Chapter 8: Object-Oriented Databases

- New Database Applications
- The Object-Oriented Data Model
- Object-Oriented Languages
- Persistent Programming Languages
- Persistent C++ Systems

New Database Applications

- Data models designed for data-processing-style applications are not adequate for new technologies such as computer-aided design, computer-aided software engineering, multimedia and image databases, and document/hypertext databases.
- These new applications requirement the database system to handle features such as:
  - complex data types
  - data encapsulation and abstract data structures
  - novel methods for indexing and querying

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 a single unit.
- The object-oriented data model is a logical 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.

Messages and Methods

- The term message does not necessarily imply physical message passing. Messages can be implemented as procedure invocations.
- Methods are programs written in a 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*
- Strictly speaking, every attribute of an entity must be represented by a variable and two methods, 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
  - variable types
  - message interface
  - methods

  They 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();
};
```

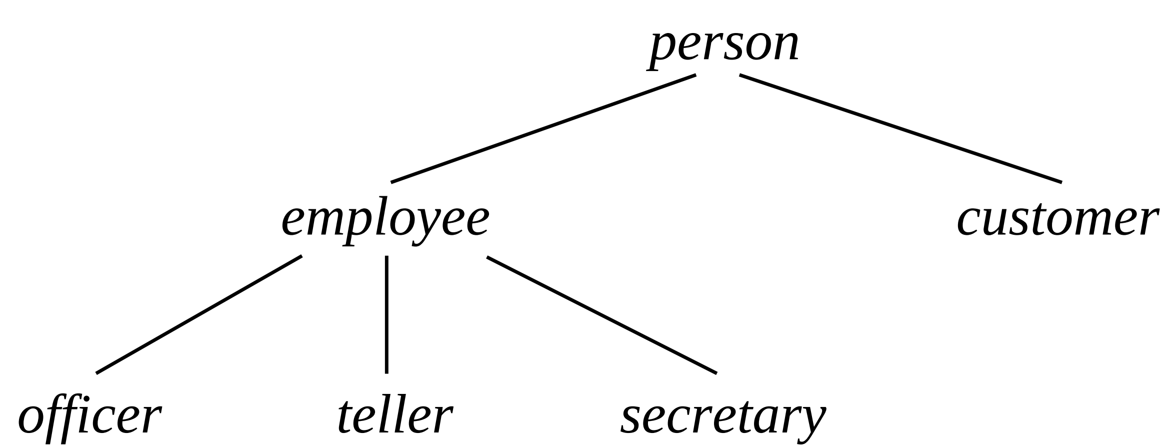
- For strict encapsulation, methods to read and set other variables are also needed
- *employment-length* is an example of a derived attribute

Inheritance

- E.g., class of bank customers similar to class of bank employees: 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 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

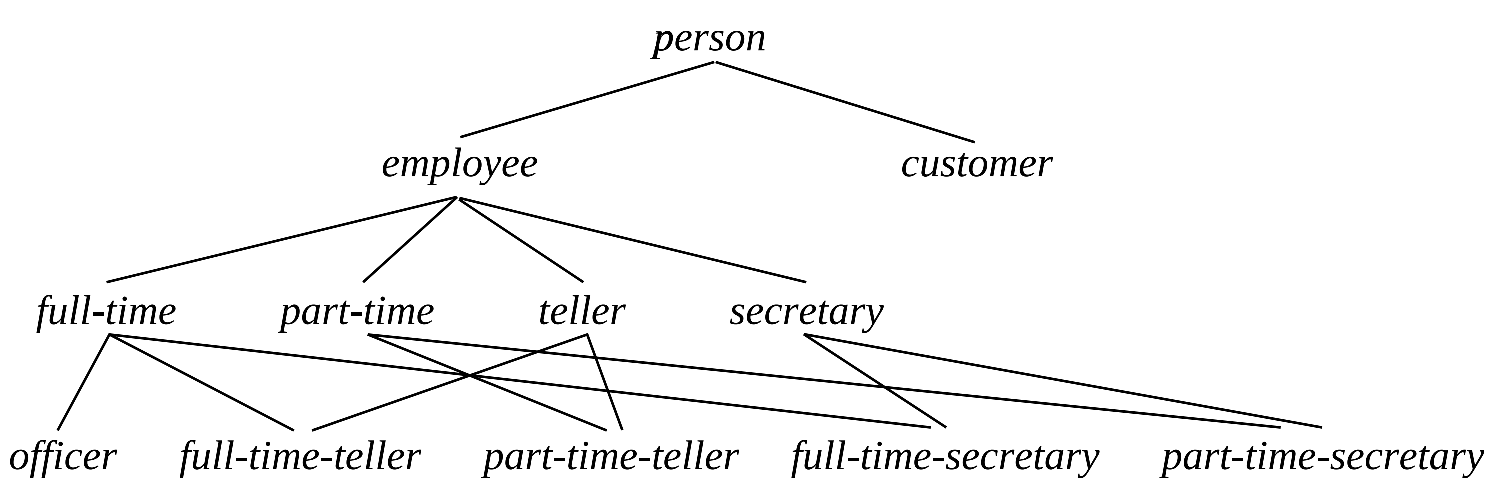
```
class person {
    string    name;
    string    address;
};
class customer isa person {
    int       credit-rating;
};
class employee isa person {
    date      start-date;
    int       salary;
};
class officer isa employee {
    int       office-number;
    int       expense-account-number;
};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

