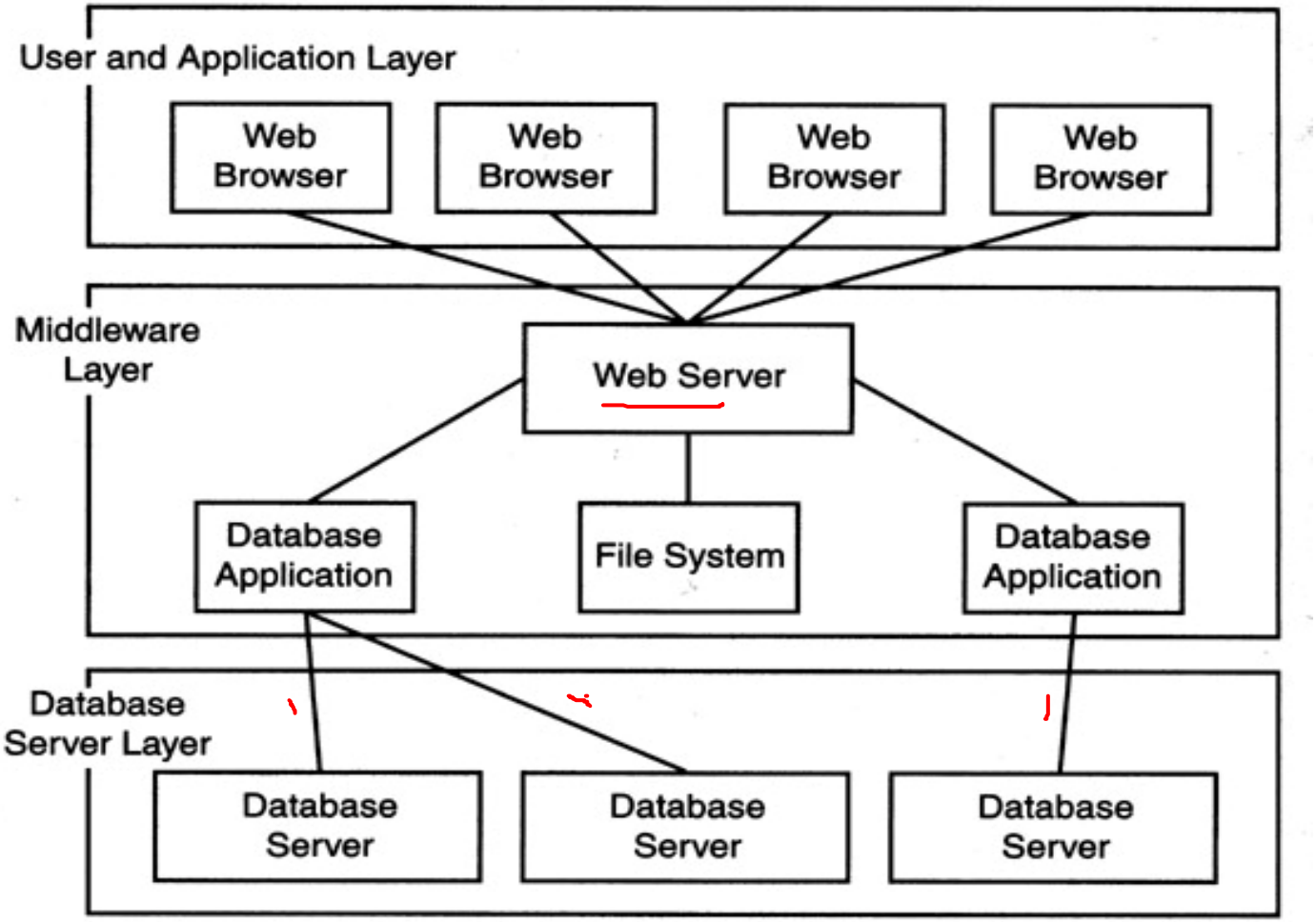


FIGURE 8.2
Architecture of a Web site supported by databases

How to Interact with Database: ODBC

- ODBC :
  - ODBC (Open Database Connectivity)
    - Provides a way for the client programs to access a wide range of databases and data sources

- ODBC stack
  - ODBC Application :Visual Basic, Excel, Access, …
  - Driver Manager :ODBC.DLL
  - ODBC Driver :ODBC drivers vary for various data sources
  - Database Transport :Database transport
  - Network Transport :TCP/IP or other communication protocols
  - Data Source :Oracle, MySQL, …

