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Chapter 6 – Object Persistence, Relationships and Queries

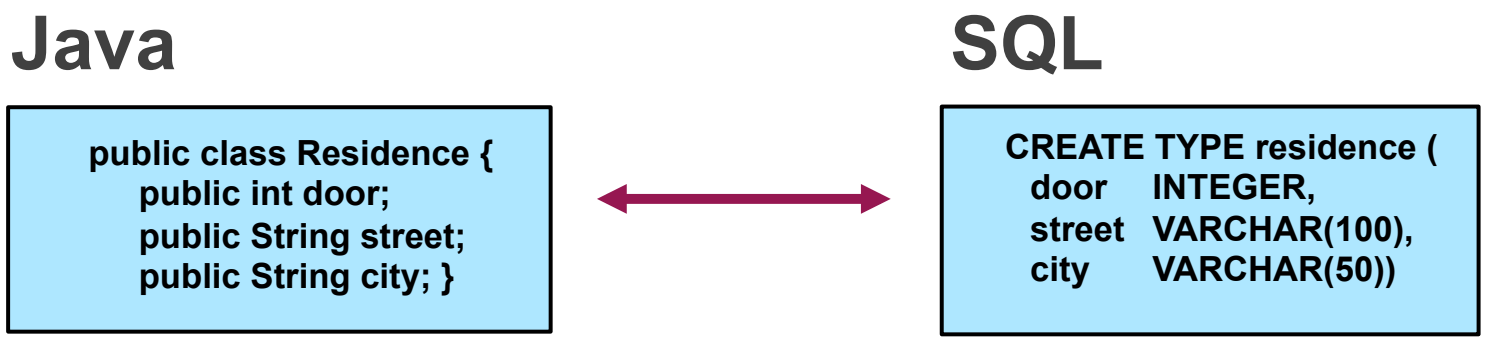
Object Persistence

- 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

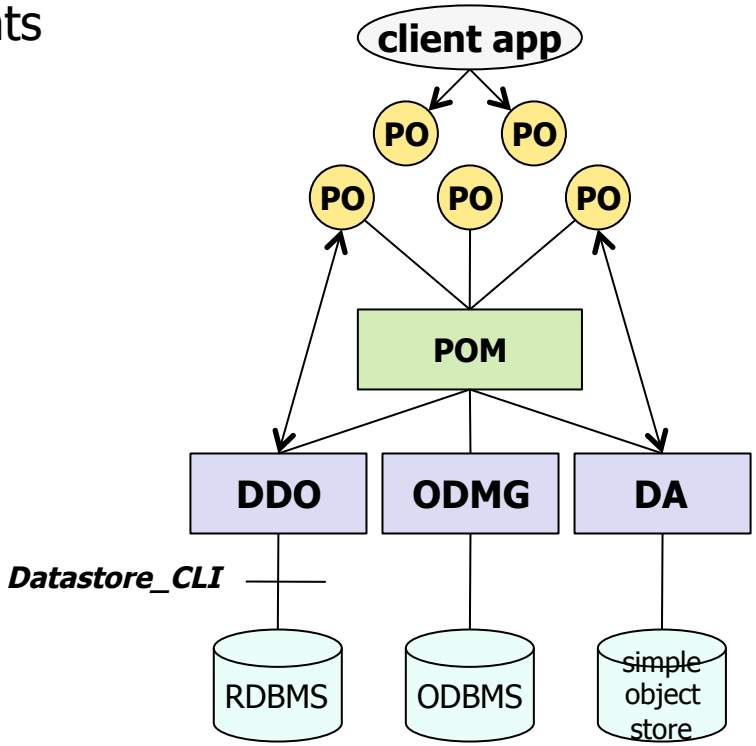
- Persistence in application server middleware
  - surfaced at the distributed object programming model, *or*
  - supported at the programming language level
- Determining object persistence
  - Statically (compile-time) – all/no objects of a certain class/type/programming model concept are persistent, *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