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*

Example of Multiple Inheritance

Class DAG for banking example.



Multiple Inheritance

- The class/subclass relationship is represented by a directed acyclic graph (DAG) — a class may have more than one superclass.
- A class inherits variables and methods from all its superclasses.
- There is potential for ambiguity. E.g., variable with the same name inherited from two superclasses. Different solutions such as flag and error, rename variables, or choose one.
- Can use multiple inheritance to model "roles" of an object.
  - A *person* can play the roles of *student*, a *teacher* or *footballPlayer*, or any combination of the three (e.g., student teaching assistants who also play football).
  - Create subclasses such as *student-teacher* and *student-teacher-footballPlayer* that inherit from multiple classes.

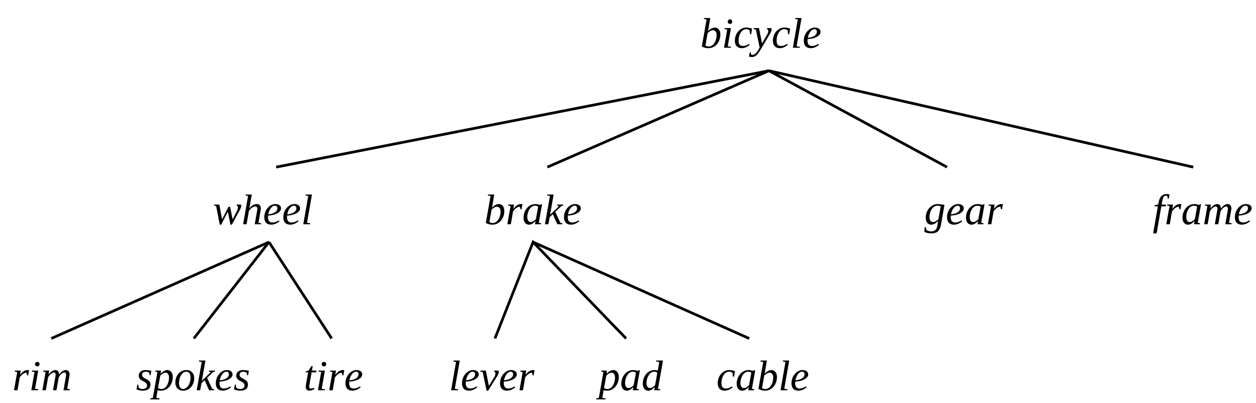
Object Identity

- 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; 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.
    - form of identity used in object-oriented systems.

