

Data Management

06 APIs (ODBC, JDBC, ORM Tools)

Matthias Boehm

Graz University of Technology, Austria
Computer Science and Biomedical Engineering
Institute of Interactive Systems and Data Science
BMK endowed chair for Data Management



Announcements/Org

#1 Video Recording

- Link in **TeachCenter** & **TUbe** (lectures will be public)
- Hybrid: HSi13 / <https://tugraz.webex.com/meet/m.boehm>
- **Apr 25:** no more COVID restrictions at TU Graz



#2 Course Evaluation and Exam

- Evaluation period: **Jun 15 – Jul 31**
- Exams: **Jul 07, 2.30pm** (i12+i13), **Jul 07, 5.30pm** (i12+13), **Jul 28, 5.30pm** (i13)



#3 Exercises

- Exercise 1 in progress of being graded (target May 01)
- Exercise 2: **May 03 + 7 late days** in TeachCenter
 - Fixed data issues (Apr 10) and expected results (Apr 14)
 - Additional help (for SQL queries without ingestion program):
https://mboehm7.github.io/teaching/ss22_db/DataExport.zip

Q&A

Announcements/Org, cont.

■ Using the Exported Data

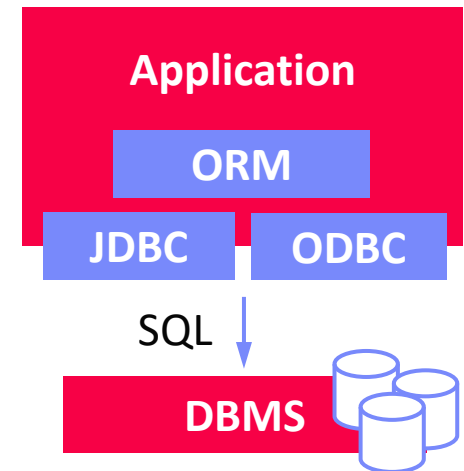
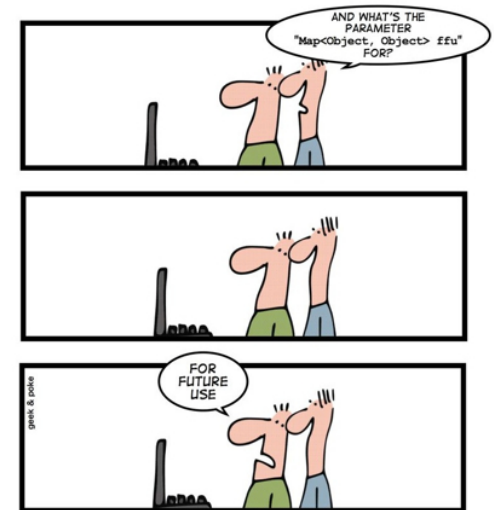
- Setup CreateSchema.sql via psql/pgAdmin-query tool
- Download DataExport.zip, unzip into directory
- From psql/pqAdmin-query tool, load data

```
COPY Districts FROM '/tmp/data/districts.csv' CSV DELIMITER ',';  
COPY PostalCodes FROM '/tmp/data/postalcodes.csv' CSV DELIMITER ',';  
COPY Streets FROM '/tmp/data/streets.csv' CSV DELIMITER ',';  
COPY StreetDistricts FROM '/tmp/data/streetdistricts.csv' CSV DELIMITER ',';  
COPY Addresses FROM '/tmp/data/addresses.csv' CSV DELIMITER ',';  
COPY InstitutionTypes FROM '/tmp/data/institutiontypes.csv' CSV DELIMITER ',';  
COPY Institutions FROM '/tmp/data/institutions.csv' CSV DELIMITER ',';  
COPY Countries FROM '/tmp/data/countries.csv' CSV DELIMITER ',';  
COPY PopByCitizenship FROM '/tmp/data/popbycitizenship.csv' CSV DELIMITER ',';  
COPY PopByGender FROM '/tmp/data/popbygender.csv' CSV DELIMITER ',';
```

What's an API and again, why should I care?

