# Chapter 8: Object-Oriented Databases

- Need for Complex Data Types
- The Object-Oriented Data Model
- Object-Oriented Languages
- Persistent Programming Languages
- Persistent C++ Systems

# Need for Complex Data Types

- Traditional database applications in data processing had conceptually simple data types
  - Relatively few data types, first normal form holds
- Complex data types have grown more important in recent years
  - E.g. Addresses can be viewed as a
    - Single string, or
    - Separate attributes for each part, or
    - Composite attributes (which are not in first normal form)
  - E.g. it is often convenient to store multivalued attributes as-is, without creating a separate relation to store the values in first normal form
- Applications
  - computer-aided design, computer-aided software engineering
  - multimedia and image databases, and document/hypertext databases.

# Object-Oriented Data Model

- Loosely speaking, an **object** corresponds to an entity in the E-R model.
- The *object-oriented paradigm* is based on *encapsulating* code and data related to an object into single unit.
- The object-oriented data model is a logical data model (like the E-R model).
- Adaptation of the object-oriented programming paradigm (e.g., Smalltalk, C++) to database systems.

# Object Structure

- An object has associated with it:
  - A set of **variables** that contain the data for the object. The value of each variable is itself an object.
  - A set of **messages** to which the object responds; each message may have zero, one, or more *parameters.*
  - A set of **methods***,* each of which is a body of code to implement a message; a method returns a value as the *response* to the message
- The physical representation of data is visible only to the implementor of the object
- Messages and responses provide the only external interface to an object.
- The term message does not necessarily imply physical message passing. Messages can be implemented as procedure invocations.

# Messages and Methods

- Methods are programs written in general-purpose language with the following features
  - only variables in the object itself may be referenced directly
  - data in other objects are referenced only by sending *messages*.
- Methods can be read-only or update methods
  - Read-only methods do not change the value of the object
- Strictly speaking, every attribute of an entity must be represented by a variable and two methods, one to read and the other to update the attribute
  - e.g., the attribute *address* is represented by a variable *address* and two messages *get-address* and *set-address*.
  - For convenience, many object-oriented data models permit direct access to variables of other objects.

# Object Classes

- Similar objects are grouped into a **class**; each such object is called an **instance** of its class
- All objects in a class have the same
  - Variables, with the same types
  - message interface
  - methods

  The may differ in the values assigned to variables
- Example:  Group objects for people into a *person* class
- Classes are analogous to entity sets in the E-R model

# Class Definition Example

```
class employee {
        /*Variables */
            string   name;
            string   address;
            date     start-date;
            int      salary;
        /* Messages */
            int      annual-salary();
            string   get-name();
            string   get-address();
            int      set-address(string new-address);
            int      employment-length();
};
```

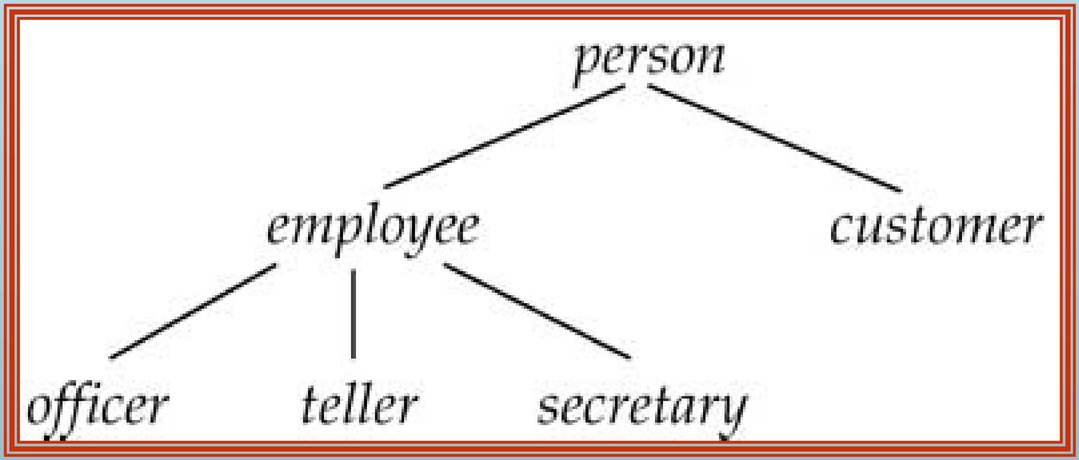
- Methods to read and set the other variables are also needed with strict encapsulation
- Methods are defined separately
  - E.g. **int** *employment-length*() { **return** *today*() – *start-date*;}
    **int** *set-address*(**string** *new-address*) { *address* = *new-address*;}

