POLITECNICO DI TORINO

e-Lite

Database access and JDBC

Tecniche di Programmazione – A.A. 2015/2016

Outline

1. Introduction to JDBC
2. Accessing a database: practical steps
3. Prepared statements
4. Design patterns (DAO)
5. Object-Relational Mapping
6. Connection pooling

I THINK WE SHOULD BUILD AN SQL DATABASE.
UH-OH
S. Adams E-mail: SCOTTADAMS@AOL.COM
DOES HE UNDERSTAND WHAT HE SAID OR IS IT SOMETHING HE SAW IN A TRADE MAGAZINE AD?
11/17 © 1995 United Feature Syndicate, Inc.(NYC)
WHAT COLOR DO YOU WANT THAT DATABASE?
I THINK MAUVE HAS THE MOST RAM.

http://dilbert.com/strips/comic/1995-11-17/

Introduction to JDBC

Database access and JDBC

Goals

- Enable Java applications to access data stored in Relational Data Bases
  - Query existing data
  - Modify existing data
  - Insert new data
- Data can be used by
  - The algorithms running in the application
  - The user, through the user interface

Goals (for Web Applications)

- Access SQL DBMS’s from JSP pages
  - JDBC technology
- Integrate SQL query results into the resulting HTML content
- Generate SQL queries according to FORM values

Goals (for GUI Applications)

- Access SQL DBMS's from the JavaFX application
  - JDBC technology
- Load 'massive' data directly from database
- Query 'on-demand' information from database
- Store computation results

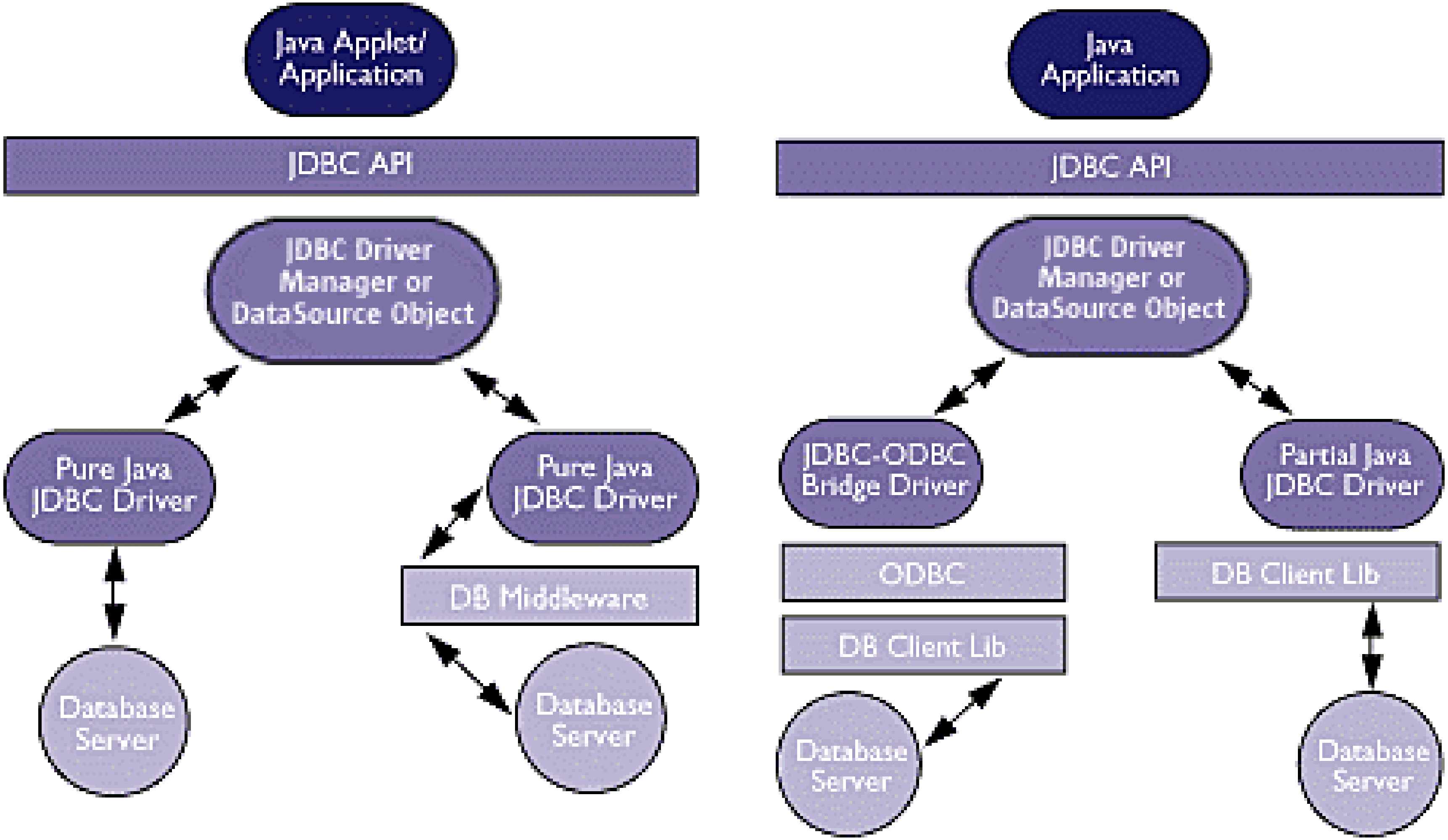
JDBC

- Standard library for accessing relational databases
- Compatible with most/all different databases
- JDBC : Java Database Connectivity
- Defined in package java.sql and javax.sql
- Documentation:
  - http://www.oracle.com/technetwork/java/javase/tech/database-137795.html
  - JDBC Overview: http://www.oracle.com/technetwork/java/overview-141217.html
  - Tutorial http://docs.oracle.com/javase/tutorial/jdbc/TOC.html