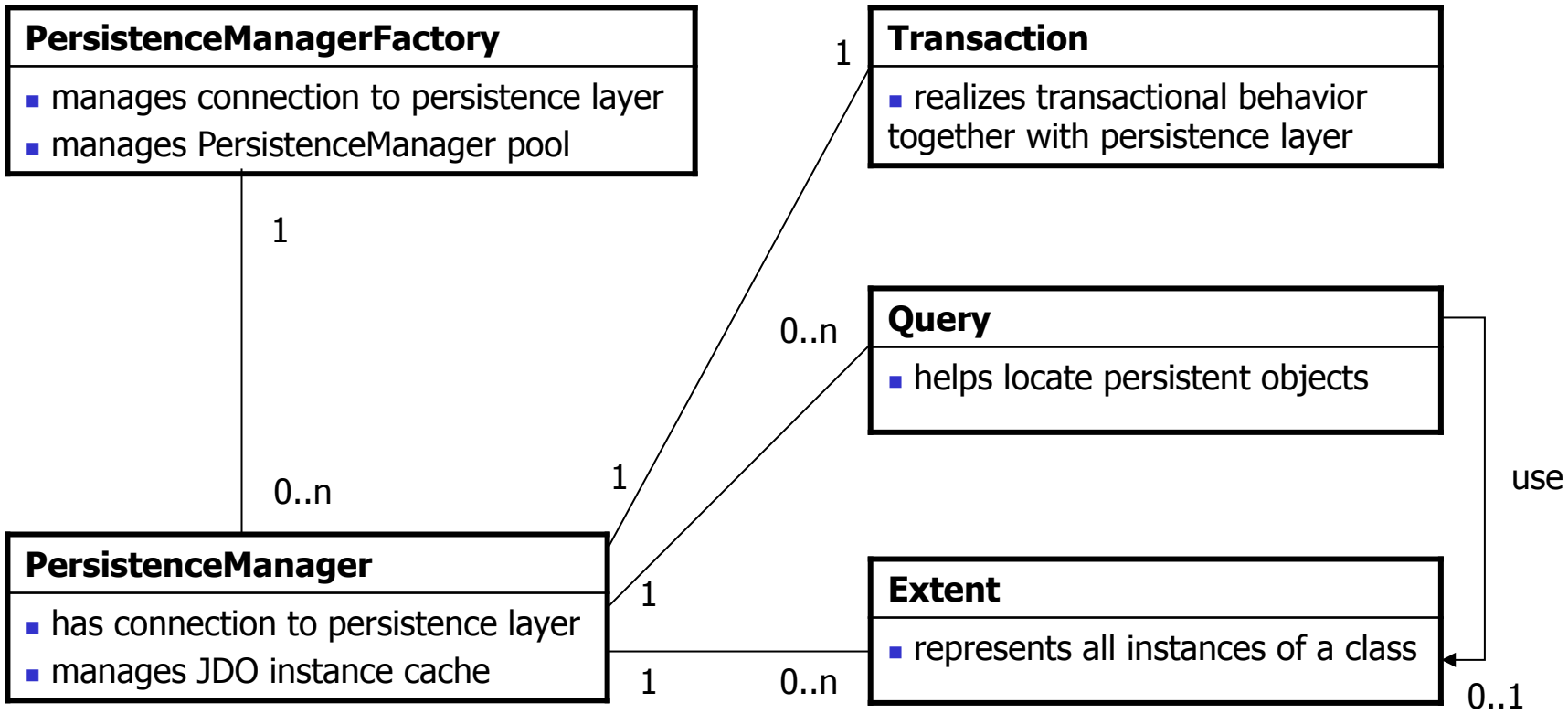
JDO – Java Data Objects

- 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


PersistenceManagerFactory
manages connection to persistence layer
manages PersistenceManager pool
Transaction
realizes transactional behavior together with persistence layer
Query
helps locate persistent objects
Extent
represents all instances of a class
PersistenceManager
has connection to persistence layer
manages JDO instance cache
1
0..n
1
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1
