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Chapter 6 – Object Persistence, Relationships and Queries

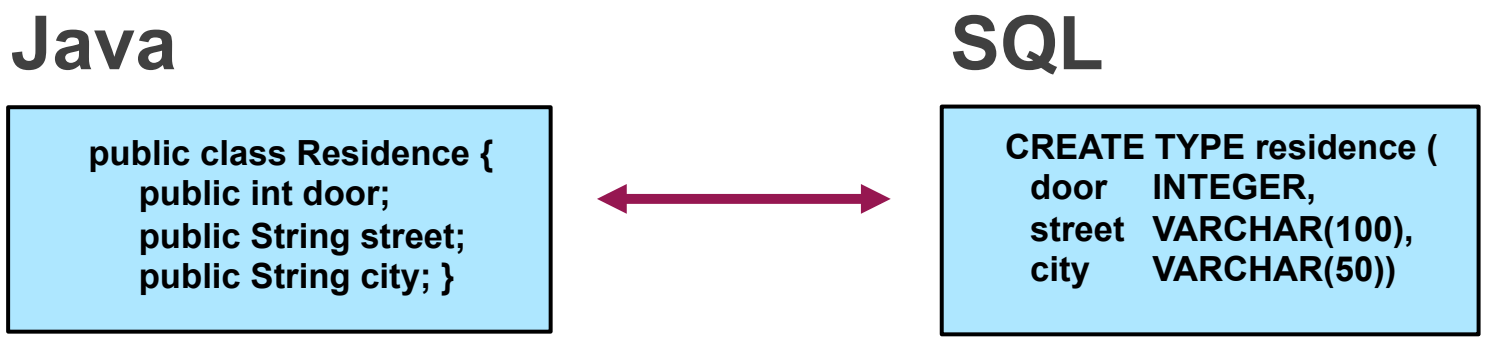
Object Persistence

- Persistent object:
  - Lifetime of a persistent object may exceed the execution of individual applications
- Goals
  - shield the application from existing data stores
    - data model, query language, API, schema
  - simplification of programming model for persistent data access and management
    - no explicit interaction with data source using SQL, JDBC, …
    - eliminate "object/relational impedance mismatch"

	objects	relations
structure	•complex values, collections •class hierarchies (inheritance)	•flat tables
relationships	•binary •1:1, 1:n, n:m (using collections) •uni-/bi-directional references	•binary •1:1, 1:n •value-based, symmetric
behavior	•methods	
access paradigm	•object navigation (follow references)	•declarative, set-oriented (queries)

Object-Relational DBMS and JDBC

- Materializing instances of SQL user-defined types as instances of corresponding Java classes
  - manipulated using existing result set or prepared statement interfaces
  - get/setObject(<column>) simply "works" for structured types
  - Example:
    ```
    ResultSet rs = stmt.executeQuery("SELECT e.addr FROM Employee e");
    rs.next( );
    Residence addr = (Residence)rs.getObject(1);
    ```
- Still requires knowledge of DB-schema, explicit SQL statements for retrieval, insertion, update, deletion of objects
- No support for building Java object references from DB-object relationships



Object Persistence Services & Frameworks

- Basic approach (both in an application server and stand-alone appl. context)
  - application interacts only with objects
    - create, delete
    - access/modify object state variables
    - method invocation
  - persistence infrastructure maps interactions with objects to operations on data sources
    - e.g., INSERT, UPDATE, SELECT, DELETE
- May involve definition of a "mapping" from objects to data store schema
  - mapping has to cover
    - datatypes
    - classes, class hierarchies
    - identifiers
    - relationships
  - *see course "Informationssysteme" (EER -> RM) for possible mapping alternatives*

Caution: inherent performance impact!

Object Persistence

- Aspects of persistence (Atkinson et.al, SIGMOD Record 1996)
  - Orthogonal persistence
    - persistence independent of data type, class
    - instances of the same class may be transient or persistent
  - Transitive persistence (aka persistence by reachability)
    - objects can be explicitly designated to become persistent (i.e., roots)
    - objects referenced by persistent objects automatically become persistent, too
  - Persistence independence (aka transparent persistence)
    - code operating on transient and persistent objects is (almost) the same
    - "client object" side: no impact when interacting with persistent objects
      - application may have to explicitly "persist" an object, but continues to use the same interface for interacting with the persistent object
      - interactions with a data store are not visible to/initiated by the client object, but happen automatically (e.g., when object state is modified or at EOT)
    - "persistent object" side: no special coding for "implementing" persistence
- Realizing the above aspects
  - requires significant efforts in programming language infrastructure
    - above goals are almost never fully achieved
  - may be considered "dangerous" (transitive persistence)

