JDBC

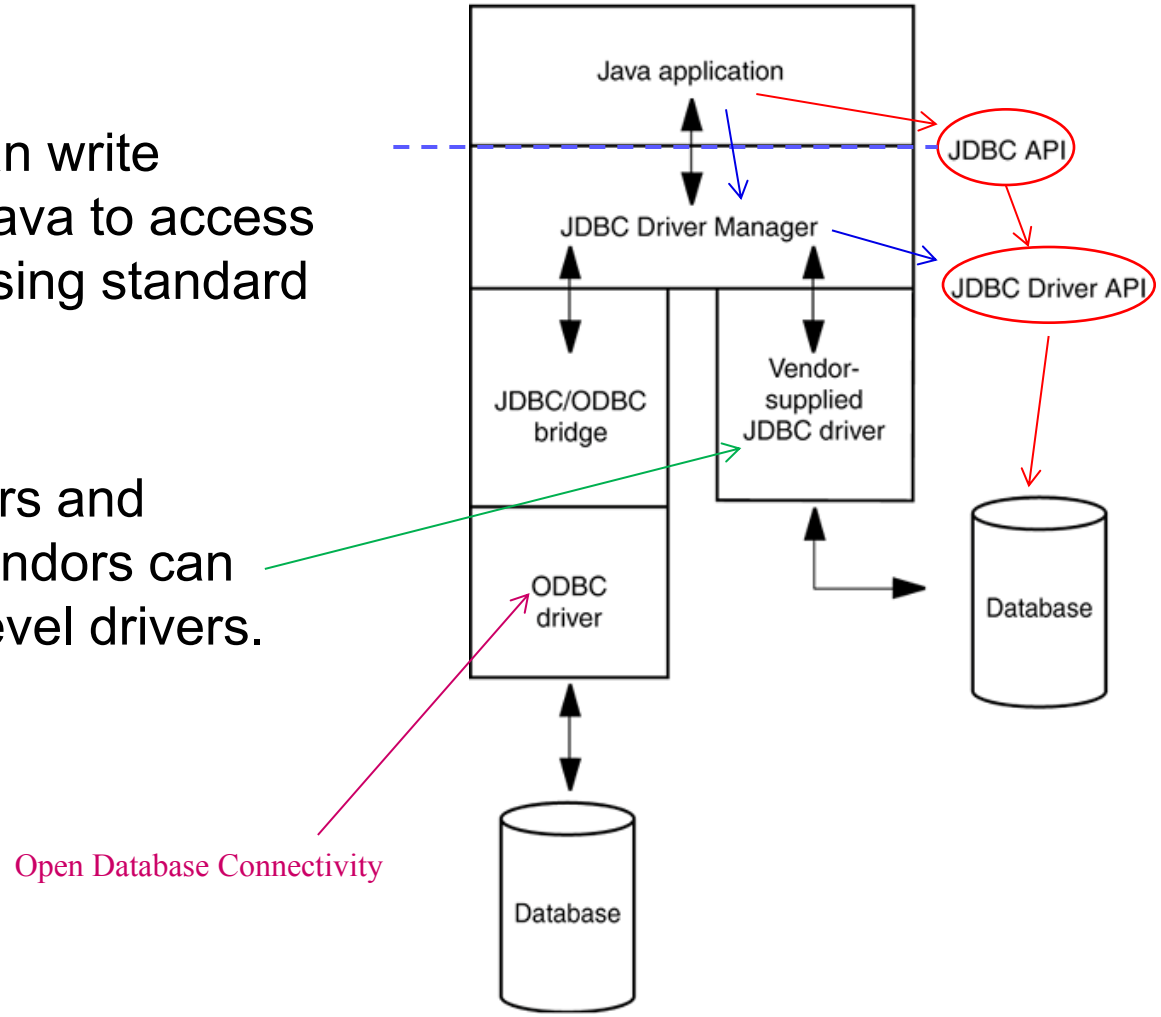
Java Database Connectivity

Java Database Connectivity (JDBC)

- A ***database*** is an organised collection of data
- A ***relational database*** stores data in related tables
- A ***database management system*** (DBMS) provides mechanisms for storing, organising, retrieving and modifying data
  - Oracle, MS SQL Server, MySQL, PostgreSQL
  - Java DB (Apache Derby)
- ***SQL*** (Structured Query Language) is used to query and manipulate data in a database
- Java applications communicate with databases and manipulate their data using Java Database Connectivity (***JDBC***) API
  - A ***JDBC driver*** is required to enable Java applications to connect to the database in a DBMS