Interaction Set-up

- Making data source available to ODBC:
  - Install ODBC driver manager
  - Install specific driver for a data source (e.g., a DB server)
  - Register the data source driver to the ODBC driver manager
- How application works with data source:
  - Contacts driver manager to request for specific data source
  - Manager finds appropriate driver for the data source

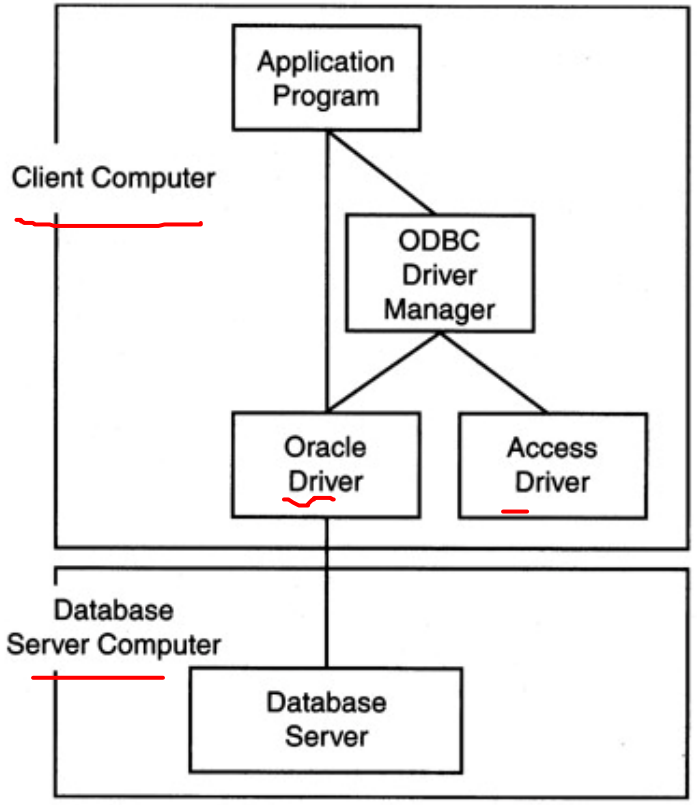


FIGURE 8.3
The ODBC architecture for database access

How to Interact with Database in Java: JDBC

- JDBC provides a standard library for accessing relational databases
  - API standardizes
    - Way to establish connection to database
    - Approach to initiating queries
    - Method to create stored (parameterized) queries
    - The data structure of query result (table)
      - Determining the number of columns
      - Looking up metadata, etc.
  - API does *not* standardize SQL syntax
  - JDBC class located in java.sql package

Note: JDBC is not officially an acronym; unofficially, "Java Database Connectivity" is commonly used

JDBC Usage Strategies

- JDBC-ODBC bridge
  - Con: ODBC must be installed
- JDBC database client
  - Con: JDBC driver for each server must be available
- JDBC middleware client
  - Pro: Only one JDBC driver is required
  - Application does not need direct connection to DB (e.g., applet)