Persistence Programming Model Design Points

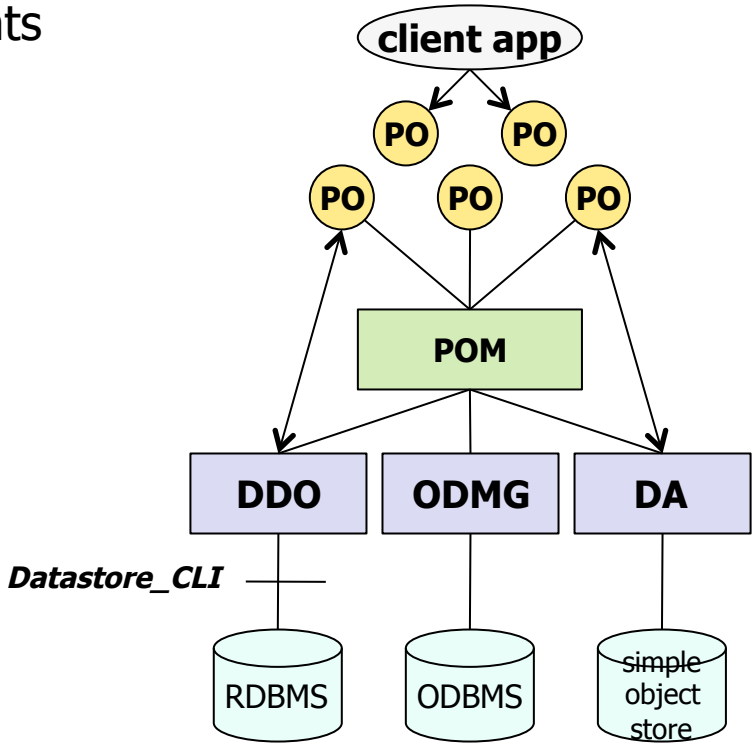
- Persistence in application server middleware
  - surfaced at the distributed object programming model, *or*
  - supported at the programming language level
- Determining object persistence
  - Statically (compile-time) – all/no objects of a certain class/type/programming model concept are persistent, *or*
  - Semi-dynamic – objects of preselected classes (persistence-capable) may become persistent dynamically at runtime, *or*
  - Dynamic (also: orthogonal persistence) – any object may be transient or persistent
- Identifying objects
  - implicit OID*, or*
  - explicit (visible) object key (primary key)
- Locating/referencing persistent objects
  - by object key (lookup)
  - by query

Persistence Programming Model Design Points (2)

- Accessing object state (from client, from server/persistent object)
  - (public) member variables*, or*
  - object methods (getter/setter, …)
- Updating persistent object state
  - explicit (methods for store, load, …)*, or*
  - automatic (immediate, deferred)*, or*
  - combination
- Handling dependencies/relationships
  - Referential integrity
  - Lazy vs. eager loading
  - "Pointer swizzling"

CORBA – Persistent Object Service

- Goal: uniform interfaces for realizing object persistence
- POS (Persistent Object Service) components
  - PO: Persistent Object
    - are associated with persistent state through a PID (persistent object identifier)
      - PID describes data location
  - POM: Persistent Object Manager
    - mediator between POs and PDS
    - realizes interface for persistence operations
    - interprets PIDs
    - implementation-independent
  - PDS: Persistent Data Service
    - mediator between POM/PO and persistent data store
    - data exchange between object and data store as defined by protocols
  - Datastore
    - stores persistent object data
    - may implement *Datastore_CLI* (encapsulates ODBC/CLI)



CORBA Persistence Model

- CORBA object is responsible for realizing its own persistence
  - can use PDS services and functions
  - implicit persistence control
    - client is potentially unaware of object persistence aspects (client persistence independence)
  - explicit persistence control
    - persistent object implements PO interface, which can then be used by the client
- Explicit persistence control by CORBA client:
  - client creates PID, PO using factory objects
  - PO Interface
    - connect/disconnect – automatic persistence for the duration of a "connection"
    - store/restore/delete – explicit transfer of data
    - delegated to POM, PDS
  - caution!: CORBA object reference and PID are different concepts
    - client can "load" the same CORBA object with data from different persistent object states

Persistence Protocols

- CORBA Persistence Service defines three protocols
  - Direct Access (DA) protocols
    - PO stores persistent state using so-called *direct access data objects* (DADOs)
      - **CORBA objects** whose interfaces only have attributes
      - defined using Data Definition Language (IDL subset)
        - precompilation is specific to CORBA/PDS environment
    - DADOs may persistently reference other DADOs, CORBA objects
  - ODMG'93 protocols
    - utilizes ODMG standard for object-oriented databases
    - persistent objects are **programming language objects**, not CORBA objects
    - definition of persistence "schema" similar to DA protocol (is a superset)
      - own DDL (ODL) for defining POs
  - Dynamic Data Object (DDO) protocols
    - "generic", **self-describing DO**
      - methods for read/update/add of attributes and values
      - manipulation of meta data
    - used for accessing record-based data sources (e.g. RDBMS) using DataStore CLI interface
      - CLI for CORBA
- Protocols are employed in the implementation of POs

EJB Version 2 – Entity Beans

- Persistence is supported at the EJB/distributed object programming model
  - explicit type of EJB for (static) persistent objects
  - invocation of remote object methods
  - life-cycle interface (*Home* interface)
    - *create, retrieve, delete*
    - *findByPrimaryKey*
    - additional, bean-specific finder methods
  - primary-key class for uniquely identifying persistent bean objects
- Follows *transparent persistence* approach on the client
  - persistence-related operations (e.g., synchronizing object state with DB contents) are hidden from the client
  - automatic update of persistent object state

Entity Beans

- Object persistence logic is implemented separately from business logic
  - entity bean "implements" call-back methods for persistence
    - ejbCreate – insert object state into DB
    - ejbLoad – retrieve persistent state from DB
    - ejbStore – update DB to reflect (modified) object state
    - ejbRemove – remove persistent object state
- Manipulation of CMP fields through access methods (get*field*(), set*field*(...))
  - access within methods of the same EB
  - client access can be supported by including access methods in the remote interface
  - provides additional flexibility for container implementation
    - lazy loading of individual attributes
    - individual updates for modified attributes