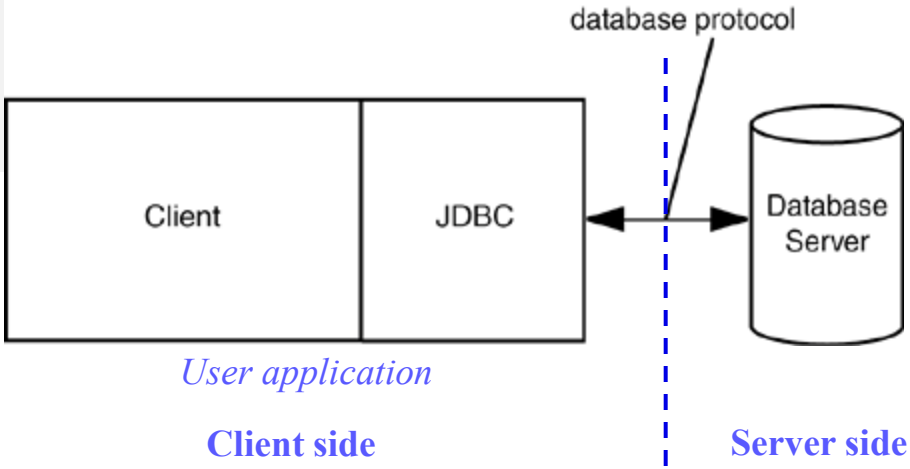
JDBC to Database Communication Path

- Programmers can write applications in Java to access any database, using standard SQL statements
- Database vendors and database tool vendors can supply the low-level drivers.