- **Application Programming Interface (API)**
 - Defined **set of functions or protocols** for system or component communication
 - Interface independent of concrete implementation → **decoupling of applications** from underlying libraries / systems
 - API stability of utmost importance
- **Examples**
 - **Linux:** kernel-user space API → system calls, POSIX (Portable Operating System Interface)
 - **Cloud Services:** often dedicated REST (Representational State Transfer) APIs
 - **DB Access:** **ODBC/JDBC and ORM frameworks**

HOW TO CREATE A STABLE API



Agenda

- **Call-level Interfaces (ODBC/JDBC) and Embedded SQL**
- **Object-Relational Mapping Frameworks**

Call-level Interfaces (ODBC/JDBC) and Embedded SQL

Call-level Interfaces vs Embedded SQL

■ #1 Call-level Interfaces

- Standardized in ISO/IEC SQL – Part 3: CLI
- **API of defined functions for dynamic SQL**
- **Examples:** ODBC (C/C++), JDBC (Java), DB-API (Python)

■ #2 Embedded SQL

- Standardized in ISO/IEC SQL – Part 2: Foundation / Part 10 OLB
- **Embedded SQL in host language** (typically static)
- **Preprocessor** to compile CLI protocol handling
 - ➔ **SQL syntax and type checking, but static** (SQL queries, DBMS)
- **Examples:** ESQL (C/C++), SQLJ (Java)

Embedded SQL

Overview

- **Mix host language constructs and SQL** in data access program → **simplicity?**
- **Precompiler translates program** into valid host language program
- Primitives for creating cursors, queries and updates, etc

→ **In practice, limited relevance**

Example SQLJ

- Cursors with and without explicit variable binding

```
#sql iterator StudIter
    (int sid, String name);
StudIter iter;
```

```
#sql iter = {SELECT * FROM Students};
```

```
while( iter.next() )
    print(iter.sid, iter.name);
```

```
iter.close();
```

```
int id = 7;
String name;
```

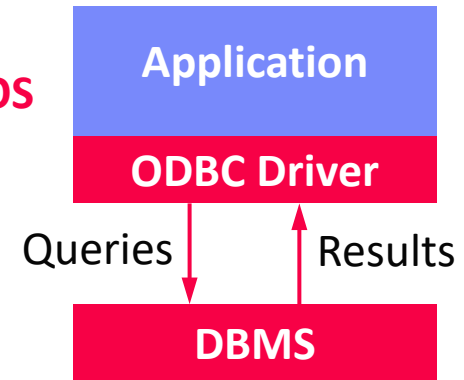
```
#sql {SELECT LName INTO :name
      FROM Students WHERE SID=:id};
```

```
print(id, name);
```


CLI: ODBC and JDBC Overview

Open Database Connectivity (ODBC)

- **API for accessing databases independent of DBMS and OS**
- Developed in the **early 1990s → 1992** by Microsoft (superset of ISO/IEC SQL/CLI and Open Group CLI)
- **All relational DBMS have ODBC implementations**, good programming language support

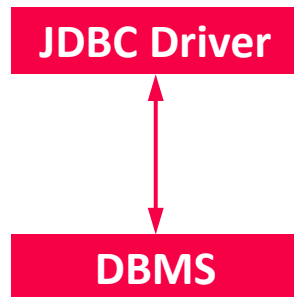


Java Database Connectivity (JDBC)

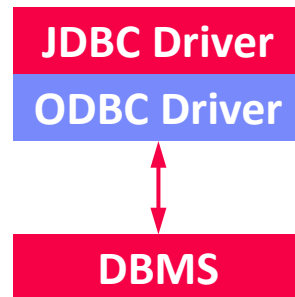
- **API for accessing databases independent of DBMS from Java**
- Developed and released by Sun in **1997**, JDBC 4.0 (2006), JDBC 4.3 in Java 9
- Most relational DBMS have JDBC implementations

