# CS 4221: Database Design

# Object-Oriented DBMS Concepts

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# Topics

- Background
- Basic OO concepts
  - object, attribute, OID, class, method, encapsulation, class hierarchy, single/multiple inheritance, extensibility, complex object, overloading, overriding, polymorphism, user-defined type
- Query language in Object-Relational DBMS
- OO data model vs other data models
- Some problems in OO data model
- Inheritance conflicts in OO systems
- OO schema design
- Some reading materials (optional)

## Some references:


- Tok Wang Ling and Pit Koon Teo, Toward Resolving Inadequacies in Object-Oriented Data Models. Information and Software Technology, vol 35, no 5, 1993. http://www.comp.nus.edu.sg/~lingtw/papers/IST93.teopk.pdf
- Tok Wang Ling and Pit Koon Teo, Inheritance conflicts in object-oriented systems. Proceedings of DEXA'93, Springer-Verlag, 1993. http://www.comp.nus.edu.sg/~lingtw/papers/dexa93.teopk.pdf
- Tok Wang Ling and Pit Koon Teo, A Normal Form Object-Oriented Entity-Relationship Diagram. Proceedings of ER'94, Springer-Verlag, 1994. http://www.comp.nus.edu.sg/~lingtw/papers/er94.teopk.pdf
- Tok Wang Ling, Pit Koon Teo, Ling-Ling Yan: Generating Object-Oriented Views from an ER-Based Conceptual Schema. DASFAA 1993: pp 148-155. http://www.comp.nus.edu.sg/~lingtw/papers/dasfaa93.teopk.pdf.

# Background

- Relational DBMSs support a small, fixed collection of data types (e.g. integer, dates, string, etc.) which has proven adequate for traditional application domains such as administrative and business data processing. RDBMSs support very high-level queries, query optimization, transactions, backup and crash recovery, etc.

- However, many other application domains need complex kinds of data such as CAD/CAM, multimedia repositories, and document management. To support such applications, DBMSs must support complex data types.

- Object-oriented strongly influenced efforts to enhance database support for complex data and led to the development of object-database systems.

Object-database systems have developed along two distinct paths:

(1) **Object-Oriented Database Systems.** The approach is heavily influenced by OO programming languages and can be understood as an attempt to add DBMS functionality to a programming language environment.

- The Object Database Management Group (ODMG) has developed a standard Object Data Model (ODM) and Object Query Language (OQL), which are the equivalent of the SQL standard for relational database systems.

(2) **Object-Relational Database Systems.** ORDB systems can be thought of as an attempt to extend relational database systems with the functionality necessary to support a broader class of application domains, provide a bridge between the relational and object-oriented paradigms. This approach attempts to get the best of both.

- The SQL:1999 (also known as SQL3) standard extends SQL to incorporate support for ORDB systems
- RDDMS vendors, such as IBM, Informix, ORACLE have added ORDBMS functionality to their products.

- Object-oriented DBMS's failed because they did not offer the efficiencies of well-entrenched relational DBMS's.
- Object-relational extensions to relational DBMS's capture much of the advantages of OO, yet retain the relation as the fundamental attraction.

# Basic OO Concepts

## Object and Class

- A conceptual **entity** is anything that exists and can be distinctly identified.

  **E.g.** a person, an employee, a car, a part

- In an OO system, all conceptual entities are modeled as **objects**.

- An object has **structural** properties defined by a finite set of **attributes** and **behavioural** properties defined by a finite set of **methods**.

- Each object is associated with a logical **non-reusable** and unique **object identifier** (**OID**).
  The OID of an object is **independent** of the values of its attributes.

- All objects with the same set of attributes and methods are grouped into a **class**, and form **instances** of that class.

- Classes are classified as **lexical classes** and **non-lexical classes**.

- A **lexical class** contains objects that can be directly represented by their values.

  **E.g.** integer, string.

- A **non-lexical class** contains objects, each of which is represented by a set of attributes and methods.

- Instances of a non-lexical class are referred to by their **OID**s.

  **E.g.** PERSON, EMPLOYEE, PART are non-lexical classes.

- In some OO systems, a class is treated as an object also, and therefore processes its own attributes and methods. These properties are called **class attributes** and **class methods**.

  (Similar to **static fields** or **class variables** in Java)

**E.g.** A class EMPLOYEE can have class attributes called NO_of_EMPLOYEES which holds a count of the number of employee instances in the class, and NEXT_ENO which holds the employee number of the next new employee.

The class EMPLOYEE can have a class method called **NEW** which is used to construct new instances of the class.

# Attribute

The **domain** of an attribute of a non-lexical class A can be one of the following:

**Case (a)** a lexical class such as integer, string. An attribute with this domain is called a **data-valued attribute**.

**Case (b)** a non-lexical class B. An attribute with this domain is called an **entity-valued attribute**.

* Note the **recursive** nature of this definition.
* There is an implicit binary relationship between attributes A and B.
* The value of the attribute A is the OID of an instance of B, which must exist before it can be assigned to the attribute. This provides **referential integrity**.

* A special case exists in which the class B is in fact A. This represents a **cyclic definition** in the OO model.

**E.g.** PART-SUBPART
COURSE-PREREQUISITE

* In **ORION** (from **MCC -** Microelectronics and Computer Technology Corporation - http://en.wikipedia.org/wiki/Microelectronics_and_Computer_Technology_Corporation), the relationship between A and B can be given semantics such as **IS-PART-OF** in which case, A is a composite object comprising B.

ORION also supports the concept of an **existentially-dependent object**, in which the existence of the object depends on the existence of its parent object.
(Similar to **EX** and **ID** relationships in ER approach).

**Case (c)** a **set**, set(E), where E is either a lexical class or a non-lexical class. An attribute with this domain is called a **set-valued attribute**.

* If E is lexical, values from E are stored in the set.

* If E is non-lexical, members of the set can either be an **instance of E or its subclasses**. In this case, the set comprises instances from possibly heterogeneous classes. Only OID of each instance is stored in the set.

* In **O2** (from **O2 Technology**) both sets and lists are supported. Note that a set has no duplicates, but members of a list may be duplicated.

**Case (d)** a **query type** whose values range over the set of possible queries coded in a query language. An attribute with this domain is called a **query-valued attribute**.

* The value of a query-valued attribute is the result of the query, which is a set of objects satisfying the query.

* **POSTGRES** (from UC Berkeley, or call PostgreSQL - http://en.wikipedia.org/wiki/PostgreSQL) allows query-valued attributes.

**Case (e)** a **tuple type**. An attribute with this domain is called a **tuple-valued attribute**.

* This represents an **aggregation of attributes** of the tuple type, which is treated as a composite attribute of A.
* An attribute of the tuple type can be a data valued, entity-valued, set-valued, query-valued, or tuple-valued attribute.
* The definition of attributes of non-lexical classes is **recursive**.

Users can define their own complex data types using the mentioned attribute types.

# Method

- A method of an object is invoked by sending a **message** (which is normally the method name) to the object. Such a **message-passing** mechanism represents a **binary interaction** between the sender of the message and the recipient.

- A method's specification is represented by a **method signature**, which provides the method name and information on the types of the method's input parameters and its results.

  The implementation of the method is separated from the specification. This provides some degrees of **data independence**.

- Methods play an important role in defining object semantics.

  **E.g.** When an employee is fired, we need to delete the employee information from the employee file, delete the employee from the employee-project file, and insert the employee information into a history file, etc.

  One method called "**Fire-employee**" can be defined that incorporates this sequence of actions.

  **E.g.** **CPF** (Central Provident Fund) method for employees.

- In OO systems that support **strong encapsulation** (e.g. **ORION, SMALLTALK -** **http://en.wikipedia.org/wiki/Smalltalk**), the only interaction with an object is through the object's methods.

  The attributes are **not** directly accessible, but are instead retrieved/updated through respective **get/set** methods.

- In OO systems that support a **relaxed form of encapsulation**, attributes may be accessed directly. Some protection mechanisms are provided to restrict access to sensitive data such as “salary”.

**E.g.** O2 provides a mechanism to partition an object’s properties into **public** and **private**.

**Example 1** This example provides definition of non-lexical classes EMPLOYEE and DEPARTMENT (using an O2-like notation).

add **class** DEPARTMENT
    type **tuple**(D#: string, Dname: string, Mgr: EMPLOYEE)

add class EMPLOYEE
    type tuple (E#: integer, Name: string, Salary: integer,
        Dept: DEPARTMENT,
        Address: tuple (street: string, city: string),
        Supervisor: EMPLOYEE,
        Supervisees: **set** (EMPLOYEE) )

add **method** compute_tax( ): integer in class EMPLOYEE

add method fire_employee( ): Boolean in class EMPLOYEE

**Note:** A cyclic definition exists in the “Supervisor” and “Supervisees” attributes. Redundancy exists. Data consistency checking is required when one of them is updated.

# Class Hierarchy

- Given 2 classes X and Y, **X ISA Y** means that each instance of X is also an instance of Y. We call X a **subclass** of Y and Y a **superclass** of X.

  **E.g.** Manger isa Employee

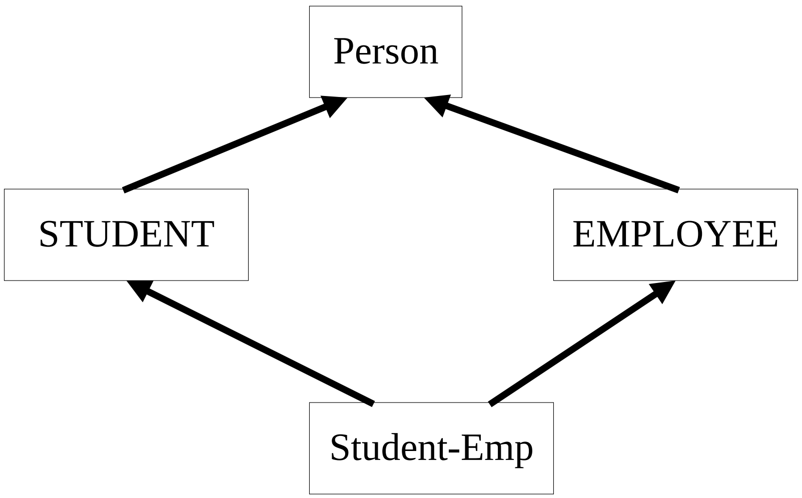
- A class hierarchy provides an **inheritance mechanism** which allows a class to inherit properties (attributes and methods) from its superclasses.

- In **single inheritance** systems, a class can have **at most one** direct superclass and therefore can only inherit from that superclass.
  The class hierarchy forms a tree.

- In **multiple inheritance** systems, a class can have **more than one** direct superclass.
  The class hierarchy is a lattice.

**Note:** In multiple inheritance systems, a class may inherit properties and methods from different super classes and therefore may have **inheritance conflicts.**

**Example 2.** A multiple inheritance example.




Person is the root of the class hierarchy.

Student_Emp has 2 superclasses, STUDENT and EMPLOYEE.

Q: Does Java allow multiple inheritance?