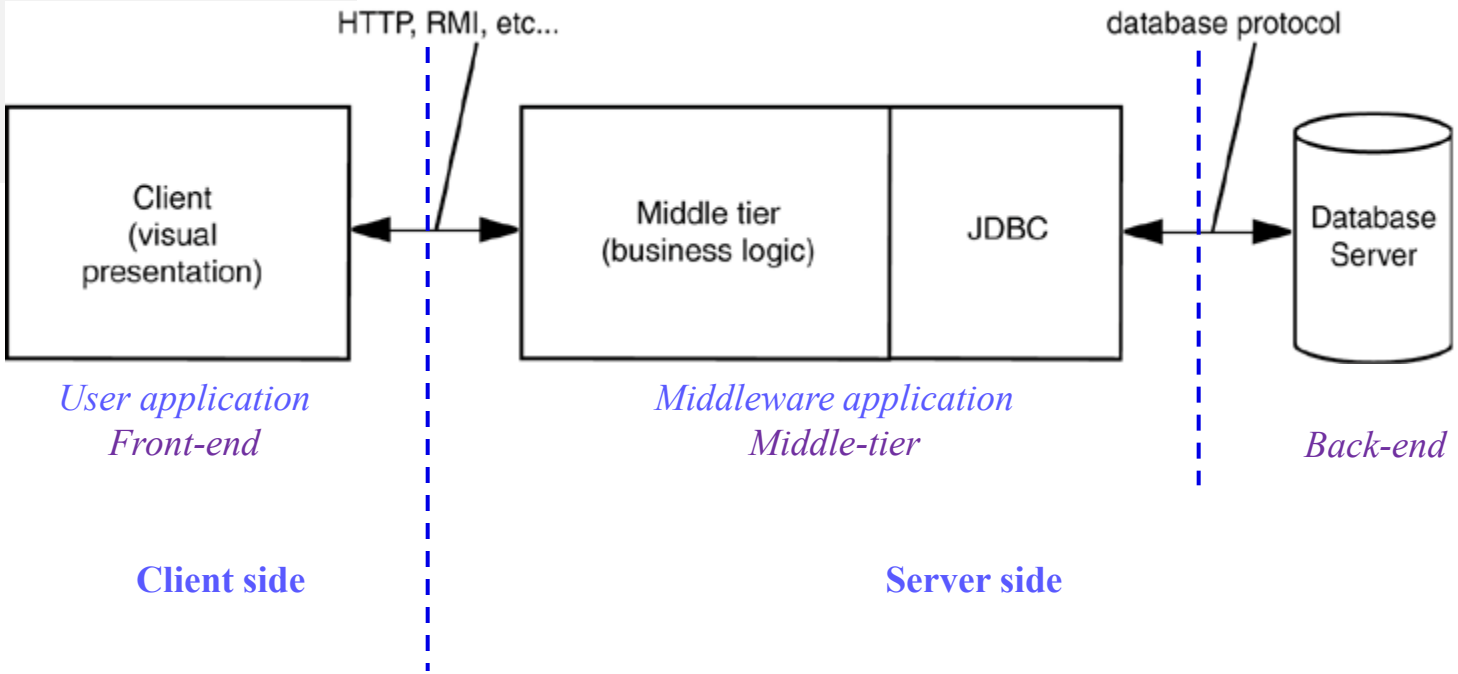
Typical Uses of JDBC

- Traditional client/server application



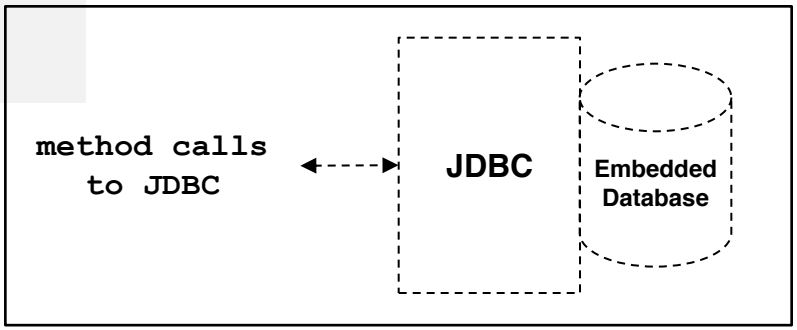
Typical Uses of JDBC

- A three-tier Application



Typical Uses of JDBC

- An Embedded Application
  - The JDBC application and embedded database run in the same JVM. The JDBC application starts up the database



User application

Database and SQL Basics

- Database and table
- Information Retrieval
  - SQL query
- SQL commands
  - Data manipulation language
  - Data definition language

A Table in a Database

Employees Table

Employee_Number	*First_name*	*Last_Name*	*Date_of_Birth*	*Car_Number*
10001	Axel	Washington	28-Aug-43	5
10083	Arvid	Sharma	24-Nov-54	null
10120	Jonas	Ginsberg	01-Jan-69	null
10005	Florence	Wojokowski	04-Jul-71	12
10099	Sean	Washington	21-Sep-66	null
10035	Elizabeth	Yamaguchi	24-Dec-59	null

Row
Record

Primary key

Column
Field

SQL Query

- **`SELECT`** statements
  - Retrieve information from a table

```
SELECT First_Name, Last_Name
FROM Employees
WHERE Car_Number IS NOT NULL
```

Result Set

FIRST_NAME	*LAST_NAME*
Axel	Washington
Florence	Wojokowski

```
SELECT *
FROM Employees
```

Producing a result set that includes the whole **`Employee`** table

SQL WHERE Clauses

- String Comparison with LIKE

```
SELECT First_Name, Last_Name
FROM Employees
WHERE Last_Name LIKE 'W%'
```

% is a wildcard

Result Set

FIRST_NAME	LAST_NAME
Axel	Washington
Florence	Wojokowski
Sean	Washington

- Numerical Comparisons

```
SELECT First_Name, Last_Name
FROM Employees
WHERE Car_Number = 12
```

Result Set

FIRST_NAME	LAST_NAME
Florence	Wojokowski

```
SELECT First_Name, Last_Name
FROM Employees
WHERE Employee_Number < 10100
  and Car_Number IS NULL
```

Result Set

FIRST_NAME	LAST_NAME
Arvid	Sharma
Sean	Washington
Elizabeth	Yamaguchi

Joined Tables

Cars Table

Car_Number	*Make*	*Model*	*Year*
5	Honda	Civic DX	1996
12	Toyota	Corolla	1999

```
SELECT Employees.First_Name, Employees.Last_Name, Cars.Make, Cars.Model, Cars.Year
FROM   Employees, Cars
WHERE  Employees.Car_Number = Cars.Car_Number
```

Result Set

FIRST_NAME	*LAST_NAME*	*MAKE*	*MODEL*	*YEAR*
Axel	Washington	Honda	Civic DX	1996
Florence	Wojokowski	Toyota	Corolla	1999

Common SQL Commands

- Data Manipulation Language (MDL)
  - SELECT — used to query and display data from a database. The SELECT statement specifies which columns to include in the result set. The vast majority of the SQL commands used in applications are SELECT statements.

```
SELECT field1, field2, …
FROM table
[WHERE criteria]
[ORDER BY fields desc/asc, …]
```

  - INSERT — adds new rows to a table. INSERT is used to populate a newly created table or to add a new row (or rows) to an already-existing table.

```
INSERT INTO table (field1, field2, …)
VALUES (value1, value2, …)
```