Types of Drivers

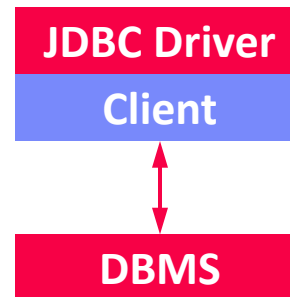
#4 Pure Java JDBC Driver



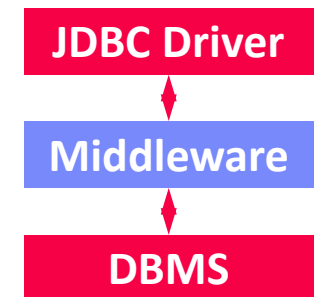
#1 JDBC/ODBC Bridge



#2 Native Client Library

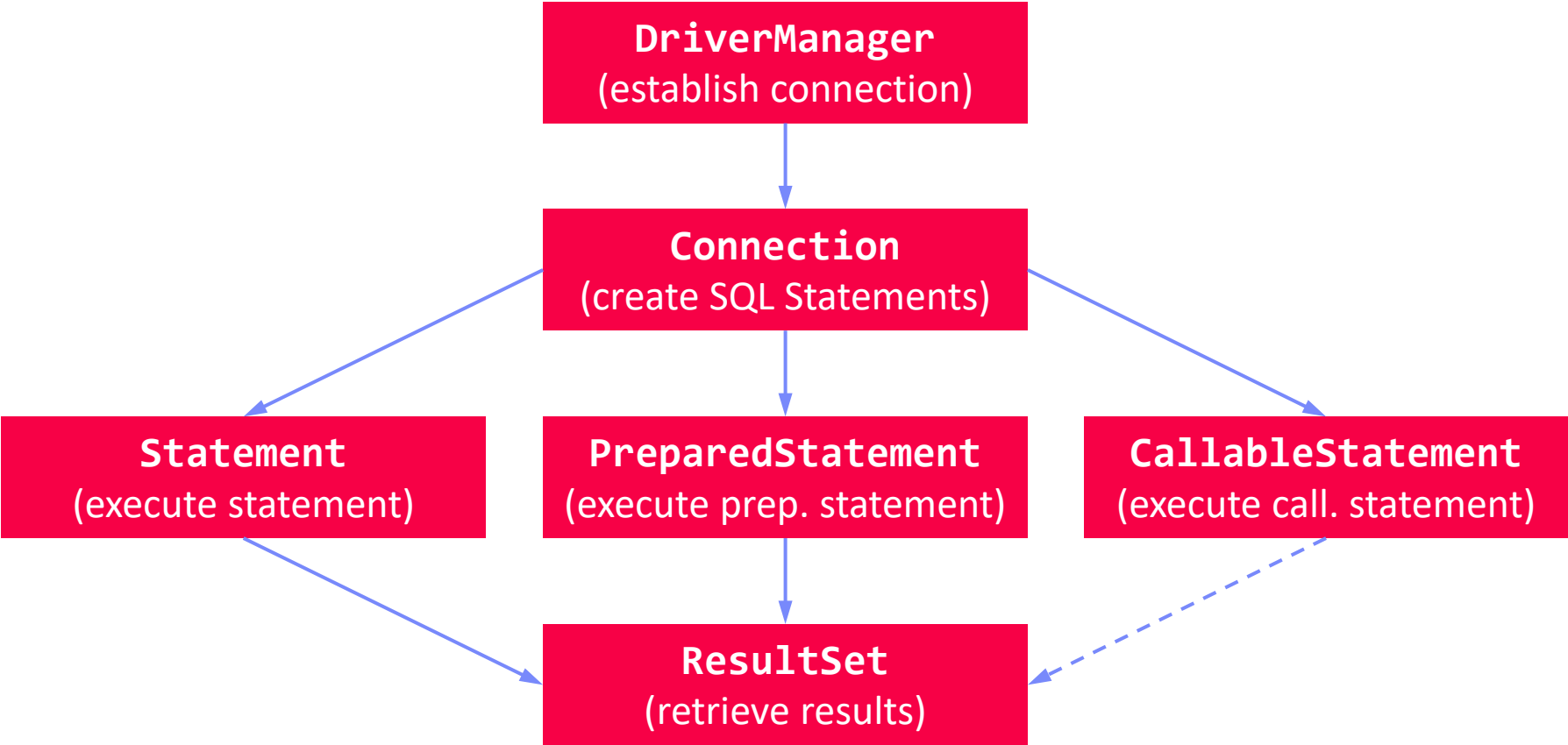


#3 Middleware



Note: Reuse of drivers from open source DBMS

JDBC Components and Flow



JDBC Connection Handling

Establishing a Connection

- DBMS-specific URL strings including host, port, and database name

```

Connection conn = DriverManager
    .getConnection("jdbc:postgresql:"+
        "//localhost:5432/db1234567",
        username, password);
    
```

- Stateful handles representing user-specific DB sessions `META-INF/services/`
- JDBC driver is usually a jar on the class path `java.sql.Driver`
- Connection and statement pooling** for performance

JDBC 4.0

- Explicit driver class loading and registration no longer required
- Improved connection management (e.g., status of DB connections)
- Other: XML, Java classes, row ID, better exception handling

```

Class.forName(
    "org.postgresql.Driver");
    
```

JDBC Statements

Execute Statement

- Use for simple SQL statements w/o parameters
- Beware of SQL injection**
- API allows fine-grained control over fetch size, fetch direction, batching, and multiple result sets

```
Statement stmt = conn.createStatement();
ResultSet rs = stmt.executeQuery(sql1);
...
int rows = stmt.executeUpdate(sql2);
stmt.close();
```

Note: PostgreSQL does not support fetch size but sends entire result

Process ResultSet

- Iterator-like cursor (app-level) w/ on-demand fetching
- Scrollable / updatable result sets possible
- Attribute access via column names or positions

```
ResultSet rs = stmt.executeQuery(
    "SELECT SID, LName FROM Students");

List<Student> ret = new ArrayList<>();
while( rs.next() ) {