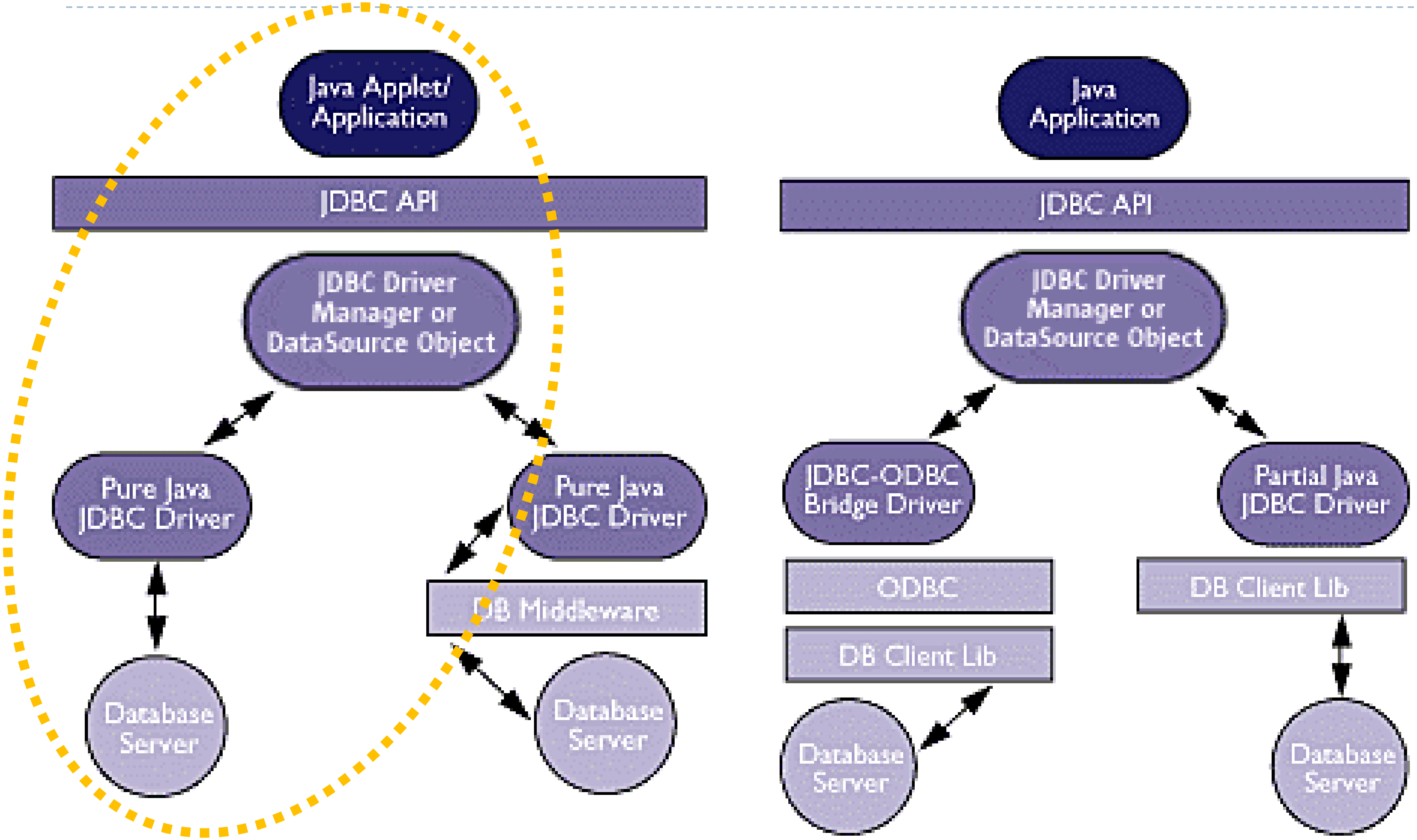
JDBC scope

- Standardizes
  - Mechanism for connecting to DBMSs
  - Syntax for sending queries
  - Structure representing the results
- Does not standardize
  - SQL syntax: dialects, variants, extensions, ...

Architecture



Architecture



Main elements

- Java application (in our case, JavaFX)
- JDBC Driver Manager
  - For loading the JDBC Driver
- JDBC Driver
  - From DBMS vendor
- DBMS
  - In our case, MySQL

Accessing a database: practical steps

Database access and JDBC

Basic steps

1. Define the connection URL
2. Establish the connection
3. Create a statement object
4. Execute a query or update
5. Process the results
6. Close the connection

JDBC Driver

- A Driver is a DMBS-vendor provided class, that must be available to the Java application
  - In general: Should reside in Project's libraries
- The application usually doesn't know the driver class name until run-time (to ease the migration to other DMBSs)
- Needs to find and load the class at run-time
  - Class.forName method in the Java Class Loader (not needed in recent versions)

MySQL JDBC driver

- MySQL Connector/J
  - http://dev.mysql.com/downloads/connector/j/
  - Provides mysql-connector-java-[version]-bin.jar
  - Copy into CLASSPATH
    - E.g.: c:\Program files\...\jre…\lib\ext
  - Copy into project libraries
  - Copy into Tomcat’s libraries
- The driver is in class
  - `com.mysql.jdbc.Driver`

1. Define the connection URL

- The Driver Manager needs some information to connect to the DBMS
  - The database type (to call the proper Driver, that we already loaded in the first step)
  - The server address
  - Authentication information (user/pass)
  - Database / schema to connect to
- All these parameters are encoded into a string
  - The exact format depends on the Driver vendor

MySQL Connection URL format

- jdbc:mysql://[host:port],[host:port].../[database][?propertyName1][=propertyValue1][&propertyName2][=propertyValue2]...
  - jdbc:mysql://
  - host:port (localhost)
  - /database
  - ?user=username
  - &password=ppppppp

2. Establish the connection

- Use `DriverManager.getConnection`
  - Uses the appropriate driver according to the connection URL
  - Returns a Connection object
- `Connection connection = DriverManager.getConnection(URLString)`
- Contacts DBMS, validates user and selects the database
- On the Connection object subsequent commands will execute queries

Example

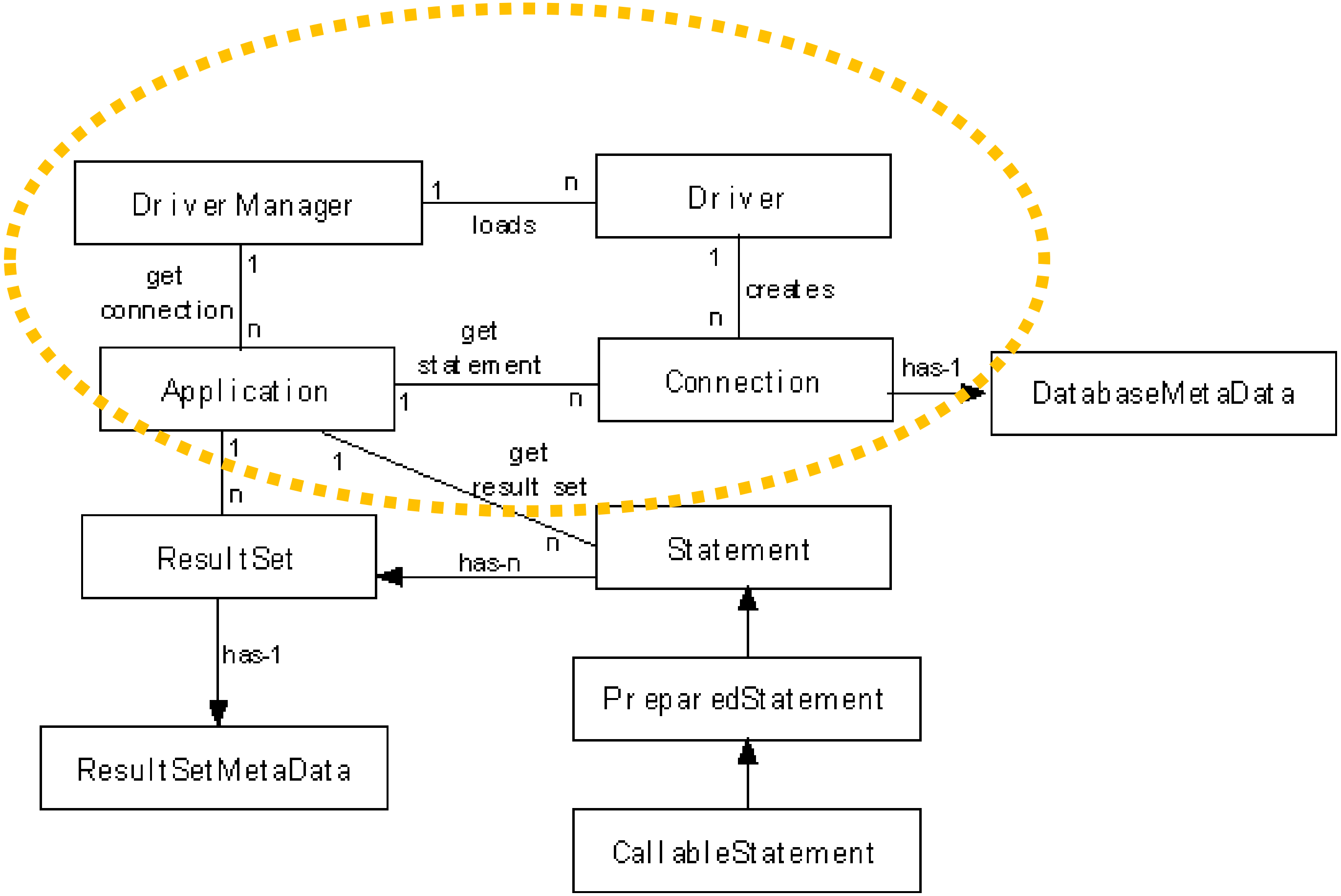
```
import java.sql.Connection;
import java.sql.DriverManager;
import java.sql.SQLException;

        try {
            Connection conn = DriverManager.getConnection(
"jdbc:mysql://localhost/test?user=monty&password=secret");

            // Do something with the Connection
           ....

        } catch (SQLException ex) {
            // handle any errors
            System.out.println("SQLException: " + ex.getMessage());
            System.out.println("SQLState: " + ex.getSQLState());
            System.out.println("VendorError: " + ex.getErrorCode());
        }
```