  - DELETE — removes a specified row or set of rows from a table

```
DELETE FROM table
WHERE criteria
```

  - UPDATE — changes an existing value in a column or group of columns in a table

```
UPDATE table
SET (field1=value1, field2=value2, …)
WHERE criteria
```

Common SQL Commands

- Data Definition Language (DDL)
  - CREATE TABLE/DATABASE — To create a table with the column names the user provides. The user also needs to specify a type for the data in each column; to create a database

```
CREATE TABLE table
(field1 type,
 field2 type,
 … )
```

```
CREATE DATABASE database
```

Data types and ranges vary from one DBMS to another

  - DROP TABLE/DATABASE — deletes all rows and removes the table definition from the database; delete a database

```
DROP TABLE table
```

```
DROP DATABASE database
```

  - ALTER TABLE — adds or removes a column from a table. It also adds or drops table constraints and alters column attributes

```
ALTER TABLE table
ADD field type
```

```
ALTER TABLE table
DROP field
```

JDBC Programming Concepts

- Drivers
  - Loading/registering drivers
- Connection
  - Database URL
  - Establishing connections
- Statements
  - Creating statement object
  - Executing statements
    - Call **`executeUpdate()`** or **`executeQuery()`**
- **`ResultSet`** interface
  - Processing **`ResultSet`**

Drivers

- Automatic registration (JDBC 4.0 – Java SE 6)
  - A Jar file can automatically register the driver class if it contains a file META-INF/servicers/java.sql.Driver
- Loading the driver class in a Java program

```
Class.forName("JDBCDriverClass").newInstance();
```

- Setting **jdbc.drivers** property with a command-line argument

```
java -Djdbc.drivers="JDBCDriverClass" MyApp
```

- Setting system property in a Java program

```
System.setProperty("jdbc.drivers", "DBCDriverClass");
```

Database	Driver Class	Source
Oracle	`oracle.jdbc.driver.OracleDriver`	Vender provided
MySQL	`com.mysql.jdbc.Driver`	Vender provided
Access	`sun.jdbc.odbc.JdbcOdbcDriver`	JDK
Derby (client)	`org.apache.derby.jdbc.ClientDriver`	derbyclient.jar
Derby (embedded)	`org.apache.derby.jdbc.EmbeddedDriver`	derby.jar

Connection

- Using the DriverManager Class

```
Connection connection = DriverManager.getConnection(dbURL);
```

`getConnection` method summary

```
static Connection   getConnection(String url)
static Connection   getConnection(String url, Properties info)
static Connection   getConnection(String url, String user, String password)
```

Database	URL Pattern
Oracle	`jdbc:oracle:thin:@hostname:port#:oracleDBSID`
MySQL	`jdbc:mysql://hostname/dbname`
Access	`jdbc:odbc:dataSource`
Derby (client)	`jdbc:derby:dbname[;attribute=value]`
Derby (embedded)	`jdbc:derby:dbname[;attribute=value]`

Statements

- Creating statements

```
Statement statement = connection.createStatement();
```

- Executing statements
  - SQL DDL or update statements

```
statement.executeUpdate("CREATE TABLE myTable(…)");
```

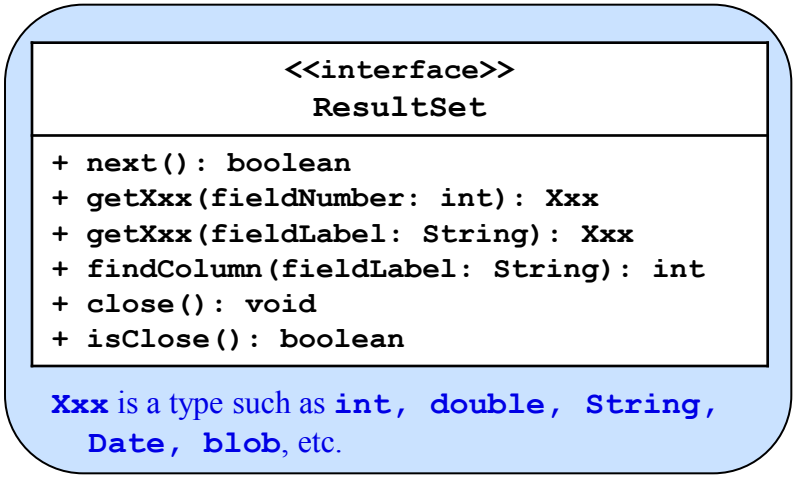
  - SQL query statements

```
ResultSet resultSet = statement.executeQuery
    ("SELECT fields FROM table WHERE criteria");
```