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use
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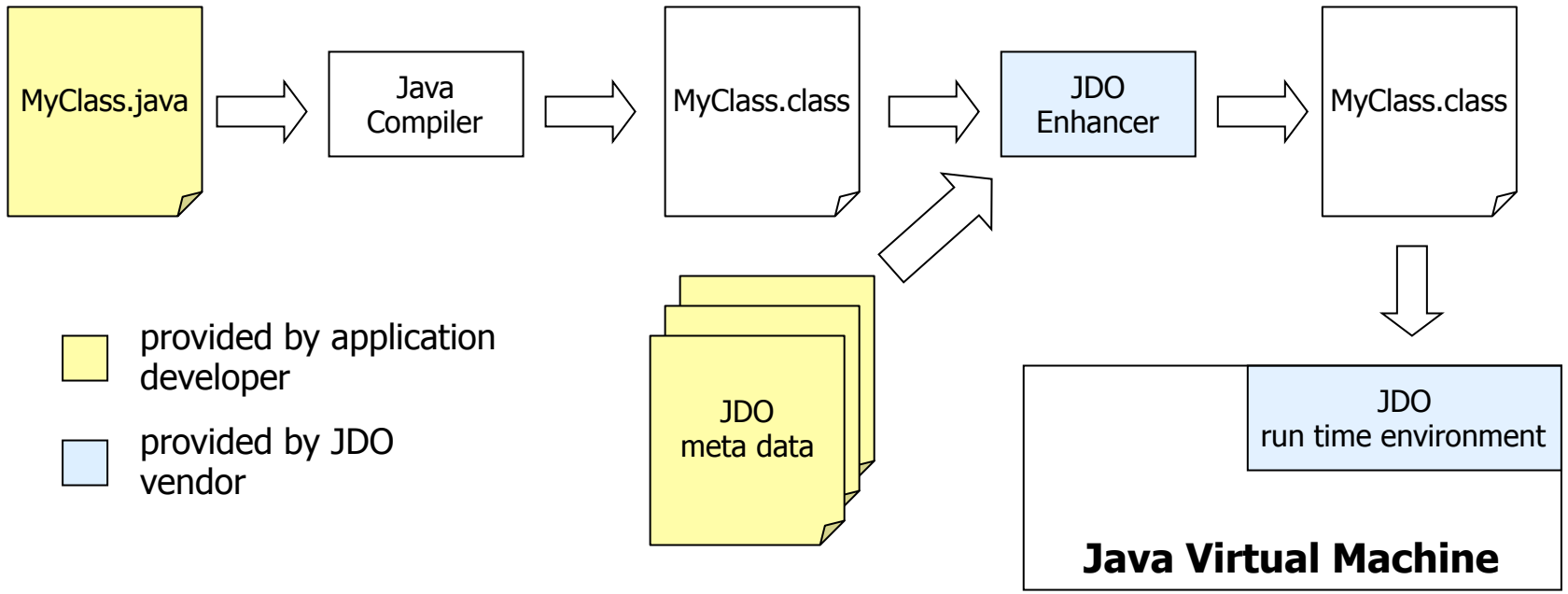
PersistenceManager API - Example

```
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

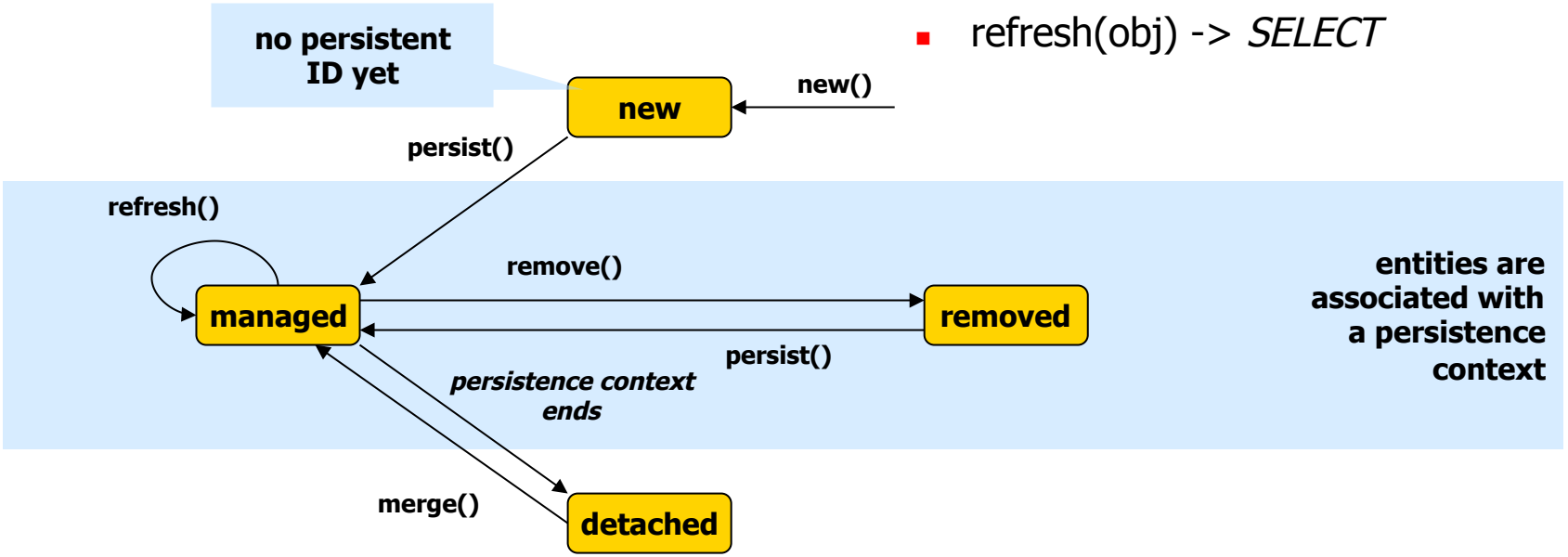
- Public, parameter-less constructor
- Top-level class, not final, methods and persistent instance variables must not be final
- Entity state is made accessible to the persistence provider runtime
  - either via instance variables (protected or package visible)
