Object-Oriented Databases
Object Persistence

- Object-Relational Mappings and Frameworks
- Serialisation
- Persistent Programming Languages

Principles of Persistence

- Data has to outlive the execution of the program
- Independence
  - persistence of data object independent of how the program manipulates that data object
- Data type orthogonality
  - all data types should be allowed the full range of persistence
- Identification
  - choice of how to provide and identify persistence at language level independent of choice of data objects in language
- Implicitness
  - data does not have to be moved or copied to be made persistent

Uniformity

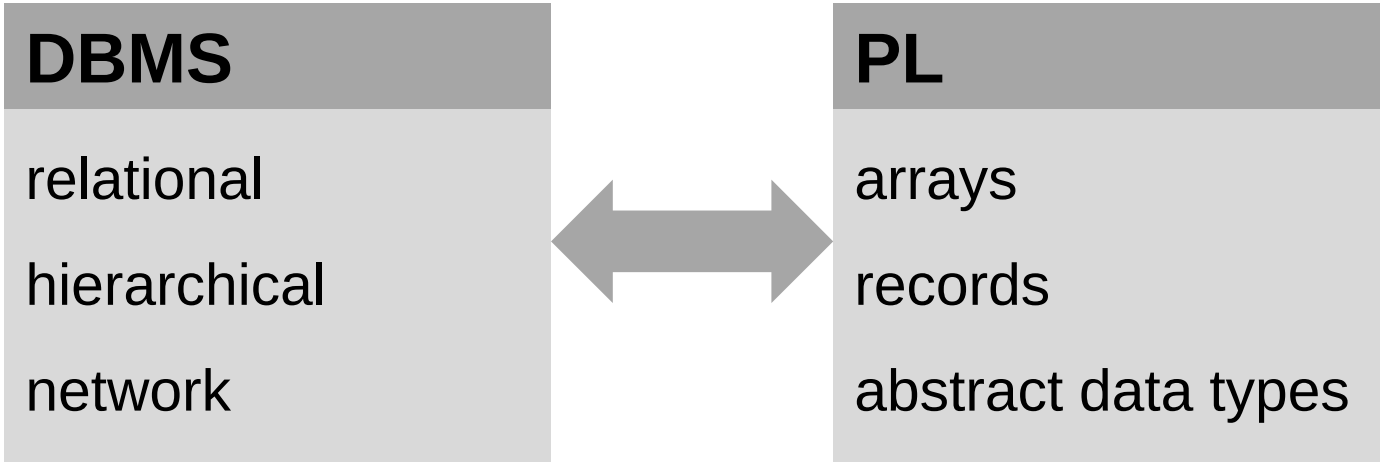
- Treat data values uniformly, independent of
  - longevity
  - size
  - type
- Achieve uniformity for all aspects of system services
  - data definition
  - operations
  - integrity
  - concurrency control
  - distribution

Range of Persistence

1	Transient results in expression evaluation
2	Local variables
3	Global variables and heap items
4	Data that lasts a whole execution of a program
5	Data that lasts for several executions of several programs
6	Data that lasts for as long as a program is being used
7	Data that outlives a successions of versions of such a program
8	Data that outlives versions of the persistent support system

Traditional Programming Languages

- Facilities for the manipulation of data whose lifetime does not extend beyond activation of the program
- Storage of data requires mapping to and from files or DBMS



Disadvantages

- Effort to understand and manage mappings from program data to stored data
  - IBM Report (1978)
    «30% of application code is concerned with transferring data to and from files or DBMS»
- Data type protection of programming language system often lost in the mapping

Databases and Programming Languages

- Database and programming languages communities research and develop products independently despite having to provide many similar services
- Database focus
  - preserve large volumes of data reliably
  - support many processes operating against data efficiently
- Programming language focus
  - help programmers be precise
  - make programs understandable

Databases and Programming Languages

- Separate development and consequent inconsistencies tend to perpetuate and grow
- Intellectual and software investment in each camp goes against adoption of other's ideas
- View of database from programming language
  - Mess of incomprehensible ad hoc design
- View of programming language from database
  - Programming languages unhelpful with real problems such as bulk types, persistence, concurrency and transactions