    int id = rs.getInt("SID");
    String name = rs.getString("LName");
    ret.add(new Student(id, name));
}
```

Recap: Beware of SQL Injection



■ Problematic SQL String Concatenation

```
INSERT INTO Students (Lname, Fname)
VALUES ('"+ @lname +"', '"+ @fname +"' );";
```

■ Possible SQL-Injection Attack



<https://xkcd.com/327/>

```
INSERT INTO Students (Lname, Fname) VALUES ('Smith', 'Robert');
DROP TABLE Students; --');
```

JDBC Prepared Statements

Execute PreparedStatement

- Use for precompiling SQL statements w/ input params
- Inherited from Statement
- Precompile SQL once**, and execute many times

➔ Performance

➔ No danger of SQL injection

```
PreparedStatement pstmt =
    conn.prepareStatement(
        "INSERT INTO Students VALUES(?,?)");
for( Student s : students ) {
    pstmt.setInt(1, s.getID());
    pstmt.setString(2, s.getName());
    pstmt.executeUpdate();
}
pstmt.close();
```

Null Handling

- Pass null object
(explicitly for primitive types)

```
pstmt.setString(2, p[1]);
pstmt.setObject(3, p[2].isEmpty() ?
    null : Integer.valueOf(p[2]),
    Types.INTEGER);
```

Queries and Updates

- Queries → `executeQuery()`
- Insert, delete, update → `executeUpdate()`

JDBC Callable Statements

- **Recap: (Stored Procedures, see 05 Query Languages (SQL))**
 - Can be **called standalone via CALL** <proc_name>(<args>);
 - Procedures return no outputs, but might have **output parameters**

- **Execute CallableStatement**

- Create prepared statement for call of a procedure
- Explicit registration of output parameters
- Example

```
CallableStatement cstmt = conn.prepareCall(
    "{CALL prepStudents(?, ?)}");

cstmt.setInt(1, 2019);
cstmt.registerOutParameter(2, Types.INTEGER);
cstmt.executeQuery();

int rows = cstmt.getInt(2);
```

Psycopg (Python PostgreSQL Adapter)