Class diagram



3. Create a Statement object

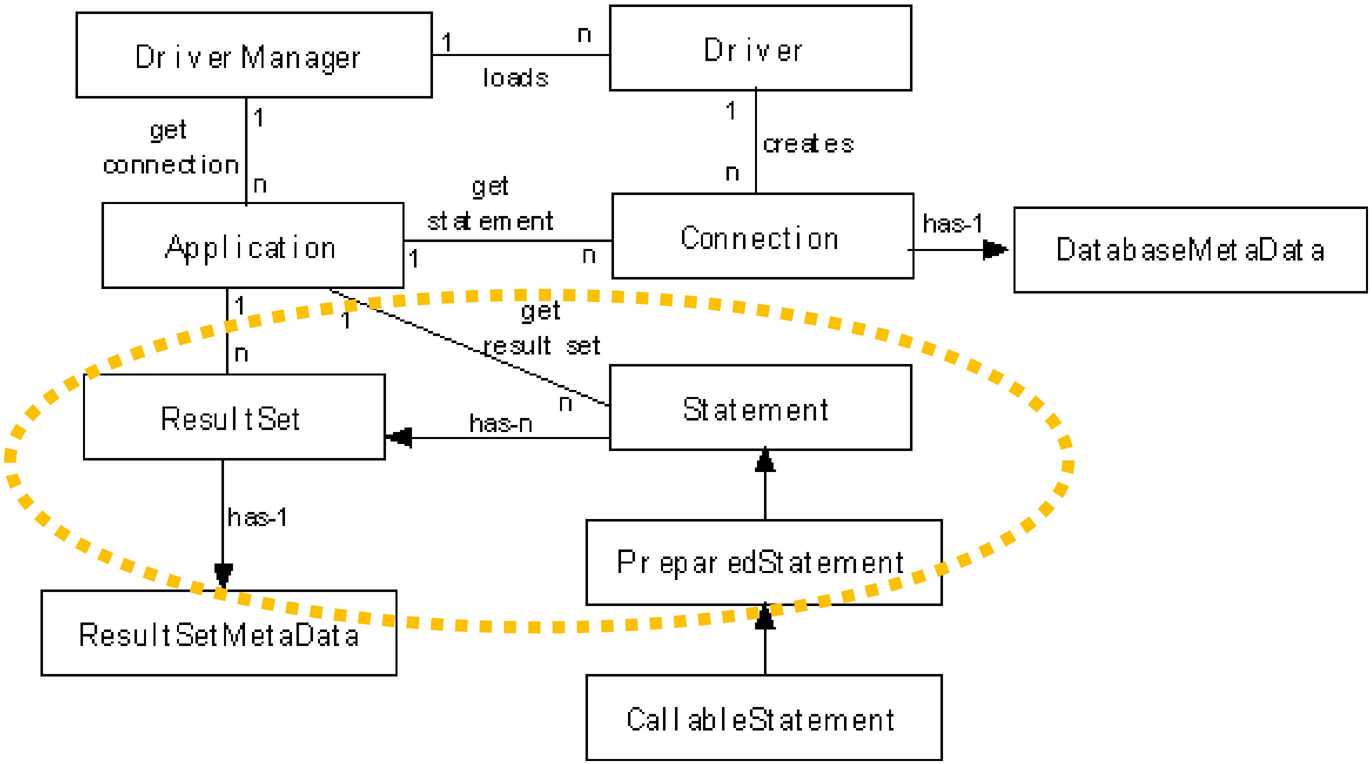
- `Statement statement = connection.createStatement() ;`
- Creates a Statement object for sending SQL statements to the database.
- SQL statements without parameters are normally executed using Statement objects.

- For efficiency and security reasons, we will always use a PreparedStatement object (see later…).

4. Execute a query

- Use the executeQuery method of the Statement class
  - `ResultSet executeQuery(String sql)`
  - `sql` contains a SELECT statement
- Returns a ResultSet object, that will be used to retrieve the query results

Class diagram



Other execute methods

- `int executeUpdate(String sql)`
  - For INSERT, UPDATE, or DELETE statements
  - For other SQL statements that don't return a resultset (e.g., CREATE TABLE)
  - returns either the row count for INSERT, UPDATE or DELETE statements, or 0 for SQL statements that return nothing

- `boolean execute(String sql)`
  - For general SQL statements

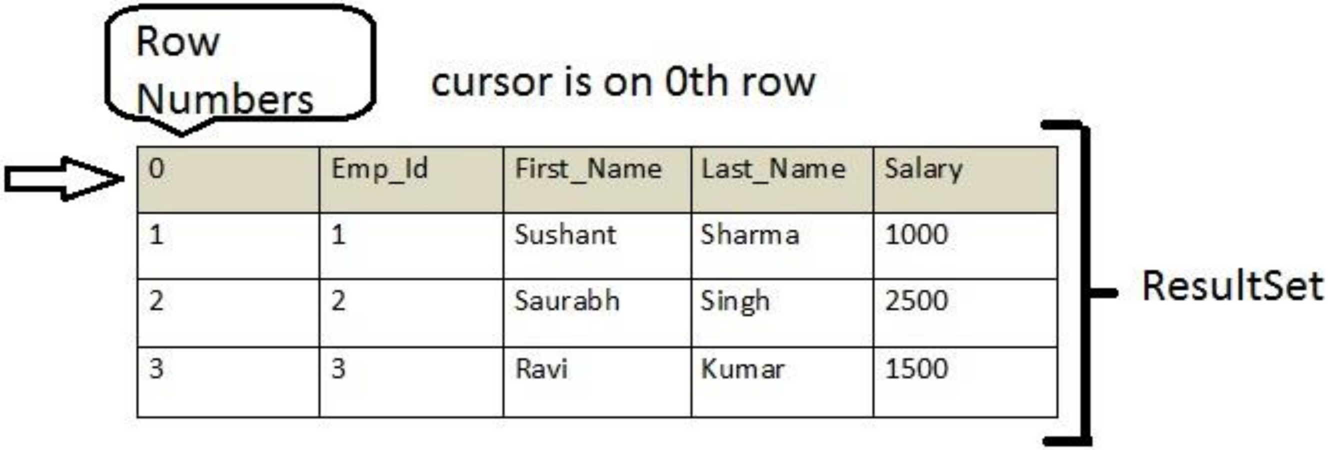
Example

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

5. Process the result

- The ResultSet object *implements a "cursor"* over the query results
  - Data are available a row at a time
    - Method ResultSet.next() goes to the next row
  - The column values (for the selected row) are available trhough **getXXX** methods
    - getInt, getString, ...
  - Data types are converted from SQL types to Java types