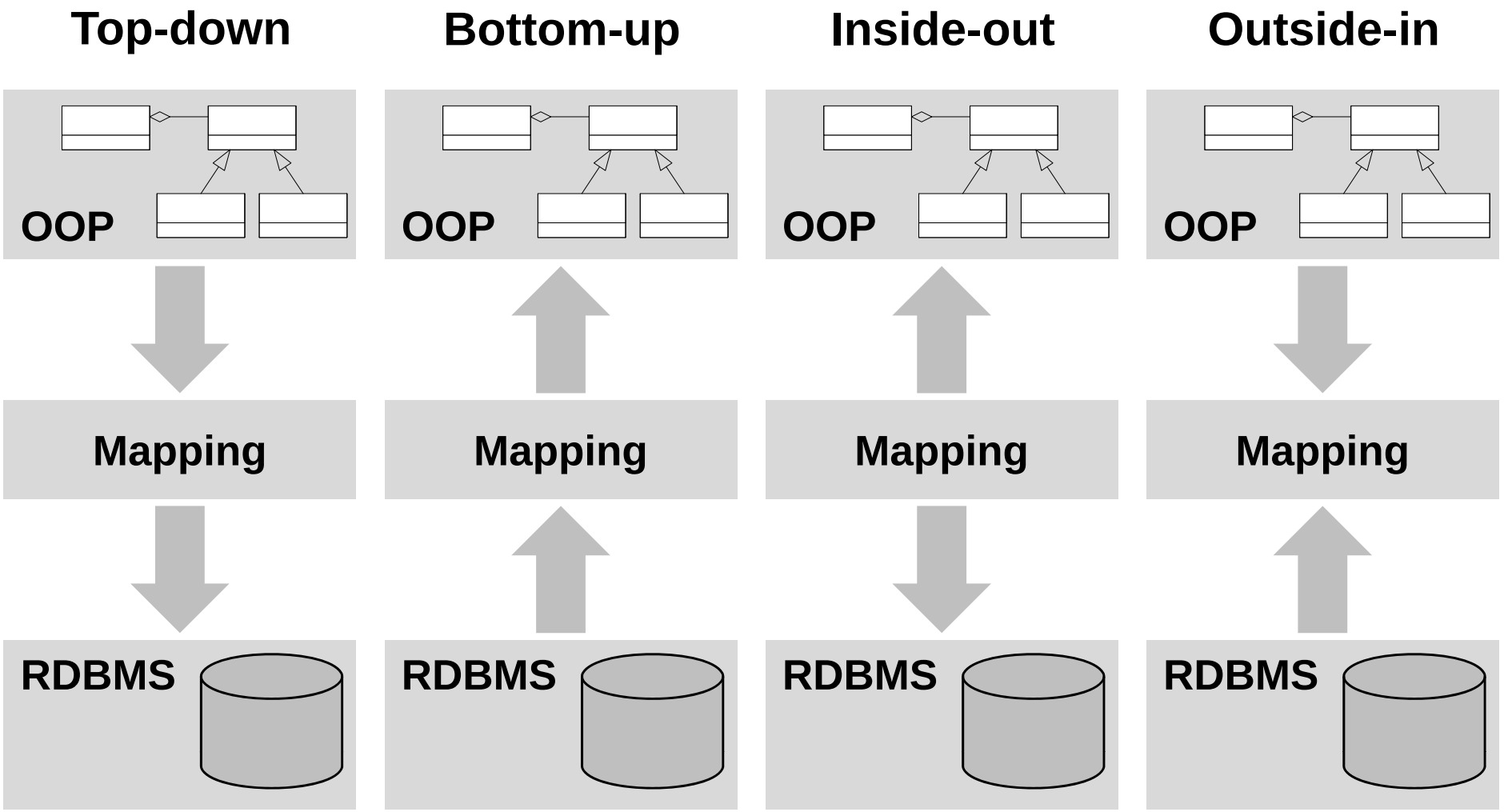
Two Approaches

- Glue current underlying technologies together
  - “glue-ware”, e.g. object-relational mappings and frameworks
  - hide technologies behind sufficient “standard” interface
  - underlying differences in semantics ultimately show through
- Complete computational environments
  - Java object serialisation
  - persistent programming languages