# Inheritance

- E.g., class of bank customers is similar to class of bank employees, although there are differences
  - ★ both share some variables and messages, e.g., *name* and *address.*
  - ★ But there are variables and messages specific to each class e.g., *salary* for employees and *credit-rating* for customers.
- Every employee is a person; thus *employee* is a specialization of *person*
- *Similarly, customer* is a specialization of *person.*
- Create classes *person, employee* and *customer*
  - ★ variables/messages applicable to all persons associated with class *person.*
  - ★ variables/messages specific to employees associated with class *employee*; similarly for *customer*

# Inheritance (Cont.)

- Place classes into a specialization/IS-A hierarchy
  - variables/messages belonging to class *person* are *inherited* by class *employee* as well as *customer*
- Result is a **class hierarchy**




Note analogy with ISA Hierarchy in the E-R model

# Class Hierarchy Definition

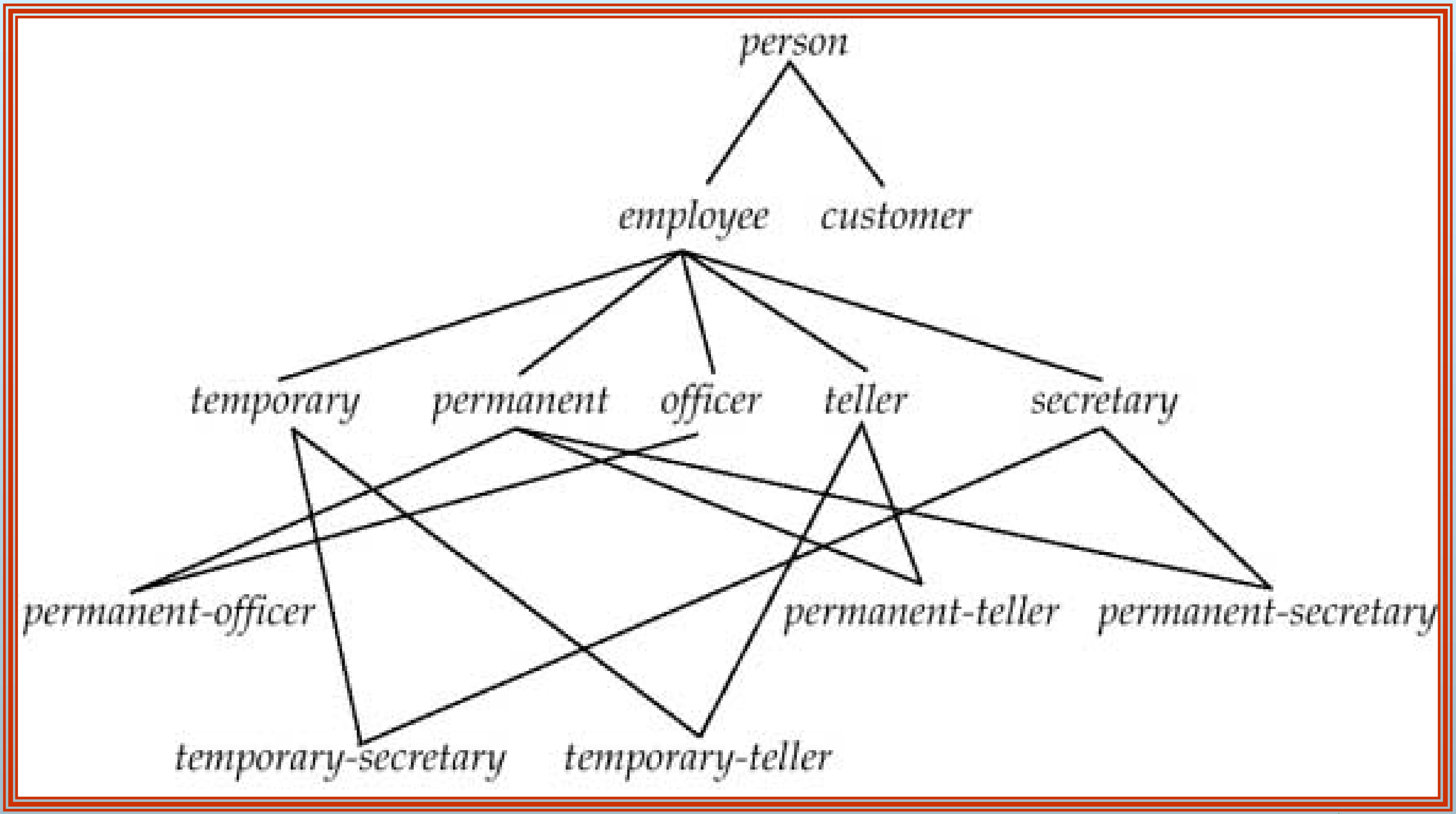
```
class person{
    string name;
    string address:
    };
class customer isa person {
    int credit-rating;
    };
class employee isa person {
    date start-date;
    int salary;
    };
class officer isa employee {
    int office-number,
    int expense-account-number,
    };
```

