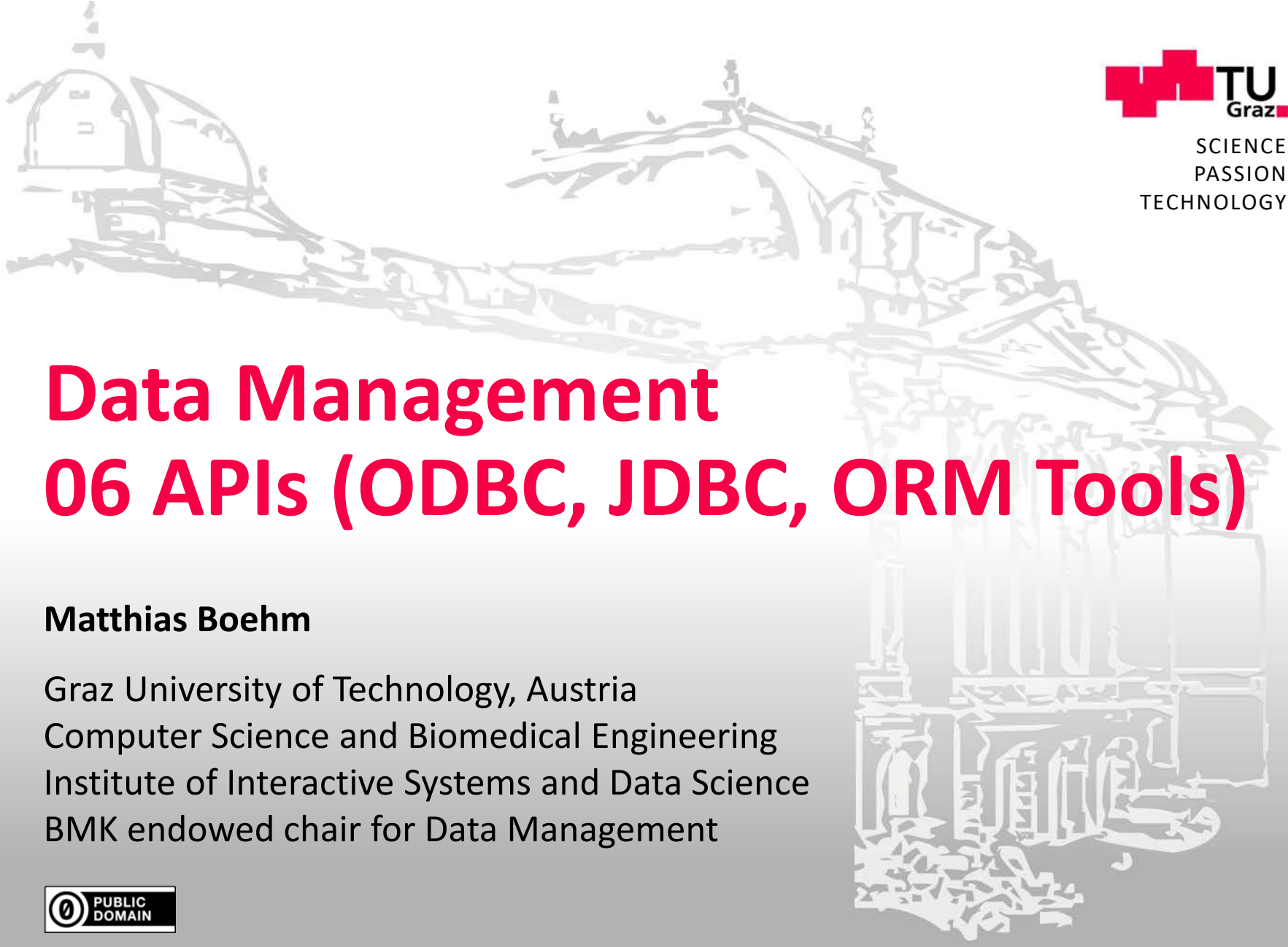

SCIENCE
PASSION
TECHNOLOGY

Data Management
06 APIs (ODBC, JDBC, ORM Tools)