Cursor



0	Emp_Id	First_Name	Last_Name	Salary
1	1	Sushant	Sharma	1000
2	2	Saurabh	Singh	2500
3	3	Ravi	Kumar	1500

`ResultSet.getXXX` methods

- XXX is the desired datatype
  - Must be compatible with the column type
  - String is almost always acceptable
- Two versions
  - `getXXX(int columnIndex)`
    - number of column to retrieve (starting from 1 – beware!)
  - `getXXX(String columnName)`
    - name of column to retrieve
    - Always preferred

ResultSet navigation methods

- `boolean next()`
  - Moves the cursor down one row from its current position.
  - A ResultSet cursor is initially positioned **before the first row**:
    - the first call to the method next makes the first row the current row
    - the second call makes the second row the current row, …

Other navigation methods (1/2)

- Query cursor position
  - `boolean isFirst()`
  - `boolean isLast()`
  - `boolean isBeforeFirst()`
  - `boolean isAfterLast()`

Other navigation methods (2/2)

- Move cursor
  - `void beforeFirst()`
  - `void afterLast()`
  - `boolean first()`
  - `boolean last()`
  - `boolean absolute(int row)`
  - `boolean relative(int rows) // positive or negative offset`
  - `boolean previous()`

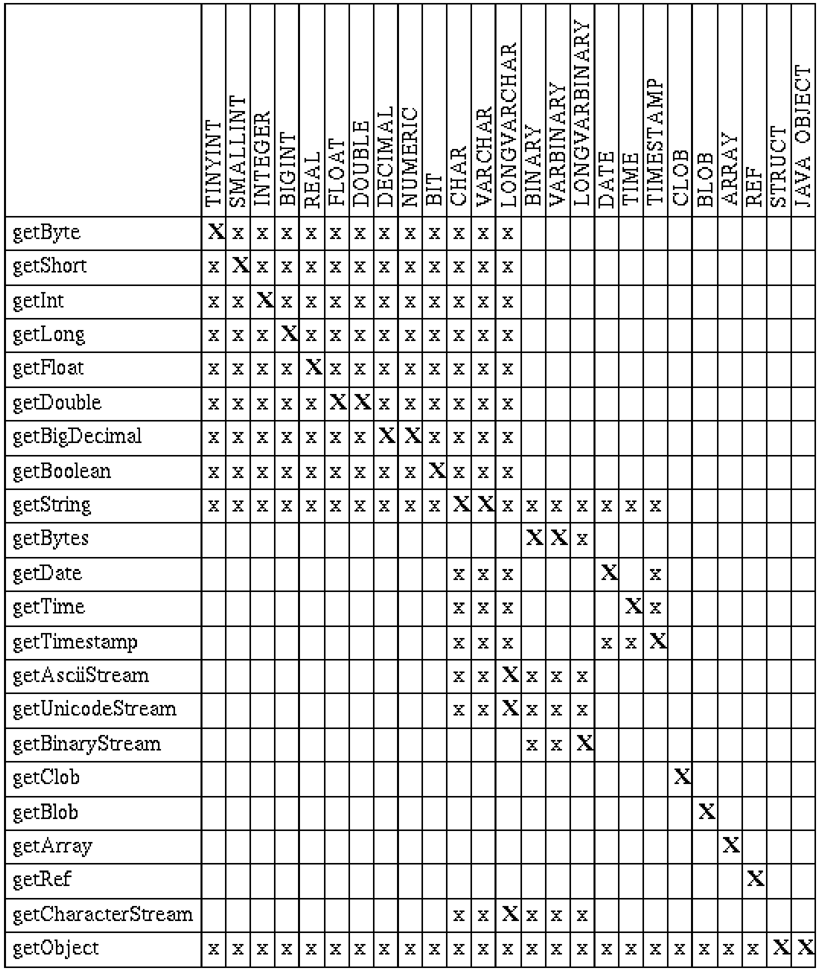
Example

```
while( resultSet.next() )
{
    out.println( "<p>" +
       resultSet.getString(1) + " - " +
       resultSet.getString(2) + " - " +
       resultSet.getString(3) + "</p>" ) ;
}
```

Datatype conversions (MySQL)

These MySQL Data Types	Can always be converted to these Java types
CHAR, VARCHAR, BLOB, TEXT, ENUM, and SET	`java.lang.String`, `java.io.InputStream`, `java.io.Reader`, `java.sql.Blob`, `java.sql.Clob`
FLOAT, REAL, DOUBLE PRECISION, NUMERIC, DECIMAL, TINYINT, SMALLINT, MEDIUMINT, INTEGER, BIGINT	`java.lang.String`, `java.lang.Short`, `java.lang.Integer`, `java.lang.Long`, `java.lang.Double`, `java.math.BigDecimal`
DATE, TIME, DATETIME, TIMESTAMP	`java.lang.String`, `java.sql.Date`, `java.sql.Timestamp`

Datatype conversions



	TINYINT	SMALLINT	INTEGER	BIGINT	REAL	FLOAT	DOUBLE	DECIMAL	NUMERIC	BIT	CHAR	VARCHAR	LONGVARCHAR	BINARY	VARBINARY	LONGVARBINARY	DATE	TIME	TIMESTAMP	CLOB	BLOB	ARRAY	REF	STRUCT	JAVA OBJECT
getByte	X	x	x	x	x	x	x	x	x	x	x	x	x												
getShort	x	X	x	x	x	x	x	x	x	x	x	x	x												
getInt	x	x	X	x	x	x	x	x	x	x	x	x	x												
getLong	x	x	x	X	x	x	x	x	x	x	x	x	x												
getFloat	x	x	x	x	X	x	x	x	x	x	x	x	x												
getDouble	x	x	x	x	x	X	X	x	x	x	x	x	x												
getBigDecimal	x	x	x	x	x	x	x	X	X	x	x	x	x												
getBoolean	x	x	x	x	x	x	x	x	x	X	x	x	x												
getString	x	x	x	x	x	x	x	x	x	x	X	X	x	x	x	x	x	x	x						
getBytes														X	X	x									
getDate											x	x	x				X		x						
getTime											x	x	x					X	x						
getTimestamp											x	x	x				x	x	X						
getAsciiStream											x	x	X	x	x	x									
getUnicodeStream											x	x	X	x	x	x									
getBinaryStream														x	x	X									
getClob																				X					
getBlob																					X				
getArray																						X			
getRef																							X		
getCharacterStream											x	x	X	x	x	x									
getObject	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	X	X

Table 5.1: Use of ResultSet.getXXX Methods to Retrieve JDBC Types

6. Close the connection

- Additional queries may be done on the same connection.
  - Each returns a different ResultSet object, unless you re-use it
  - When no longer needed, ResultSet resources can be freed by 'closing' it: `resultSet.close()`
- When no additional queries are needed, close the connection to the database:
  - `connection.close() ;`

Prepared statements
Callable statements

Database access and JDBC

What’s wrong with statements?