⋮

# Class Hierarchy Example (Cont.)

- Full variable list for objects in the class *officer:*
  - *office-number, expense-account-number:* defined locally
  - *start-date, salary:* inherited from *employee*
  - *name, address:* inherited from *person*
- Methods inherited similar to variables.
- **Substitutability** — any method of a class, say *person,* can be invoked equally well with any object belonging to any subclass, such as subclass *officer* of *person.*
- **Class extent***:* set of all objects in the class. Two options:
  1. Class extent of *employee* includes all *officer, teller* and *secretary* objects.
  2. Class extent of *employee* includes only employee objects that are not in a subclass such as *officer, teller,* or *secretary*
     - This is the usual choice in OO systems
     - Can access extents of subclasses to find all objects of subtypes of employee

# Example of Multiple Inheritance




Class DAG for banking example.

# Multiple Inheritance

- With multiple inheritance a class may have more than one superclass.
  - The class/subclass relationship is represented by a **directed acyclic graph** (**DAG**)
  - Particularly useful when objects can be classified in more than one way, which are independent of each other
    - E.g. temporary/permanent is independent of Officer/secretary/teller
    - Create a subclass for each combination of subclasses
      - Need not create subclasses for combinations that are not possible in the database being modeled
- A class inherits variables and methods from all its superclasses
- There is potential for ambiguity when a variable/message N with the same name is inherited from two superclasses A and B
  - No problem if the variable/message is defined in a shared superclass
  - Otherwise, do one of the following
    - flag as an error,
    - rename variables (A.N and B.N)
    - choose one.

# More Examples of Multiple Inheritance

- Conceptually, an object can belong to each of several subclasses
  - ★ A *person* can play the roles of *student*, a *teacher* or *footballPlayer,* or any combination of the three
    - ➢ E.g., student teaching assistant who also play football
- Can use multiple inheritance to model “roles” of an object
  - ★ That is, allow an object to take on any one or more of a set of types
- But many systems insist an object should have a **most-specific class**
  - ★ That is, there must be one class that an object belongs to which is a subclass of all other classes that the object belongs to
  - ★ Create subclasses such as *student-teacher* and *student-teacher-footballPlayer* for each combination
  - ★ When many combinations are possible, creating subclasses for each combination can become cumbersome

# Object Identity

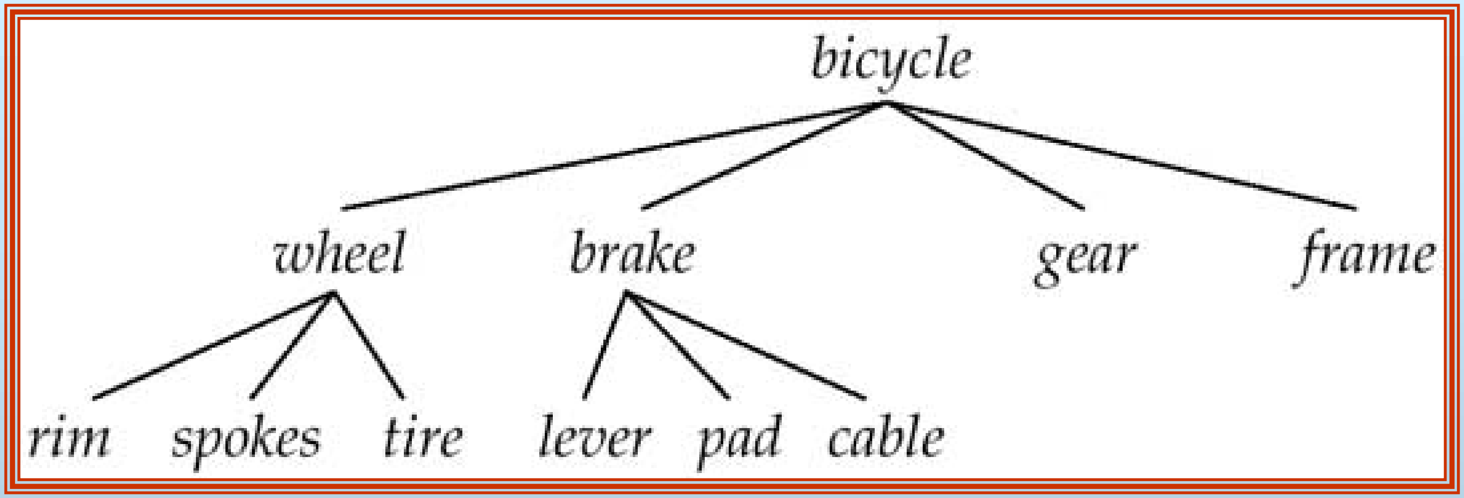
- An object retains its identity even if some or all of the values of variables or definitions of methods change over time.
- Object identity is a stronger notion of identity than in programming languages or data models not based on object orientation.
  - Value – data value; e.g. primary key value used in relational systems.
  - Name – supplied by user; used for variables in procedures.
  - Built-in – identity built into data model or programming language.
    - no user-supplied identifier is required.
    - Is the form of identity used in object-oriented systems.