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ISDS

Announcements/Org

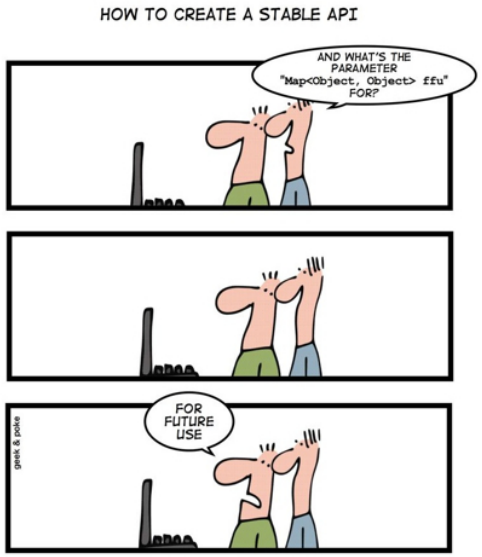
- **#1 Video Recording**
  - Link in **TeachCenter** & **TUbe** (lectures will be public)
  - Currently via https://tugraz.webex.com/meet/m.boehm

- **#2 Exercises**
  - Exercise 1 in progress of being graded
  - Exercise 2: **Nov 30 + 7 late days** in TeachCenter

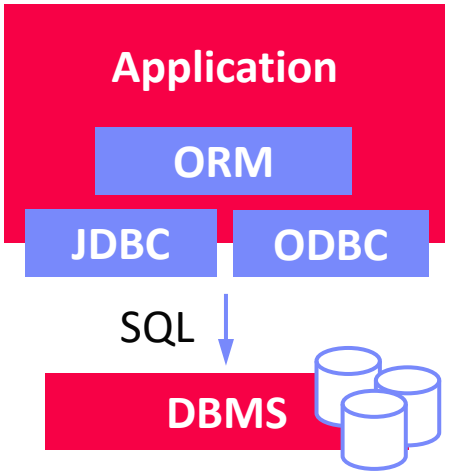
- **#3 Course Evaluation and Exam**
  - Evaluation period: **Jan 01 – Feb 15**
  - Exam dates: **Feb 04, 12.30pm** and **Feb 04, 5.30pm**
    (90+min written exam, start 10 late)

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**



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**

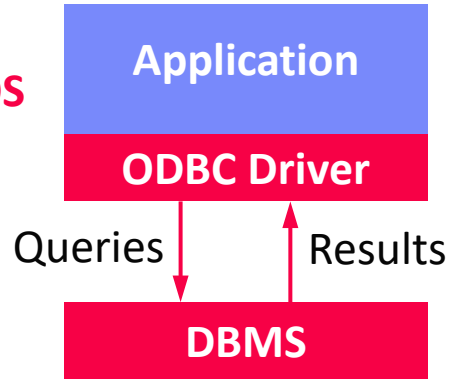
- **Example SQLJ**
  - Cursors with and without explicit variable binding

```
#sql iterator StudIter
   (int sid, String name);
StudIter iter;
#sql iter = {SELECT * FROM Students};

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

iter.close();
```