# Extensibility

- **Extensibility** is another important feature of the OO paradigm. It allows the creation of new data types, i.e. user-defined types, and operations on these new data types from built-in atomic data types and user defined data types using the type constructor.

- A **type constructor** is a mechanism for building new domains.

  A **complex object** is built using type constructors such as sets, tuples, lists and nested combinations.

- A combination of an user-defined type and its associated methods is called an abstract data type (ADT).

# Extensibility (cont.)

- Hiding of ADT internals (implementation) is called encapsulation.

- Most OODBMSs, e.g., ORION, O2, IRIS support data type extensibility.

  **E.g.** A new data type called POLYGON can be added to handle geometric objects. The user can define an operator AE (Area Equal) which allows two polygons to be compared for area equality. A method “draw” allows a polygon to be plotted.

  **E.g.** One might define operations on an image data type (jpeg_image) such as compress, rotate, shrink, crop on an image, and overlay two images.

- In the OO paradigm, different classes may have methods with the same name.

**E.g.** Consider 3 classes, PERSON, EMPLOYEE and SECRETARY, and the ISA relationships:

EMPLOYEE ISA PERSON
SECRETARY ISA EMPLOYEE

All 3 classes have a method called “Print”.

The implementation of “Print” in SECRETARY **redefines** and **overrides** the “Print” method in EMPLOYEE, which in turn, redefines and overrides the “Print” method in PERSON. All these 3 “Print” methods are different.

An **overloading** of the “Print” method has occurred.

- A feature related to the use of overloaded methods is **polymorphism**. Polymorphism is the ability of different objects to respond differently to the same message.

**Example 3** Consider a linked list comprising objects from PERSON, EMPLOYEE and SECRETARY classes. A traversal of the linked list can be done so that each node in the list a ‘Print’ method is invoked. This C++ like program provides a piece of polymorphic code to perform the traversal.

```
void Print (Person *p) {
    for (Person * ptr = p; ptr; ptr = ptr -> next)
        ptr -> Print( );
}
```

The type of the pointer ptr is resolved during runtime to be one of PERSON, EMPLOYEE or SECRETARY.

The appropriate “Print” method is then invoked depending on the type.

Resolution of the type of an object during runtime is referred to as **late binding**.

# Query Language in Object-Relational DBMS

**Example**. from SQL/X of UniSQL, Inc. UniSQL is the earliest proposal to add object-oriented features into relational DBMS.

```
create class PERSON
        ( Name      CHAR(20),
          Sex       CHAR(1),
          BirthDay    DATE )
     METHOD
          Age ( )  INTEGER;

create class EMPLOYEE
        ( Job       CHAR(20),
          Salary    FLOAT,
          Hobby     SET-OF ACTIVITY,
          WorksFor      COMPANY )
     METHOD
          CPF-CONTRIBUTION ( ) INTEGER
     AS SUBCLASS OF PERSON;
```

create class **ACTIVITY**

```
( Name       CHAR(20),
  NumPlayers INTEGER);
```

create class **COMPANY**

```
( Name     CHAR(30),
  Location CHAR(20),
  Budget   FLOAT);
```

**Query:** Single class query

**select** Name, Salary
**from** EMPLOYEE
**where** Job = "Engineer";

Note: Name is inherited from the superclass PERSON

**Query:** Two-class Join Query

**select** EMPLOYEE.Name, Job, WorksFor.Name
**from** EMPLOYEE, COMPANY
**where** Employee.Name = Company.Name;

Note: Both Employee and COMPANY have a property called "Name".

**Q:** What is the meaning of this query?

**Query:** Path Query

```
select    Name, Job
from      EMPLOYEE
where     "Tennis" IN Hobby.Name   AND
          WorksFor.Name = "NUS";
```

**Query:** Query with Group By

```
select    Job, AVG(Salary)
from      EMPLOYEE
where     "Tennis"  IN  Hobby.Name
group by Job;
```

**Query:** Query with a nested subquery.

```
select    Name, Salary
from      EMPLOYEE
where     Salary >
      0.01 * ( select   MIN (Budget)
               from     COMPANY
               where    Location = "Jurong");
```

**Query:** Query against a class and all its subclasses

```
select   Name, BirthDay
from     ALL PERSON
where    Sex = "M";
```

The keyword **ALL** is used in order to find all subclasses of person.

**Query:** Query with method

```
select   Name, Hobby, Age
from     EMPLOYEE
where    Job = "Sales"   AND
         CPF-contribution > 500;
```

Note: Queries cannot involve methods with side effects. Why?

# OO data model *vs* hierarchical data model

- The nested structure of objects and the nested structure of records in hierarchical databases are similar.
- The essential difference is that the OO data model uses logical and non-reusable OIDs to link related objects while the hierarchical model uses physical reusable pointers to physically link related records. Hierarchical model has no object and OID concepts.
- Another difference is that the OO data model allows cyclic definition within object structures.

  **E.g.** a course can refer to other courses as its pre-requisite courses.

  To support cyclic definition in the hierarchical data model, dummy record types (e.g. prerequisite record) are needed.

# OO Data Model *vs* Nested Relations

- In the nested relation approach, an attribute of a relation can itself be a relation.

  The nested relation is stored physically within the base relation.

  This approach does not allow the nested relation to be shared among relations.

  There may be a redundant storage of data which can lead to updating anomalies.

- In the OO approach, nested relations are simulated by using the **OIDs** of tuples of a relation that are to be nested within a base relation.

  Because OIDs are used, sharing of tuples of nested relation is possible. There is less redundancy.

  **Question:** Any redundancy? Yes! Why?

# OODBMS *vs* OOPL

- There is a strong parallel between developments in OODBMS's and OO programming languages (OOPL's).
- Developments in OOPL's have taken one of the two approaches:

  (a) Take an existing PL and extends it with OO constructs.

  **E.g.** C++ and objective-C extend C
  CLOS and LOOPS extend LISP

  (b) Develops a new OOPL

  **E.g.** Java, Smalltalk, Eiffel

- In the OODBMS community, 2 similar approaches:

  (a) Extend the relational DBMS to incorporate OO concepts (i.e. object relational model).

  **E.g.** POSTGRES, UNISQL, DB2, ORACLE, Informix, Microsoft SQL Server

  (b) Develop a DBMS around an OO data model.

  **E.g.** ORION, IRIS, O2

- Differences between OOPL's and OODBMS's

  (a) OOPL's do not have the amenities of databases such as **data persistency** and **concurrency**.

  **E.g.** an OOPL does not have inherent data persistence and cannot share data across multiple sessions, except through a programmer-manipulated file system.

  (a) The type systems of OOPL's and OODBMS's differ. Database calls are **declarative** and operate on a **set** at a time basis, while an OOPL is **imperative** and suited for handling a **record** at a time processing.

# Some problems and proposed solutions in Object-Oriented Data Models

## 1. General disagreement on OO concepts

- Several OO data models have been proposed that offer somewhat different interpretation of OO concepts. No common agreement for a long period.
- Wide diversity in implementation of the data models.

**E.g.** Gemstone (from Servio Logic) adopts the **object/message paradigm**, and Vbase (from Ontologic) uses an **abstract data type paradigm** to encapsulate data and operation

**E.g.** IRIS (from HP) uses a **functional approach** in which methods and attributes are modeled by mathematical functions and POSTGRES (from UC Berkeley) extends the relational model to support OO concepts.

- Despite this diversity, a core set of OO concepts is common across these data models, such as **object**, **attribute**, **method**, **class**, **class hierarchy**, **encapsulation**, and **polymorphism**.

## 2. Navigational Model of Computation

- The value of an attribute of an object may be an **OID** (**object identifier**) of another object, which is in turn may reference another object, leading to a complex and nested structure. Wide diversity in implementation of the data models.
- The use of **explicit reference** is similar to the CODASYL approach - network model, which uses pointers.
- This **navigational component** causes several problems:

(a) Consider the schema and below 2 person objects:

(Ob1, < name: “John”, spouse: Ob2>)
(Ob2, < name: “Mary”, spouse: Ob1>)

where Ob1 and Ob2 are OIDs.

This example uses an **inverse relationship reference**. This causes the update problem, contradicts to the easy maintainability objective of the OO paradigm.

(b) For a navigational interface, access to data is hard-coded and therefore does not enjoy the benefit of a **query optimizer**.

(c) The navigational approach does not preserve **data independency** any better than the hierarchical or network model.

- An OODBMS can be augmented with a declarative query language to complement the navigational access.

## 3. Issues in Use of Methods

The message passing mechanism that is used to trigger methods in OO systems presents some problems.

(a) Message passing is **binary**.

n-ary (n>2) relationships need to be redefined as binary relationships. This will result in information loss.

(b) The OID of the receiving object must be **known before** a message can be sent. Such OID may sometimes not be available.

E.g. *Find the names of Employees who are younger than 30 and are male.*

However, it is useful to have methods that provide better semantics for object behaviour,

E.g. *fire-employee method*

E.g. *CPF computation for employee objects*

Unlike attributes, it may not be possible to index methods. Why?

## 4. Standard Declarative Query Language

- Unlike relational DBMS's which have adopted SQL as the de facto standard, no generally agreed upon standard declarative query language was available for OODBMS's for a long period.

- Object Data Management Group (ODMG) http://www.odbms.org/odmg designed a query language Object Query Language (OQL) modeled after SQL as a query language standard for OODBMS. Because of its overall complexity no vendor has ever fully implemented the complete OQL.

- In OODBMS's that lack query language, methods need to be defined to handle queries. It faces at least 2 problems:

(a) It is impossible to pre-empt all possible queries and provide methods for them.

(b) Consider the following query on SPJ db:

*Find all suppliers who supply at least one red part to more than one project.*

This is not a trivial method to write.

This method cannot be defined as a method for supplier object. A more appropriate level is either declare it as a class method, or as a method at meta class level.

- A query language is needed to handle complex queries.
- Optimizing queries in the presence of arbitrary methods is a difficult issue.
- IRIS only allows methods without side-effects to participate in queries.

  POSTGRES restricts methods to contain only data manipulation commands that can be optimized.

  Other systems do not permit methods in queries.

## 5. Access Methods and Data Type Extensibility

- Most OODBMS's such as ORION, O2, IRIS allow new data types (i.e. user-defined types) to be added.

  E.g. Add a new type POLYGON together with an operator called AE (Area Equal) and a method 'draw'.

- Conventional DBMS's already provide standard access methods (e.g. B-trees, hash tables, etc.) to support an efficient database access. To provide efficient access instances of new, specialized user-defined types, access methods beyond those provided by the DBMS's are required.

- Some proposed that users provide their own access methods to support their new data types. However, supporting these user-defined access methods is difficult. Query optimizers have problem to use user defined access methods for query optimization processing.

# 6. Support for complex objects

- Many applications need to define and manipulate a set of objects as a single logical complex entity.

- Complex objects can be built using list, set, record and nested combinations of these.

- Most OODBMS's e.g. O2, ORION, support complex objects.
  In ORION, semantic relationships such as **IS-PART-OF** are assigned to inter-object references within complex objects.