Object Identifiers

- *Object identifiers* used to uniquely identify objects
  - can be stored as a field of an object, to refer to another object.
  - E.g., the *spouse* field of a *person* object may be an identifier of another *person* object.
  - can be system generated (created by database) or external (such as social-security number)

Object Containment



- Each component in a design may contain other components
- Can be modeled as containment of objects. Objects containing other objects are called *complex* or *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 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 without any explicit format changes (format changes are carried out transparently).
  - allow objects to be manipulated in-memory – do not need to explicitly load from or store to the database.
  - allow data to be manipulated directly from the programming language without having to go through a data manipulation language like SQL.
- 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 very well.

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.
  - Creation – extend the syntax for creating transient objects to create persistent objects.
  - Marking – an object that is to persist beyond program execution is marked as persistent before program termination.
  - Reference – declare (root) persistent objects; objects are persistent if they are referred to (directly or indirectly) from a root object.

Object Identity and Pointers

- A persistent object is assigned a persistent object identifier.
- Degrees of permanence of identity:
  - Intraprocedure – identity persists only during the execution 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.
  - 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.

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 to 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 dereference operator `->`) when applied to new types
- Providing persistence without extending the C++ language is
  - relatively easy to implement
  - but more difficult to use

ODMG C++ Object Definition Language

- Standardize language extensions to C++ to support persistence
- ODMG standard attempts to extend C++ as little as possible, providing most functionality via template classes and class libraries
- Template class **`Ref<class>`** used to specify references (persistent pointers)
- Template class **`Set<class>`** used to define sets of objects. Provides methods such as **`insert_element`** and *delete_element*.
- The C++ object definition language (ODL) extends the C++ type definition syntax in minor ways.

  Example: Use notation **inverse** to specify referential integrity constraints.

ODMG C++ ODL: Example

```
class Person :  public Persistent_Object {
public:
   String name;
   String address;
};
class Customer :  public Person {
public:
   Date member_from;
   int customer_id;
   Ref<Branch> home_branch;
   Set<Ref<Account>> accounts inverse Account::owners;
};
```

ODMG C++ ODL: Example (Cont.)

```
class Account :  public Persistent_Object {
private:
   int balance;
public:
   int number;
   Set<Ref<Customer>> owners inverse Customer::accounts;
   int find_balance();
   int update_balance(int delta);
};
```

ODMG C++ Object Manipulation Language

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

  ```
  Ref<Account> account = new(bank_db) Account;
  ```

  `new` allocates the object in the specified database, rather than in memory
- Dereference operator `->` when applied on a `Ref<Customer>` object loads the referenced object in memory (if not already present) and returns in-memory pointer to the object.
- *Constructor* for a class – a special method to initialize objects when they are created; called automatically when `new` is executed
- *Destructor* for a class – a special method that is called when objects in the class are deleted

ODMG C++ OML: Example

```
int create_account_owner(String name, String address) {
    Database * bank_db;
    bank_db = Database::open("Bank-DB");
    Transaction Trans;
    Trans.begin();

    Ref<Account> account = new(bank_db) Account;
    Ref<Customer> cust = new(bank_db) Customer;
    cust->name = name;
    cust->address = address;
    cust->accounts.insert_element(account);
    account->owners.insert_element(cust);
    ...  Code to initialize customer_id, account number etc.
    Trans.commit();
}
```

ODMG C++ OML: Example of Iterators

```
int print_customers() {
    Database * bank_db;
    bank_db = Database::open("Bank-DB");
    Transaction Trans;
    Trans.begin();
    Iterator<Ref<Customer>> iter =
        Customer::all_customers.create_iterator();
    Ref<Customer> p;
    while(iter.next(p)) {
        print_cust(p);
    }
    Trans.commit();
}
```

- Iterator construct helps step through objects in a collection.