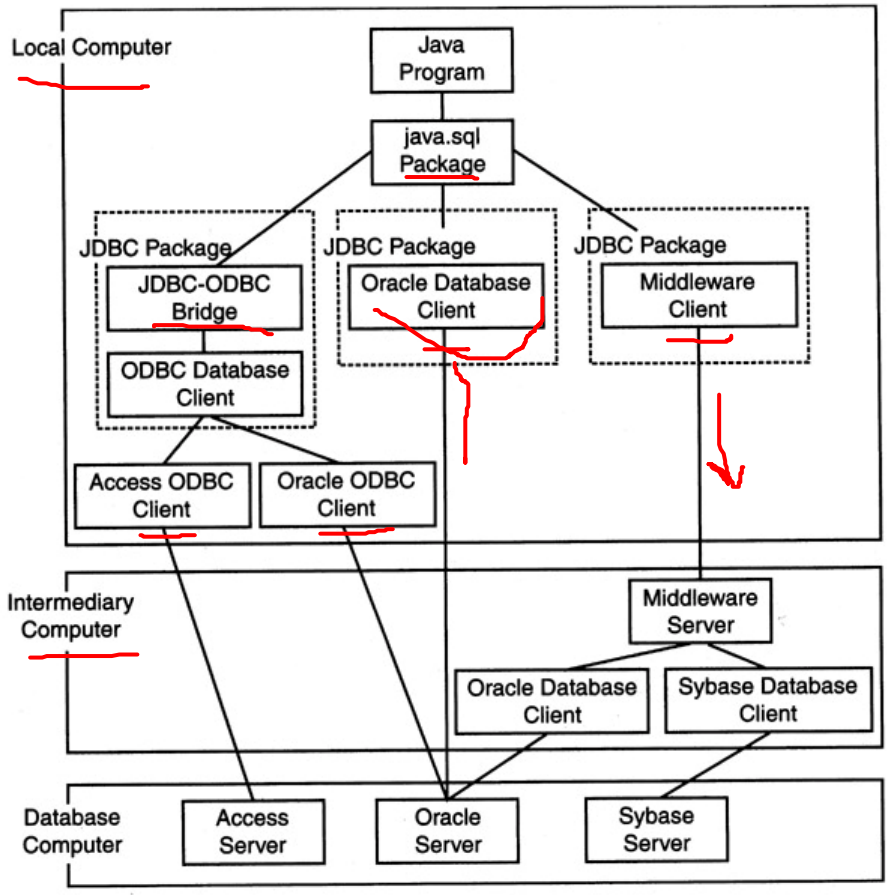
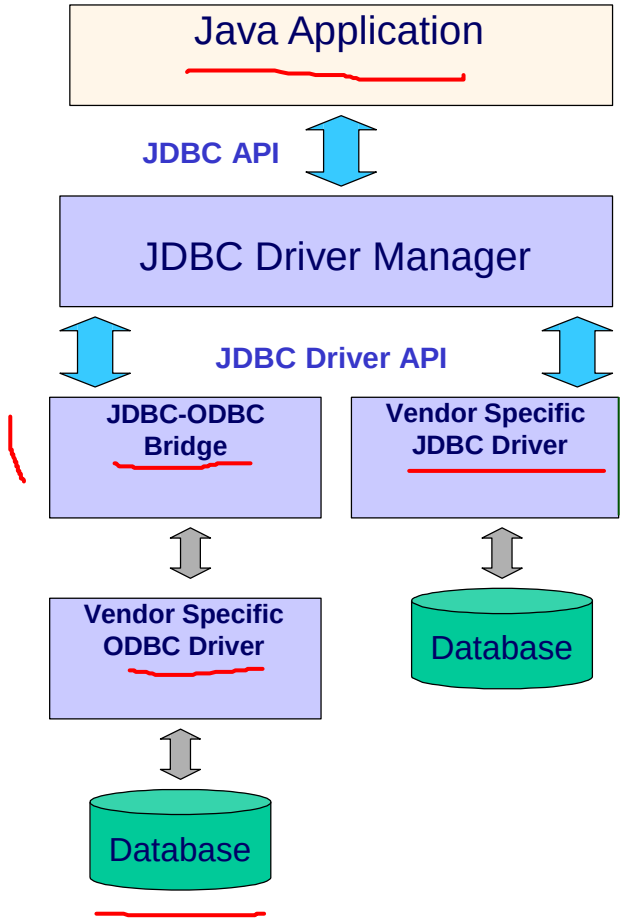


FIGURE 8.4
Strategies for implementing JDBC packages

JDBC Components

- JDBC consists of two parts:
  - JDBC API, a purely Java-based API
  - JDBC Driver Manager,which communicates with vendor-specific drivers that perform the real communication with the database
    - Translation to vendor format is performed on the client
      - No changes needed to server
      - Driver (translator) needed on client



JDBC API

- Collection of interfaces and classes:
  - DriverManager: Loads the driver
  - Driver: Creates a connection
  - Connection: Represents a connection
  - DatabaseMetaData: Information about the DB server
  - Statement: Executing queries
  - PreparedStatement: Precompiled and stored query
  - CallableStatment: Execute SQL stored procedures
  - ResultSet: Results of execution of queries
  - ResultSetMetaData: Meta data for ResultSet

JDBC Data Types

JDBC Type	Java Type
BIT	boolean
TINYINT	byte
SMALLINT	short
INTEGER	int
BIGINT	long
REAL	float
FLOAT DOUBLE	double
BINARY VARBINARY LONGVARBINARY	byte[]
CHAR VARCHAR LONGVARCHAR	String

JDBC Type	Java Type
NUMERIC DECIMAL	BigDecimal
DATE	java.sql.Date
TIME TIMESTAMP	java.sql.Timestamp
CLOB	Clob*
BLOB	Blob*
ARRAY	Array*
DISTINCT	mapping of underlying type
STRUCT	Struct*
REF	Ref*
JAVA_OBJECT	underlying Java class