# Object Identifiers

- **Object identifiers** used to uniquely identify objects
  - Object identifiers are unique:
    - no two objects have the same identifier
    - each object has only one object identifier
  - E.g., the *spouse* field of a *person* object may be an identifier of another *person* object.
  - can be stored as a field of an object, to refer to another object.
  - Can be
    - system generated (created by database) or
    - external (such as social-security number)
  - System generated identifiers:
    - Are easier to use, but cannot be used across database systems
    - May be redundant if unique identifier already exists

# Object Containment




- Each component in a design may contain other components
- Can be modeled as containment of objects. Objects containing; other objects are called **composite** objects.
- Multiple levels of containment create a **containment hierarchy**
  - ★ links interpreted as **is-part-of,** not **is-a.**
- Allows data to be viewed at different granularities by different users.

# Object-Oriented Languages

- Object-oriented concepts can be used in different ways
  - Object-orientation can be used as a design tool, and be encoded into, for example, a relational database
    - analogous to modeling data with E-R diagram and then converting to a set of relations)
  - The concepts of object orientation can be incorporated into a programming language that is used to manipulate the database.
    - **Object-relational systems** – add complex types and object-orientation to relational language.
    - **Persistent programming languages** – extend object-oriented programming language to deal with databases by adding concepts such as persistence and collections.

# Persistent Programming Languages

- Persistent Programming languages allow objects to be created and stored in a database, and used directly from a programming language
  - ★ allow data to be manipulated directly from the programming language
    - ➢ No need to go through SQL.
  - ★ No need for explicit format (type) changes
    - ➢ format changes are carried out transparently by system
    - ➢ Without a persistent programming language, format changes becomes a burden on the programmer
      - – More code to be written
      - – More chance of bugs
  - ★ allow objects to be manipulated in-memory
    - ➢ no need to explicitly load from or store to the database
      - – Saved code, and saved overhead of loading/storing large amounts of data

# Persistent Prog. Languages (Cont.)

- Drawbacks of persistent programming languages
  - ★ Due to power of most programming languages, it is easy to make programming errors that damage the database.
  - ★ Complexity of languages makes automatic high-level optimization more difficult.
  - ★ Do not support declarative querying as well as relational databases

# Persistence of Objects

- Approaches to make transient objects persistent include establishing
  - ★ Persistence by Class – declare all objects of a class to be persistent; simple but inflexible.
  - ★ Persistence by Creation – extend the syntax for creating objects to specify that that an object is persistent.
  - ★ Persistence by Marking – an object that is to persist beyond program execution is marked as persistent before program termination.
  - ★ Persistence by Reachability - declare (root) persistent objects; objects are persistent if they are referred to (directly or indirectly) from a root object.
    - ➢ Easier for programmer, but more overhead for database system
    - ➢ Similar to garbage collection used e.g. in Java, which also performs reachability tests

# Object Identity and Pointers

- A persistent object is assigned a persistent object identifier.
- Degrees of permanence of identity:
  - Intraprocedure – identity persists only during the executions of a single procedure
  - Intraprogram – identity persists only during execution of a single program or query.
  - Interprogram – identity persists from one program execution to another, but may change if the storage organization is changed
  - Persistent – identity persists throughout program executions and structural reorganizations of data; required for object-oriented systems.