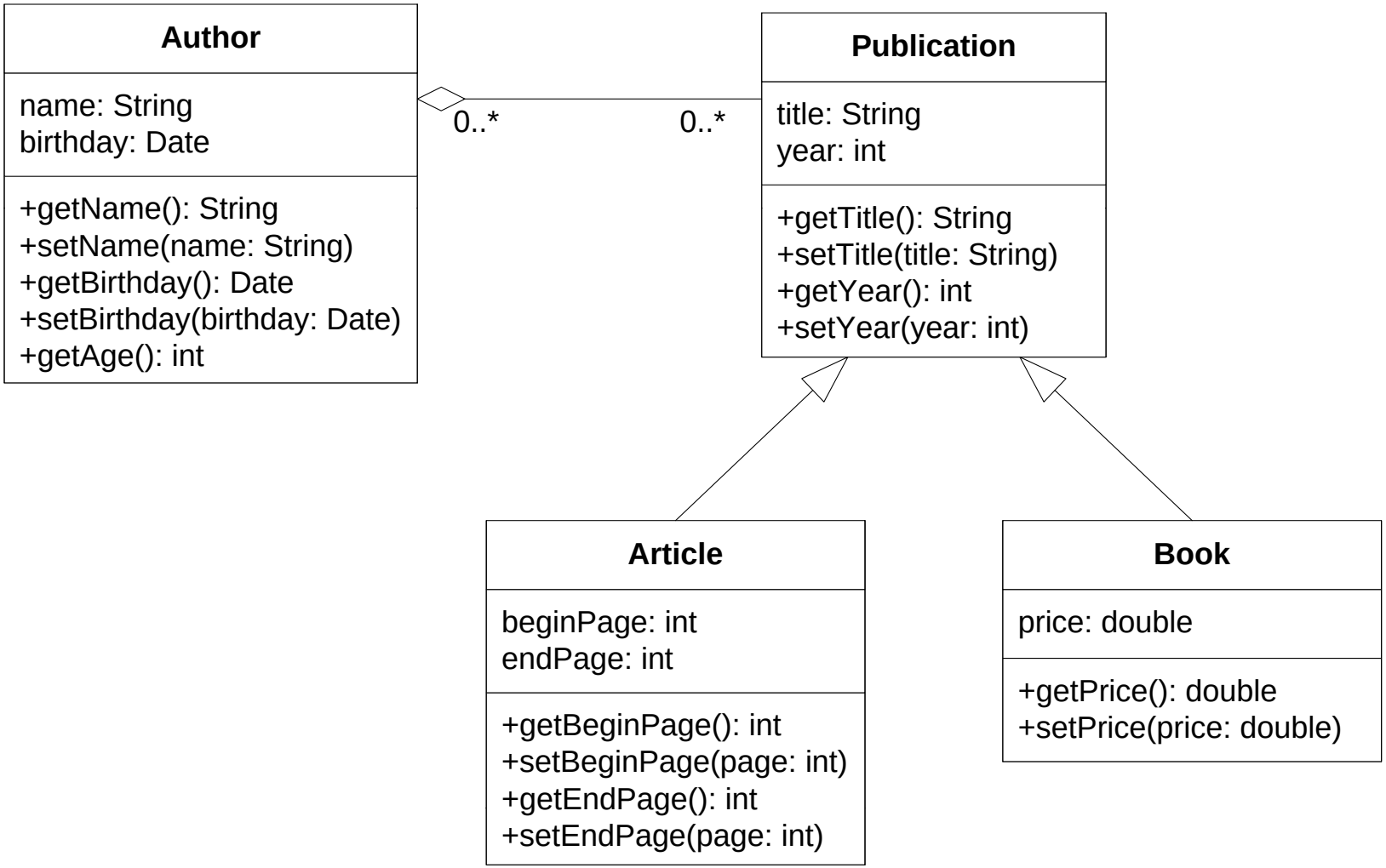
Object-Relational Mappings

- Map object-oriented domain model to relational database
- Free developer of persistence-related programming task
- Hibernate
  - maps Java types to SQL types
  - transparent persistence for classes meeting certain requirements
  - generates SQL for more than 25 dialects behind the scenes
  - provides data query and retrieval using either HQL or SQL
  - can be used stand-alone with Java SE or in Java EE applications
- Java Persistence API (JPA)
  - Enterprise Java Beans Standard 3.0
  - introduced annotations to define mapping
  - **`javax.persistence`** package

Designing a Object-Relational Mapping



Example Class Hierarchy



Mapping Classes

```
public class Author {

   private long id;
   private String name;
   private Date birthday;
   private Set<Publication> publications;

   /**
    * No-argument constructor is a required by Hibernate.
    */
   Author() {   }

   public Author(String name) {
      this.name = name;
      this.publications =
         new HashSet<Publication>();
   }
   ...
}
```

Mapping Classes

```
<?xml version="1.0"?>
<!DOCTYPE hibernate-mapping PUBLIC
        "-//Hibernate/Hibernate Mapping DTD 3.0//EN"
        "http://hibernate.sourceforge.net/hibernate-mapping-3.0.dtd">

<hibernate-mapping>
   <class name="ch.ethz.globis.oodb.hibernate.domain.Author"
      table="AUTHORS">
      <id name="id" column="AUTHOR_ID">
         <generator class="native" />
      </id>
      <property name="name" />
      <property name="birthday" />
      <set name="publications" table="AUTHORSPUBLICATIONS" cascade="all">
         <key column="AUTHOR_ID" />
         <many-to-many column="PUBLICATION_ID"
            class="ch.ethz.globis.oodb.hibernate.domain.Publication" />
      </set>
   </class>
</hibernate-mapping>
```