ResultSet Interface

- The **ResultSet** object contains a table of data representing a database result set, usually generated by executing a query statement
- The **next()** method moves to the next row
  - The initial row position is **null**
- The various **getXxx()** method retrieves values from current row

```
try {
    statement = connection.createStatement();
    ResultSet resultSet = statement.executeQuery("…");
    while (resultSet.next()) {
      …
      resultSet.getSting(1);
      resultSet.getInt("fieldLabel");
      …
}catch (SQLException e){ … }
finally {
  if (statement != null) statement.close();
}
```



Example (since Java SE 5)

```
private String driver ="org.apache.derby.jdbc.EmbeddedDriver";
private String url= "jdbc:derby:MyDatabase"; //"MyDatabase" is the database name
 . . .
1 Class.forName(driver).newInstance();     //not necessary since JDBC 4.0 - Java SE 6
2 Connection conn = DriverManager.getConnection(url + ";create=true");
 . . .                                              //create it if the database does not exist
try{
3    Statement stat = conn.createStatement();
     //necessary if you need to create a new table
     stat.executeUpdate("CREATE TABLE Greetings (Message CHAR(22))");
     stat.executeUpdate("INSERT INTO Greetings VALUES ('Hello, World!')");
     stat.executeUpdate("INSERT INTO Greetings VALUES ('Hello, World again!')");

4    ResultSet result = stat.executeQuery("SELECT * FROM Greetings");
     if (result.next())
        System.out.println(result.getString(1));
     result.close();
     stat.executeUpdate("DROP TABLE Greetings");
5 } catch (SQLException sqle) {
     // handling SQLException chain
}
finally{
     try { if (stat != null) stat.close();} catch (SQLException sqle) {…}
     try { if (conn != null) conn.close();} catch (SQLException sqle) {…}
}
```

Don't forget

```
Hello, Database!
Hello, Database again!
```

Example (since Java SE 7)

```
private String url= "jdbc:derby:MyDatabase";   //"MyDatabase" is the database name

try ( Connection conn = DriverManager.getConnection(url + ";create=true");
        Statement stat = conn.createStatement();){ //create it if the database does not exist

   //necessary if you need to create a new table
   stat.executeUpdate("CREATE TABLE Greetings (Message CHAR(22))");

   stat.executeUpdate("INSERT INTO Greetings VALUES ('Hello, Database!')");
   stat.executeUpdate("INSERT INTO Greetings VALUES ('Hello, Database again!')");

   try (ResultSet result = stat.executeQuery("SELECT * FROM Greetings")){
       while (result.next())
          System.out.println(result.getString(1));
   }
   stat.executeUpdate("DROP TABLE Greetings");
                                        //Otherwise next time, CREATE TABLE will fail
} catch (SQLException sqle) {
      // handling SQLException chain
}
```

1 2 3 4 5

```
Hello, Database!
Hello, Database again!
```

SQL Exceptions

- Each **`SQLException`** has a chain of **`SQLException`** objects that is retrieved with the **`getNextException`** method
- This exception chain is in addition to the "cause" chain of **`Throwable`** objects that every exception has
- Use a loop to enumerate all exceptions
  - **`SQLException`** implements **`Iterable<Throwable>`** interface

```
for (Throwable t : sqlException) {
        //do something with t, eg. t.printStackTrace();
}
```

- In addition, the database driver can report nonfatal conditions as warnings
  - You can retrieve warnings from connections, statements, and result sets. The SQLWarning class is a subclass of SQLException (even though a SQLWarning is not thrown as an exception). You call getSQLState and getErrorCode to get further information about the warnings. Similar to SQL exceptions, warnings are chained

```
SQLWarning w = stat.getWarning();
while (w != null) {
      //do something with w
      w = w.nextWarning();
}
```

Overview of SQLEception

- A description of the error
  - **`SQLException.getMessage()`**
- A SQLState code
  - Codes (five alphanumeric characters) standardised by ISO/ANSI and Open Group (X/Open)
  - **`SQLException.getSQLState()`**
- An error code
  - Codes (an integer) implementation-specific
  - **`SQLException.getErrorCode ()`**
- A cause
  - A **`SQLException`** instance might have a causal relationship
  - Recursively call the method **`SQLException.getCause()`**
- A reference to any chained exceptions
  - **`SQLException.getNextException()`**