# Object Identity and Pointers (Cont.)

- In O-O languages such as C++, an object identifier is actually an in-memory pointer.
- Persistent pointer – persists beyond program execution
  - ★ can be thought of as a pointer into the database
    - ➢ E.g. specify file identifier and offset into the file
  - ★ Problems due to database reorganization have to be dealt with by keeping forwarding pointers

# Storage and Access of Persistent Objects

How to find objects in the database:

- Name objects (as you would name files)
  - Cannot scale to large number of objects.
  - Typically given only to class extents and other collections of objects, but not objects.
- Expose object identifiers or persistent pointers to the objects
  - Can be stored externally.
  - All objects have object identifiers.
- Store collections of objects, and allow programs to iterate over the collections to find required objects
  - Model collections of objects as **collection types**
  - **Class extent** - the collection of all objects belonging to the class; usually maintained for all classes that can have persistent objects.

# Persistent C++ Systems

- C++ language allows support for persistence to be added without changing the language
  - Declare a class called Persistent_Object with attributes and methods to support persistence
  - **Overloading** – ability to redefine standard function names and operators (i.e., +, –, the pointer deference operator –>) when applied to new types
  - **Template classes** help to build a type-safe type system supporting collections and persistent types.
- Providing persistence without extending the C++ language is
  - relatively easy to implement
  - but more difficult to use
- Persistent C++ systems that add features to the C++ language have been built, as also systems that avoid changing the language

# ODMG C++ Object Definition Language

- The Object Database Management Group is an industry consortium aimed at standardizing object-oriented databases
  - in particular persistent programming languages
  - Includes standards for C++, Smalltalk and Java
  - ODMG-93
  - ODMG-2.0 and 3.0 (which is 2.0 plus extensions to Java)
    - Our description based on ODMG-2.0
- ODMG C++ standard avoids changes to the C++ language
  - provides functionality via template classes and class libraries

# ODMG Types

- Template class d_Ref<class> used to specify references (persistent pointers)
- Template class d_Set<class> used to define sets of objects.
  - ★ Methods include insert_element(e) and delete_element(e)
- Other collection classes such as d_Bag (set with duplicates allowed), d_List and d_Varray (variable length array) also provided.
- d_ version of many standard types provided, e.g. d_Long and d_string
  - ★ Interpretation of these types is platform independent
  - ★ Dynamically allocated data (e.g. for d_string) allocated in the database, not in main memory

# ODMG C++ ODL: Example

```
class Branch  :  public d_Object {
 ....
}
class Person  :  public d_Object {
   public:
     d_String    name;       // should not use String!
     d_String    address;
};
class Account : public d_Object {
   private:
     d_Long      balance;
   public:
     d_Long      number;
     d_Set <d_Ref<Customer>> owners;
     int           find_balance();
     int           update_balance(int delta);
};
```

# ODMG C++ ODL: Example (Cont.)

```
class Customer  :  public Person {
    public:
      d_Date              member_from;
      d_Long              customer_id;
      d_Ref<Branch> home_branch;
      d_Set <d_Ref<Account>> accounts; };
```

# Implementing Relationships

- Relationships between classes implemented by references
- Special reference types enforces integrity by adding/removing inverse links.
  - Type d_Rel_Ref<Class, InvRef> is a reference to Class, where attribute InvRef of Class is the inverse reference.
  - Similarly, d_Rel_Set<Class, InvRef> is used for a set of references
- Assignment method (=) of class d_Rel_Ref is overloaded
  - Uses type definition to automatically find and update the inverse link
  - Frees programmer from task of updating inverse links
  - Eliminates possibility of inconsistent links
- Similarly, insert_element() and delete_element() methods of d_Rel_Set use type definition to find and update the inverse link automatically

# Implementing Relationships

- E.g.

```
extern const char _owners[ ],   _accounts[ ];
class Account : public d.Object {
        ....
        d_Rel_Set <Customer, _accounts> owners;
}
  // .. Since strings can't be used in templates ...
const char _owners= "owners";
const char _accounts= "accounts";
```

# ODMG C++ Object Manipulation Language

- Uses persistent versions of C++ operators such as new(db)

```
d_Ref<Account> account = new(bank_db, "Account") Account;
```

  - ★ new allocates the object in the specified database, rather than in memory.
  - ★ The second argument ("Account") gives typename used in the database.
- Dereference operator -> when applied on a d_Ref<Account> reference loads the referenced object in memory (if not already present) before continuing with usual C++ dereference.
- Constructor for a class – a special method to initialize objects when they are created; called automatically on new call.
- Class extents maintained automatically on object creation and deletion
  - ★ Only for classes for which this feature has been specified
    - ➢ Specification via user interface, not C++
  - ★ Automatic maintenance of class extents not supported in earlier versions of ODMG