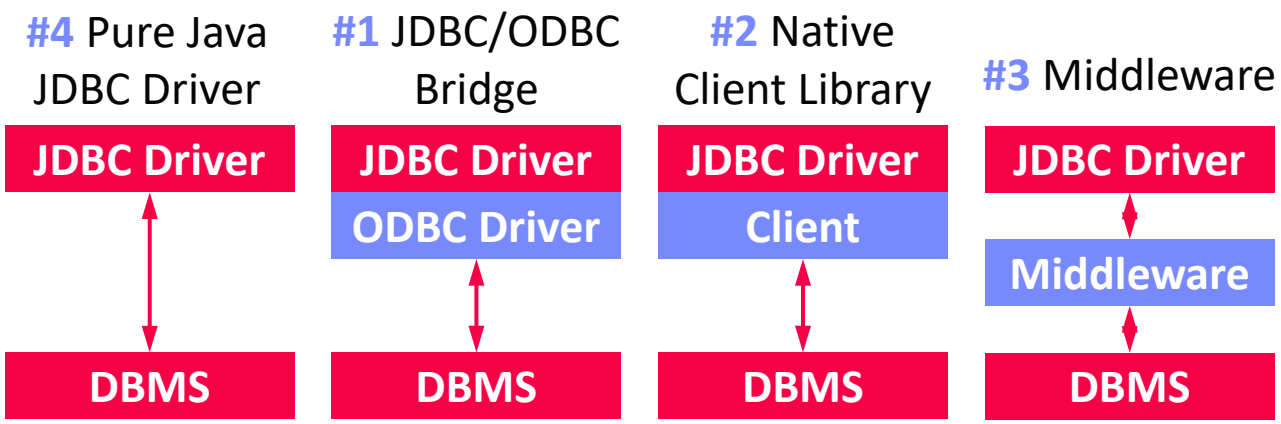
```
int id = 7;
String name;

#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

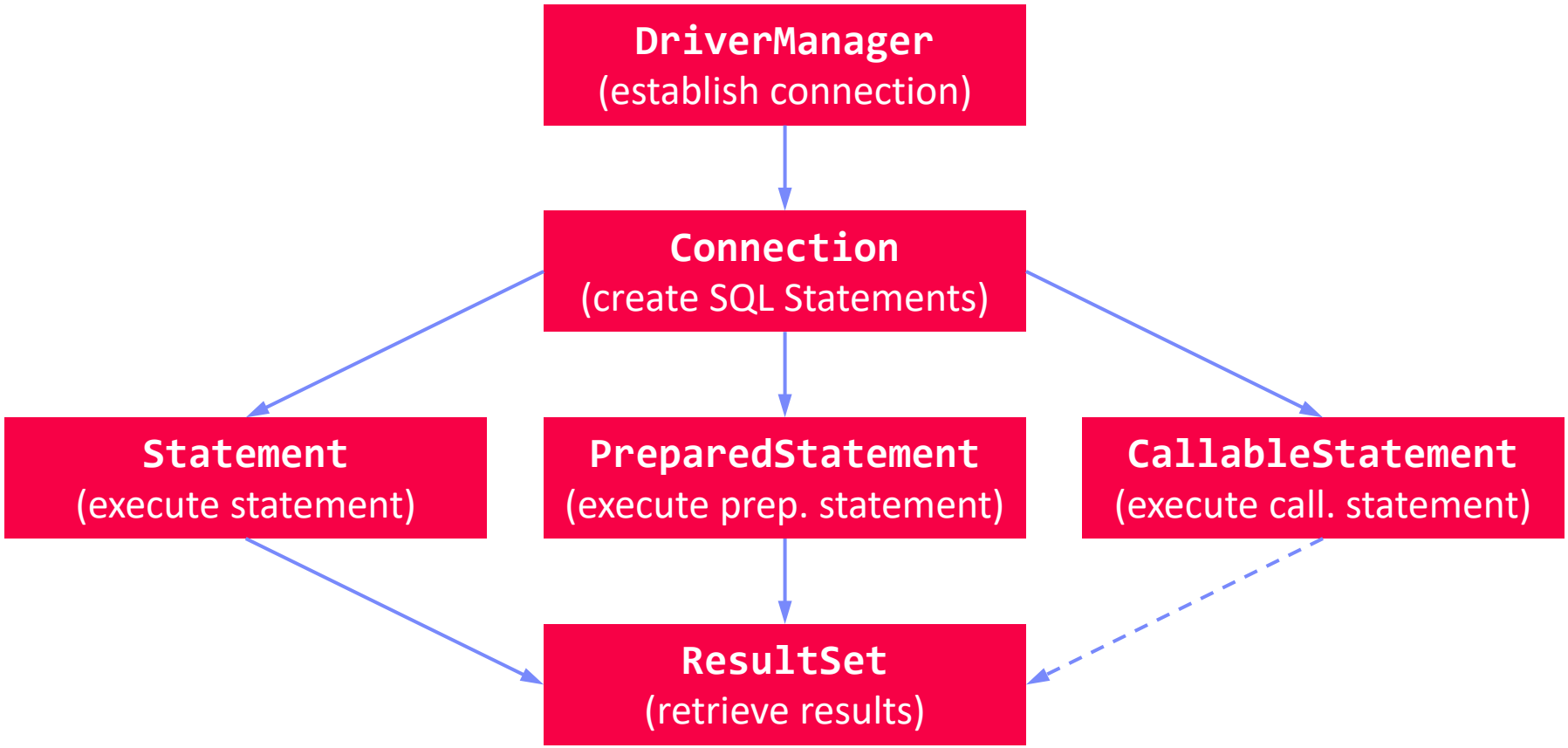


- **Java Database Connectivity (JDBC)**
  - **API for accessing databases independent of DBMS from Java**
  - Developed and released by Sun in **1997**, JDBC 4.0 (2006), JDBC 4.3 in Java 9
  - Most relational DBMS have JDBC implementations
  - Types of Drivers



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
  - Stateful handles representing user-specific DB sessions
  - JDBC driver is usually a jar on the class path
  - **Connection and statement pooling** for performance

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