*SQL3 data type supported in JDBC 2.0

Seven Basic Steps in Using JDBC

1. Load the driver
2. Define the Connection URL
3. Establish the Connection
4. Create a Statement object
5. Execute a query
6. Process the results
7. Close the Connection

JDBC: Details of Process

1. Load the Driver

```
try {
  Class.forName("oracle.jdbc.driver.OracleDriver");
  Class.forName("com.mysql.jdbc.Driver");
} catch { ClassNotFoundException cnfe) {
  System.out.println("Error loading driver: " cnfe);
}
```

2. Define the Connection URL

```
String host = "dbhost.yourcompany.com";
String dbName = "someName";
int port = 1234;
String oracleURL = "jdbc:oracle:thin:@" + host +
                   ":" + port + ":" + dbName;
String mysqlURL = "jdbc:mysql://" + host   +
                  ":" + port + "/" + dbName;
```

- Add the PATH to the JDBC driver to your CLASSPATH
- Using IDE -> when you add the JDBC jar file as an external library, the CLASSPATH will be automatically updated
- W/O IDE: At compile time, specify CLASSPATH using the –cp option
  - javac –cp <path_to_jdbc_driver> <java_code.java>
  - java –cp path_to_jdbc_driver> <java_code>

JDBC: Details of Process (cont'd)

3. Establish the Connection

```
String username = "test";
String password = "test";
Connection connection = DriverManager.getConnection(oracleURL,
                                                    username,
                                                          password);
```

- Optionally, get information about the db system

```
DatabaseMetaData dbMetaData = connection.getMetaData();
String productName =
  dbMetaData.getDatabaseProductName();
System.out.println("Database: " + productName);
String productVersion =
  dbMetaData.getDatabaseProductVersion();
System.out.println("Version: " + productVersion);
```

JDBC: Details of Process (cont'd)

4. Create a Statement

```
Statement statement = connection.createStatement();
 // discuss PreparedStatements later
```

5. Execute a Query

```
String query = "SELECT col1, col2, col3 FROM sometable";
ResultSet resultSet = statement.executeQuery(query);
```

- To modify the database, use **`executeUpdate`**, supplying a string that uses **`UPDATE`**, **`INSERT`**, or **`DELETE`**
- Use **`statement.setQueryTimeout`** to specify a maximum delay to wait for results

JDBC: Details of Process (cont'd)

6. Process the Result

```
while(resultSet.next()) {
System.out.println(resultSet.getString(1) + " " +
                   resultSet.getString(2) + " " +
                   resultSet.getString(3));
}
```

- First column has index 1, not 0
- **ResultSet** provides various **getXxx** methods that take a column index or name and returns the data

7. Close the Connection

```
connection.close();
```

- As opening a connection is expensive, postpone this step if additional database operations are expected

Basic JDBC Example

```
import java.sql.*;

public class TestDriver {
  public static void main(String[] Args) {
     try {
       Class.forName("com.mysql.jdbc.Driver").newInstance();
     }
     catch (Exception E) {
       System.err.println("Unable to load driver.");
       E.printStackTrace();
     }

      try {
       Connection C = DriverManager.getConnection(
                     "jdbc:mysql://test.sjsu.edu:3307/testDB",
                     "root", "xyz"); //?user=root&password=xyz");
```

Basic JDBC Example (cont'd)

```
 Statement s = C.createStatement();
 String sql="select * from pet";
 s.executeQuery(sql);
 ResultSet res = s.getResultSet();

 if (res!=null) {
       while(res.next()) {
                 System.out.println("\n"+res.getString(1)
                         + "\t"+res.getString(2));
                         }
    }
   c.close();
}
catch (SQLException E) {
   System.out.println("SQLException:" + E.getMessage());
    System.out.println("SQLState:" + E.getSQLState());
   System.out.println("VendorError:" + E.getErrorCode());
       }
}
}
```

ResultSet

- Overview
  - A ResultSet contains the results of the SQL query
    - Represented by a table with rows and columns
- Useful Methods
    - All methods can throw a SQLException
  - close
    - Releases the JDBC and database resources
    - The result set is automatically closed when the associated Statement object executes a new query
  - getMetaDataObject
    - Returns a ResultSetMetaData object containing information about the columns in the ResultSet

ResultSet (cont'd)

- Useful Methods
  - next
    - Attempts to move to the next row in the ResultSet
      - If successful true is returned; otherwise, false
      - The first call to next positions the cursor at the first row
      - Calling next clears the SQLWarning chain
  - getWarnings
    - Returns the first SQLWarning or null if no warnings occurred

ResultSet (cont'd)