■ Overview Psycopg

- Implements [Python Database API Specification v2.0](#) (DB API 2.0)
- Call-level interface for dynamic SQL, very similar to JDBC

■ Establish Connection

```
conn = psycopg2.connect(
    host="localhost", port="5432",
    database="db1234567", user=username,
    password=password)
```

■ Execute Statements

- Use local cursors

```
cur = conn.cursor()
cur.execute("INSERT INTO Students VALUES(...)")
```

■ Process Result Sets

```
cur.execute("SELECT SID, LName FROM Students")
students = cur.fetchall()
for row in students:
    print("SID = ", row[0], end = ',')
    print("Lname = ", row[1])
```


Psycopg (Python PostgreSQL Adapter), cont.

- **Execute Prepared Statements**

```

cur = conn.cursor()
sql = "INSERT INTO Students VALUES(%s, %s)"
for s in students:
    cur.execute(sql, (s.getID(),s.getName()))
conn.commit()
                
```

- **Execute Callable Statement**

```

cur = conn.cursor()
cur.callproc("prepStudents", (2019, 2))
cur.fetchone()
                
```

 - Result set
 - No output parameters

- **Close Connection**

```

cur.close()
conn.close()
                
```

Preview Transactions

Database Transaction

- A transaction (TX) is a **series of steps** that brings a database from a **consistent state** into another (not necessarily different) **consistent state**
- **ACID properties** (atomicity, consistency, isolation, durability)
- See lecture **08 Transaction Processing and Concurrency**

Example

- Transfer 100 Euros from Account 107 to 999

```

START TRANSACTION ISOLATION LEVEL SERIALIZABLE;
    UPDATE Account SET Balance=Balance-100
        WHERE AID = 107;
    UPDATE Account SET Balance=Balance+100
        WHERE AID = 999;
COMMIT TRANSACTION;
    
```

Transaction Isolation Level

- **Tradeoff:** isolation (and related guarantees) vs performance
- READ UNCOMMITTED (~~lost update~~, ~~dirty read~~, ~~unrepeatable read~~, ~~phantom R~~)
- READ COMMITTED (~~lost update~~, ~~dirty read~~, ~~unrepeatable read~~, ~~phantom R~~)
- REPEATABLE READ (~~lost update~~, ~~dirty read~~, ~~unrepeatable read~~, ~~phantom R~~)
- SERIALIZABLE (~~lost update~~, ~~dirty read~~, ~~unrepeatable read~~, ~~phantom R~~)

JDBC Transaction Handling

■ JDBC Transaction Handling

- **Isolation levels** (incl NONE) and (auto) **commit** option
- **Savepoint** and **rollback** (undo till begin or savepoint)
- **Note:** TX handling on connection not statements

■ Beware of Defaults

- DBMS-specific default isolation levels

(SQL Standard: **SERIALIZABLE**, PostgreSQL: **READ COMMITTED**)

```
conn.setTransactionIsolation(
    TRANSACTION_SERIALIZABLE);
conn.setAutoCommit(false);
```

```
PreparedStatement pstmt = conn
    .prepareStatement("UPDATE Account
    SET Balance=Balance+? WHERE AID = ?");
```

```
Savepoint save1 = conn.setSavepoint();
```

```
pstmt.setInt(1,-100); pstmt.setInt(107);
pstmt.executeUpdate();
```

```
if( rand()<0.1 )
    conn.rollback(save1);
```

```
pstmt.setInt(1,100); pstmt.setInt(999);
pstmt.executeUpdate();
```

```
conn.commit();
```

JDBC Transaction Handling, cont.