- ORION also supports the concept of an **existentially-dependent object** (weak entity in ER approach), in which the existence of the object depends on the existence of its parent object.

  The deletion of an object triggers a **cascading delete** of all objects that are existentially dependent on the deleted object. This adds to the integrity features of the ORION data model.

- While the use of complex objects has an important semantic value, the efficient retrieval of complex object (and its components) is still a difficult issue.

- Several techniques e.g. **clustering** & **indexing**, have been proposed to improve the performance of complex object retrieval for navigational based or query-based retrieval.

- **Clustering** is suitable when an object is navigated using inter-object references. In clustering, components of a  complex objects are stored together on a physical transfer unit (e.g. page), and hence they can be retrieved efficiently.

  However, any clustering of objects is optimal for one type of access to the objects, but sub-optimal for most other types of access. It is left to the users to specify a preferred clustering strategy.

- The idea of using indexes (of RDBMS's) has been extended to OODBMS's.

  The notion of a class hierarchy index and nested attribute index have been proposed.

  - A **class hierarchy index** is defined on an attribute of a class and instances that are indexed belong to the class and its subclasses, if any (e.g. ORION).

    **E.g.** A query "Find all students who are 21 years old" on the class hierarchy in Example 2 (page 20) has the search condition that he or she should be a Student as well as the predicate that he or she should be 21 years old. Here, all TAs can also be considered Students by the ISA relationship imposed on the class hierarchy. Therefore, objects of all classes in the hierarchy rooted at Student should be searched for this example query. How to index the age attribute of the classes?

  - A **nested attribute** is an attribute of a nested component object of a complex object. Queries on a complex object can be predicated on a nested attribute.

    By defining an index on the nested attribute, the queries can be more efficiently supported. How?

# 7. Object Identity

There have been debates on the relative merit of supporting **OIDs** and user-defined **keys** (as in RDBMS's)

Some proposed that OIDs should be assigned if keys are not available.

Some believed that OIDs are unnecessary and undesirable because:

(1) All keys e.g. SSN, E#, PART#, etc. are actually user created. In fact, all attributes are artificially created by users. Therefore, a key can always be artificially created by the user for an object class that does not possess one.

(2) Keys are more natural and human readable comparable to OIDs, which are implementation specific (e.g. pointer-based OIDs).

(3) Overhead incurred by OIDs.

4 common implementation techniques of OIDs:

1. Physical Address (memory address or disk address)
2. Structured Address (logical page no. + record no. in the page)
3. Untyped Surrogate key (positive integer value)
4. Typed surrogate key (record type + positive integer value)

If **physical addresses** are used for implementing OIDs, reorganization of disk storage (e.g. remove deleted objects in order to improve disk usage and performance) may not be possible.

On the other hand, if **logical pointers** are used for implementing OIDs, one more table lookup access is required to access an object.

(4) While values of keys can change because of changing conditions, such changes represent a conscious effort on the part of the user, and can be done in a controlled environment.

**E.g.** Change all 7 digit house phone numbers to 8 digit phone numbers by adding a leading digit 6. The changes can be done offline.

(5) Multi-databases. In order to identify or find a real world object, key value (or some attribute value) is needed. Also a real world object which appears in two different databases, sure have different (system generated) OID values. To determine whether two objects from 2 different databases are referred to the same real world object, key values are needed.

(6) Object migration problem. When an object moves to its superclass or subclass (e.g. an employee is promoted to manager position) whether the object's OID should be changed or not? How to implement OIDs in order to avoid changing of OIDs when objects migrate?

**One approach:** Implement OIDs by untyped surrogate keys. Why?

Q: Does Java allow object migration such as promotion of employees?

(7) Weak entity. The semantics of a weak entity requires that it should be accessed in conjunction with its parent entity. However, the use of OIDs allows the weak entity (i.e. existentially dependent object) to be directly accessed. This weakens the semantics of weak entities.

(8) View object. For RDB, we can create view relations (external relations). For example, we want to create a view relation called GoodStudent, to store all the good students who have CAP >=4.50. If we can create view objects, then how to design/create the OIDs for the view objects?

## 8. Should attributes be directly accessible?

There were debates on whether attributes of an object should be directly accessible.

- **Approach 1**: access to an object's attribute (e.g. Sex, DOB of a person) should be through the object's (public) methods. This approach shields applications from changes in the implementation of attributes and provide data independence. However, it appears trivial and redundant to generate public access methods (e.g. **get/set**) for attributes.
- **Approach 2**: subject to a separate authorization scheme, attributes of objects should be directly accessible. This is because a query language optimizer needs to access the object's values directly.

- Use methods to access object's attribute values generate unnecessary overhead. Approach one will have difficulty to write methods to answer queries such as:

  **E.g.** Find all male employees who are older than 30 but younger than 50 and work for Sales or Personnel Department .

- However, e.g. the CPF contribution of an employee should be implemented as a method. Whenever the CPF contribution computation formula changes, only the method's implementation needs to be changed; applications that use this method are not affected.

  **Note** that CPF contribution of an employee is not an attribute. CFP contribution rates can be found on

  http://mycpf.cpf.gov.sg/Members/Gen-Info/Con-Rates/ContriRA

**Note:** Java provides different types of access control using field (attributes) modifiers such as public, protected, no modifier, and private.

The following slides discuss some **OO data modeling issues** which can be resolved by applying concepts and techniques from ER data modeling.

## 9. Everything as Objects?

- SMALLTALK has "successfully" demonstrated the usefulness of a consistent treatment of everything as objects in a programming environment.
- It may be less useful to treat everything as objects in a database environment.
- In database design, it is important to **distinguish** among **attributes**, **entities**, and **relationships**.

## 10. Formal Foundation for OO paradigm

- RDBS have the relational model, which has a mathematical basis in **first order logic**. **Normalization** and **data dependency** theories can be applied to a RDB schema to determine its quality.
- Initially, no equivalent theories (e.g. FD, MVD theories and normalization) were available for OO database design, it is difficult to judge whether an OO schema is ‘good’.
- [1] extended ER Diagram with methods, called **OOER diagram**, to represent OO schemas. Normal form OOER diagram was proposed to determine quality of an OO schema.

[1] Tok Wang Ling, Pit Koon Teo: A Normal Form Object-Oriented Entity Relationship Diagram. ER 1994: 241-258, 1993

## 11. Lack of support for explicit relationships

- Most OO data models (e.g. O2, ORION) use inter-object references (using OIDs) and the class hierarchy to support relationship among objects.
  Inter-object references provide only **implicit binary relationship** between 2 objects.

- Using this approach, the modeling of **m:m**, **n-ary** and **recursive relationships** are problematic and introduce problems similar to those faced by hierarchical and network models.

  **Note:** Object Definition Language (ODL) from Object Data Management Group (ODMG) allows user to define the reverse relationship of a m:m binary relationship in a class.

- The class hierarchy allows object classes that are related by ISA relationship to be organized into a hierarchy. However, special relationship types such as UNION, INTERSECTION, DECOMPOSE, etc. are not supported.

Several problems arise from this.

**(a)** ***Nested relations***

Consider the nested relation

DEPT (D#, Dname, EMP **(**E#, Name, Sex**)** )

in which EMP attribute is itself a relation.

Such a nested relation imposes a strictly hierarchical structure which does not facilitate symmetric queries.

* In OODBMS's, there are at least 2 approaches to support the DEPT nested relation.

(i) **Approach 1**: Treat the EMP attribute in DEPT as a multivalued attribute, as its value, a list of OIDs that identifies the employee working in the department. This approach is adopted in O2 and allows object sharing. However, it is difficult to handle symmetric queries.

**(ii) Approach 2**: This approach is adopted in POSTGRES. It allows the value of an attribute in a relation to be a relational query.

It assume that there exist 2 physical tables:

EMP(E#, Name, Sex, D#)
DEPT(D#, Dname, EMPS)

The EMPS attribute in DEPT can be defined to hold a query such as:

```
select   E#, Name, Sex
from     EMP
where    EMP.D# = D#;
```

The problem with this approach is that update on the EMPS attribute (which is a view) of DEPT must be translated to updates on the base EMP tables. This may not always be possible in general.
The performance may not be good.

**Question:** Where to store the query?

## (b) *M:M, N-ary and Recursive Relationships*

Consider the SP database, in which S and P are related by an m:m relationship type SP.

* One can store S, P, and SP as objects with (logical) pointers linking them.
  ORION adopted this approach, which provides a navigational component that may be hard to maintain.

* An alternative is to store P within S. This impose a hierarchical structure which cannot handle symmetric queries effectively.

  It also introduces redundancy and leads to updating anomalies.

  Recall: Object Definition Language (ODL) from Object Data Management Group (ODMG) allows user to define the reverse relationship of an m:m binary relationship in a class.

* The above modeling problems are amplified when n-ary (n>2) relationships are considered, e.g. SPJ database.

* There is no feasible solution for modeling an n-ary relationship using inter-object binary references in the OO paradigm.

* Some suggested that new "**relationship**" object classes must be created to represent ternary (and higher degree) relationships.
* Similar problems occur for modeling **recursive relationships** such as course-prerequisite, part-subpart, etc.

One way to represent this in ORION and O2 is to define a set valued attribute called pre-requisite in a course class, with data type course also.

Deeper levels and **transitive closures** must be computed. The recursive nature is lost in this representation.

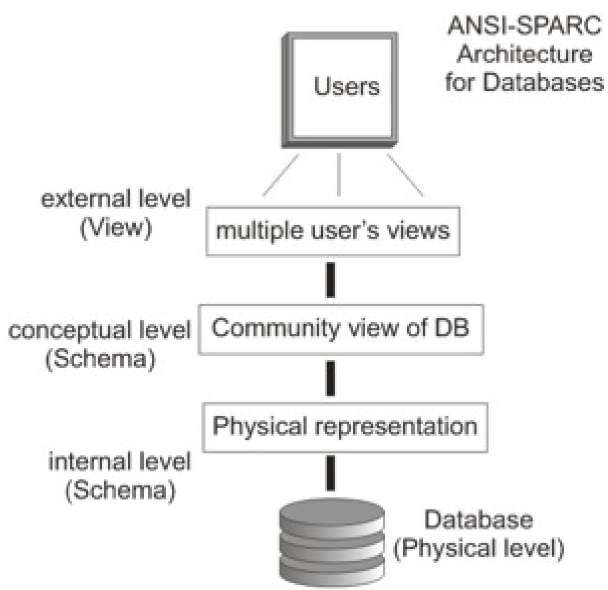
In some OODBMS's, the query language is enhanced with syntactic constructs to support the computation of the transitive closure of a recursive relation.