Container-Managed Persistence (CMP)

- Bean developer defines an *abstract persistence schema* in the deployment descriptor
  - persistent attributes (*CMP fields*)
- Mapping of CMP fields to DB-structures (e.g., columns) in deployment phase
  - depends on DB, data model
  - tool support
    - *top-down, bottom-up, meet-in-the-middle*
- Container saves object state
  - bean does not worry about persistence mechanism
    - call-back methods don't contain DB access operations
    - may be used to compress/decompress values, derive attribute values, …

Bean-Managed Persistence (BMP)

- Callback-methods contain explicit DB access operations
  - useful for interfacing with legacy systems or for realizing complex DB-mappings (not supported directly by container or CMP tooling)
- No support for container-managed relationships
- Finder-methods
  - have to be implemented in Java
  - no support for EJB-QL

Entity Beans (and CORBA) - Problems

- Distributed component vs. persistent object
  - granularity
  - potential overhead (and possible performance problems)
    - solution in EJB 2.0: local interfaces
    - but: semantic differences (*call-by-value* vs. *call-by-reference*)
  - complexity of development process
- Missing support for class hierarchies with inheritance

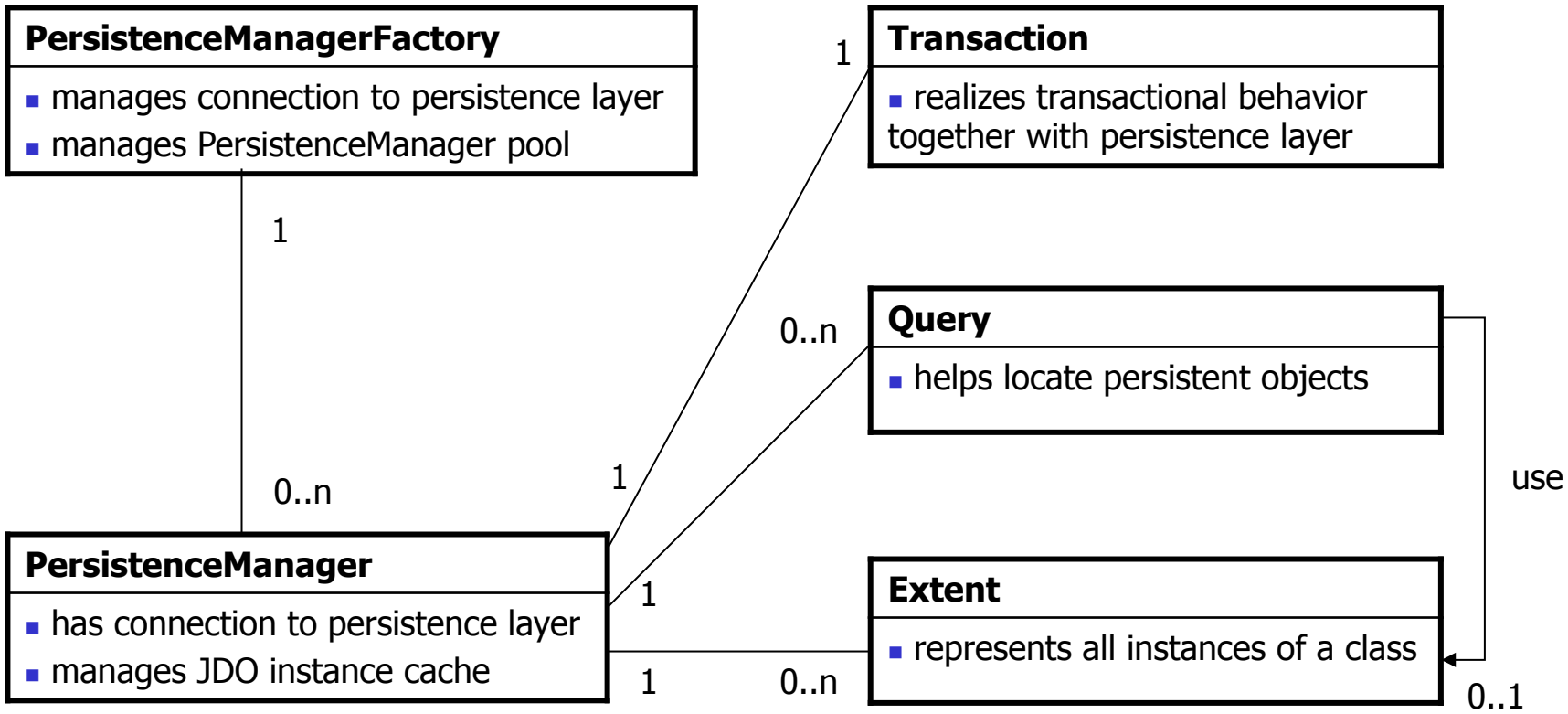
JDO – Java Data Objects

- JDO was developed as a standard for persistence in Java-based applications
  - first JDO specification 1.0 released in March 2002 (after ~ 3 years) through Suns JCP (Java Community Process)
  - > 10 vendor implementations plus open-source projects
  - *mandatory features* and *optional features* in the specification (i.e., some optional features are „standardized" → promises better portability).
- Features, elements
  - orthogonal, transitive persistence
  - native Java objects (inheritance)
  - byte code enhancement
  - mapping to persistence layer using XML-metadata
  - transaction support
  - JDO Query Language
  - JDO API
  - JDO identity
  - JDO life cycle
  - integration in application server standard (J2EE)