```
META-INF/services/
java.sql.Driver
```

- **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

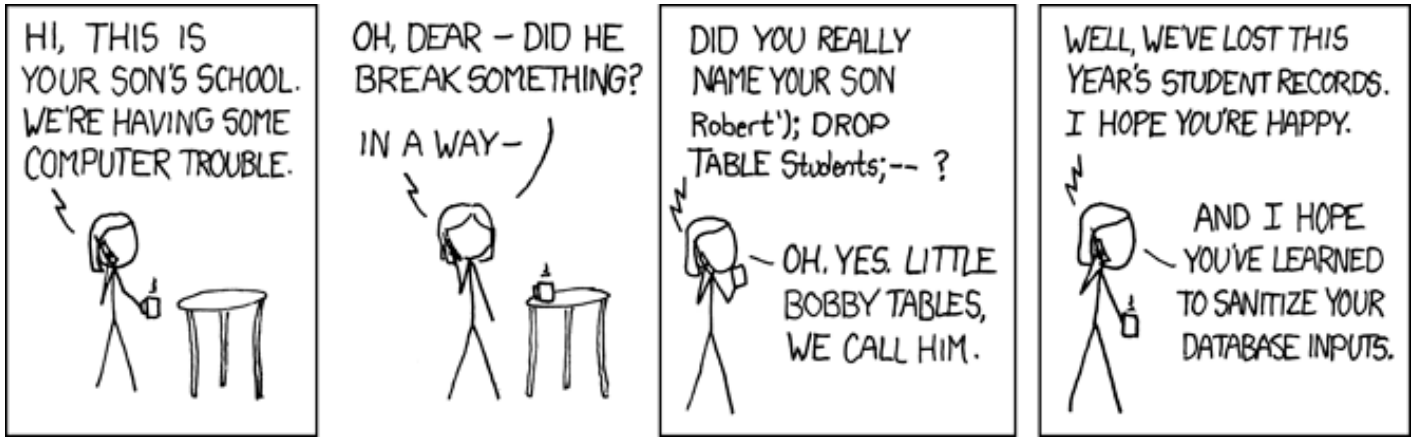
```
ResultSet rs = stmt.executeQuery(
   "SELECT SID, LName FROM Students");

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**
  - Result set
  - No output parameters