Mapping Associations

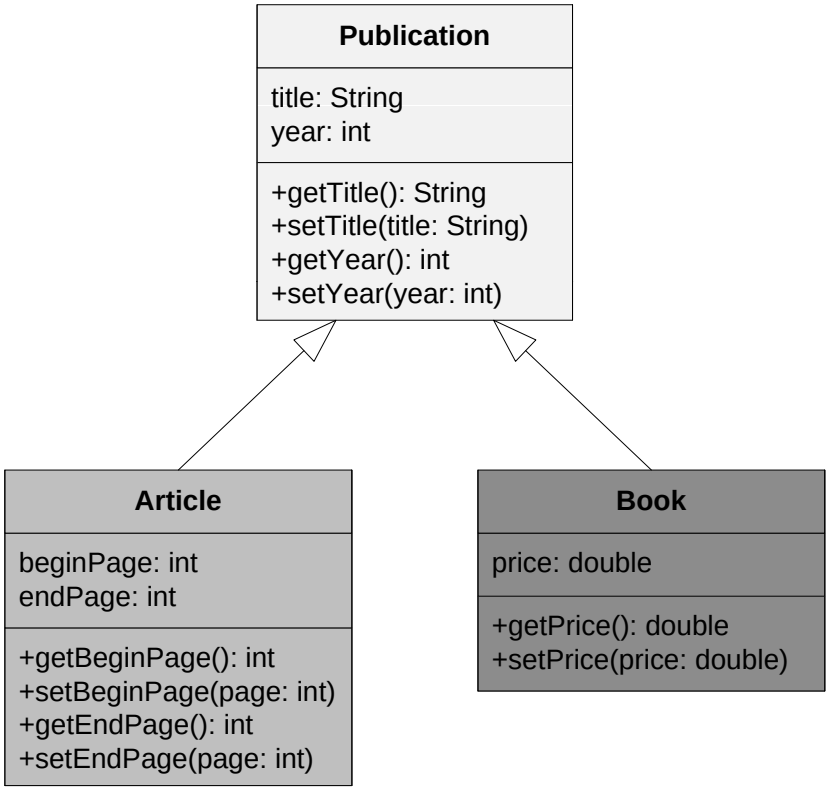
- Unidirectional and bidirectional associations
- Unordered and ordered associations
- Association cardinality types
  - one-to-one
  - many-to-one and one-to-many
  - many-to-many
- Join Tables to map complex associations

```
CREATE TABLE AUTHOR(AUTHOR_ID BIGINT NOT NULL PRIMARY KEY, ...)
CREATE TABLE AUTHORSPUBLICATIONS(
   AUTHOR_ID BIGINT NOT NULL,
   PUBLICATION_ID BIGINT NOT NULL,
   PRIMARY KEY(AUTHOR_ID, PUBLICATION_ID))
CREATE TABLE PUBLICATION(PUBLICATION ID BIGINT NOT NULL PRIMARY KEY, ... )
```

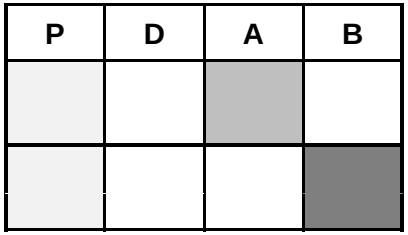
Mapping Inheritance

- Multiple strategies to map inheritance
  - one table per class hierarchy
  - one table per subclass
  - one table per concrete class
- Mapping strategies can be mixed for different branches of an inheritance hierarchy
- Implicit polymorphism
  - one table per concrete class
  - common interface is not mentioned in the mapping
  - common properties are mapped in every table