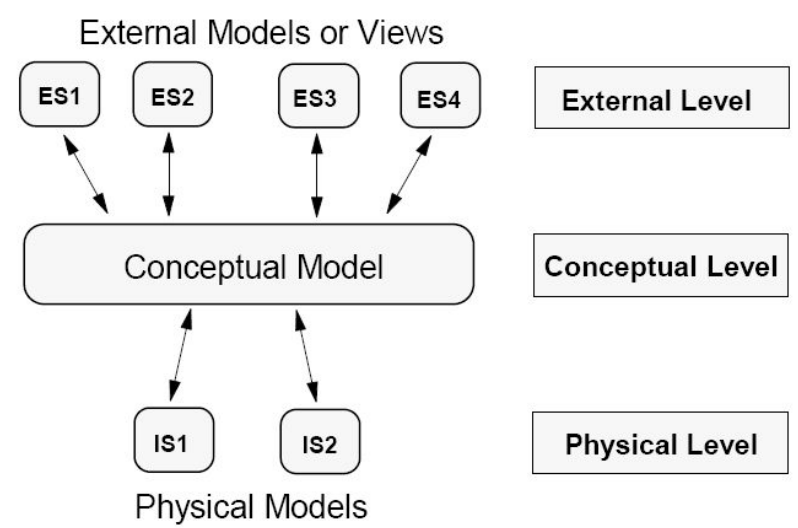
E.g. POSTGRES has a transitive operator "*".

# 12. Lack of General View Support

- Except for those OODBMS's that are based on the extended relational model (e.g. POSTGRES), most OODBMS's do not fit into the 3-level schema architecture framework as spelled out in ANSI/X3/SPARC proposal (American National Standards Institute, Standards Planning And Requirements Committee) in 1975.

Note: The ANSI-SPARC model however never became a formal standard.



The 3 level of schemas are:

- **External Level (User Views)** : A user's view of the database describes a part of the database that is relevant to a particular user. It excludes irrelevant data as well as data which the user is not authorised to access.

- **Conceptual Level :** The conceptual level is a way of describing what data is stored within the whole database and how the data is inter-related. The conceptual level does not specify how the data is physically stored.

- **Internal Level :** The internal level involves how the database is physically represented on the computer system. It describes how the data is actually stored in the database and on the computer hardware.

- Users of most OODBMS's are often presented with a large-grained conceptual schema, with little or no facility for defining views.

- Several proposal have been made to incorporate views in OODBMS's, but most of the proposals do not provide the same generality and flexibility of a declarative relational view mechanism.

**(i)** **Approach 1:** Some only allows to define multiple views to a class.
Joins of classes and selections on classes are not allowed for defining views. A view of a class contains a subset of methods and attributes of the class.
**Question:** What is the value of a view object's OID?

**(ii)** **Approach 2**: Use a query based view mechanism to derive subclasses from superclass.
Such views are not updatable or updates apply only to non-recursive views that are based on a join of the primary key of the base tables.
They cannot handle other kinds of relationships, such as m:m, n-ary relationships.

(iii) **Approach 3**: An OO schema is represented by an OOER (schema) diagram. Mapping rules are proposed to generate external schemas (i.e. views) from the OOER diagram. Views of the OO schema are represented as views of the OOER diagram.

## 13. Conflicts in Class Hierarchy and Multiple Inheritance

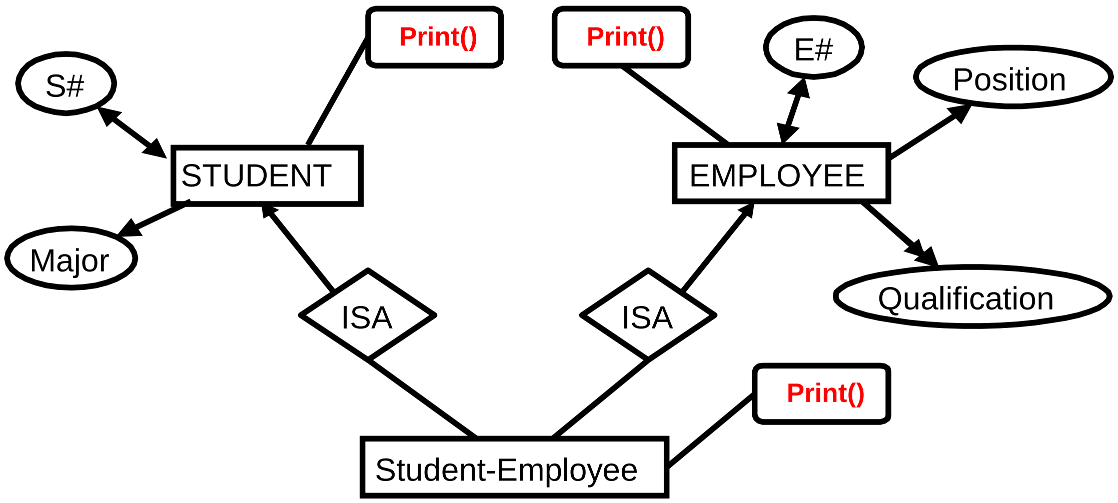
- There may have attribute and/or method name conflicts among a class and its superclasses.
- Details in the following slides.

# Inheritance Conflicts in OO Systems

- In the OO paradigm, classes related through the ISA relationship are organized into a **class hierarchy**.
- There may have attribute and/or method name conflicts among a class and its superclasses.
- A class **inherits** properties (attributes and methods) from its superclasses in the class hierarchy.
- When a class inherits several commonly named properties of its superclasses, a conflict situation occurs which is resolved differently in different OO systems.

**Ref:** Tok Wang Ling, Pit Koon Teo: Inheritance Conflicts in Object-Oriented Systems. DEXA 1993: 189-200

# Example




- "Print" is a method in EMPLOYEE that display information such as E#, Position, and Qualifications of an EMPLOYEE object. STUDENT has a similarly named method "Print" which displays information such as S# and Major of a STUDENT object.

  **Note:** We append "( )" to a string to denote the string is the name of a method. Method is represented by a round rectangle in the OOER diagram.

- The semantics of "Print" in these 2 classes are different.

- The subclass Student-Employee can define a similarly named method “Print” which has a different semantics from the 2 “Print” methods of its superclasses. “Print” is an **overloaded method**.

- The use of a common method name in a class hierarchy allows the exploitation of the notion of **polymorphism**, i.e. the ability of different objects to response differently to the same message (method name).

- There is **no conflict**.

# 1. Motivating Example

- In Figure 1, the class SUBMARINE needs to determine "SIZE" attribute to inherit from its 2 direct superclasses, i.e..

MOTORISED_VEHICLE and WATER_VEHICLE.

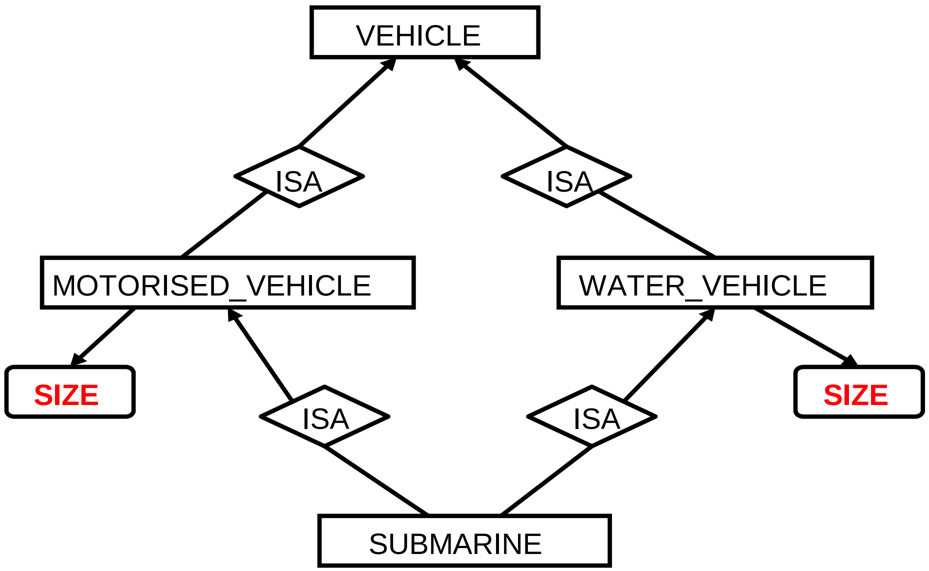


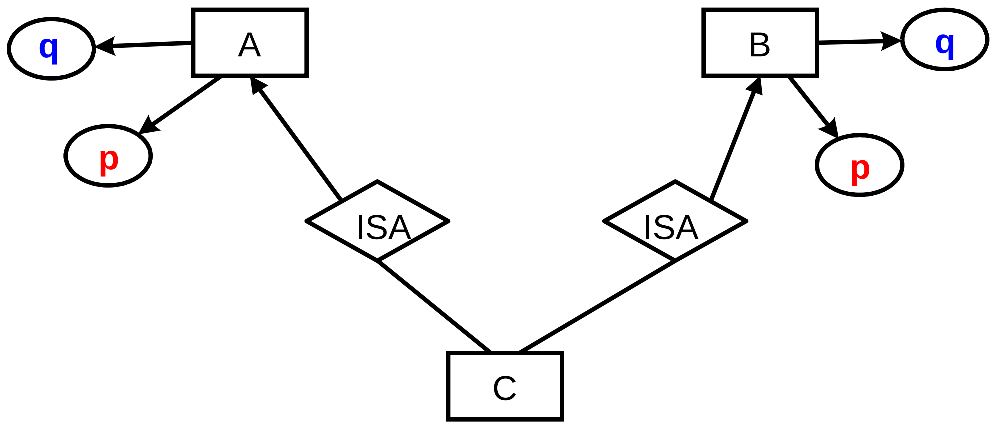

Fig. 1. Motivating Example

**Q:** Which SIZE to be inherited by SUBMARINE?

- Several resolution techniques have been proposed for OODBMS's to handle conflicts in multiple inheritance situations.

(i) The method used in ORION is to choose the first in the list of superclasses.

* This approach is somewhat arbitrary and may not yield the required semantics




**Q:** We want C to inherit p from A and q from B. How to express these 2 requirements in ORION?

(ii) POSTGRES does not allow the creation of a subclass that inherits conflicting attributes.

* This approach is not flexible.

(iii) O2 allows the explicit selection of the properties to inherit by specifying the **inheritance path**.

(iv) IRIS: the property of the most specific class is chosen. If a single most specific property cannot be found, user specified rules will apply.