Persistence in JDO

- (Semi-) dynamic persistence
  - Java class supports (optional) persistence (implements PersistenceCapable)
  - not all instances of the class need to be persistent
    - application can/must explicitly turn a transient object into a persistent object (and vice versa)
- Persistence logic is transparent for client at the Java level
  - interacting with transient and persistent objects is the same
- Transitive persistence (i.e., by reachability)

JDO API



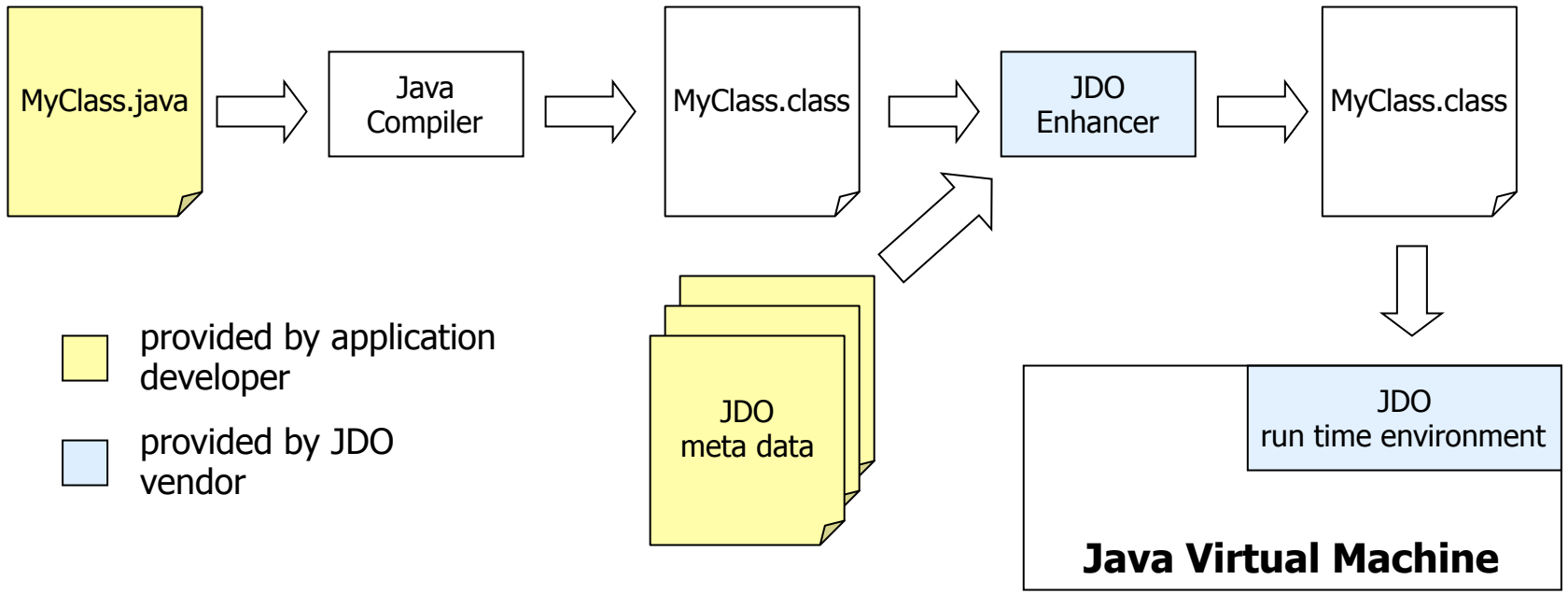
PersistenceManager API - Example

```
1  Author author1 = new Author("John", "Doe");
2  PersistenceManager pm1 = pmf.getPersistenceManager();
3  pm1.currentTransaction.begin();
4  pm1.makePersistent(author1);
5  Object jdoID = pm1.getObjectId(author1);
6  pm1.currentTransaction.commit();
7  pm1.close();

8  // Application decides that author1
9  // must be deleted
10 PersistenceManager pm2 = pmf.getPersistenceManager();
11 pm2.currentTransaction.begin();
12 Author author2 = (Author)pm2.getObjectById(jdoID);
13 pm2.deletePersistent(author2);
14 pm2.currentTransaction.commit();
15 pm2.close();
```

Byte-Code-Enhancement

- Java bytecode (*.class) and metadata (*.jdo)
- Same object class (now implements PersistenceCapable)
- O/R-mapping specification is vendor-specific



Java Persistence API

- Result of a major 'overhaul' of EJB specification for persistence, relationships, and query support
  - simplified programming model
  - standardized object-to-relational mapping
  - inheritance, polymorphism, "polymorphic queries"
  - enhanced query capabilities for static and dynamic queries
- API usage
  - from within an EJB environment/container
  - outside EJB, e.g., within a standard Java SE application
- Support for pluggable, third-party persistence providers

Entities

- *"An entity is a lightweight persistent domain object"*
  - entities are not remotely accessible (i.e., they are local objects)
  - no relationship with the EntityBeans concept, but co-existence
- Simplified programming model for EJB entities
  - entity is a POJO (plain old Java object)
    - marked as *Entity* through annotations or deployment descriptor
    - no additional local or home interfaces required
    - no implementation of generic EntityBean methods needed
  - entity state (instance variables) is **encapsulated**, client access only through accessor or other methods
  - use of annotations for persistence and relationship aspects
    - no XML deployment descriptor required
- Entities and inheritance
  - abstract and concrete classes can be entities
  - entities may extend both non-entity and entity classes, and vice versa