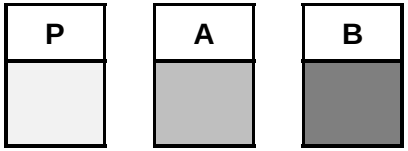
Mapping Strategies



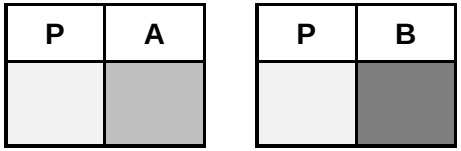
- **One Table Per Class Hierarchy**



- **One Table Per Subclass**



- **One Table Per Concrete Class**



One Table Per Class Hierarchy

```
<class name="Publication" table="PUBLICATION">
   <id name="id" type="long" column=" PUBLICATION_ID">
      <generator class="native"/>
   </id>
   <discriminator column="PUBLICATION_TYPE" type="string"/>
   <property name="title" column="TITLE"/>
   <property name="year" column="YEAR"/>
   <subclass name="Article" discriminator-value="ARTICLE">
      <property name="beginPage" column="BEGIN_PAGE"/>
      <property name="endPage" column="END_PAGE"/>
   </subclass>
   <subclass name="Book" discriminator-value="BOOK">
      <property name="price" column="PRICE"/>
   </subclass>
 </class>
```

One Table Per Subclass

```
<class name="Publication" table="PUBLICATION">
   <id name="id" type="long" column="PUBLICATION_ID">
      <generator class="native"/>
   </id>
   <property name="title" column="TITLE"/>
   <property name="year" column="YEAR"/>
   <joined-subclass name="Article" table="ARTICLE">
      <key column="PUBLICATION_ID"/>
      <property name="beginPage" column="BEGIN_PAGE"/>
      <property name="endPage" column="END_PAGE"/>
   </joined-subclass>
   <joined-subclass name="Book" table="BOOK">
      <key column="PUBLICATION_ID"/>
      <property name="price" column="PRICE"/>
   </joined-subclass>
</class>
```

One Table Per Concrete Class

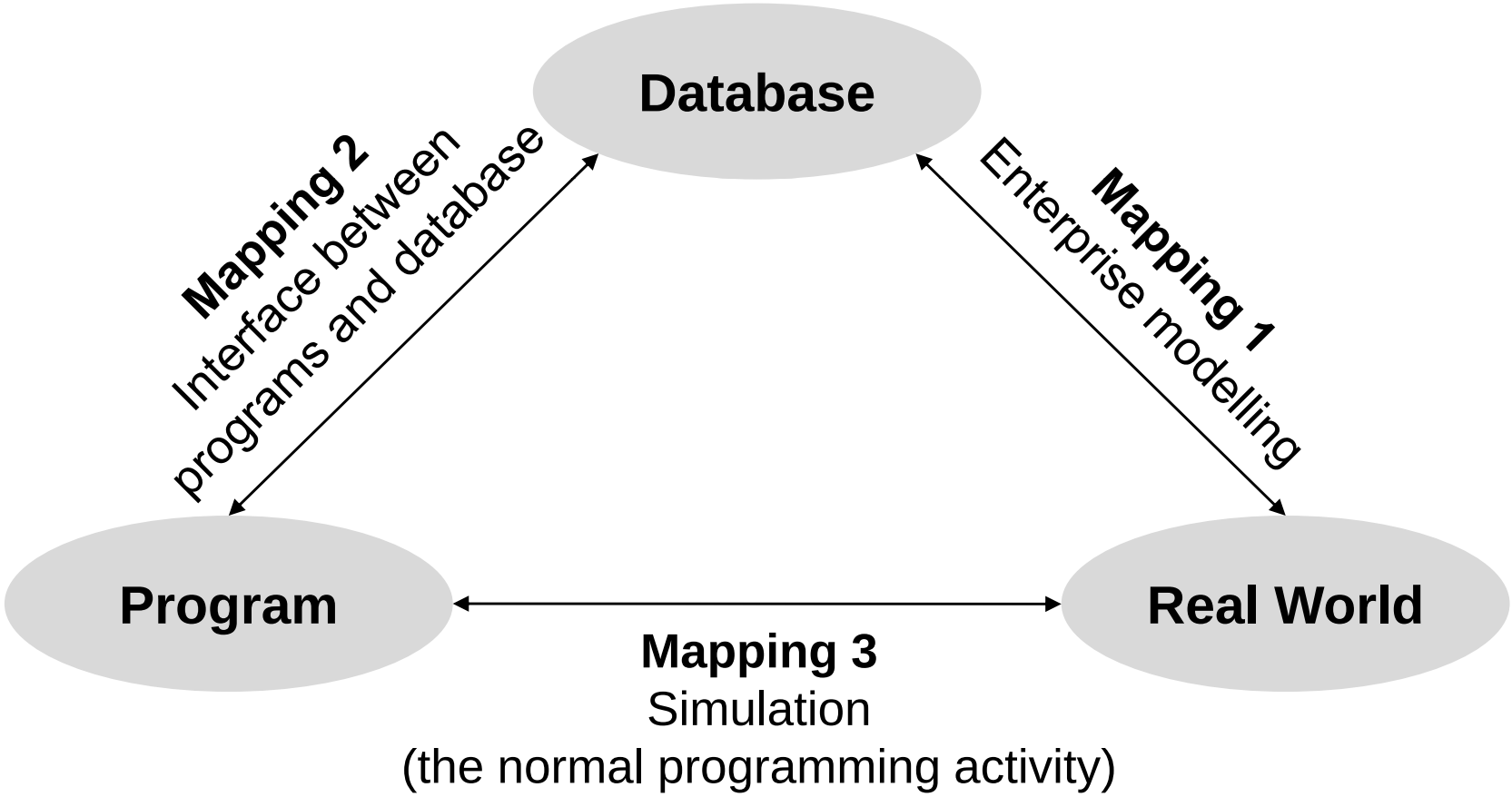
```
<class name="Publication">
   <id name="id" type="long" column="PUBLICATION_ID">
      <generator class="sequence"/>
   </id>
   <property name="title" column="TITLE"/>
   <property name="year" column="YEAR"/>
   <union-subclass name="Article" table="ARTICLE">
      <property name="beginPage" column="BEGIN_PAGE"/>
      <property name="endPage" column="END_PAGE"/>
   </union-subclass>
   <union-subclass name="Boook" table="BOOK">
      <property name="price" column="PRICE"/>
   </union-subclass>
</class>
```