■ Batching of Inserts

- Batching multiple inserts in one transaction can improve performance

```

conn.setAutoCommit(false);
PreparedStatement pstmt = conn.prepareStatement(
    "INSERT INTO Persons(AKey, Name, Website, IKey) VALUES(?,?,?,?)");
for( String[] p : tmp ) {
    pstmt.setInt(1, Integer.valueOf(p[0].substring(1)));
    pstmt.setString(2, p[1]);
    pstmt.setString(3, p[5].isEmpty() ? null : p[5]);
    pstmt.setObject(4,
        orgs.get(p[3]+"_" +p[4]),
        Types.INTEGER);
    pstmt.executeUpdate();
}
conn.commit();

```

Performance Ref Implementation SS2020:
 (36K authors, 28K papers, 101K author-papers)

* Auto Commit: 23.7s
 * Batched Commits: 12.5s

Performance Ref Implementation SS2021:
 (116K athletes, 158K team-athletes, 219K results)

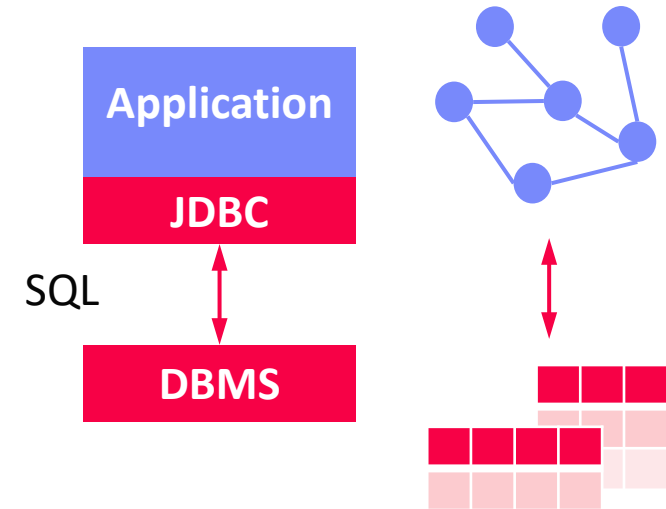
* Auto Commit: 68.7s
 * Batched Commits: 36.3s

Object-Relational Mapping Frameworks

The “Impedance Mismatch” Argument

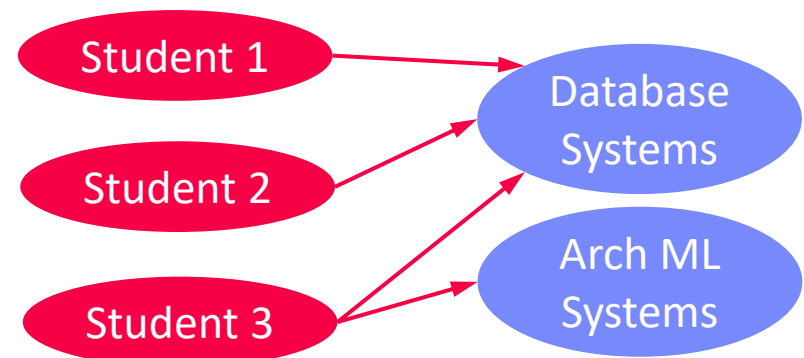
■ Problem Description

- Applications rely on **object-oriented programming languages** with hierarchies or graphs of objects
- Data resides in **normalized “flat” tables** (note: ~~OODBMS~~, object-relational)
- Application is responsible for **bridging this structural/behavioral gap**



■ Example

- **SELECT * FROM Students**
- **SELECT C.Name, C.ECTS FROM Courses C, Attendance A WHERE C.CID = A.CID AND A.SID = 7;**
- ... **A.SID = 8;**