- `String user = txtUserName.getText() ; // JavaFX`
- `String user = request.getParameter("username") ; // JSP`

- `String sql = "select * from users where username='" + user + "'" ;`

- Problems:
  - Security
  - Performance

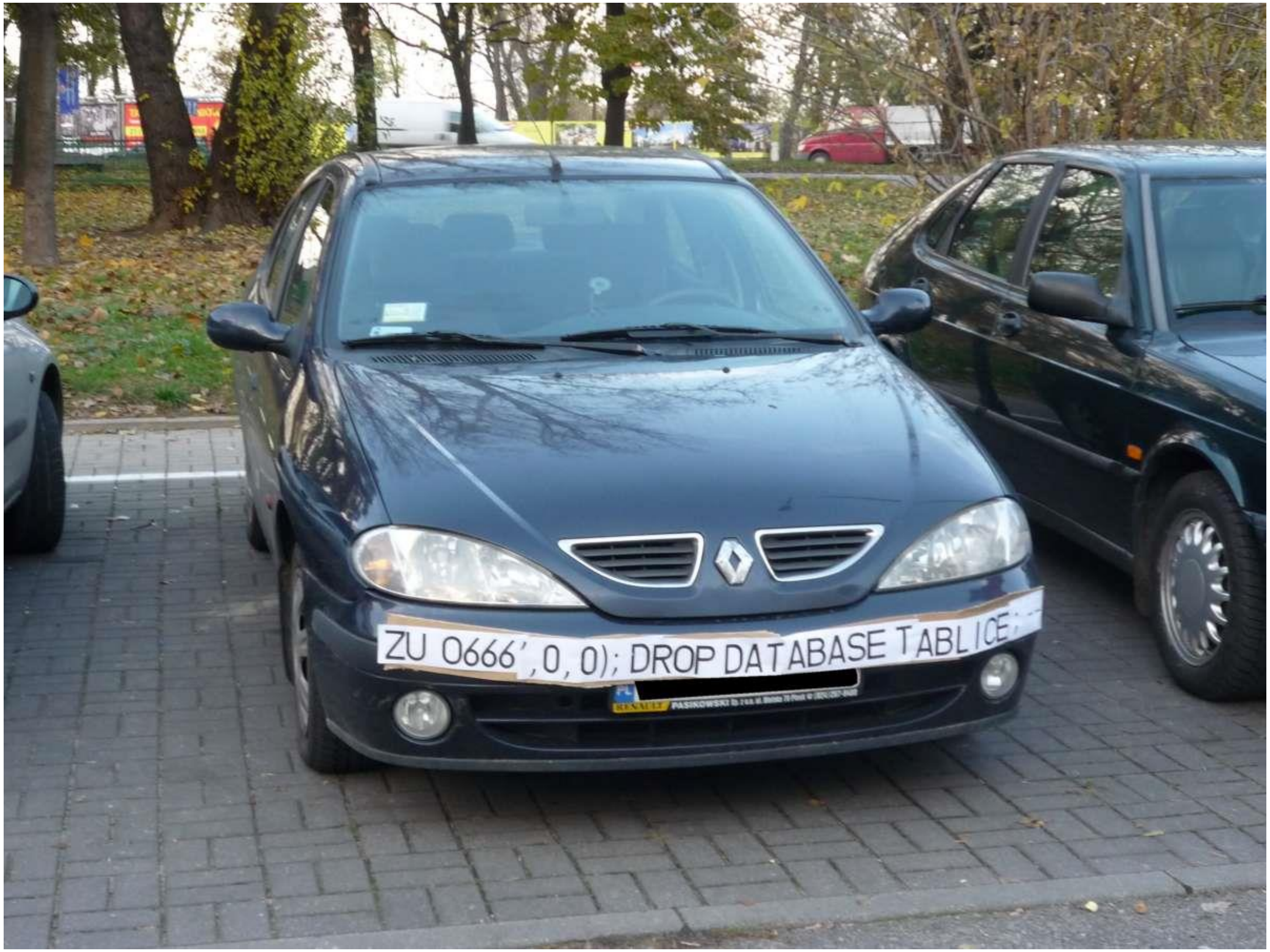
Security risk

- SQL injection – syntax errors or privilege escalation
- Example
  - Username : `'; delete * from users ; --`

```
select * from users where
username=''; delete * from
users ; -- '
```

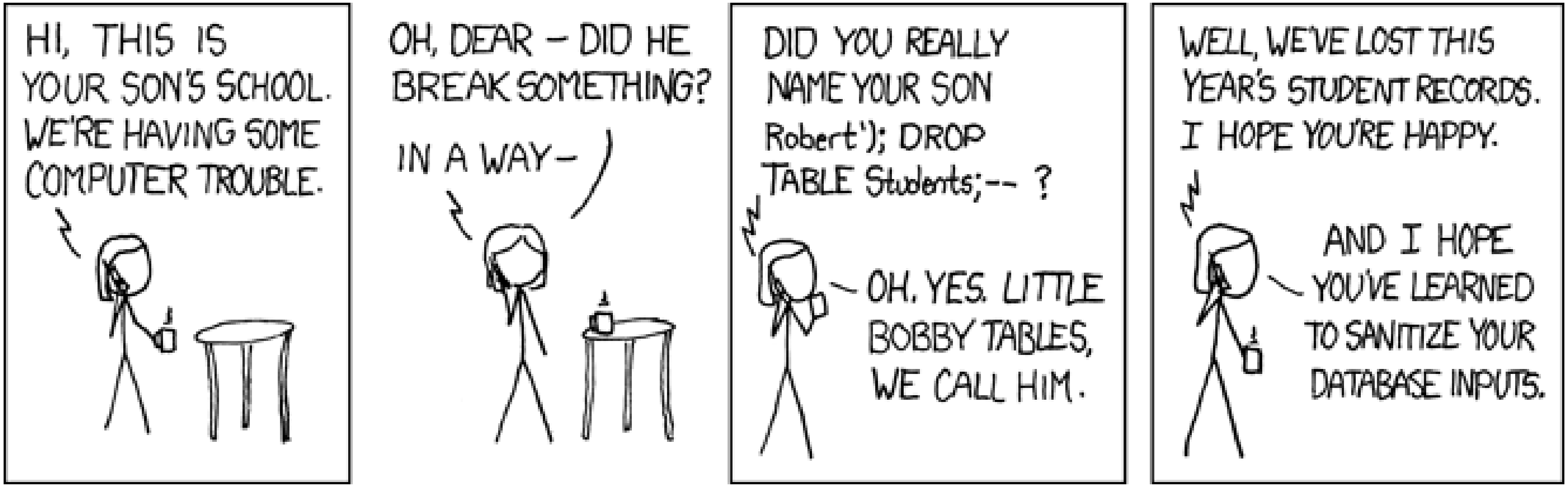
- **Must** detect or escape all dangerous characters!
  - Will **never** be perfect…
- **Never** trust user-entered data. Never. Not once. Really.