- Useful Methods
  - findColumn
    - Returns the corresponding integer value corresponding to the specified column name
    - Column numbers in the result set do not necessarily map to the same column numbers in the database
  - getXxx
    - Returns the value from the column specified by column name or column index as an Xxx Java type
    - Returns 0 or null (if the value is a SQL NULL)
    - Legal **`getXxx`** types:

double	byte	int	Date	String
float	short	long	Time	Object

  - wasNull
    - To check if the last getXxx read was a SQL NULL

Using MetaData

- Idea
  - From a ResultSet (the return type of executeQuery), derive a ResultSetMetaData object
  - Use that object to look up the number, names, and types of columns
- ResultSetMetaData answers the following questions:
  - How many columns are in the result set?
  - What is the name of a given column?
  - Are the column names case sensitive?
  - What is the data type of a specific column?
  - What is the maximum character size of a column?
  - Can you search on a given column?

Useful MetaData Methods

- getColumnCount
  - Returns the number of columns in the result set
- getColumnDisplaySize
  - Returns the maximum width of the specified column in characters
- getColumnName
  - The getColumnName method returns the database name of the column
- getColumnType
  - Returns the SQL type for the column to compare against types in java.sql.Types

Useful MetaData Methods (cont'd)

- isNullable
  - Indicates whether storing a NULL in the column is legal
  - Compare the return value against ResultSet constants: columnNoNulls, columnNullable, columnNullableUnknown
- isSearchable
  - Returns true or false if the column can be used in a WHERE clause
- isReadOnly/isWritable
  - The isReadOnly method indicates if the column is definitely not writable
  - The isWritable method indicates whether it is possible for a write to succeed

Using MetaData: Example

```
Connection connection =
DriverManager.getConnection(url, username, password);

// Look up info about the database as a whole.
DatabaseMetaData dbMetaData =
                    connection.getMetaData();
String productName =
  dbMetaData.getDatabaseProductName();
System.out.println("Database: " + productName);
String productVersion =
    dbMetaData.getDatabaseProductVersion();
...
Statement statement = connection.createStatement();
String query = "SELECT * FROM pet";
ResultSet resultSet = statement.executeQuery(query);
```

Using MetaData: Example

```
// Look up information about a particular table.
ResultSetMetaData resultsMetaData =
   resultSet.getMetaData();
int columnCount = resultsMetaData.getColumnCount();
// Column index starts at 1 (a la SQL) not 0 (a la Java).
for(int i=1; i<columnCount+1; i++) {
  System.out.print(resultsMetaData.getColumnName(i) +
                   "   ");
}
System.out.println();

// Print results.
while(resultSet.next()) {
  // Quarter
  System.out.print("     " + resultSet.getInt(1));
  // Number of Apples
  ...
}
```

Using the Statement Object

- Overview
  - Through the Statement object, SQL statements are sent to the database.
  - Different types of statement objects are available:
    - Statement
      - for executing a simple SQL statements
    - PreparedStatement
      - for executing a precompiled SQL statement passing in parameters
    - CallableStatement
      - for executing a database stored procedure

Useful Statement Methods

- executeQuery
  - Executes the SQL query and returns the data in a table (ResultSet)
  - The resulting table may be empty but never null

```
ResultSet results =
  statement.executeQuery("SELECT a, b FROM table");
```

- executeUpdate
  - Used to execute for INSERT, UPDATE, or DELETE SQL statements
  - The return is the number of rows that were affected in the database
  - Supports Data Definition Language (DDL) statements CREATE TABLE, DROP TABLE and ALTER TABLE

```
int rows =
  statement.executeUpdate("DELETE FROM EMPLOYEES" +
                          "WHERE STATUS=0");
```

Useful Statement Methods (cont'd)

- getMaxRows/setMaxRows
  - Determines the number of rows a ResultSet may contain
  - Unless explicitly set, the number of rows are unlimited (return value of 0)
- getQueryTimeout/setQueryTimeout
  - Specifies the amount of a time a driver will wait for a STATEMENT to complete before throwing a SQLException

Prepared Statements (Precompiled Queries)

- Idea
  - If you are going to execute similar SQL statements multiple times, using "prepared" (parameterized) statements can be more efficient
  - Create a statement in standard form that is sent to the database for compilation before actually being used
  - Each time you use it, you simply replace some of the marked parameters using the setXxx methods
- PreparedStatement's execute methods have no parameters
  - execute()
  - executeQuery()
  - executeUpdate()