# ODMG C++OML: Database and Object Functions

- Class d_Database provides methods to
  - open a database: open(databasename)
  - give names to objects: set_object_name(object, name)
  - look up objects by name: lookup_object(name)
  - rename objects: rename_object(oldname, newname)
  - close a database (close());
- Class d_Object is inherited by all persistent classes.
  - provides methods to allocate and delete objects
  - method mark_modified() must be called *before* an object is updated.
    - Is automatically called when object is created

# ODMG C++ OML: Example

```
int create_account_owner(String name, String Address){
    Database bank_db.obj;
    Database * bank_db= & bank_db.obj;
    bank_db =>open(“Bank-DB”);
    d.Transaction Trans;
    Trans.begin();

    d_Ref<Account> account = new(bank_db) Account;
    d_Ref<Customer> cust = new(bank_db) Customer;
    cust->name - name;
    cust->address = address;
    cust->accounts.insert_element(account);
    ... Code to initialize other fields

    Trans.commit();
}
```

# ODMG C++ OML: Example (Cont.)

- Class extents maintained automatically in the database.
- To access a class extent:
  d_Extent<Customer> customerExtent(bank_db);
- Class d_Extent provides method
  d_Iterator<T> create_iterator()
  to create an iterator on the class extent
- Also provides select(pred) method to return iterator on objects that satisfy selection predicate pred.
- Iterators help step through objects in a collection or class extent.
- Collections (sets, lists etc.) also provide create_iterator() method.

# ODMG C++ OML: Example of Iterators

```
int print_customers() {
    Database bank_db_obj;
    Database * bank_db = &bank_db_obj;
    bank_db->open ("Bank-DB");
    d_Transaction Trans; Trans.begin ();

    d_Extent<Customer> all_customers(bank_db);
    d_Iterator<d_Ref<Customer>> iter;
    iter = all_customers–>create_iterator();
    d_Ref <Customer> p;
    while{iter.next (p))
        print_cust (p);  // Function assumed to be defined elsewhere
    Trans.commit();
}
```

# ODMG C++ Binding: Other Features

- Declarative query language OQL, looks like SQL
  - Form query as a string, and execute it to get a set of results (actually a bag, since duplicates may be present)

```
d_Set<d_Ref<Account>> result;
d_OQL_Query q1("select a
                from Customer c, c.accounts a
                where c.name='Jones'
                      and a.find_balance() > 100");
d_oql_execute(q1, result);
```

- Provides error handling mechanism based on C++ exceptions, through class d_Error
- Provides API for accessing the schema of a database.

# Making Pointer Persistence Transparent

- Drawback of the ODMG C++ approach:
  - Two types of pointers
  - Programmer has to ensure mark_modified() is called, else database can become corrupted
- ObjectStore approach
  - Uses *exactly* the same pointer type for in-memory and database objects
  - Persistence is transparent applications
    - Except when creating objects
  - Same functions can be used on in-memory and persistent objects since pointer types are the same
  - Implemented by a technique called pointer-swizzling which is described in Chapter 11.
  - No need to call mark_modified(), modification detected automatically.