Identity and Embeddable Classes

- Entities must have primary keys
  - defined at the root, exactly once per class hierarchy
  - may be simple or composite
    - key class required for composite keys
  - must not be modified by the application
    - more strict than primary key in the RM
- Embeddable classes
  - "fine-grained" classes used by an entity to represent state
  - instances are seen as embedded objects, do not have a persistent identity
    - mapped with the containing entities
    - not sharable across persistent entities

Requirements on Entity Class

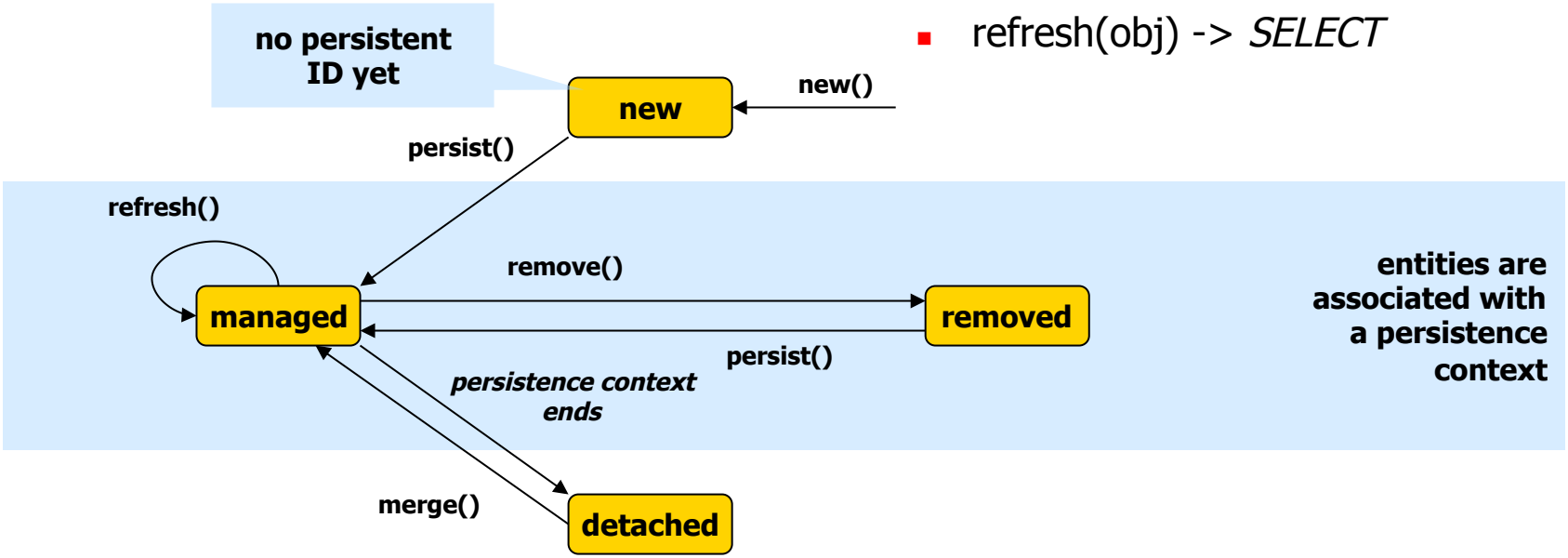
- Public, parameter-less constructor
- Top-level class, not final, methods and persistent instance variables must not be final
- Entity state is made accessible to the persistence provider runtime
  - either via instance variables (protected or package visible)
  - or via (bean) properties (get*Property*/set*Property* methods)
  - consistently throughout the entity class hierarchy
- Collection-valued state variables have to be based on (generics of) specific classes in java.util

Mapping to RDBMS

- Entity mapping
  - default table/column names for entity classes and persistent fields
    - can be customized using annotations, deployment descriptor
  - mapping may define a primary table and one or more secondary tables for an entity
    - state of an entity/object may be distributed across multiple tables
- Inheritance mapping strategies supported for the mapping
  - single table with discriminator column (default)
    - table has columns for all attributes of any class in the hierarchy
    - tables stores all instances of the class hierarchy
  - horizontal partitioning
    - one table per entity class, with columns for all attributes (incl. inherited)
    - table stores only the **direct** instances of the class
  - vertical partitioning
    - one table per entity class, with columns for newly defined attributes (i.e., attributes specific to the class)
    - table stores information about **all** (i.e., **transitive**) instances of the class

Entity Life Cycle and Persistence

- Orthogonal persistence
  - instances of entity classes may be transient or persistent
  - persistence property controlled by application/client (e.g., a SessionBean)
- Entity manager manages entity state and lifecycle within persistence context
  - persist(obj) -> *INSERT*
  - merge(obj) -> *UPDATE*
  - remove(obj) -> *DELETE*
  - find(class, pKey) -> *SELECT*
  - refresh(obj) -> *SELECT*



