Database Systems
06 APIs (ODBC, JDBC, ORM Tools)

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Announcements/Org

- **#1 Video Recording**
  - Since lecture 03, video/audio recording
  - Link in TeachCenter & TUbe (but not public yet)
  - Issues lectures 04 and 05

- **#2 Statistics Exercise 1**
  - Submissions so far: 261+19/400 (DB), 63+6/96 (DB1)
  - double check draft status! at least, try!
  - Additional email submissions: 12
  - Last chance tomorrow EOD (including 7 late days)

- **#3 Exercise 2**
  - Task details introduced today
  - Submission opens Apr 22, Deadline: Apr 30 11.59pm
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

- Exercise 2: Query Languages and APIs
- Call-level Interfaces (ODBC/JDBC) and Embedded SQL
- Object-Relational Mapping Frameworks
Exercise 2:
Query Languages and APIs
Recap: Soccer World Cup 1954-2014

**Dataset**
- Public-domain, derived (parsed, cleaned) from Openfootball Worldcup Dataset
- Clone or download your copy from https://github.com/tugraz-isds/datasets.git
  ➔ Updated Apr 07 (improved data quality)

**Exercises**
- 01 Data modeling (relational schema)
- 02 Data ingestion and SQL query processing
- 03 Tuning, query processing, and transaction processing
- 04 Large-scale data analysis (distributed data ingestions and query processing)
Task 2.1: Schema Creation via SQL (3/25 points)

- **Schema creation via SQL**
  - Relies on lectures [04 Relational Algebra](#) and [05 Query Languages (SQL)](#)
  - #1 Setup DBMS PostgreSQL
  - #2 Create database db<studentID> and **setup relational schema**

- **Recommended Schema**
  - TODO (after Apr 9, 11.59pm)
Task 2.2 Data Ingestion via CLI (9/25 points)

- **Data Ingestion via ODBC/JDBC**
  - Relies on lectures 05 Query Languages (SQL) and 06 APIs (ODBC, JDBC)
  - #3 Write a program that performs stateful data ingestion

- **Two-Phase Ingestion**

```
IngestData ./1954_2010_Squads.csv \
  ./1954_2010_Matches.csv \
  ./1954_2010_Goals.csv <host>:<port>/<database>

IngestData ./2014_Squads.csv ./2014_Matches.csv \
  ./2014_Goals.csv <host>:<port>/<database>
```
Task 2.3: SQL Query Processing (10/25 points)

- **SQL Query Processing**
  - Relies on lecture 05 Query Languages (SQL)
  - #4 Write SQL script for the 10 given queries

- **Example Queries**
  - **Q01**: In which tournaments did Austria participate between 1954 and 2014 (inclusive)?
  - **Q05**: With how many distinct clubs where players of Germany affiliated between 2002 and 2014?
  - **Q06**: How many players from Sturm Graz ever participated in a world cup tournament.
  - **Q07**: Which player(s) shot more than two goals in a single game in 2014?
  - **Q10**: Construct the final group table for Group G of the 2014 tournament (matches, wins, draws, losses, goal difference, points), ranked by points and goal differences.
Task 2.4: Query Plans (3/25 points)

- Explain Query Plans
  - Relies on lecture 04 Relational Algebra
  - #5 Obtain and analyze execution plans of at least two queries

- Example
  - Recap: Participants and Locations of Database Research Self Assessment 2018
  - Text: 
    ```sql
    EXPLAIN VERBOSE SELECT L.location, count(*)
    FROM Participant P, Locale L
    WHERE P.lid = L.lid
    GROUP BY L.location HAVING count(*) > 1
    ```

---

Explanation of Query Plans

- **Base relations**
- **Projection π**
- **Join**
- **Grouping γ**
- **Selection σ**
Call-level Interfaces (ODBC/JDBC) and Embedded SQL
Call-level Interfaces vs Embedded SQL

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

- **Call-level Interfaces**
  - Standardized in ISO/IEC SQL – Part 3: CLI
  - API of defined functions for dynamic SQL
  - **Examples:** ODBC, JDBC, Python DB-API
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

```java
#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**
  - #1 JDBC/ODBC Bridge
  - #2 Native Client Library
  - #3 Middleware
  - #4 Pure Java JDBC Driver

  **Note:** Reuse of drivers from open source DBMS
JDBC Components and Flow

**DriverManager**
- (establish connection)

**Connection**
- (create SQL Statements)

**Statement**
- (execute statement)

**PreparedStatement**
- (execute prep. statement)

**CallableStatement**
- (execute call. statement)

**ResultSet**
- (retrieve results)
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

- **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

```java
Connection conn = DriverManager.getConnection("jdbc:postgresql://localhost:5432/db1234567", username, password);
Class.forName("org.postgresql.Driver");
META-INF/services/java.sql.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

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

```java
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

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));
}
```
JDBC Prepared Statements

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

  ➔ **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();
```

- **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

```java
CallableStatement cstmt = conn.prepareCall("{CALL prepStudents(?, ?)}");
cstmt.setInt(1, 2019);
cstmt.registerOutParameter(2, Types.INTEGER);
cstmt.executeQuery();
int rows = cstmt.getInt(2);
```
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, unrepeateable read, phantom R**)
  - REPEATABLE READ (**lost update, dirty read, unrepeateable read, phantom R**)
  - SERIALIZABLE (**lost update, dirty read, unrepeateable 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**)
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

<table>
<thead>
<tr>
<th>ORM Tool Implementation</th>
<th>Meta data</th>
<th>Persistence / Query API</th>
</tr>
</thead>
<tbody>
<tr>
<td>JDBC</td>
<td>RDBMS</td>
<td>Graph DBs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Key-Val Stores</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Doc Stores</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Other (e.g., files)</td>
</tr>
</tbody>
</table>
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](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

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

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

```xml
<?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

```java
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

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

- **Exercise Reminder**
  - Exercise 1: **Last chance tomorrow EOD** (including 7 late days)
  - Exercise 2: Submission opens Apr 22, deadline: **Apr 30 11.59pm**

- **Next Lectures**
  - Apr 29: **07 Physical Design and Tuning**
  - May 6: **08 Query Processing**
  - May 13: **09 Transaction Processing and Concurrency**