# Persistent Java Systems

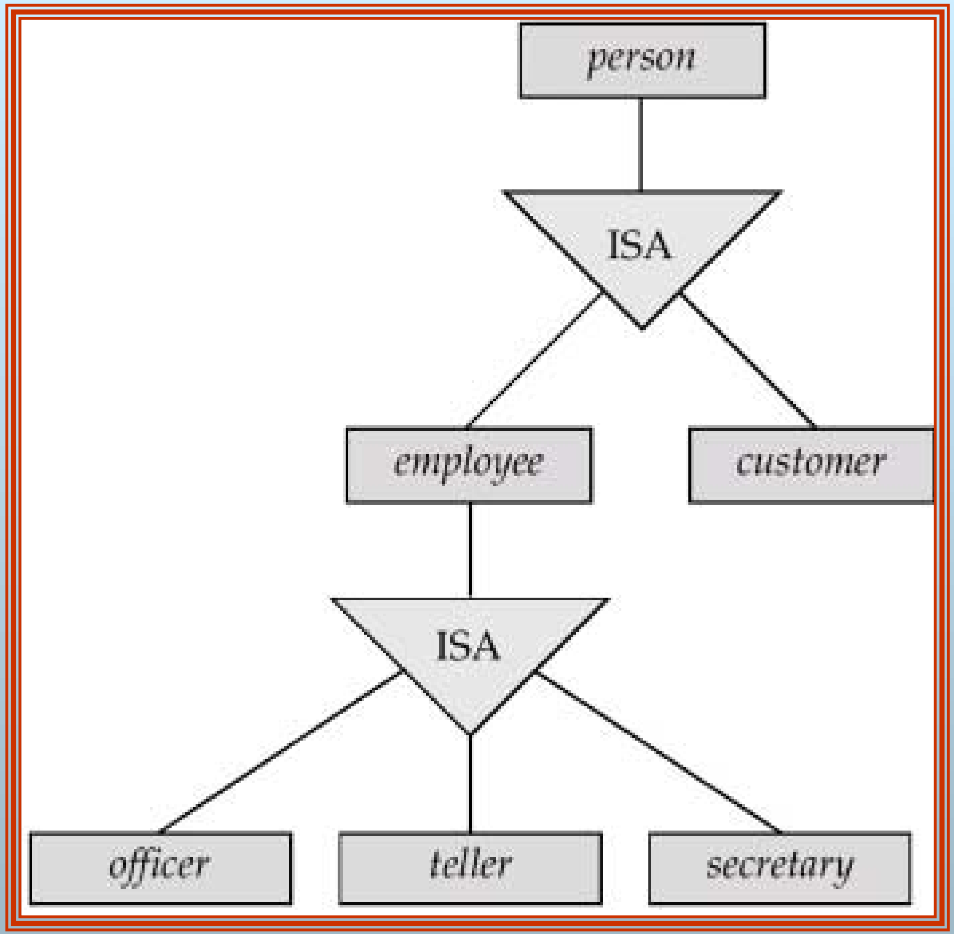
- ODMG-3.0 defines extensions to Java for persistence
  - Java does not support templates, so language extensions are required
- Model for persistence: persistence by reachability
  - Matches Java's garbage collection model
  - Garbage collection needed on the database also
  - Only one pointer type for transient and persistent pointers
- Class is made **persistence capable** by running a post-processor on object code generated by the Java compiler
  - Contrast with pre-processor used in C++
  - Post-processor adds mark_modified() automatically
- Defines collection types DSet, DBag, DList, etc.
- Uses Java iterators, no need for new iterator class

# ODMG Java

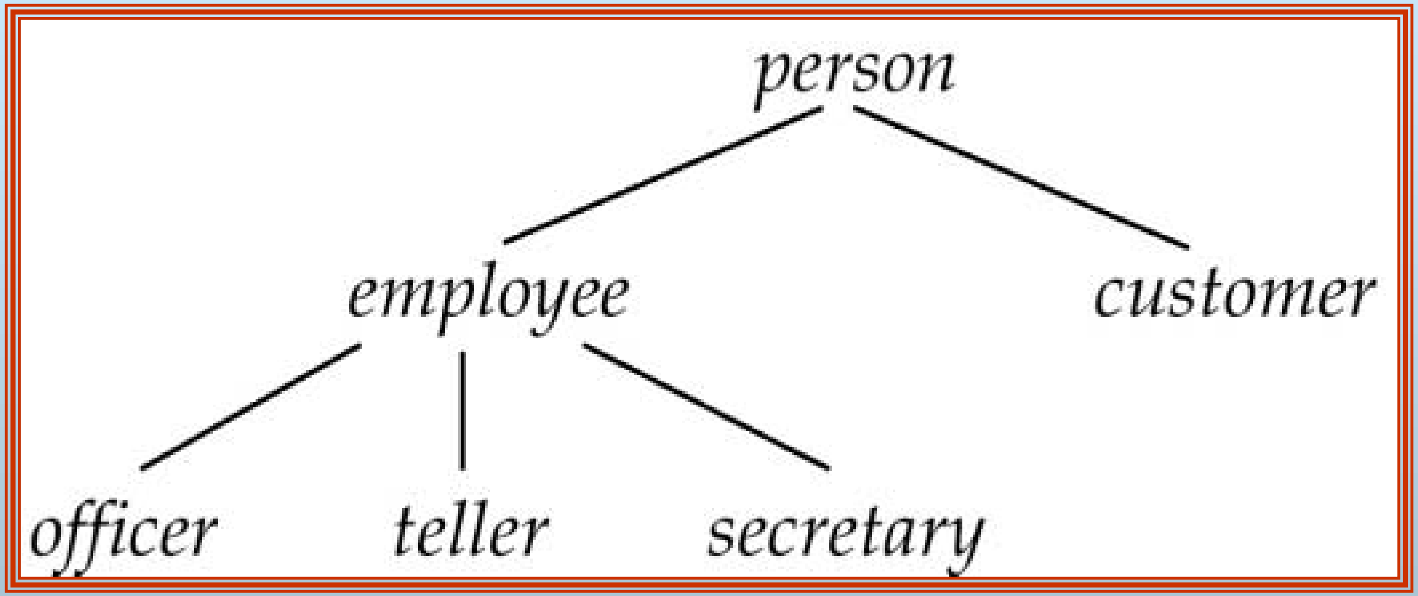
- Transaction must start accessing database from one of the root object (looked up by name)
  - ★ finds other objects by following pointers from the root objects
- Objects referred to from a fetched object are allocated space in memory, but not necessarily fetched
  - ★ Fetching can be done lazily
  - ★ An object with space allocated but not yet fetched is called a hollow object
  - ★ When a hollow object is accessed, its data is fetched from disk.