Retrieve SQLExceptions

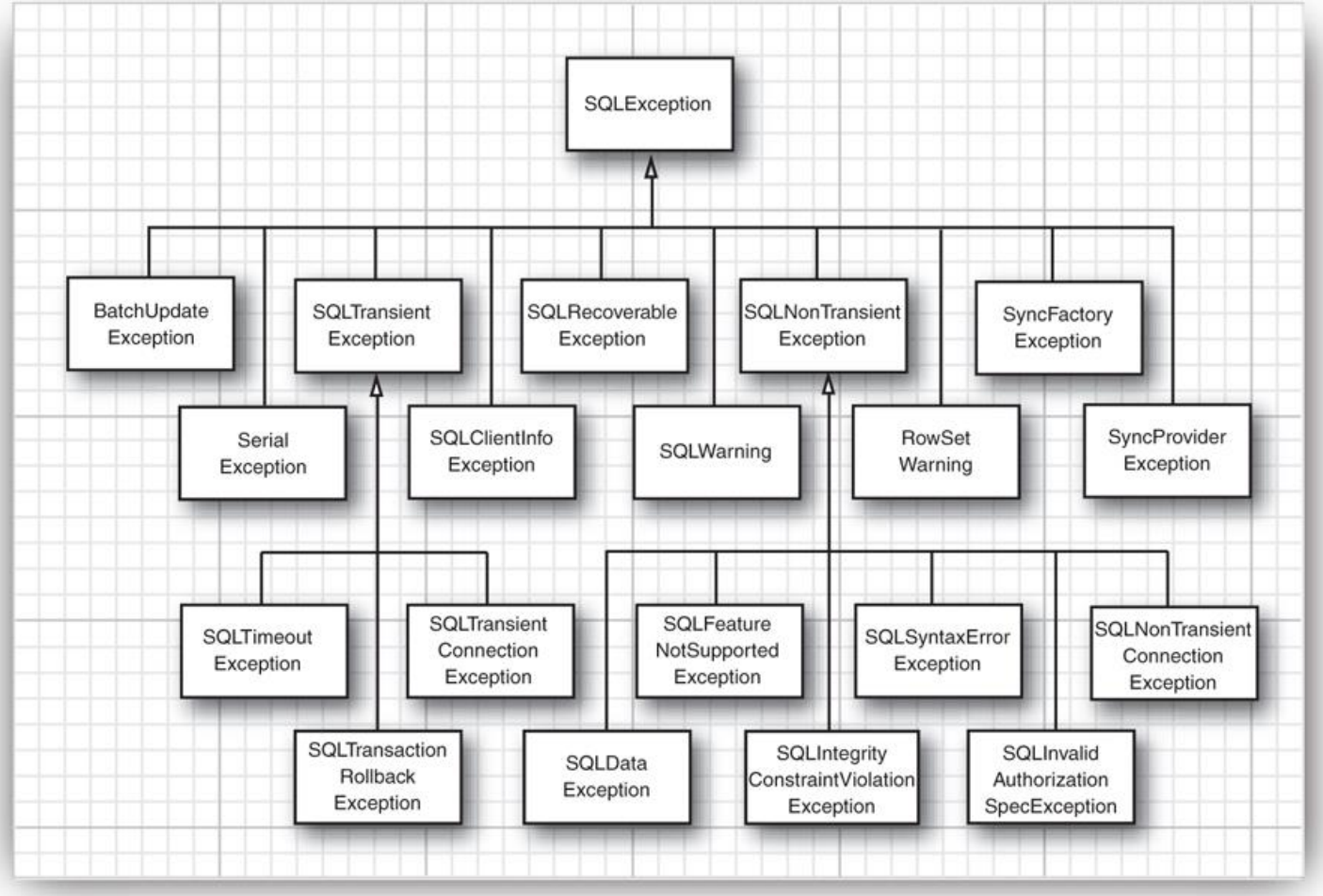
```
for (Throwable e : sqle) {
        if (e instanceof SQLException) {

                e.printStackTrace(System.err);
                System.err.println("SQLState: " +
                    ((SQLException)e).getSQLState());

                System.err.println("Error Code: " +
                    ((SQLException)e).getErrorCode());

                System.err.println("Message: " + e.getMessage());

                Throwable t = sqle.getCause();
                while(t != null) {
                    System.out.println("Cause: " + t);
                    t = t.getCause();
                 }
        }
}
```