Relationships

- Persistence model needs to be complemented by relationship support
  - represent relationships among data items (e.g., tuples) at the object level
  - support persistence of native programming language concepts for "networks" of objects
    - references, pointers
- Alternatives
  - value-based relationships at the object level (see relational data model)
    - requires to issue a query (over objects) to locate related object(s)
    - no "navigational" access
  - relationships are part of persistent object interface(s) or implementation
    - getter/setter methods or properties/fields to represent relationship roles of participating entities
    - relationships are always binary, collection support required for 1:n, n:m
    - uni-directional or bi-directional representation
      - consistency?
  - separate relationship concept/service, independent of persistent object interfaces

CORBA Relationships

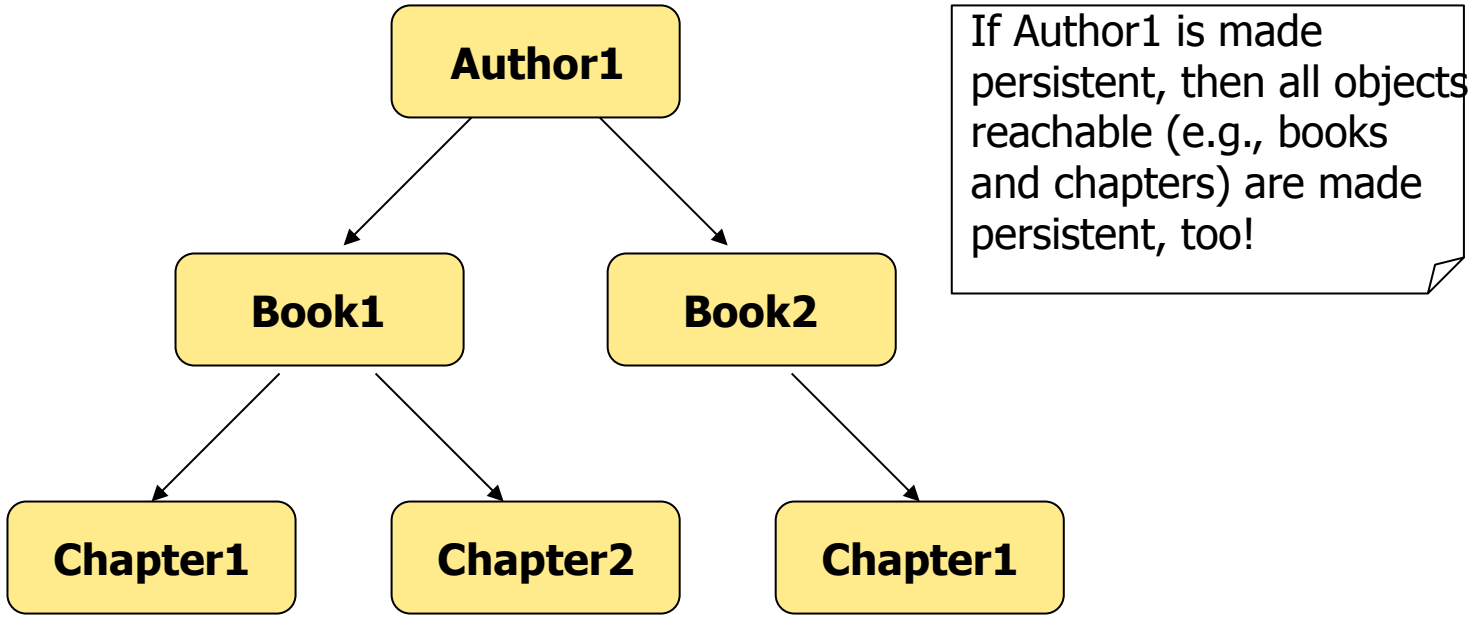
- Relationship Service
  - management of object dependencies, separate from object state or interface
  - relationship involves: type, role, cardinality
    - type: types of objects that may participate in a specific relationship type
    - role: role names of participating entities
  - major goals
    - multi-directional use/navigation and relationship maintenance
    - decouple relationship from CORBA object reference maintained by each participating object
    - graph traversal
    - attributes and behavior for relationships
  - generic IDL interfaces for roles, relationships, ...
    - to be subtyped for application-specific relationships (e.g., *Emp-Dept*)
    - supplemented by additional interfaces for relationship graph traversal
- Relationships are separate (CORBA) objects
  - highly dynamic, powerful, but very complex to use
  - not really suitable for (fine-grained) data-level relationships

EJB - Container-managed Relationships

- Relationships can be defined in deployment descriptor or through annotations
  - part of abstract persistence schema
- Relationships may be uni-directional ("reference") or bi-directional
- Relationship types: 1:1, 1:n, n:1, n:m
- Access methods for accessing objects participating in a relationship
  - like CMP field methods (get/set)
  - Java Collection interface for set-valued reference attributes
- Container generates code for
  - relationship maintenance
    - cardinality, inverse relationship field consistency are guaranteed
  - persistent storage, involves mapping definition as well
- No transitive persistence
  - relationship can only be established among entityBeans, which are already persistent
- Only supported for CMP EntityBeans

JDO – Relationships and Transitive Persistence

- All **`PersistenceCapable`** objects reachable from persistent object through standard Java references within an object graph are made persistent, too
- No managed inverse relationships



Relationships in Java Persistence API

- Relationships are represented in the same way as persistent attributes
  - member variables, get/set method pairs
- Supports uni- and bi-directional binary relationships of the same types as EJB CMR
  - but does not provide automatic maintenance of inverse relationships
    - a designated owning side "wins" at the persistent data store
- Selective transitive persistence
  - defined using CASCADE options on relationships
- Relationship mapping
  - represented using primary key/foreign key relationships
  - table for the "owning" side of the relationship contains the foreign key
  - N:M-relationships represented using a relationship table