Prepared Statement, Example

```
Connection connection =
  DriverManager.getConnection(url, user, password);
PreparedStatement statement =
  connection.prepareStatement("UPDATE employees " +
                              "SET salary = ? " +
                              "WHERE id = ?");
float[] newSalaries = getSalaries();
int[] employeeIDs = getIDs();
for(int i=0; i<employeeIDs.length; i++) {
  statement.setFloat(1, newSalaries[i]);
  statement.setInt(2, employeeIDs[i]);
  statement.executeUpdate();
}
```

Exception Handling

- SQL Exceptions
  - Nearly every JDBC method can throw a SQLException in response to a data access error
  - If more than one error occurs, they are chained together
  - SQL exceptions contain:
    - Description of the error: getMessage
- The SQLState (Open Group SQL specification) identifying the exception: getSQLState
    - A vendor-specific integer error code:, getErrorCode
    - A chain to the next exception: getNextException

SQL Exception Example

```
try {

     ... // JDBC statement.

} catch (SQLException sqle) {
  while (sqle != null) {
    System.out.println("Message:  " + sqle.getMessage());
    System.out.println("SQLState: " + sqle.getSQLState());
    System.out.println("Vendor Error: " +
                       sqle.getErrorCode());
    sqle = sqle.getNextException();
  }
}
```

- Don't make assumptions about the state of a transaction after an exception occurs
- The safest best is to attempt a rollback to return to the initial state

SQL Warnings

- SQLWarnings are rare, but provide information about the database access warnings
- Chained to object whose method produced the warning
- The following objects can receive a warning:
  - Connection
  - Statement (also, PreparedStatement, CallableStatement)
  - ResultSet
- Call `getWarning` to obtain the warning object, and `getNextWarning` (on the warning object) for any additional warnings
- Warnings are cleared on the object each time the statement is executed

SQL Warning, Example

```
ResultSet results = statement.executeQuery(someQuery);
SQLWarning warning = statement.getWarnings();
while (warning != null) {
  System.out.println("Message: " + warning.getMessage());
  System.out.println("SQLState: " + warning.getSQLState());
  System.out.println("Vendor Error: " +
                     warning.getErrorCode());
  warning = warning.getNextWarning();
}
while (results.next()) {
  int value = rs.getInt(1);
     ... // Call additonal methods on result set.
  SQLWarning warning = results.getWarnings();
  while (warning != null) {
    System.out.println("Message: " + warning.getMessage());
    System.out.println("SQLState: " + warning.getSQLState());
    System.out.println("Vendor Error: " +
                       warning.getErrorCode());
    warning = warning.getNextWarning();
  }
 }
```

Transactions

- Idea
  - By default, after each SQL statement is executed the changes are automatically committed to the database
  - Turn auto-commit off to group two or more statements together into a transaction

```
connection.setAutoCommit(false)
```

  - Call commit to permanently record the changes to the database after executing a group of statements
  - Call rollback if an error occurs

Transactions: Example

```
Connection connection =
  DriverManager.getConnection(url, username, passwd);
connection.setAutoCommit(false);
try {
  statement.executeUpdate(...);
  statement.executeUpdate(...);
  ...
} catch (Exception e) {
  try {
    connection.rollback();
  } catch (SQLException sqle) {
     // report problem
  }
} finally {
  try {
    connection.commit();
    connection.close();
  } catch (SQLException sqle) { }
}
```

Useful Connection Methods (for Transactions)

- getAutoCommit/setAutoCommit
  - By default, a connection is set to auto-commit
  - Retrieves or sets the auto-commit mode
- commit
  - Force all changes since the last call to commit to become permanent
  - Any database locks currently held by this Connection object are released
- rollback
  - Drops all changes since the previous call to commit
  - Releases any database locks held by this Connection object

Summary of Hints

- In JDBC, can only step forward (`next`) through the `ResultSet`
- `MetaDataResultSet` provides details about returned `ResultSet`
- Improve performance through prepared statements
- Be sure to handle the situation where `getXxx` returns a NULL
- By default, a connection is auto-commit
- SQL Exceptions and Warnings are chained together

On-line Resources

- Oracle's JDBC Site
  - https://www.oracle.com/java/technologies/
- JDBC Tutorial
  - https://docs.oracle.com/javase/tutorial/jdbc/basics/index.html
- API for java.sql
  - https://www.oracle.com/database/technologies/appdev/jdbc-downloads.html
- JDBC Sample Code for Oracle
  - https://www.oracle.com/technology/sample_code/tech/java/sqlj_jdbc/