Try to query a table "MyGreeting" that does not exist:

```
stat.executeQuery("SELECT * FROM MyGreetings")
```

```
SQLState: 42X05
Error Code: 30000
Message: Table/View 'MYGREETINGS' does not exist.
Cause: java.sql.SQLException: Table/View 'MYGREETINGS' does not exist.
Cause: ERROR 42X05: Table/View 'MYGREETINGS' does not exist.
```

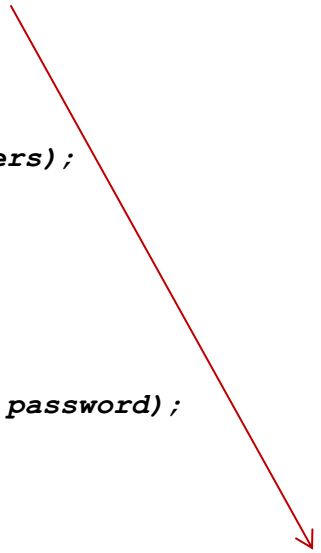
SQL Exception Tree



Configure Connection Using `Properties`

- Using **`Properties`** object and properties file

```
Properties props = new Properties();

FileInputStream in = new FileInputStream("database.properties");
props.load(in);
in.close();

String drivers = props.getProperty("jdbc.drivers");
if (drivers != null) System.setProperty("jdbc.drivers", drivers);
                        // setting system-wide properties

String url = props.getProperty("jdbc.url");
String username = props.getProperty("jdbc.username");
String password = props.getProperty("jdbc.password");

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



database.properties

```
jdbc.drivers=org.apache.derby.jdbc.ClientDriver
jdbc.url=jdbc:derby:MyDatabase;create=true
jdbc.username=derbyuser
jdbc.password=secret
```

PreparedStatement

- **`Statement`** interface executes static SQL statements without parameters

- **`PreparedStatement`** interface (extending **`Statement`**) executes a precompiled SQL statement with/without parameters
  - Efficient for repeated executions

```
Statement preparedStatement = conn.prepareStatement
     ("SELECT fields FROM table WHERE field1=? and field2=?");

prepareStatement.setX(int parameterIndex, X value);        // X is a type
ResultSet resultSet = prepareStatement.executeQuery();
```

Scrollable and Updatable Result Sets

- Scrollable: Move forward and backward in the result set;
- Updatable: edit the **`ResultSet`** and have the changes automatically reflected in the database.
- Create different statement object:

```
Statement stat = conn.createStatement(type, concurrency)
PreparedStatement stat = conn.prepareStatement(command, type, concurrency)
```

- ResultSet Types

Value	Explanation
TYPE_FORWARD_ONLY	The result set cannot be scrolled; its cursor moves forward only. (Default)
TYPE_SCROLL_INSENSITIVE	The result can be scrolled and is insensitive to database changes.
TYPE_SCROLL_SENSITIVE	The result can be scrolled and is sensitive to database changes.

- ResultSet Concurrency

Value	Explanation
CONCUR_READ_ONLY	The ResultSet object cannot be used to update the database. (Default)
CONCUR_UPDATABLE	The ResultSet object can be used to update the database; not all queries return updatable result sets; use the `getConcurrency()` to find out.

Examples: Scrollable `ResultSet`

```
Statement stat = conn.createStatement(
                 ResultSet.TYPE_SCROLL_INSENSITIVE, ResultSet.CONCUR_READ_ONLY);
ResultSet rs = stat.executeQuery(query);
```

```
rs.previous();   // scroll backward

rs.relative(n);  // move forward (n>0) or backward (n<0)

rs.absolute();   // move to a particular row number

int currentRow = rs.getRow(); // get the current row number
```

Examples: Updatable `ResultSet`

```
Statement stat = conn.createStatement(
                 ResultSet.TYPE_SCROLL_INSENSITIVE, ResultSet.CONCUR_UPDATABLE);
ResultSet rs = stat.executeQuery(query);