# 2. A Model of Inheritance

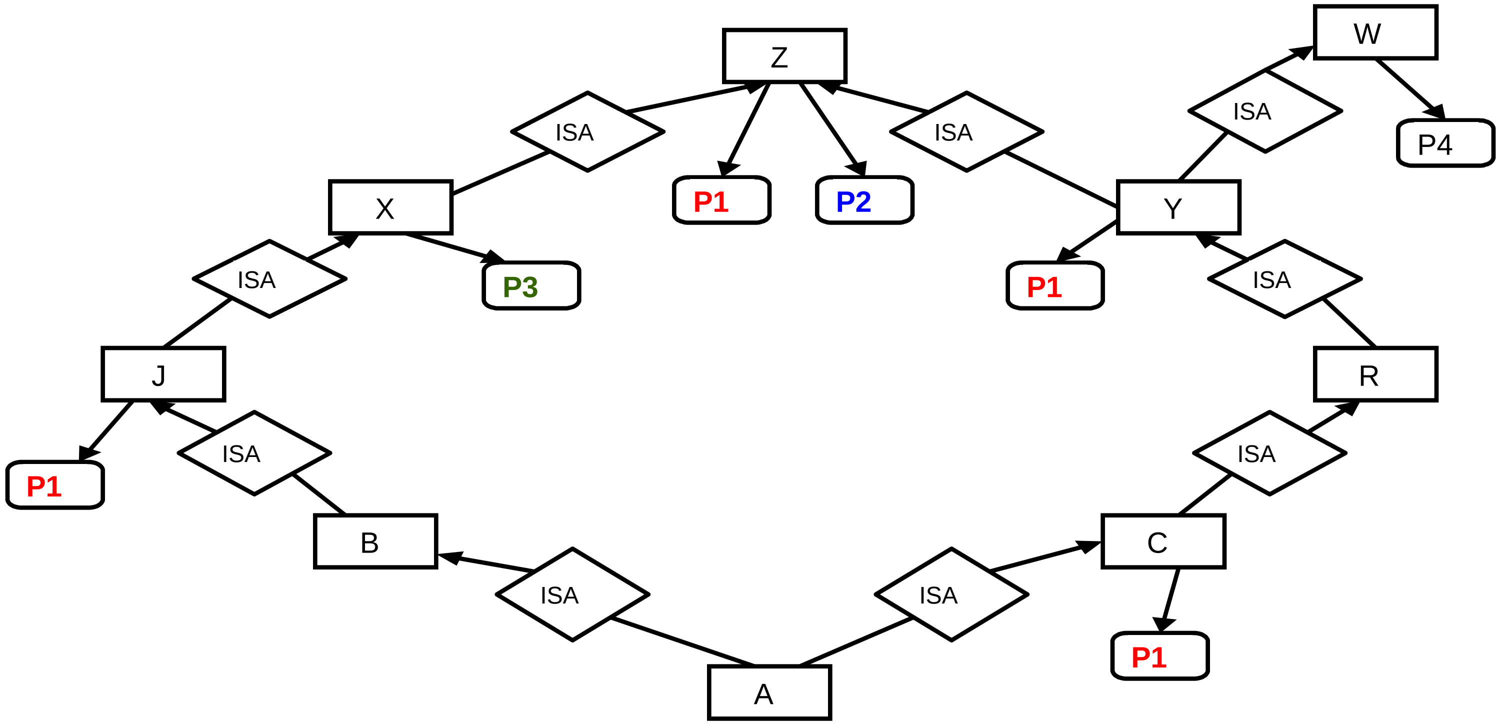



Fig. 2. An Inheritance Diagram

- A property is **specified** in a class if it is either defined or redefined for the class.
- A redefined property overloads a similar property in some superclass(es) of the class.
- An inherited property is **well defined** if it is specified in one and only one superclass, possibly indirect.
- A **conflict** situation exists when an inherited property is not well-defined, i.e., 2 or more superclasses specify the same property.

E.g. In Fig. 2,

* Property p1 is redefined in classes Y, J, and C.
* Class B inherits p1 from class J, and p2, p3 from classes Z, X.
* P1 contributes to a conflict situation in class A, but p2 is well-defined in class A.

  Most OODBMS's consider p2 in class A as a conflict situation.

# 3. Conflict Resolution Algorithm

Given an OO schema with ISA hierarchies

FOR each conflict situation in the hierarchy DO
  IF it is a single-inheritance situation THEN /* Case I: SI (section 5.1) */
    adopt precedence rule that prefers subclass properties, and ensure semantics is understood

IF it is a multiple-inheritance situation THEN
  /* Check for ISA redundancy arising from ISA transitivity property */
  IF conflicts arises because of ISA redundancy THEN
  /* Case II: MI with ISA Redundancy (Section 5.2) */
    resolve conflict by removing ISA redundancy
  ELSE
    BEGIN
      Let the MI conflict situation be classes A, B1, …, Bn (n > 1) where B1, …, Bn are
      the nearest superclasses of A that specify a property p.
      /* Note that a superclass of some Bi may itself specify a property p. */
      /* Check the semantics of p in B1, …, Bn */
      IF semantics of p is the same in B1, …, Bn THEN
      BEGIN
        IF intersection of B1, …, Bn is empty THEN
          /* Case III: MI-same semantics (Empty Subclass) (Section 5.3) */
          Design error, since class A (which is, in fact, the intersection of B1, …, Bn) is empty

ELSE /* Case IV: MI-same semantics (Factoring) (Section 5.4) */

IF there exists a more general class K which is UNION of B1, …, Bn THEN

Factor p to class K /* see section 5.4 for explanation */

ELSE

Resolve the conflict by either:

(a) creating a general class K that is the UNION of B1, …, Bn and factoring p to K. Add new ISA relationships Bi ISA K for i = 1, …, n. For each *maximal* superclass Ci of Bi such that K is a superset of Ci, add the ISA relationship Ci ISA K and remove the redundant ISA relationship BI ISA K.

IF there exists a class Y such that Y is a *minimal* superset of K THEN

Insert new ISA relationship K ISA Y.

/* Option (a) removes data redundancy but may create some ISA redundancies which will be removed by applying Case II */

OR

(b) Explicitly choosing one superclass to inherit the property.

/* data redundancy exists which must be managed */

END

```
ELSE
 BEGIN          /* Case V: MI-properties with different semantics (Section 5.5) */
    Let G1, G2, …, Gm be sets of mutually exclusive classes from B1, …, Bn such
    that classes in a group share the same semantics for p. Resolve the conflict in A
    by adopting one of the following:
    (a)  redefine p in class A, /* not a good solution: see Section 5.5 */ or
    (b)  Rename p in Gj to, say, p_Gj for j = 1, …, m to reflect their different
         semantics. To conform to the unique name assumption. Each p in the schema
         that has the same semantics as P_Gj must be renamed to p_Gj.
         FOR each group Gj (j = 1, …, m) with 2 or more classes having property
         p_Gj DO
         /* An MI situation exists between class A and the classes in Gj; */
         /* p_Gj has the same semantics in the classes of Gj */
            Resolve the conflict in class A using the method described in class III and
         IV.
         ENDFOR
    END
  END
ENDFOR
```

## Case 1 Single Inheritance Situation.

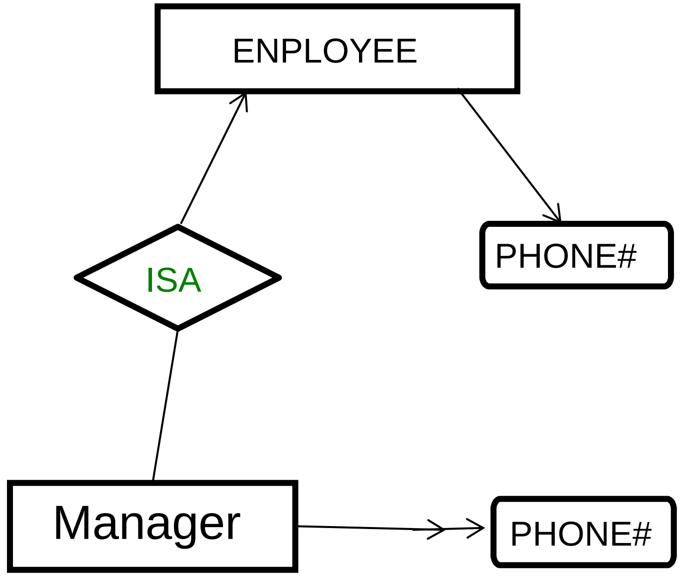



**Fig. 3**. PHONE# is overridden in MANGER and treated as multi-valued

* From a conventional database design viewpoint, Fig. 3 is erroneous. However, OO approach allows this. Here MANAGER overrides the PHONE# of its superclass EMPLOYEE and redefines PHONE# as a multivalued attribute in MANAGER.

## Case 2 Multiple inheritance with ISA Redundancy

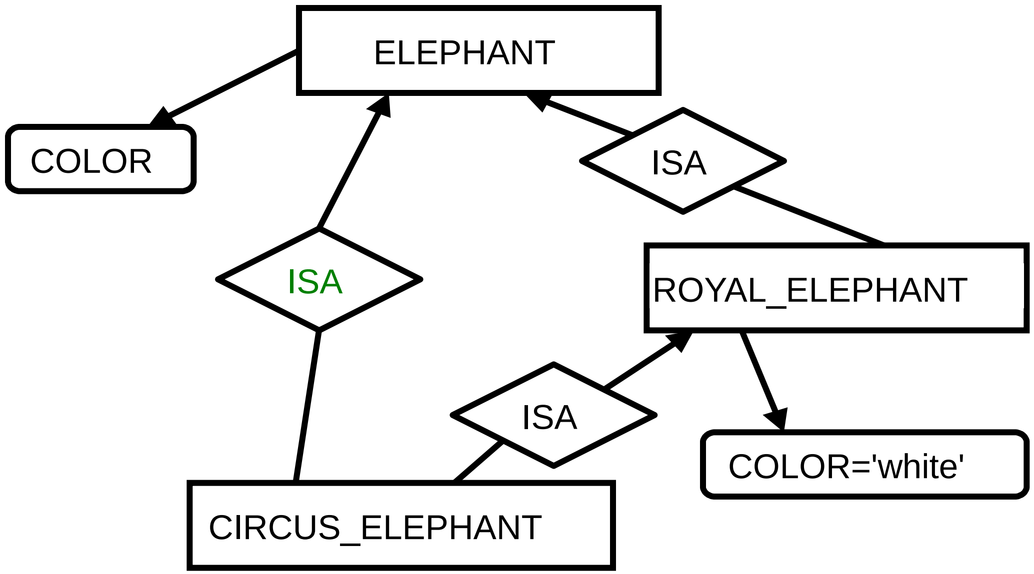



Fig 4. Removing Redundant ISA Relationship

* The ISA link between ELEPHANT and CIRCUS_ELEPHANT is redundant and can be removed.