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

- **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();
```

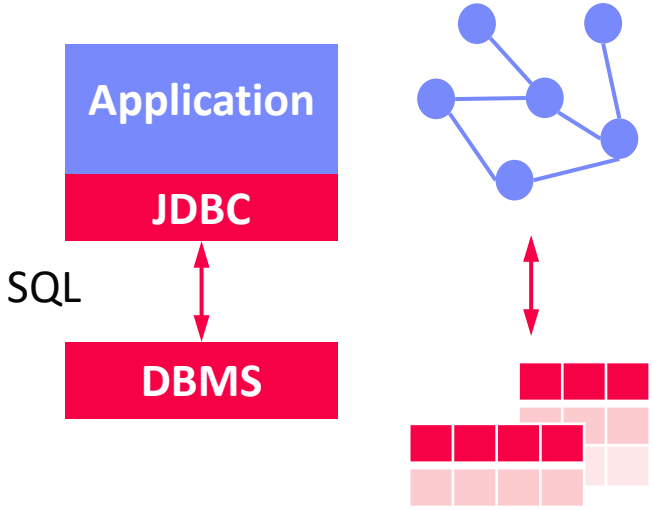
Performance Ref Implementation SS2020:
(36K authors, 28K papers, 101K author-papers)
* Auto Commit: 23.7s
* Batched Commits: 12.5s

Performance Ref Implementation SS2021:
(116K athletes, 158K team-athletes, 219K results)
* Auto Commit: 68.7s
* Batched Commits: 36.3s

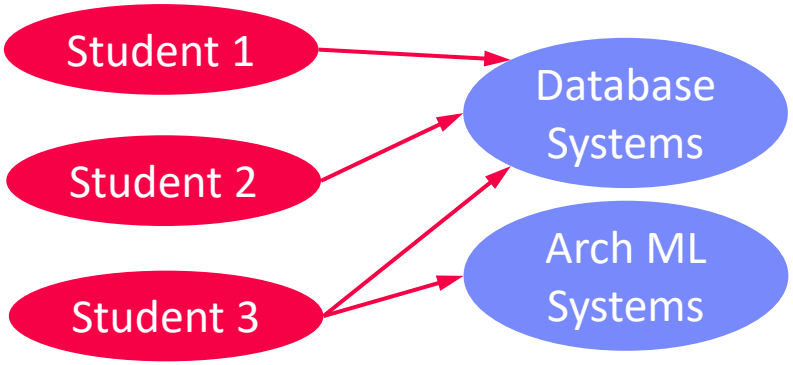
Object-Relational Mapping Frameworks

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**



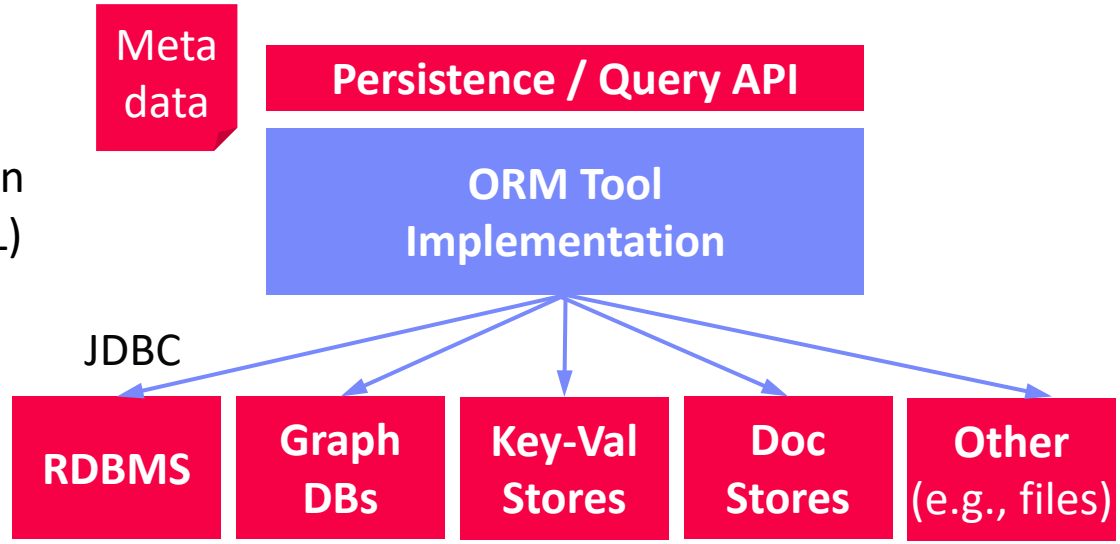
- **Example**
  - `SELECT * FROM Students`
  - `SELECT C.Name, C.ECTS FROM Courses C, Attendance A WHERE C.CID = A.CID AND A.SID = 7;`
  - `… A.SID = 8;`



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

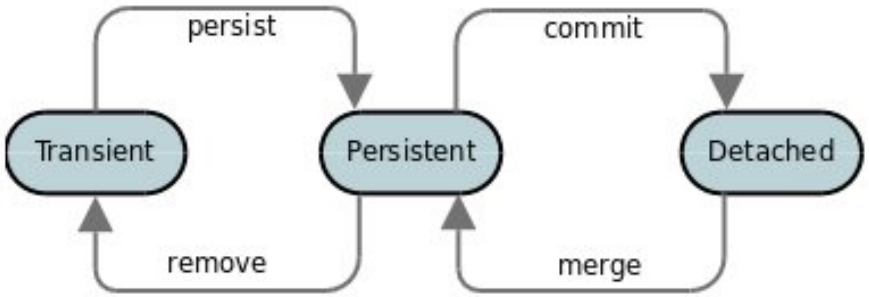
```
@Entity
public class Student {
   @Id
   private int SID = -1;
   private String Fname;
   private String Lname;
   @ManyToMany
   private List<Course> ...
}
```

- **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=... xsi:schemaLocation=...>
   <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




```
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
```

[**Credit:** Data Nucleus, JPA Persistence Guide (v5.2), http://www.datanucleus.org/products/accessplatform/jpa/persistence.html#lifecycle]

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);

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

- **JPQL Criteria API**
  - JPQL syntax and semantics with a programmatic API

```
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]