/* update row values */
double price = rs.getDouble("Price");
rs.updateDouble("Price", price + increase);   // new price in ResultSet
rs.updateRow();  // send all updates in the row to database; must be done before
                    moving to another row otherwise this row's updates are
                    discarded
. . .
/* add a new row */
rs.moveToInsertRow();  // move to the special insert row
rs.updateString("Title", title);
. . .                    // build up a new row using updateXxx()
rs.updateDouble("Price", price + increase);
rs.insertRow();  // send the new row to the database
rs.moveToCurrentRow();// move back to the position
                      // before the call to moveToInsertRow()
. . .
/* delete the row under the cursor */
rs.deleteRow();  // immediately remove the row from ResultSet and the database
```

Row Sets

- Major drawback of **`ResultSet`**: need to keep the database connection
- **`RowSet`**: not have to tied to a database connection
  - extending **`ResultSet`**
- **`RowSet`** object contains tabular data in a way more flexible and easier to use than a **`ResultSet`**

Value	Explanation
`JdbcRowSet`	Connected scrollable and updatable **`RowSet`** and turning the **`ResultSet`** into a JavaBean component
`CachedRowSet`	Disconnected operations of extension of **`JdbcRowSet`**; populate itself with **`ResultSet`**; reconnect to write changes back to the database
`WebRowSet`	Extension of **`CachedRowSet`**; can be saved to an XML file
`FilteredRowSet/JoinRowSet`	Extension of **`WebRowSet`**; equivalent to SQL SELECT/JOIN on row set without having to make a database connection

Reading and Writing LOBs

- Many database can store *large objects* (**LOB**s) such as images or other data
- In SQL, binary LOBs are called **BLOB**s and character LOBs are called **CLOB**s
- Use stream I/O to read and write LOBs
  - Retrieve BLOB

```
Blob blob = resultSet.getBlob(fieldIndex);
InputStream in = blob.getInputStream();
```

  - Store BLOB

```
Blob clob = Connection.createBlob();
OutputStream out = blob.setBinaryStream(offset);  //offset=0
. . . // write to out

PrepareStatement stat = connection.prepareStatement("INSERT INTO field VALUES (?, ?)");
stat.set(1, id);
stat.set(2, blob);
stat.executeUpdate();
```

Transactions

- A transaction is a set of one or more SQL statements that make up a logical unit of work
- The transaction can be *commit*ted when all has gone well. Or, if an error has occurred in one of them, it can be *rolled back* as if none of the commands had been issued
- Major reason: *database integrity*
  - Scenario

    One statement to debit one account and another statement to credit another account.

    Do you like the system to fail after debiting your account but before crediting the other account?

- By default, a database connection is in *autocommit* mode, and each SQL command is committed to the database as soon as it is executed. Once a command is committed, you cannot roll it back.

Example

```
//Turn off autocommit mode
conn.setAutoCommit(false);

//Create a statement object in the normal way
Statement stat = conn.createStatement();

//Call executeUpdate any number of times
stat.executeUpdate(command1);
stat.executeUpdate(command2);
stat.executeUpdate(command3);
. . .

//Call the commit method when all commands have been executed
conn.commit();

//Call the rollback method if an error occurred
conn.rollback();    // Typically a rollback is issued
                    // when a transaction was interrupted
                    // by a SQLException.
```

SQL vs Java Data Types

SQL Data Type	Java Data Type
INTEGER or INT	int
SMALLINT	short
NUMERIC(m,n), DECIMAL(m,n) or DEC(m,n)	java.math.BigDecimal
FLOAT(n)	double
REAL	float
DOUBLE	double
CHARACTER(n) or CHAR(n)	String
VARCHAR(n)	String
BOOLEAN	boolean
DATE	java.sql.Date
TIME	java.sql.Time
TIMESTAMP	java.sql.Timestamp
BLOB	java.sql.Blob
CLOB	java.sql.Clob
ARRAY	java.sql.Array

DataSources in Enterprise Infrastructure

- When a JDBC application is deployed in an enterprise environment, the management of database connections is integrated with the Java Naming and Directory Interface (JNDI)
- The properties of data sources across the enterprise can be stored in a *directory*. Using a directory allows for centralized management of user names, passwords, database names, and JDBC URLs
- Reason:
  - **`DriverManager`** etc require programs to have built-in constants for things like URL of the database and the name of the driver class
  - This makes it harder to switch database being used

DataSources

- DataSources
  - View them as little data structures that a program can load at runtime
  - These structures contain all the information needed to connect to database
  - Relatively easy to substitute different data structure and so change database used.
  - Program simply has a symbolic name for the datasource structure that it wants to use

Establish Connection

```
Context jndiContext = new InitialContext();
DataSource source =
     (DataSource) jndiContext.lookup("java:comp/env/jdbc/MyDatabase");
Connection conn = source.getConnection();
```

- The **`DriverManager`** is no longer involved. Instead, the JNDI service locates a data source

Supporting Infrastructure

- But where do these data structures get loaded from?
  - That symbolic name in the program – how does it get mapped to a record with the right **`datasource`** structure
- Supporting infrastructure
  - a directory service where can lookup symbolic name and find resource
  - JNDI – naming and directory services are required