Relationships – Additional Aspects

- Discussions about benefits and drawbacks of transitive persistence
  - easy to use from a development perspective, but
  - implicit definition of persistence
    - developer needs to understand what to expect in terms of number of resulting insert operations
  - and what about the "reverse" semantics for object deletion: when should an object that was implicitly made persistent be deleted?
    - when the originally referencing object causing implicit persistence is deleted or removes the reference?
    - when the object is no longer referenced by other persistent objects (garbage collection)?
      - still could be retrieved using its primary key value
    - when it is explicitly deleted?
- Cascading delete rules are usually the only mechanism offered to implement automatic deletion
  - relationships can be flagged to cause deletion, if "parent" object is deleted
    - often mapped to referential integrity constraints in the DB-mapping
  - what is the resulting object state in the application, if the deleted object is still referenced?

Queries Over Persistent Objects

- Accessing persistent objects through primary key or navigation over relationships
  - is a useful basic mechanism that fits the OO programming model
  - but is a severe restriction when accessing collections of persistent objects
  - and can cause severe performance impact through tuple-by-tuple operations
- Object retrieval through a query language
  - required to solve the above problems
  - but should not force the developer to drop down to the data store query language (and schema) again
- Object query language
  - continues to shield the developer from data store (and mapping) details
  - requires persistence framework to transform object queries into corresponding data store queries based on the object-to-relational mapping

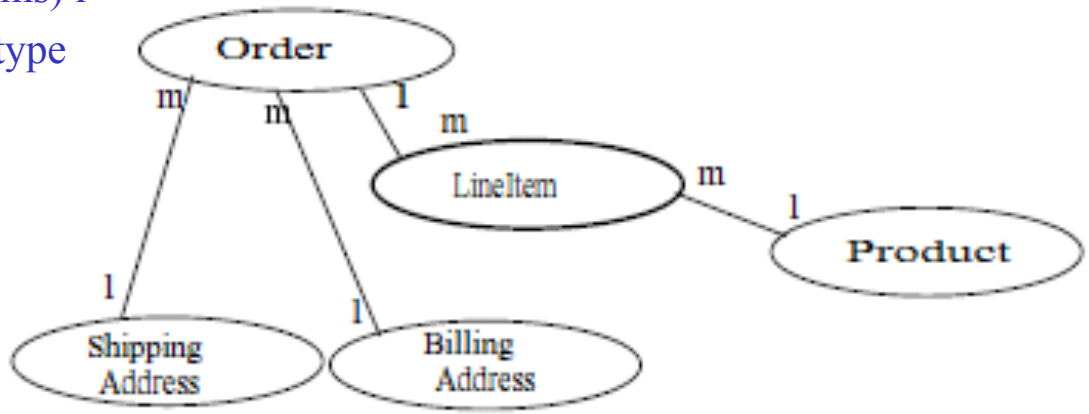
CORBA Queries

- Query Service
  - set-oriented queries for locating CORBA objects
  - SQL, OQL (ODMG) can be used as query languages
  - query results are represented using Collection objects
    - iterators
  - not restricted to persistent query objects
- Query can be optionally delegated to a "query evaluator" (e.g., the query engine of a RDBMS or ODBMS) or to a "queryable collection"
  - a query evaluator may iterate over a collection of CORBA objects and access attributes or evaluate methods, or
  - it may involve other queryableCollections to evaluate subqueries and then do the join processing after retrieving the results
- Queries can only access the public attributes of CORBA objects
  - everything is based on the remote interfaces of objects
    - performance? optimization?
- There is no conceptual mapping from query language concepts (e.g., tables, object collections) to CORBA concepts provided

EJB Query Language (EJB-QL)

- Introduced as a query language for CMP EntityBeans
  - used in the definition of user-defined Finder methods of an EJB Home interface
    - no arbitrary (embedded or dynamic) object query capabilities!
  - uses abstract persistence schema as its schema basis
  - SQL-like
- Example:

```
SELECT DISTINCT OBJECT(o)
FROM Order o, IN(o.lineItems) l
WHERE l.product.product_type
    = 'office_supplies'
```



Java Persistence Query Language

- Extension of EJB-QL
  - named (static) and dynamic queries
  - range across the class extensions including subclasses
    - a *persistence unit* is a logical grouping of entity classes, all to be mapped to the same DB
    - queries can not span across persistence units
  - includes support for
    - bulk updates and delete
    - outer join
    - projection
    - subqueries
    - group-by/having
- Prefetching based on outer joins
  - Example:

```
SELECT d
FROM Department d LEFT JOIN FETCH d.employees
WHERE d.deptno = 1
```

JDO Query Language

- A JDOQL query has 3 parts
  - *candidate class*: class(es) of expected result objects
    → restriction at the class level
  - *candidate collection*: collection/extent to search over
    → (optional) restriction at the object extent level
  - *filter*: boolean expression with JDOQL (optional: other query language)
- JDOQL characteristics
  - read-only (no INSERT, DELETE, UPDATE)
  - returns JDO objects (no projection, join)
  - query submitted as string parameter → dynamic processing at run-time
  - logical operators, comparison operators: e.g. !,==,>=
  - JDOQL-specific operators: type cast using "( )", navigation using "."
  - no method calls supported in JDOQL query
  - sort order (ascending/descending)
  - variable declarations