SQL injection attempt ☺



[redacted]

SQL injection attempt ☺


HI, THIS IS YOUR SON'S SCHOOL. WE'RE HAVING SOME COMPUTER TROUBLE.
OH, DEAR – DID HE BREAK SOMETHING?
IN A WAY–
DID YOU REALLY NAME YOUR SON Robert'); DROP TABLE Students;-- ?
OH. YES. LITTLE BOBBY TABLES, WE CALL HIM.
WELL, WE'VE LOST THIS YEAR'S STUDENT RECORDS. I HOPE YOU'RE HAPPY.
AND I HOPE YOU'VE LEARNED TO SANITIZE YOUR DATABASE INPUTS.

http://xkcd.com/327/

Performance limitations

- Performance limit
  - Query must be re-parsed and re-optimized every time
  - Complex queries require significant set-up overhead
- When the same query is repeated (even with different data), parsing and optimization wastes CPU time in the DBMS server
  - Increased response-time latency
  - Decreased scalability of the system

Prepared statements

- Separate statement **creation** from statement **execution**
  - At creation time: define SQL syntax (**template**), with placeholders for variable quantities (**parameters**)
  - At execution time: define actual quantities for placeholders (**parameter values**), and run the statement
- Prepared statements can be re-run many times
- Parameter values are automatically
  - Converted according to their Java type
  - Escaped, if they contain dangerous characters
  - Handle non-character data (serialization)

Example

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

String template =
"UPDATE music SET price = ? WHERE id = ?";

PreparedStatement statement =
connection.prepareStatement(template);

float[] newPrices = getNewPrices();
int[] recordingIDs = getIDs();

for(int i=0; i<recordingIDs.length; i++) {
    statement.setFloat(1, newPrices[i]);  // Price
    statement.setInt(2, recordingIDs[i]); // ID

    statement.execute();
}
```

Prepared statements

- Easier to write
  - Data type conversion done by JDBC library
- Secure (no SQL injection possible)
  - Quoting is done by JDBC library
- More efficient
  - Query re-use
  - Parameter values sent in binary form

- The bottom line: **Always use prepared statements**.

Callable statements

- Many DBMSs allow defining "stored procedures", directly defined at the DB level
- Stored procedures are SQL queries (with parameters), or sequences of queries
  - Language for defining stored procedures is DBMS-dependent: not portable!
- MySql: http://dev.mysql.com/doc/refman/5.5/en/stored-programs-views.html (chapter 18)
- Calling stored procedures: use CallableStatement in JDBC
  - Example: http://dev.mysql.com/doc/refman/5.5/en/connector-j-usagenotes-basic.html#connector-j-examples-stored-procedure

Design patterns (DAO)

Database access and JDBC

Problems

- Database code involves a lot of «specific» knowledge
  - Connection parameters
  - SQL commands
  - The structure of the database
- Bad practice to «mix» this low-level information with main application code
  - Reduces portability and maintainability
  - Creates more complex code
  - Breaks the «one-class one-task» assumption
- What it a better code organization?

Goals

- Encapsulate DataBase access into separate classes, distinct from application ones
  - All other classes should be shielded from DB details
- DataBase access should be indepentent from application needs
  - Potentially reusable in different parts of the application
- Develop a reusable development patterns that can be easily applied to different situations

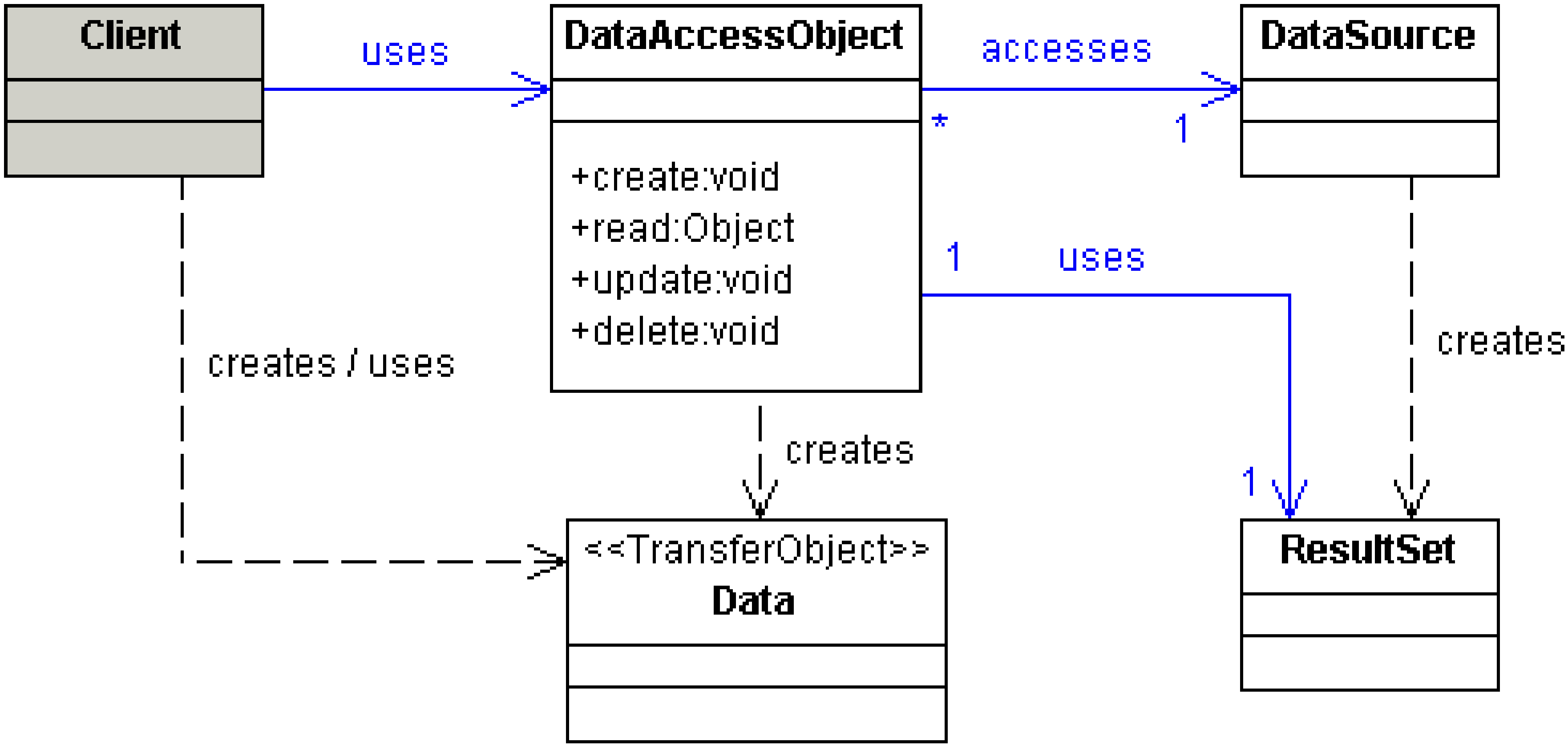
Data Access Object (DAO) – 1/2