# Case 3 Multiple Inheritance - Same Semantics (Empty Subclass)

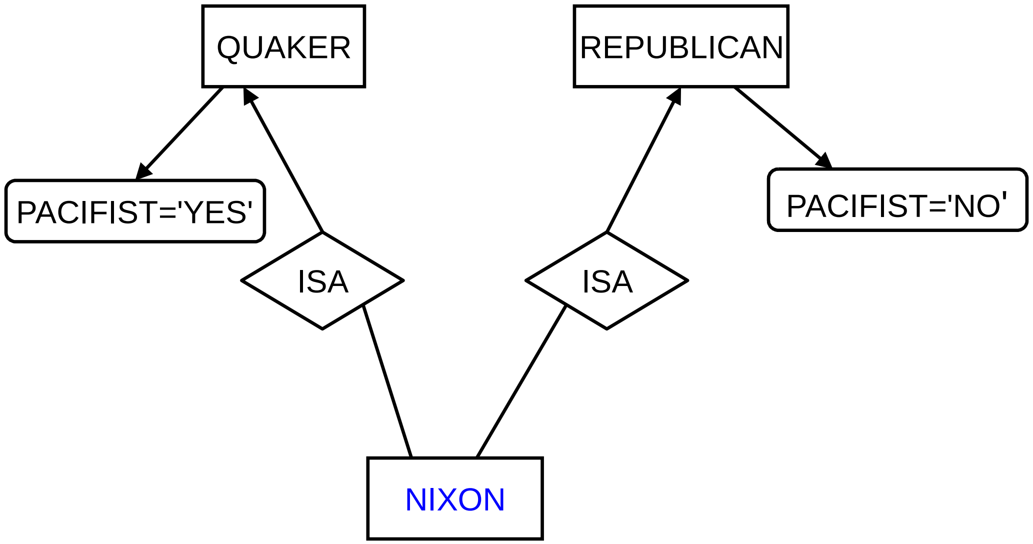


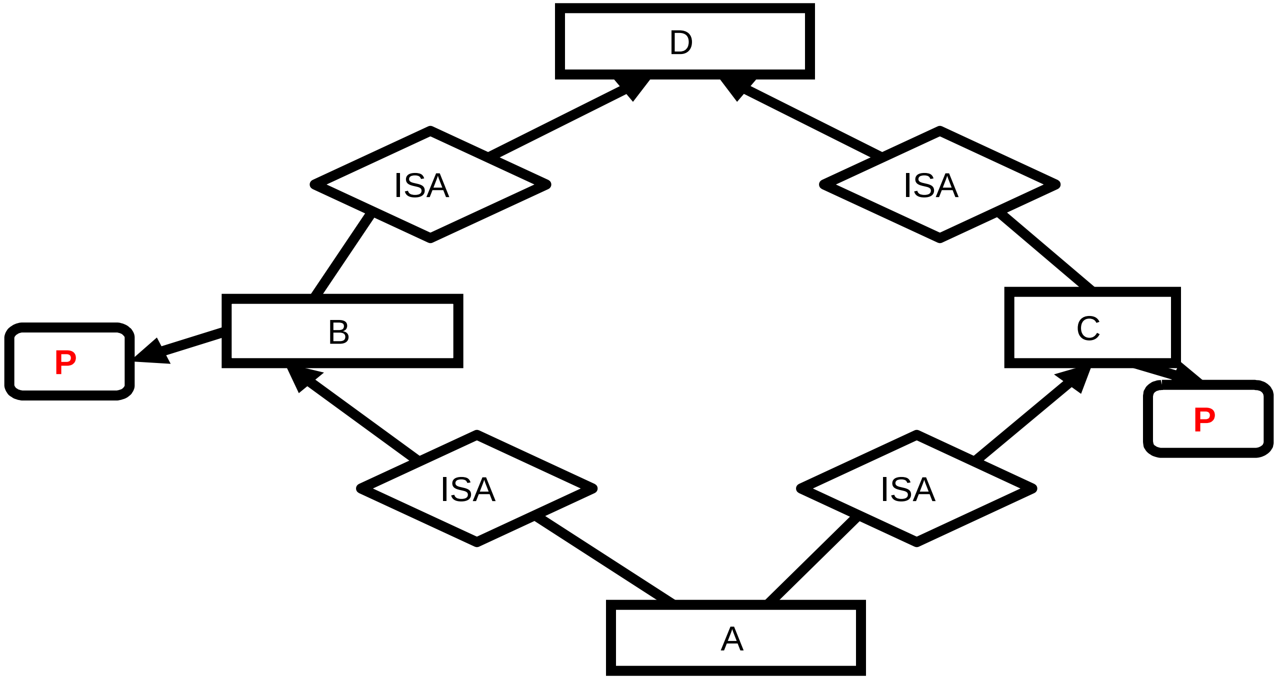

**Fig.** 5. 'PACIFIST' is overloaded and should be renamed to resolve conflict

- We assume that NIXON in Fig. 5 refers to a class of NIXON-like people.
- If the property PACIFIST has the same semantics in both QUAKER and REPUBLICAN, then there is clearly a design error.

A quaker is a member of the Society of Friends, a Christian religious group that meets without any formal ceremony or priests and that is opposed to violence.

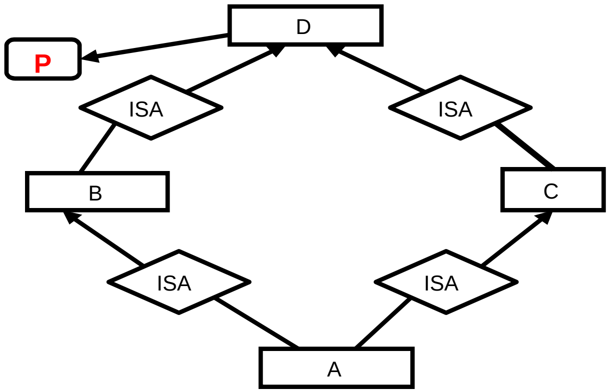
A pacifist is someone who believes that wars are wrong and who refuses to use violence.

## Case 4 Multiple Inheritance - Same Semantic (Factoring)

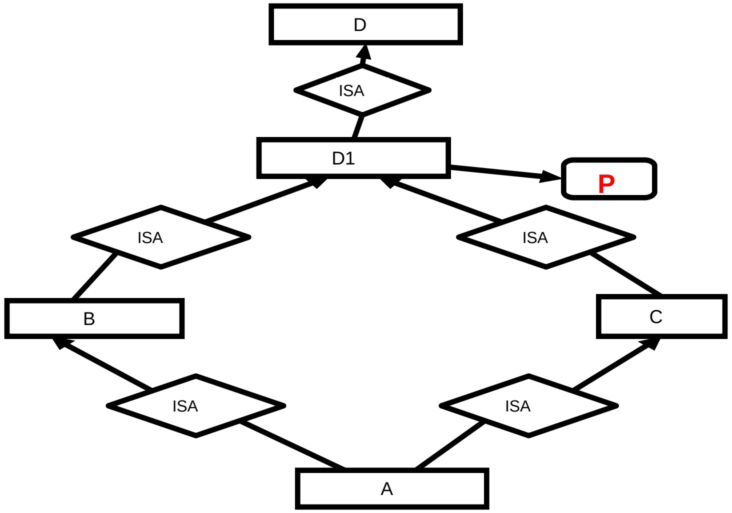



Both P in classes B and C are of same semantics

Case (4.a) If **D = B ∪ C**, then factor P to D.




Case (4.b) IF **D ⊃ B ∪ C**, then create D1 such that D1 = B ∪ C, and factor P to D1.



## Case 5 **Multiple inheritance -** Properties with different semantics

E.g. In Fig. 1, if the 2 SIZE are of different semantics, there are 2 options:

(1) user can redefine or overload the property "SIZE" in SUBMARINE, e.g., explicitly mention

"SIZE" in SUBMARINE is "SIZE" in WATER_VEHICLE.

Problem: SUBMARINE can't inherit SIZE of MOTORISED_VEHICLE.

(2) Rename the property "SIZE" in either MOTORISED_VEHICLE or WATER_VEHICLE or both.

## **Summary on inheritance conflict resolution approaches:**

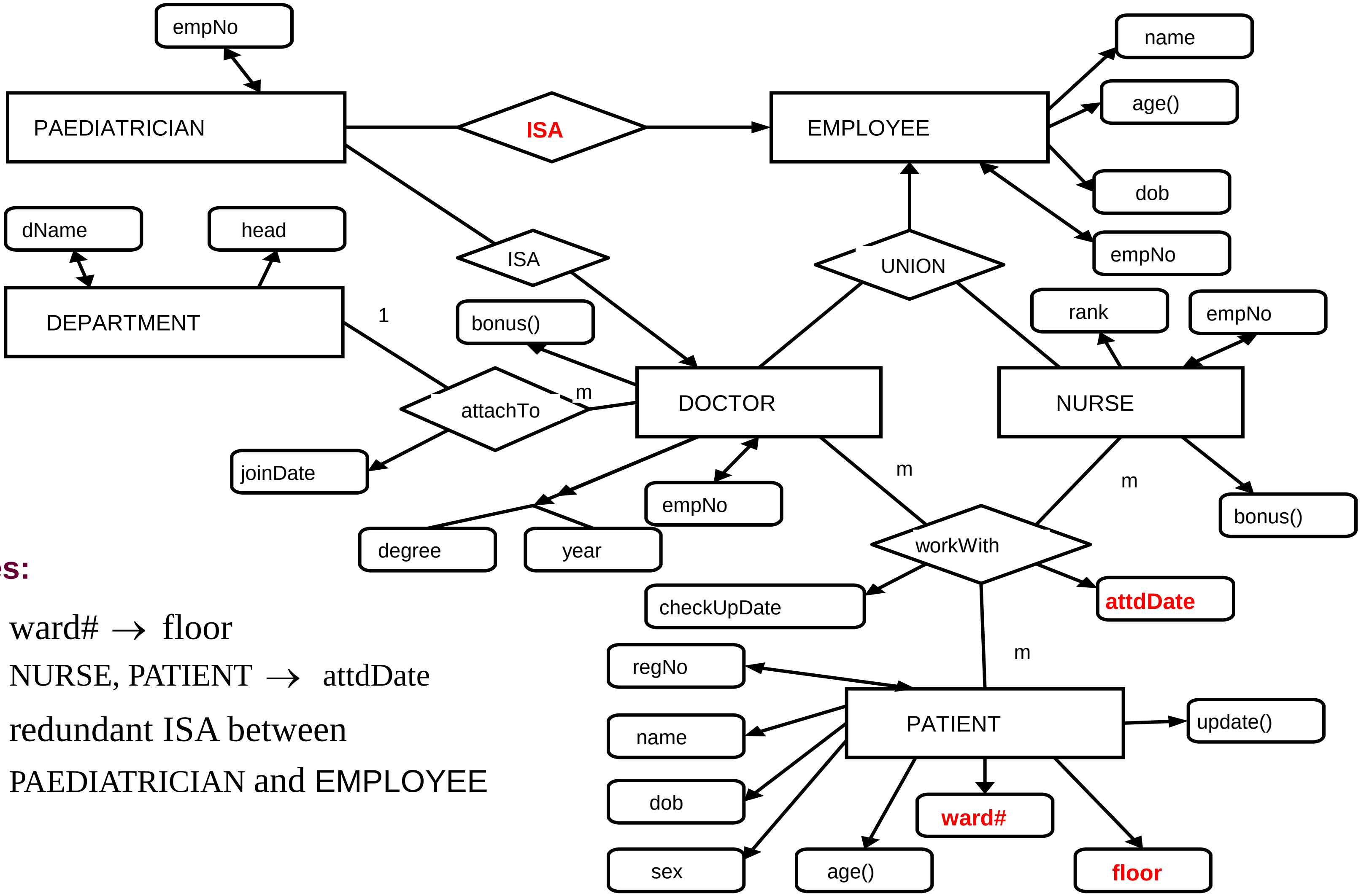
- renaming properties
- redefining (or overriding) an overloaded property
- removing redundant ISA relationship
- explicitly selecting an inheritance class
- redesigning the schema (e.g. factoring)

# OO Schema Design

- Entity-Relationship Diagrams can be extended to support OO schema design.
- All the structural properties of the OO approach can be expressed in or derived from an ER diagram.