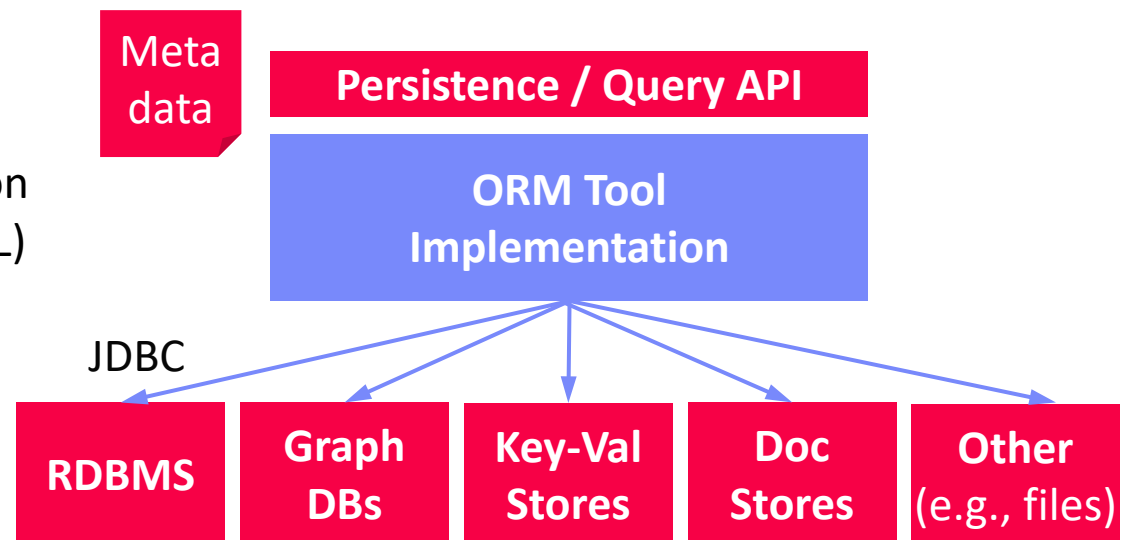
Overview Object-Relational Mapping

Goals of ORM Tools

- Automatic **handling of object persistence lifecycle** and querying of the underlying data stores (e.g., RDBMS)
- Reduced development effort → **developer productivity**
- Improved testing and independence of DBMS

Common High-Level Architecture

- **#1** Persistence definition (meta data → e.g., XML)
- **#2** Persistence API
- **#3** Query language / query API



History and Landscape

- **History of ORM Tools** (aka persistence frameworks)
 - Since 2000 J2EE EJB **Entity Beans** (automatic persistence and TX handling)
 - Since 2001 **Hibernate** framework (close to ODMG specification)
 - Since 2002 **JDO** (Java Data Objects) via class enhancement
 - 2006 **JPA** (**Java Persistence API**), reference implementation **TopLink**
 - 2013 JPA 2, reference implementation **EclipseLink**
 - Late 2000s/early 2010s: **explosion of ORM alternatives, but criticism**
 - **2012 - today**: ORM tools just part of a much more diverse eco system

- **Example Frameworks**

- <http://java-source.net/open-source/persistence>
- Similar lists for .NET, Python, etc



JPA – Class Definition and Meta Data

Entity Classes

- **Define persistent classes** via annotations
- Add details for IDs, relationship types, and specific behavior on updates
- Some JPA implementations require enhancement process as post compilation step

@Entity

```
public class Student {
    @Id
    private int SID = -1;
    private String FName;
    private String LName;
    @ManyToMany
    private List<Course> ...
}
```

Persistence Definition

- **Separate XML meta data**
META-INF/persistence.xml
- Includes connection details

```
<?xml version="1.0" encoding="UTF-8" ?>
<persistence
  xmlns="http://xmlns.jcp.org/xml/ns/persistence"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xsi:schemaLocation="http://xmlns.jcp.org/xml/ns/persistence
    http://xmlns.jcp.org/xml/ns/persistence/persistence.xml"
  <persistence-unit name="UniversityDB">
    <class>org.tugraz.Student</class>
    <class>org.tugraz.Course</class>
    <exclude-unlisted-classes/>
    <properties> ... </properties>
  </persistence-unit>
</persistence>
```

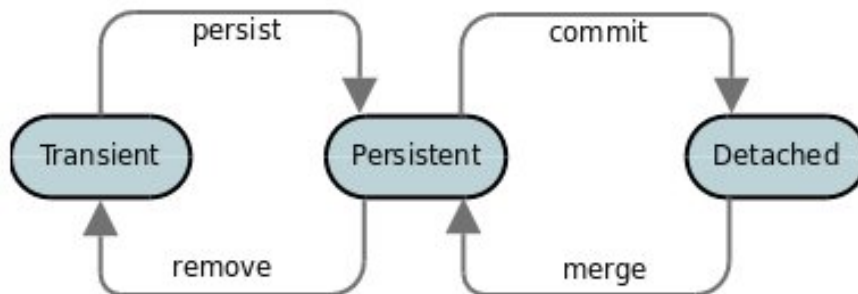
JPA – Object Modification

■ CRUD Operations

- Insert by making objects persistent
- Update and delete objects according to object lifecycle states