  - or via (bean) properties (get*Property*/set*Property* 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

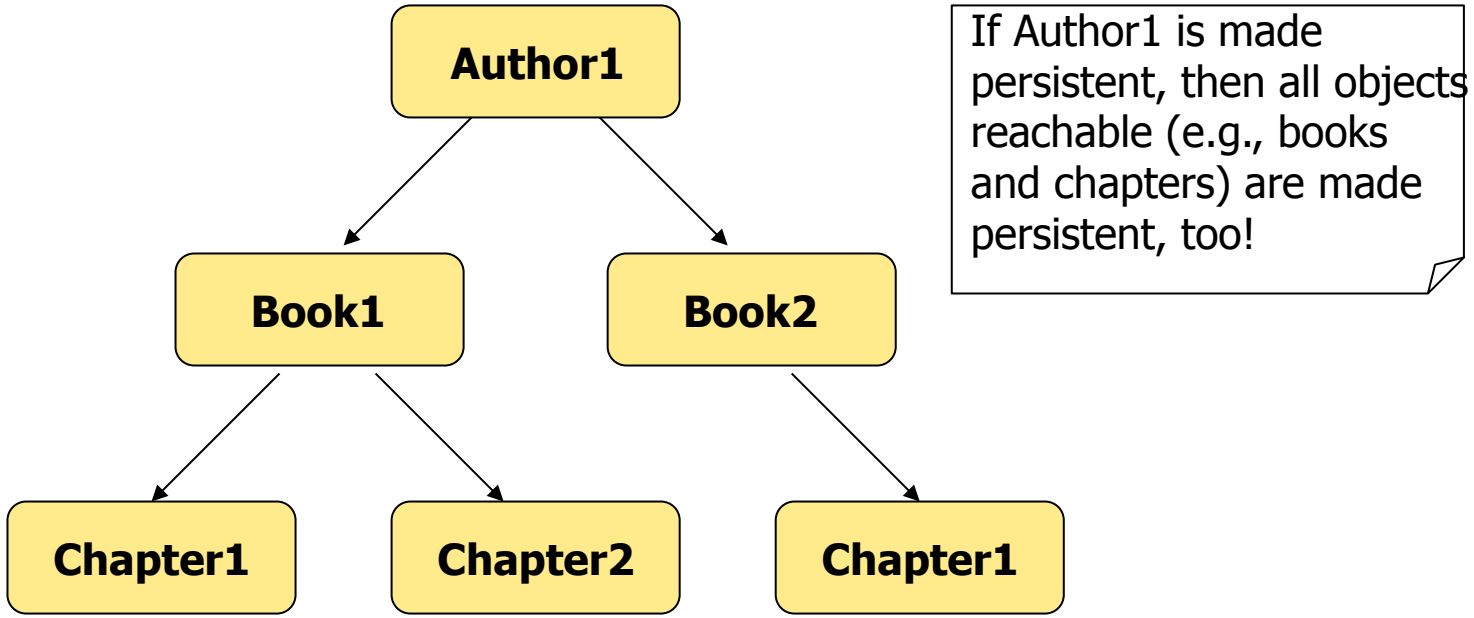
- Relationship Service
  - management of object dependencies, separate from object state or interface
  - relationship involves: type, role, cardinality
    - type: types of objects that may participate in a specific relationship type
    - role: role names of participating entities
  - major goals
    - 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

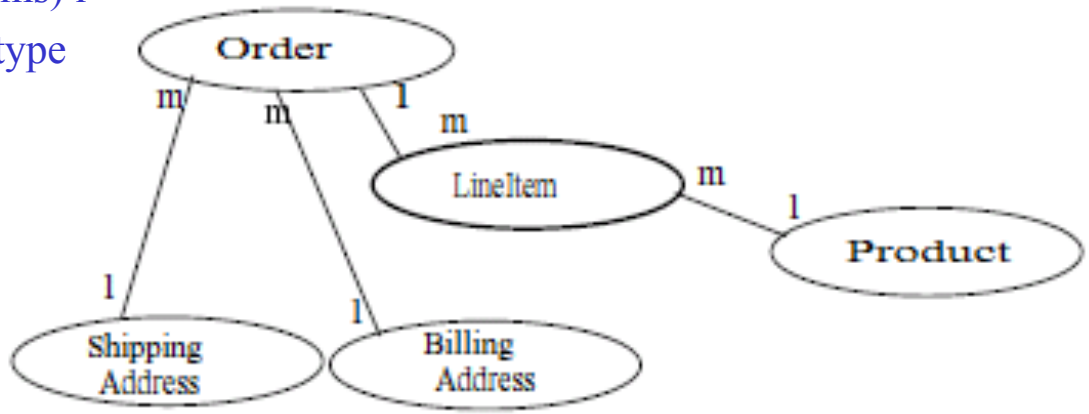
CORBA Queries

- 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!