Query

- JDO-Query with JDOQL for locating JDO instances:

```
1  String searchname = "Doe";
2  Query q = pm.newQuery();
3  q.setClass(Author.class);
4  q.setFilter("name == \"" + searchname +"\"");
5  Collection results =(Collection)q.execute();
6  Iterator it = results.iterator();
7  while (it.hasNext()){
8      // iterate over result objects
9  }
10 q.close(it);
```

JDOQL Examples

- Sorting:

```
1 Query query = pm.newQuery(Author.class);
2 query.setOrdering("name ascending, firstname ascending");
3 Collection results = (Collection) query.execute();
```

- Variable declaration

```
1  String filter = "books.contains(myBook) &&  " +
2                  "(myBook.name == \"Core JDO\")";
3  Query query = pm.newQuery(Author.class, filter);
4  query.declareVariables("Book myBook");
5  Collection results = (Collection) query.execute();
```

Realizing Automatic Persistence

- Strategies for "loading" objects from the persistent store during navigational access
  - "lazy" loading – object is retrieved only when accessed based on primary key or reference (relationship)
    - easy to implement
    - may cause increased communication with data source, resulting in performance drawbacks
  - "eager" loading
    - when an object is requested, transitively load all the objects reachable through references
    - requires construction/generation of complex data store queries
    - may cause a lot of unnecessary objects to be loaded
- Persistence frameworks usually offer a combination of the above strategies
  - relationships can be explicitly designated as eager or lazy
    - at deployment time? separate definitions depending on the application scenario?
  - can be generalized to arbitrary persistent attributes
    - e.g., to pursue lazy loading of large objects

Realizing Automatic Persistence (2)

- How to write object changes back to the data store
  - there may be many fine-grained (i.e., attribute-level) updates on a persistent object during a transaction
  - immediate update: write changes to the DB after every attribute modification
    - easy to implement/support, but many interactions with the DBMS
  - deferred update: record changes and combine them into a single update per tuple at the end of the transaction
    - more complex to implement, unless one always updates the complete tuple
      - the latter will result in unnecessary processing overhead at the DBMS
    - approach needs to be refined to account for consistent query results
      - write back changes also before any object query statements are executed
- Concurrency control strategy (determined in combination with the persistent data store)
  - pessimistic, using locking at the DBMS-level
    - requires long read locks to avoid lost updates
  - optimistic, by implementing "optimistic locking"

Optimistic Locking and Concurrency

- Note: most DBMSs don't support optimistic concurrency control
- Example JPA: *optimistic locking* is assumed, with the following requirements for application portability
  - isolation level "read committed" or equivalent for data access
    - no long read locks are held, DBMS does not prevent lost updates, inconsistent reads
  - declaration of a *version* attribute for all entities to be enabled for optimistic locking
    - persistence provider uses the attribute to detect and prevent lost updates
      - provider changes/increases the version during a successful update
      - compares original version with the current version stored in the DB, if the version is not the same, a conflict is detected and the transaction is rolled back
  - inconsistencies may arise if entities are not protected by a version attribute
  - does not guarantee consistent reads
  - conflicts can only be detected at the end of a (possibly long) transaction

Transactions in JDO

- JDO transactions supported at the object level
- Datastore Transaction Management (standard):
  - JDO synchronizes transaction with the persistence layer
  - transaction strategy of persistence layer is used
- Optimistic Transaction Management (optional):
  - JDO progresses object transaction at object level
  - at commit time, transaction is synchronized with persistence layer
- Transactions and object persistence are orthogonal

object characteristics	transactional	non-transactional
persistent	standard	optional
transient	optional	standard (JVM)

Transactions and Concurrency Control

- Access of persistent data resulting from persistent object manipulation always occurs in the scope of a transaction
- What happens at transaction roll-back?
  - state of entities in the application is not guaranteed to be rolled back, only the persistent state
- What happens if a transaction terminates and objects become "detached"?
  - objects can still be modified "offline"
- What happens when objects are merged "re-attached" to a new transaction context?
  - objects are NOT automatically refreshed
  - potential for lost updates
  - can be controlled by explicit refresh or using optimistic locking

Summary

- Object persistence supported at various levels of abstraction
  - CORBA
    - standardized "low-level" APIs
    - powerful, flexible, but no uniform model for component developer
      - various persistence protocols
    - explicit vs. implicit (client-side transparent) persistence
  - EJB/J2EE Entity Beans
    - persistent components
      - CMP: container responsible for persistence, maintenance of relationships
    - uniform programming model
    - transparent persistence
  - JDO
    - persistent Java objects
    - orthogonal, transparent, transitive persistence
  - Java Persistence API
    - successor of EJB entity beans
    - standardized mapping of objects to relational data stores
    - influenced partly by JDO, Hibernate
    - can be used outside the EJB context as well

Summary (2)

- Query Support
  - CORBA: queries over object collections
    - no uniform query language
      - uses SQL, OQL
    - persistent object schema?
  - EJB-QL: queries over abstract persistence schema
    - limited functionality, only for definition of Finder methods
    - more or less a small SQL subset
  - JDO: queries over collections, extents
    - limited functionality
    - proprietary query language
  - Java Persistence Query Language
    - based on EJB-QL (and therefore on SQL)
    - numerous language extensions for query, bulk update
    - static and dynamic queries
  - Queries over multiple, distributed data sources are not mandated by the above approaches!