Using Annotations

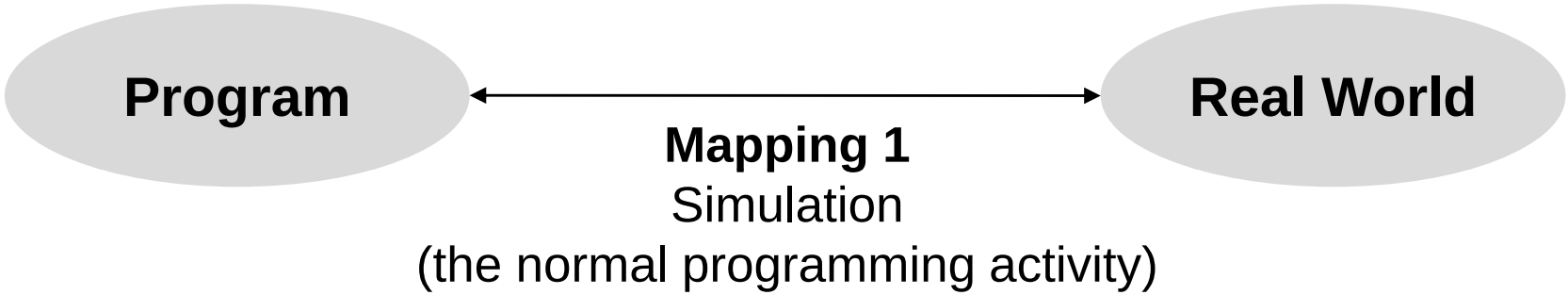
- Java annotations have been introduced in Java 5
- Enterprise Java Beans 3.0 includes Java Persistence API
- Uses Java annotations instead of XML descriptors to capture mappings
- Standardises object-relational mappings
- Hibernate implements JPA

```
public class Author {

   @Id @GenerateValue
   private long id;
   private String name;
   private Date birthday;

   @ManyToMany(fetch=FetchType.EAGER)
   @JoinTable(
      name="PUBLICATIONSAUTHORS",
      joinColumns=@JoinColumn(
         name="AUTHOR_ID",
         referencedColumnName="id"),
      inverseJoinColumns=@JoinColumn(
         name="PUBLICATION_ID",
         referencedColumnName="id")
      )
   )
   private Set<Publication> pubs;

}
```

Use of Database and Programming Language



Complete Computational Environments



- All data supported consistently whatever happens
- Programmers only have to understand one model and maintain one mapping

Java Programming Language

- Powerful object model
- Strong typing
- Automatic storage management
- Concurrency support

- Objects do not outlive execution of virtual machine
- Java object serialisation

Java Object Serialisation

- Stores and retrieves objects in serial form
- Maintain type safety
- Extensible mechanism
  - provide default mechanism
  - per class implementation for customisation
  - allow object to define its external format
- Persistence by reachability handles complex objects
- Intention
  - data exchange
  - "lightweight persistence"
  - object archiving for later use by same program