■ Lifecycle States

- Lifecycle state transitions via specific persistence contexts
- Explicit and implicit transitions



[Credit: Data Nucleus, JPA Persistence Guide (v5.2),

<http://www.datanucleus.org/products/accessplatform/jpa/persistence.html#lifecycle>]

```
EntityManager em = factory  
    .createEntityManager();
```

```
tx.begin();
```

```
Student s = new  
    Student(7, "Jane", "Smith");  
s.addCourse(new Course(...));  
s.addCourse(new Course(...));
```

```
em.persist(s);
```

```
tx.commit();  
em.close
```

JPA – Query Languages

■ JPQL: Java Persistence Query Language

- SQL-like object-oriented query language
- Parameter binding similar to embedded SQL

```
EntityManager em = factory
    .createEntityManager();
Query q = em.createQuery(
    "SELECT s FROM Student s
    WHERE s.age > :age");
q.setParameter("age", 35);
```

■ JPQL Criteria API

- JPQL syntax and semantics with a programmatic API

```
Iterator iter = q
    .getResultList().iterator();
while( iter.hasNext() )
    print((Student)iter.next());
```

```
CriteriaQuery<Student> q = bld.createQuery(Student.class);
Root<Student> c = q.from(Student.class);
q.select(c).where(bld.gt(c.get("age"), bld.parameter(...)));
```

■ Native SQL Queries

- Run native SQL queries if necessary
- Designed as “leaky abstraction”

```
em.createNativeQuery("SELECT *
    FROM Students WHERE Age > ?1");
```

Jdbi (Java Database Interface)

[<http://jdbi.org/>]

■ Jdbi Overview

- Fluent API built on top of JDBC w/ same functionality exposed
- Additional simplifications for row to object mapping

■ Example

```
Jdbi jdbi = Jdbi.create("jdbc:postgresql://.../db1234567");  
Handle handle = jdbi.open();
```

```
jdbi.registerRowMapper(Student.class, (rs, ctx)  
-> new Student(rs.getInt("sid"), rs.getString("lname")));
```

```
List<Student> ret = handle  
    .createQuery("SELECT * FROM Students WHERE LName = :name")  
    .bind(0, "Smith")  
    .map(Student.class)  
    .list();
```

A Critical View on ORM

■ Advantages

- **Simple CRUD operations** (insert/delete/update) and simple queries
- **Application-centric development** (see boundary crossing)

■ Disadvantages

- **Unnecessary indirections** and complexity (meta data, mapping)
- **Performance problems** (hard problem and missing context knowledge)
- **Application-centric development** (schema ownership, existing data)
- **Dependence** on evolving framework APIs

■ Sentiments (additional perspectives)

- Omar Rayward: Breaking Free From the ORM: Why Move On?, **2018**
medium.com/building-the-system/dont-be-a-sucker-and-stop-using-orms-190add65add4
- Vedra Bilopavlović: Can we talk about ORM Crisis?, **2018**
linkedin.com/pulse/can-we-talk-orm-crisis-vedran-bilopavlovi%C4%87
- Martin Fowler: ORM Hate, **2012** martinfowler.com/bliki/OrmHate.html

➔ **Awareness of strength and weaknesses / hybrid designs**

Conclusions and Q&A

■ Summary

- **Call-level Interfaces (ODBC/JDBC)** as fundamental access technology
- **Object-Relational Mapping (ORM)** frameworks existing (**pros and cons**)

■ Next Lectures

- **07 Physical Design and Tuning** [Nov 22]
- **08 Query Processing** [Nov 29]
- **09 Transaction Processing and Concurrency** [Dec 06]