  E.g. subclass-superclass relationship: ISA, UNION
  composite object: IS-PART-OF
  existentially dependent object: EX and ID dependent relationships
- Methods and derived attributes can be defined for both entity types and relationship types
- An ER diagram augmented with methods is called an **OOER diagram**.
- An OOER diagram is a **normal form OOER** diagram if its corresponding ER diagram is a NF-ER diagram, and there are no inheritance conflicts in its ISA hierarchies.

**Ref:** Tok Wang Ling, Pit Koon Teo: A Normal Form Object-Oriented Entity Relationship Diagram. ER 1994: 241-258




**Notes:**

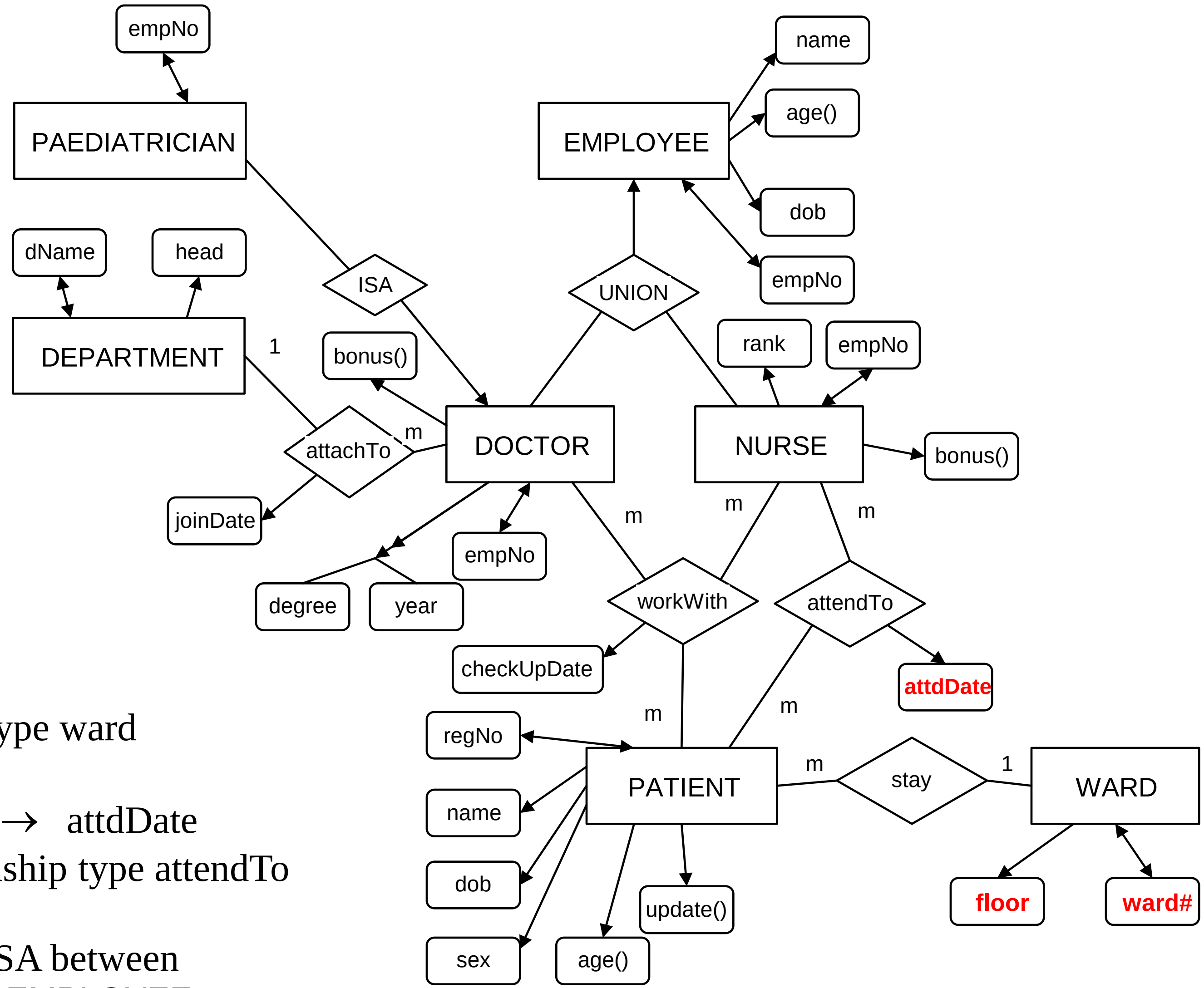
(1) ward# → floor

(2) NURSE, PATIENT → attdDate

(3) redundant ISA between PAEDIATRICIAN and EMPLOYEE

floor

Fig. 1. An OOER diagram




(1) ward# → floor

- create a new entity type ward

(2) NURSE, PATIENT → attdDate

- create a new relationship type attendTo

(3) Remove redundant ISA between PAEDIATRICIAN and EMPLOYEE

Fig. 2. Normal Form OOER Diagram

# Deriving Normal Form OOER Diagrams

Steps to convert an OOER diagram to a normal form OOER diagram:

Step 1 Ensure all property names within each entity type and relationship type are distinct and of different semantics. Ensure all key attributes are unique.

Step 2 Convert the ER diagram to normal form ER diagram.

Step 3 Remove any inheritance conflicts from ISA hierarchies.

Note: In step 1, we adopt the relaxed universal relation assumption mentioned earlier.

# Generating OO Schemas

- Three approaches can be adopted.

(1) **Approach 1**. The underlying OO data model supports the notion of relationship directly.

- Each entity type, m:m, n-ary or recursive relationship type can be mapped directly into a class in the OO schema.

E.g. The attendTo relationship type of Fig. 2.

```
class NURSE inherits EMPLOYEE type tuple
          (rank: string)
          method bonus(): integer;
end;
class attendTo type tuple
          (nurse: NURSE,
           patient: PATIENT,
           attdDate: integer)
end;
```

**Ref:** Tok Wang Ling, Pit Koon Teo, Ling-Ling Yan: Generating Object-Oriented Views from an ER-Based Conceptual Schema. DASFAA 1993: 148-155

(2) **Approach 2.** The underlying OO data model does not support relationship.

- Each entity type is mapped into a class.
- Each relationship type is mapped into each of its participating entity type's object class using inter-object references.

**Problem.** Redundancies may occur.
However, these redundancies are known and can be controlled.

## E.g. The relationship type attendTo and workWith in Fig. 2.

```
class NURSE inherits EMPLOYEE type tuple
        (rank: string,
         attendTo: set(tuple(patient: PATIENT, attdDate: string)),
         workWith : set(tuple(doc : DOCTOR, patient : PATIENT,
                                        checkUpDate : string)))
        method bonus() : integer
end;

class PATIENT type tuple
        (regNo : string,
         name : string,
         dob : string,
         sex : char,
         attendTo : set(tuple(nurse : NURSE, attdDate : string)),
         workWith : set(tuple(doc : DOCTOR, nurse : NURSE,
                                        checkUpDate : string)))
        method age() : integer,
               update()
end;
```

**Note:** FDs such as NURSE, PATIENT --> attDate, are not captured.

(3) **Approach 3.** Treat each OO schema as a view of a normal form OOER diagram

- Rules for generating OO external views are needed. Updatability of view objects needed to be determined.

- Any redundancies in the external view is virtual.

# E.g. An external schema of Fig. 2

```
class EMPLOYEE type tuple
          (empNo : string,
           name : string,
           dob : integer)
          method age() : integer
end;
class DOCTOR inherits EMPLOYEE type tuple
          (qual : set(tuple(year : string, degree : string)),
           Doc-Pat : set(PATIENT))
          method bonus() : integer
end;
class NURSE inherits EMPLOYEE type tuple
          (rank: string,
           Nurse_Pat : set(tuple(patient : PATIENT,
                                 attdDate : integer))) /* via attendTo */
          method bonus() : integer
end;
class PATIENT type tuple
          (regNo : string,
           name : string,
           dob : string,
           sex : char,
           Pat-Doc : set(DOCTOR),
           Pat-Nurse : set(NURSE)) /* via workWith */
          method age() : integer,
                 update()
end;
```

**Note:** Some information may be dropped,

E.g. workWith relationship type is not included in NURSE.

# Summary

- Basic OO concepts
- OO data model vs hierarchical data model, nested relation model, and OOPL
- Some problems in OO data model
  - OID vs key, relationships among objects, view, multiple inheritance, etc.
  - ❖ You may want to study on whether Java and Object-Relational Database Systems have resolved some or all of these mentioned problems.
- OO schema design

You may want to read materials on the below topics: (These topics will **not** be covered in the examination)

- Object Query Language (OQL)
- Object Relational Model (OR Model)
- SQL 1999 (SQL3), SQL 2003, SQL 2008
- Unified Modeling Language (UML)

1. Object Query Language (OQL)

- **Object Query Language** (OQL) is a query language standard for object-oriented databases modelled after SQL. OQL was developed by the Object Data Management Group (ODMG).
- **Object Definition Language** (**ODL**):
  Closer in spirit to object-oriented models
  To define classes in an OODB

ODL Class Declarations

```
Interface  <name> {
    attributes:   <type>  <name>;
    relationships  <range type>  <name>;
    methods
}
```

**Method example:**

**float** CAP (in: Student)

Arbitrary function can compute the value of CAP, based on a student object given as input.

**Example:** a student can take many courses but may as TA of at most one course

```
interface Student (extent Students, key SID) {
        attribute integer SID;
        attribute string name;
        attribute integer age;
        attribute float GPA;
        relationship Set<Course> takeCourses
                inverse Course::students;
        relationship Course assistCourse
                inverse Course::TAs;
};

interface Course (extent Courses, key CID) {
        attribute string CID;
        attribute string title;
        relationship Set<Student> students
                inverse Student::takeCourses;
        relationship Set<Student> TAs
                inverse Student::assistCourse;
};
```

Example: find CID and title of the course assisted by Lisa.

```
SELECT s.assistCourse.CID, s.assistCourse.title
FROM Students s
WHERE s.name = "Lisa";
```

**Example:** find CID and title of the courses taken by Lisa

- /* WRONG Answer! */

```
SELECT s.takeCourses.CID, s.takeCourses.title
FROM Students s
WHERE s.name = "Lisa";
```

Problem: "." must be applied to a single object, never to a collection of objects
Solution: use correlated variables in the FROM clause

- /* Correct answer */

```
SELECT c.CID, c.title
FROM
        (SELECT s.takeCourses
         FROM Students s
         WHERE s.name = "Lisa")  c;
```

# Two more examples

**Simple query**

The following example illustrates how one might retrieve the CPU-speed of all PCs with more than 64MB of RAM from a fictional PC database:

```
SELECT pc.cpuspeed
FROM PCs pc
WHERE pc.ram > 64;
```

**Query with grouping and aggregation**

The following example illustrates how one might retrieve the average amount of RAM on a PC, grouped by manufacturer:

```
SELECT manufacturer, AVG(SELECT part.pc.ram FROM partition part)
FROM PCs pc
GROUP BY manufacturer: pc.manufacturer;
```

The GROUP BY operator creates a set of tuples with two fields. The first has the type of the specified GROUP BY attribute. The second field is the set of tuples that match that attribute. By default, the second field is called PARTITION.