- «Client» classes:
  - Application code that needs to access the database
  - Ignorant of database details (connection, queries, schema, ...)
- «DAO» classes:
  - Encapsulate all database access code (JDBC)
  - The only ones that will ever contact the database
  - Ignorant of the goal of the Client

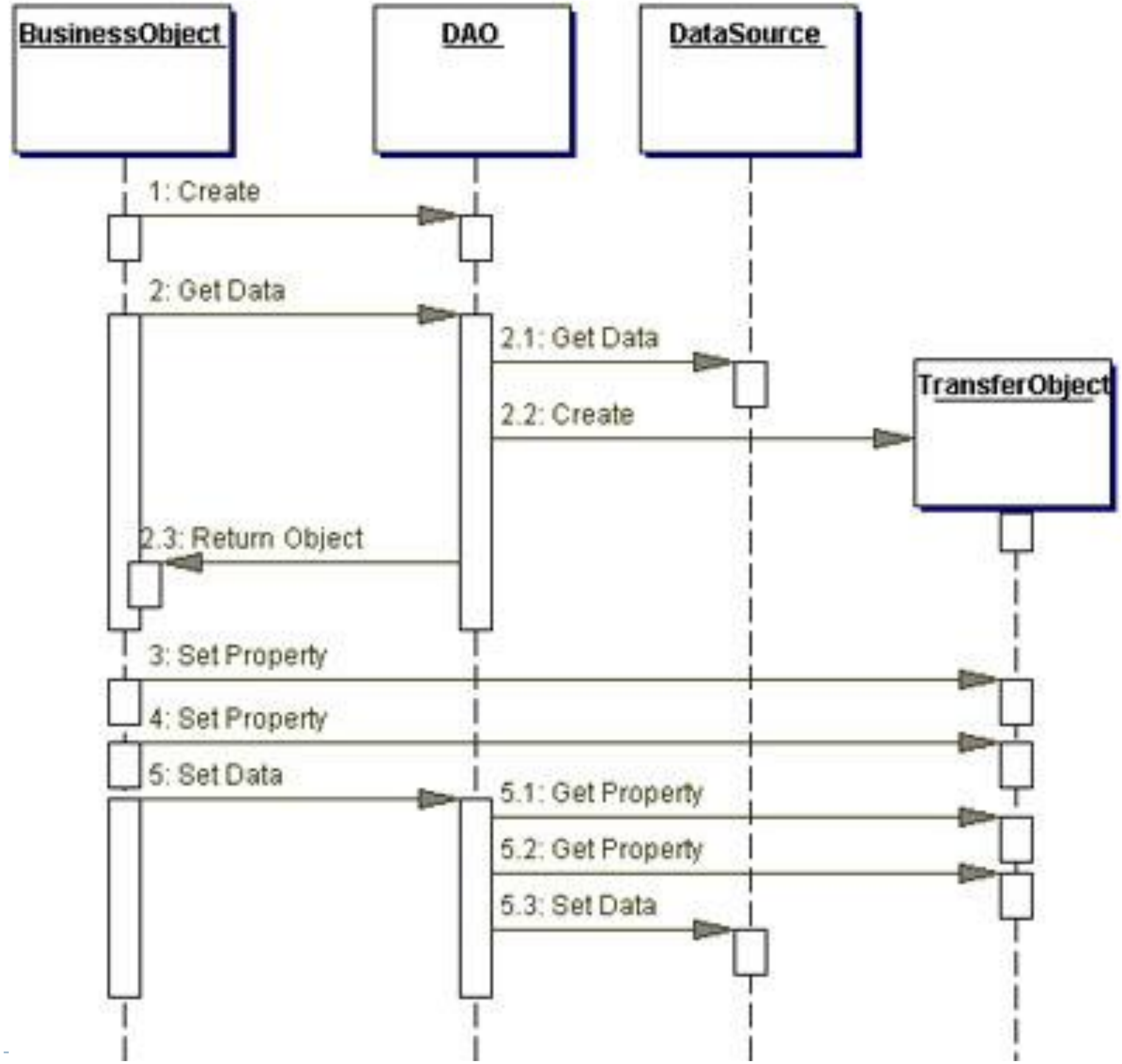
Data Access Object (DAO) – 2/2

- Low-level database classes: DriverManager, DataSource, ResultSet, etc
  - Used by DAO (only!) but invisible to Client
- «Transfer Object» (TO) or «Data Transfer Object» (DTO) classes
  - Contain data sent from Client to Dao and/or returned by DAO to Client
  - Represent the data model, as seen by the application
  - Usually POJO or JavaBean
  - Ignorant of DAO, ignorant of database, ignorant of Client

DAO class diagram



DAO Sequence diagram



DAO design criteria

- DAO has no state
  - No instance variables (except Connection - maybe)
- DAO manages one ‘kind’ of data
  - Uses a small number of DTO classes and interacts with a small number of DB tables
  - If you need more, create many DAO classes
- DAO offers CRUD methods
  - Create, Read, Update, Delete
- DAO may offer search methods
  - Returning collections of DTO

public interface/class UserDAO

- `public User find(Long id)`
  - `public boolean find(Long id, User u)`
  - `public boolean find(User u) // uses u.id`
- `public User find(String email, String password)`
- `public List<User> list()`
- `List<User> searchUserByName(String name)`
  - `List<User> searchByName(User u) ; // only u.name matters`

public interface/class UserDAO

- `public void create(User user)`
  - `public Long create(User user) // returns new ID`
- `public void update(User user) // modify all except ID`
- `public void delete(User user)`
- `public boolean existEmail(String email)`
- `public void changePassword(User user)`

Object-Relational Mapping

Database access and JDBC

Mapping Tables to Objects

- Goal: guidelines for creating a set of Java Beans (DTO) to represent information stored in a relational database
- Goal: guidelines for designing the set of methods for DAO objects

Tables → Beans

- Create one Java Bean per each main database entity
  - except tables used to store n:n relationships!)
- Bean names should match table names (in the singular form)
- The bean should have one private property for each column in the table, with matching names
  - according to Java naming conventions (NUMERO_DATI -> numeroDati)
  - Except columns uses as foreign keys
- The main constructor must accept all the fields in the bean
  - Fields corresponding to foreign keys may not be present in the constructor (lazy object creation)
- Add get()/set() methods for all properties
- Define equals and hashCode, using the exact set of fields that compose the primary key of the table

Relationships, Foreign keys

- Define additional attributes in the Java Bean classes, for every relationship that we want to easily navigate in our application
  - Not necessarily *all* relationships!

- A relationship with cardinality **1** maps to an attribute referring to the corresponding Java object (not the PK value). Use singular nouns.
- A relationship with cardinality **n** maps to an attribute containing a collection, whose elements are corresponding Java objects (not PK values). Use plural nouns.
- The collection may be Set or List.
- The bean should have methods for reading (get, …) and modifying (add, …) the collection

1:1 relationship