# End of Chapter

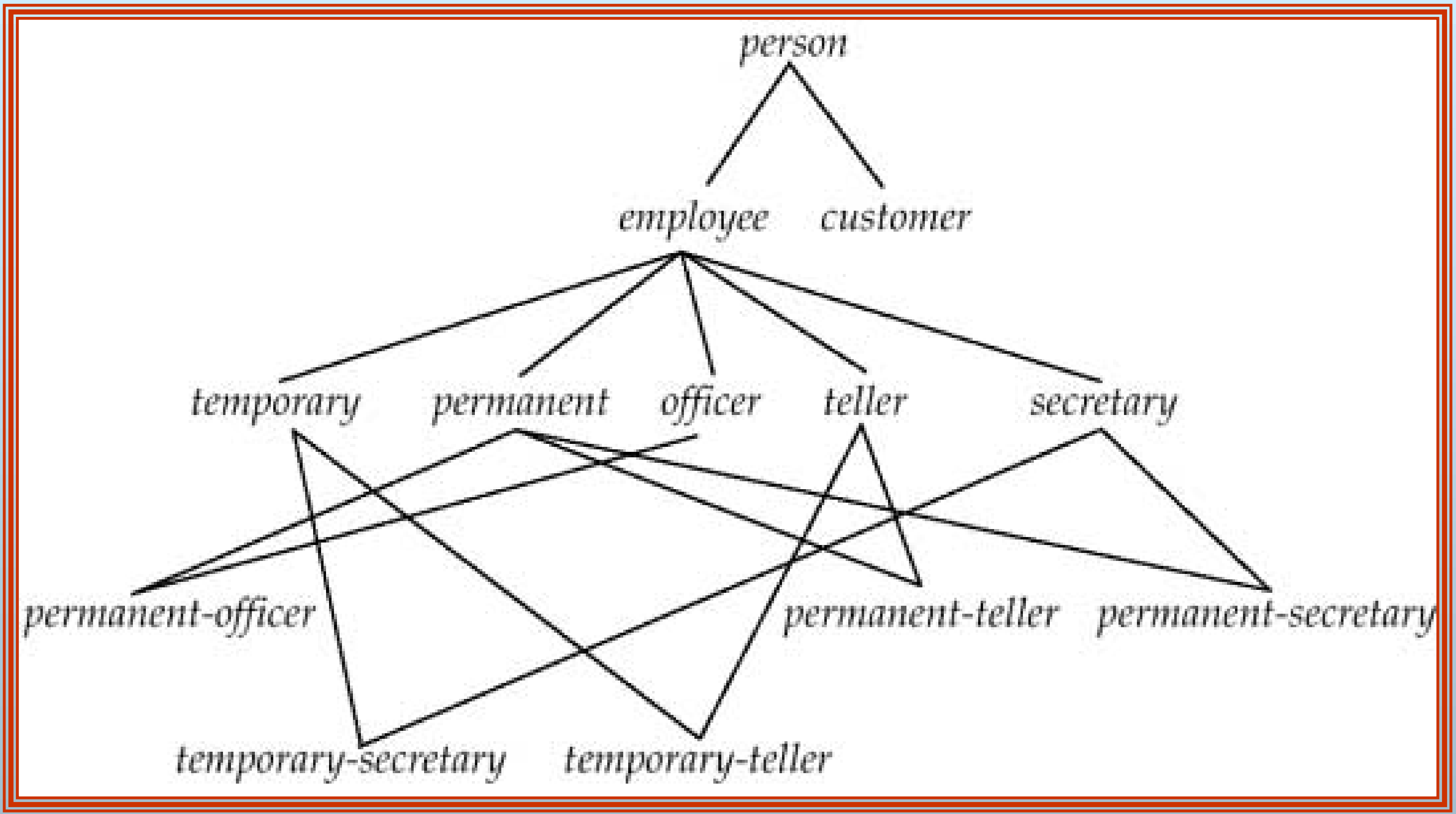
# Specialization Hierarchy for the Bank Example



# Class Hierarchy Corresponding to Figure 8.2



# Class DAG for the Bank Example



# Containment Hierarchy for Bicycle-Design Database