Java Object Serialisation Framework

- Interfaces for persistent object
  - **`Serializable`**
  - **`Externalizable`**
- Object streams to handle output and input
  - **`ObjectOutputStream`**
  - **`ObjectInputStream`**
- Interfaces defining output and input
  - **`ObjectOutput`** extends **`DataOutput`**
  - **`ObjectInput`** extends **`DataInput`**

Java Object Serialisation

- No special methods have to be implemented
- Method **`writeObject`** of class **`ObjectOutputStream`**
  - serialises objects
  - traverses references to other objects in the object graph
  - uses handles to preserve sharing and circular references
- Type information is stored together with objects
- Entire object graphs are read and written at same time
- Special handling is only required for
  - arrays
  - enum constants
  - objects of type **`Class`**, **`ObjectStreamClass`** and **`String`**

Java Object Serialisation

- A serialisable class must do the following
  - implement the **`java.io.Serializable`** interface
  - identify the fields that should be serialisable
    - non-transient and non-static fields are serialised by default
    - use the **`serialPersistentField`** member or the **`transient`** keyword
  - have access to the no-argument constructor of its first non-serialisable superclass
- Optionally, the class can define the following methods
  - **`writeObject`** controls saved data or appends information
  - **`readObject`** reads data corresponding to **`writeObject`**
  - **`writeReplace`** nominates a replacement object to be written
  - **`readResolve`** designates a replacement object when reading from the input stream

Java Object Serialisation Example

```
public class Address extends Serializable {
   // Class Definition
}
```

```
// Serialise an object
FileOutputStream f = new FileOutputStream("tmp");
ObjectOutput out = new ObjectOutputStream(f);
out.writeObject(new Address());
out.flush();
out.close();
```

```
// Deserialise an object
FileInputStream f = new FileInputStream("tmp");
ObjectInput in = new ObjectInputStream(f);
Address address = (Address) in.readObject();
in.close();
```

Versioning of Serialisable Objects

- Simple versioning of serialised objects supported
- Bidirectional communication between versions of a class
- Evolved class is responsible to maintain contract established by non-evolved class
  - evolved class must not break assumptions about the interface provided by original version
  - later version must provide sufficient and equivalent information to allow earlier version to continue to satisfy non-evolved contract
- Compatible changes are changes that do not affect the contract between the class and its callers
- Field **`serialVersionUID`** to identifies class version

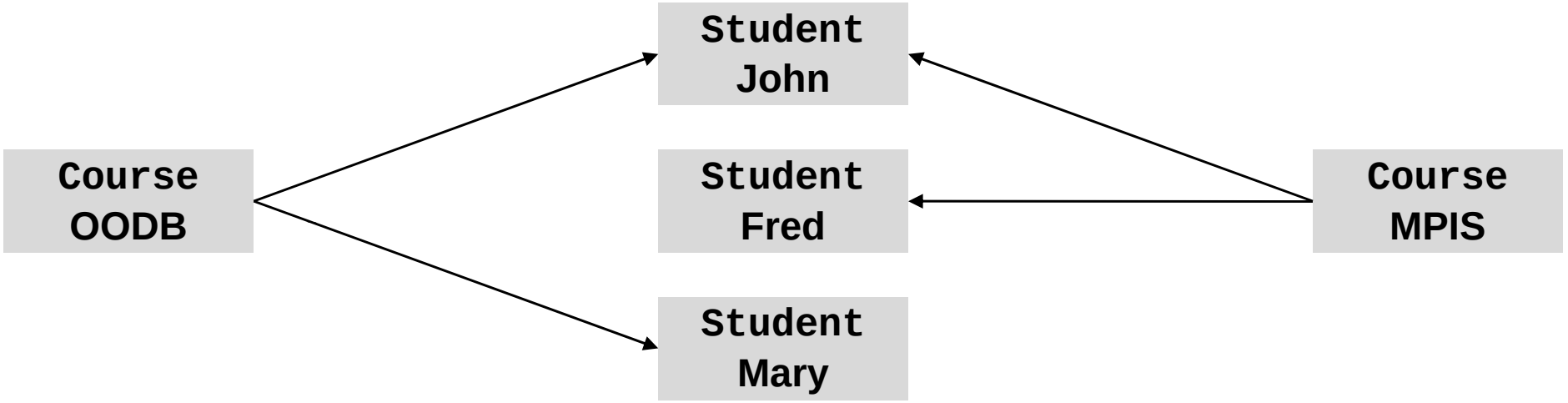
Incompatible and Compatible Changes

- Delete fields
- Move classes within the hierarchy
- Change non-static fields to static or non-transient fields to transient
- Change declared type of a field
- Change **`writeObject`** and **`readObject`** methods
- Change class from **`Serializable`** to **`Extenalizable`** or vice-versa
- Change from non-enum type to enum type
- Remove either **`Serializable`** or **`Extenalizable`**
- Adding **`writeReplace`** or **`readResolved`** method
- Add fields
- Add classes
- Remove classes
- Adding **`writeObject`** or **`readObject`** method
- Remove **`writeObject`** or **`readObject`** method
- Add **`Serializable`**
- Change access to a field
- Change static fields to non-static or transient fields to non-transient