```
STUDENTE       PERSONA
--------       -------
matricola (PK) codice_fiscale (PK)
fk_persona     fk_studente


class Studente { private Persona persona ; }
class Persona  { private Studente studente ; }
```

1:N relationship

```
STUDENTE               CITTA
--------               -------
matricola (PK)         cod_citta (PK)
fk_citta_residenza     nome_citta

class Studente {
   private Citta cittaResidenza ; }

class Citta {
  private Collection<Studente>
      studentiResidenti ; }
```

N:M relationship

ARTICLE AUTHORSHIP CREATOR

```
class Article
  { private Collection<Creator> creators ; }
class Creator
  { private Collection<Article> articles ; }
```

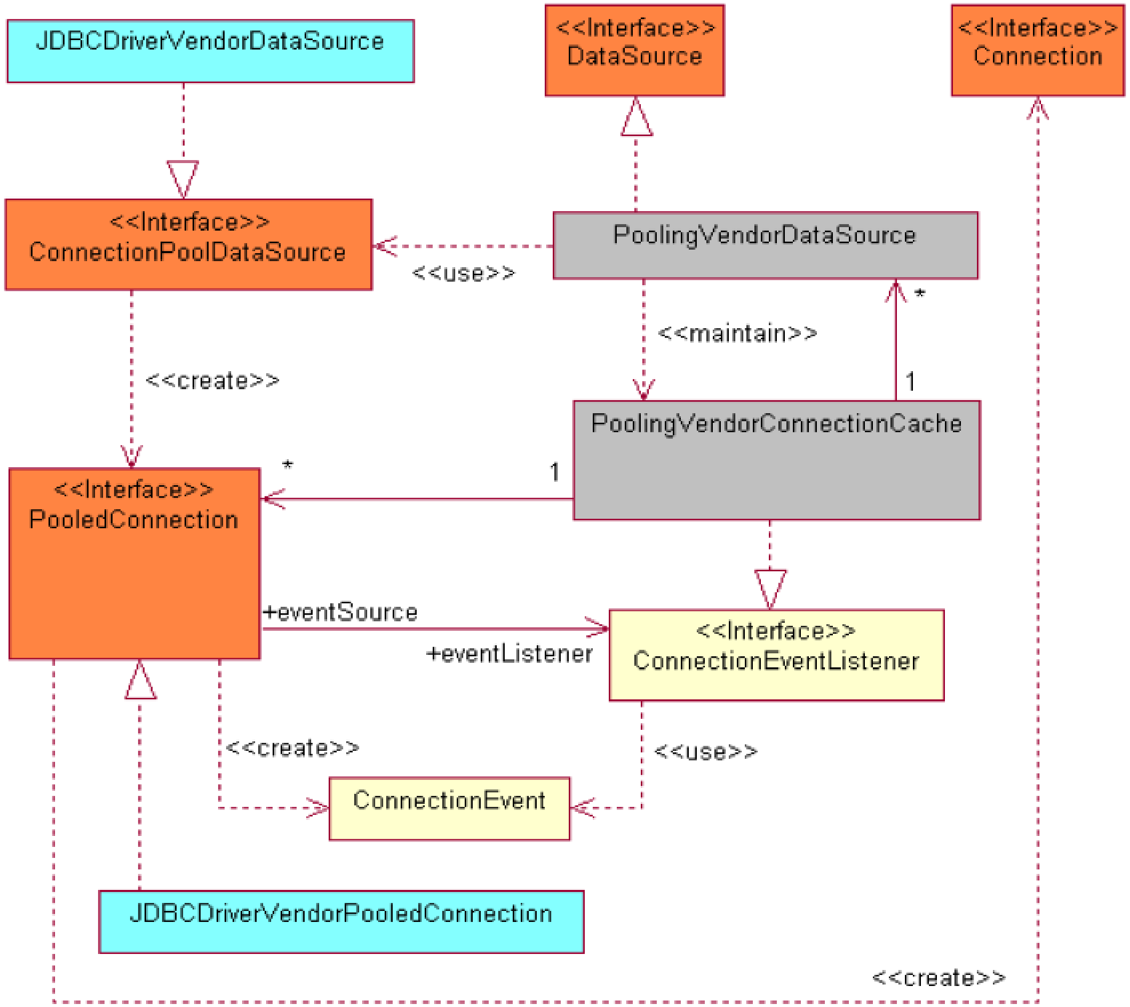
Connection pooling

Database access and JDBC

Connection pooling

- Opening and closing DB connection is expensive
  - Requires setting up TCP/IP connection, checking authorization, …
  - After just 1-2 queries, the connection is dropped and all partial results are lost in the DBMS
- Connection pool
  - A set of "already open" database connections
  - DAO methods "lend" a connection for a short period, running queries
  - The connection is then returned to the pool (not closed!) and is ready for the next DAO needing it

JDBC 3.0 Connection pooling architecture

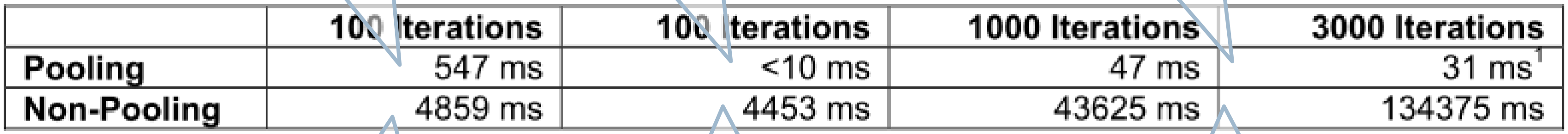


Benchmarks

The first time, the connections must be created

Second time, reuse connections

Negligible overhead



	100 Iterations	100 Iterations	1000 Iterations	3000 Iterations
Pooling	547 ms	<10 ms	47 ms	31 ms[1]
Non-Pooling	4859 ms	4453 ms	43625 ms	134375 ms

10x slower

No improvement

Linear increase

Support in J2EE and Tomcat

- The Java EE Platform Specification requires:
  - Java EE Application Servers must provide a *DataSource* implementation
  - DataSource is a connection pool for JDBC connections
  - Tomcat implements this specification
- DataSource – interface javax.sql.DataSource
  - Alternative to DriverManager
  - DataSOurce implementations can be located through JNDI (Java Naming and Directory)
  - Tomcat implements a simplified JNDI service

Configure JNDI

- Tomcat’s JNDI is stored in WEB-INF/web.xml
- Define a resource to access a DataSource object, with a symbolic reference name

```
<resource-ref>
    <description>
        Resource reference to a factory for java.sql.Connection
        instances that may be used for talking to a particular
        database that is configured in the <Context> configuration
        for the web application.
    </description>

    <res-ref-name>jdbc/TestDB</res-ref-name>

    <res-type>javax.sql.DataSource</res-type>

    <res-auth>Container</res-auth>

</resource-ref>
```

Configure the connection factory

- Implementation instructions are stored in META-INF/context.xml

```
<Context ...>
    ...
    <Resource
        name="jdbc/TestDB"
        auth="Container"
        type="javax.sql.DataSource"
        maxActive="100"
        maxIdle="30"
        maxWait="10000"
        username="utente1" password="utente1"
        driverClassName="com.mysql.jdbc.Driver"
        url="jdbc:mysql://localhost:3306/nazioni?autoReconnect
        =true"
    />
    ...
</Context>
```

Get a connection from the pool

- Lookup the DataSource, then get a new connection

```
/* JNDI query to locate the DataSource object */
Context initContext = new InitialContext();

Context envContext  = 
(Context)initContext.lookup("java:/comp/env") ; // JNDI 
standard naming root

DataSource ds = (DataSource)envContext.lookup("jdbc/TestDB");

/* Ask DataSource for a connection */
Connection conn = ds.getConnection();

... use this connection to access the database ...

conn.close() ; // return connection to the pool
```

c3p0 library for connection pooling

- Open source library for adding connection pooling capabilities to JDBC drivers
  - http://www.mchange.com/projects/c3p0/
- Connection Pooling
- Prepared Statement Pooling
  - Automatically caches, recognizes and re-uses previously used prepared statements

Using c3p0

The DataSource object:
`cpds.getConnection()`
lends a connection from the pool

```
import com.mchange.v2.c3p0.*;

...

ComboPooledDataSource cpds = new ComboPooledDataSource();

cpds.setDriverClass( "org.postgresql.Driver" );
      //loads the jdbc driver

cpds.setJdbcUrl( "jdbc:postgresql://localhost/testdb" );

cpds.setUser("dbuser");
cpds.setPassword("dbpassword");
```

Closing up

- To release a connection to the pool:
  - `connection.close() ;`
  - …otherwise the pool will run out of available connections!
- To destroy the connection pool and clean up resources:
  - `cpds.close();`
  - Also disconnects from database.
  - May be placed in a `stop()` method in the main JavaFX class

References

- JDBC Basics: Tutorial
  - http://docs.oracle.com/javase/tutorial/jdbc/TOC.html
  - http://pdf.coreservlets.com/Accessing-Databases-JDBC.pdf
- JDBC reference guide
  - http://docs.oracle.com/javase/6/docs/technotes/guides/jdbc/gettingstart/GettingStartedTOC.fm.html
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