Problems of Java Object Serialisation

- Not orthogonal
  - serialisable classes need to implement a special interface
- Not complete
  - class definition is not serialised along with objects
  - problems with evolution and versioning
- Not persistent
  - object identity is lost
  - relationship between static and instance variables is lost
- Not scalable
  - entire object graphs are serialised and deserialised
- Not transactional, recoverable nor concurrent

Problems of Object Identity



- If two object graphs are stored in separate serialisations, common substructures are duplicated when deserialised
- Similar effect occurs if a program re-reads data structure while holding parts of the original structure in memory
- Programmer must take great care when hashing objects

Persistent Programming Languages

- Orthogonal persistence
  - all objects may be made persistent
- Completeness or transitivity
  - everything needed to use persistent data must be preserved
  - object behaviour must also be preserved
  - persistence by reachability from named, persistent root objects
- Persistence independence
  - indistinguishable whether code operating on transient or persistent data
  - semantics of the language must not change
  - minimise what programmers have to learn to use persistence

PJama

- Persistent Java (PJama)
  - University of Glasgow
  - Sun Microsystems
- Assumptions
  - Java is used as implementation language for many applications
  - many applications will require long-term data management
- Goals
  - Orthogonality, persistence independence, durability, scalability, schema evolution, platform migration, endurance, openness, transactional, performance

PJama Architecture

- Standard Java applications
- Persistence is provided by a modified Java virtual machine
  - object faulting
  - promotion to persistence
  - recoverable and transactional operation
- Sphere
  - persistent object store
  - general purpose
  - supports disk garbage collection, evolution, …

Creating Persistent Data

```
public class Department {
   ...
   public static void main (String[] args) {
      // start transaction
      Course c = new Course("OODB");
      Person p = new Person("Fred");
      try {
         PJavaStore pjs = PJavaStore.getStore();
         pjs.newPRoot("OODB", c);
      } catch (PJSException e) {
         ...
      }
      // implicit commit
   }
}
```

Persistence Independence

```
Hashtable courses = new Hashtable();
try {
   PJavaStore pjs = PJavaStore.getStore();
   pjs.newPRoot("Courses", courses);
} catch (PJSException e) {
   ...
}
...
Student student = new Student("Fred");
Course oodb = new Course("Object Oriented Databases");
Course webeng = new Course("Web Engineering");
courses.add(oodb.getTopic(), oodb);
oodb.attendedBy(student);
webeng.attendedBy(student);
...
courses.add(webeng.getTopic(), webeng);
...
```

Accessing Persistent Objects

```
...
try {
   PJavaStore pjs = PJavaStore.getStore();
   Hashtable courses = (Hashtable) pjs.getPRoot("courses");
} catch (PJSException e) {
   ...
}
...
Course oodb = (Course) courses.get("Object Oriented Databases");
oodb.display();
...
```

Achievements of PJama

- Type safety
  - class information also stored in the persistent store
  - direct or indirect object access through named persistent roots
  - matching then performed of expected type and actual type
- Orthogonality
  - achieved approximation good enough for many applications
  - open issues with JDBC, CORBA and **`java.lang.Thread`**
- Persistence independence
  - no changes to language, core classes or compiler
  - persistence provided via additional API consisting mainly of methods of class **`PJavaStore`**

Achievments of PJama

- Durability
  - recovery points through explicit "stabilize" calls
- Endurance
  - Issues with recovery, schema evolution and platform migration that require application to be restarted
- Transactional
  - simple default model with implicit start and commit
  - different transaction models possible through specialisation of the class **`TransactionShell`**
- Performance
  - modified JVM/JIT is 15%-20% slower than unmodified JVM/JIT

Literature

- Christian Bauer and Gavin King: **Java Persistence with Hibernate**, *Manning Publications 2006*
- M. Atkinson: **Persistence and Java – A Balancing Act**, In: *Proceedings of Conference on Objects and Databases, Springer Verlag, 2000*

Next Week
db4o: Part 1

- Managing Databases, Storing and Retrieving Objects
- Query by Example, Native Queries, SODA
- Simple and Complex Objects, Activation, Transactions