Note the use of the keyword partition, as opposed to aggregation in traditional SQL.

## 2. Object Relational Model (OR Model)

- http://codex.cs.yale.edu/avi/db-book/db4/slide-dir/ch9.pdf
- http://en.wikipedia.org/wiki/Object-relational_database
- Extend the relational data model by including object orientation and constructs to deal with added data types.
- Allow attributes of tuples to have complex types, including non atomic values such as nested relations.
- Preserve relational foundations, in particular the declarative access to data, while extending modeling power.
- Upward compatibility with existing relational languages.

# 3. SQL 1999 (SQL3), SQL 2003, SQL 2008

- **SQL:1999**. SQL3 Added regular expression matching, recursive queries, triggers, support for procedural and control-of-flow statements, non-scalar types, and some object-oriented features.
- http://www.objs.com/x3h7/sql3.htm

  The parts of SQL3 that provide the primary basis for supporting object-oriented structures are:
  - *user-defined types* (*ADT*s, *named row types*, and *distinct types*)
  - type constructors for *row types* and *reference types*
  - type constructors for *collection types* (sets, lists, and multisets)
  - *user-defined functions and procedures*
  - support for *large objects* (BLOBs and CLOBs)

- **SQL:2003**. Introduced XML-related features, *window functions*, standardized sequences, and columns with auto-generated values (including identity-columns).
- **SQL:2006**. ISO/IEC 9075-14:2006 defines ways in which SQL can be used in conjunction with XML. It defines ways of importing and storing XML data in an SQL database, manipulating it within the database and publishing both XML and conventional SQL-data in XML form. In addition, it enables applications to integrate into their SQL code the use of XQuery, to concurrently access ordinary SQL-data and XML documents.
- **SQL:2008**. Legalizes ORDER BY outside cursor definitions. Adds INSTEAD OF triggers. Adds the TRUNCATE statement.

# Complex Types and SQL:1999

- Extensions to SQL to support complex types include: Collection (**set** and **array**) and large object types (**clob**: Character large objects and **blob**: binary large objects).
  - Nested relations are an example of collection types
- Structured types
  - Nested record structures like composite attributes
- Inheritance

**E.g.** **create type** Person
(name **varchar**(20),
address **varchar**(20))
**create type** Student
**under** Person
(degree **varchar**(20),
department **varchar**(20))
**create table** people **of** Person
**create table** students **of** Student
**under** people

- Object orientation
  - Including object identifiers and references

**E.g.** **create type** *Department*
*(name* **varchar(20)**,
*head* **ref**(*Person*) **scope** *people*)
We can then create a table *departments* as follows
**create table** *departments* **of** *Department*

# Initializing Reference Typed Values in SQL:1999

E.g. to create a department with name CS and head being the person named John, we use

**insert into** *departments*
 **values** (`CS’, null)

**update** *departments*
 **set** *head* = (**select ref**(*p*)
 **from** *people* **as** *p*
 **where** *name*=`John’)
 **where** *name* = `CS’

# Object-Relational Features of Oracle

- Defining Types

Oracle allows users to define types similar to the types of SQL. The syntax is

```
CREATE TYPE t AS OBJECT (
    list of attributes and methods
  );
  /
```

Note the slash at the end, needed to get Oracle to process the type definition. We will omit “/” in our examples.

E.g. define a point type as two numbers:

```
CREATE TYPE PointType AS OBJECT (
    x NUMBER,
    y NUMBER
  );
```

- Then we might define a line type by:

```
CREATE TYPE LineType AS OBJECT (
    end1 PointType,
    end2 PointType
);
```

- Then, we could create a relation that is a set of lines with ``line ID's'' as:

```
CREATE TABLE Lines (
        lineID   INT,
        line     LineType
 );
```

- Constructing object values

```
INSERT INTO Lines
  VALUES(27, LineType (
    PointType(0.0, 0.0),
    PointType(3.0, 4.0)
              )
   );
```

- Declaring and Defining Methods

```
CREATE TYPE LineType AS OBJECT (
    end1 PointType,
    end2 PointType,
    MEMBER FUNCTION length(scale IN NUMBER) RETURN NUMBER,
        PRAGMA RESTRICT_REFERENCES(length, WNDS)
);
```

# 4. Unified Modeling Language (UML)

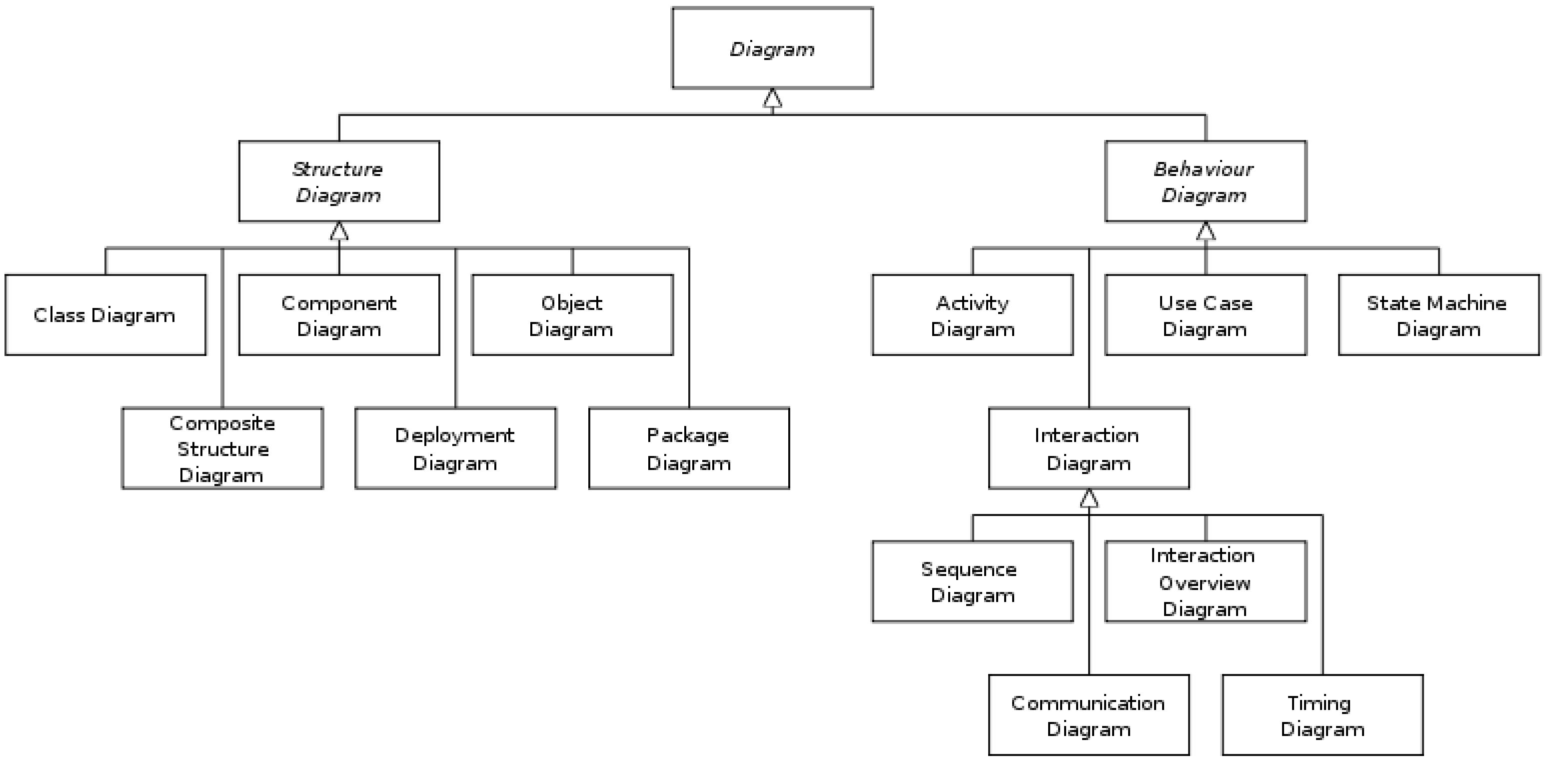
- It is a standardized general- purpose modeling language in the field of software engineering. The standard is managed, and was created by, the Object Management Group (OMG).

- The OMG specification states:

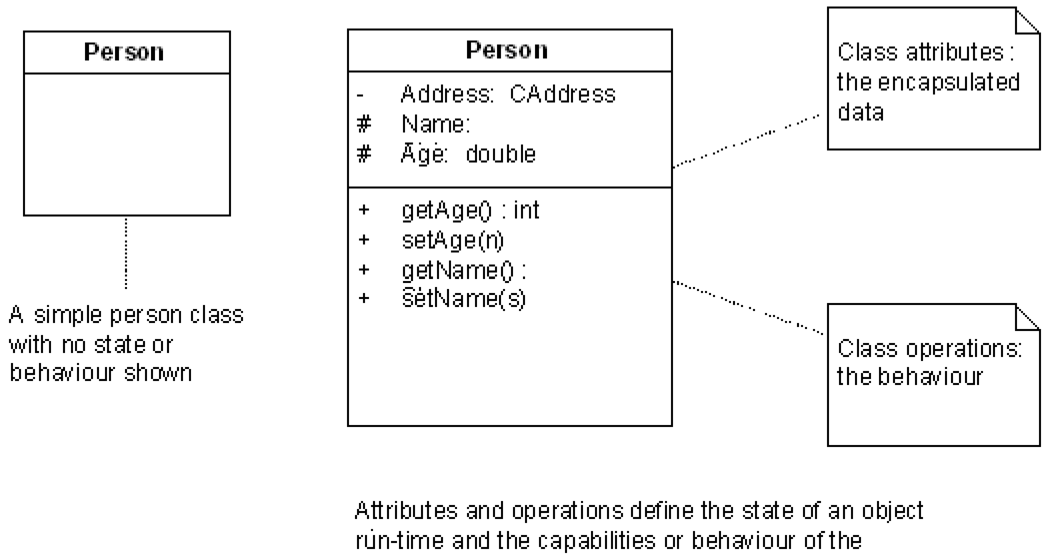
"The Unified Modeling Language (UML) is a graphical language for visualizing, specifying, constructing, and documenting the artifacts of a software-intensive system.

- The UML offers a standard way to write a system's blueprints, including conceptual things such as business processes and system functions as well as concrete things such as programming language statements, database schemas, and reusable software components."

# Hierarchy of UML 2.0 Diagrams, shown as below:

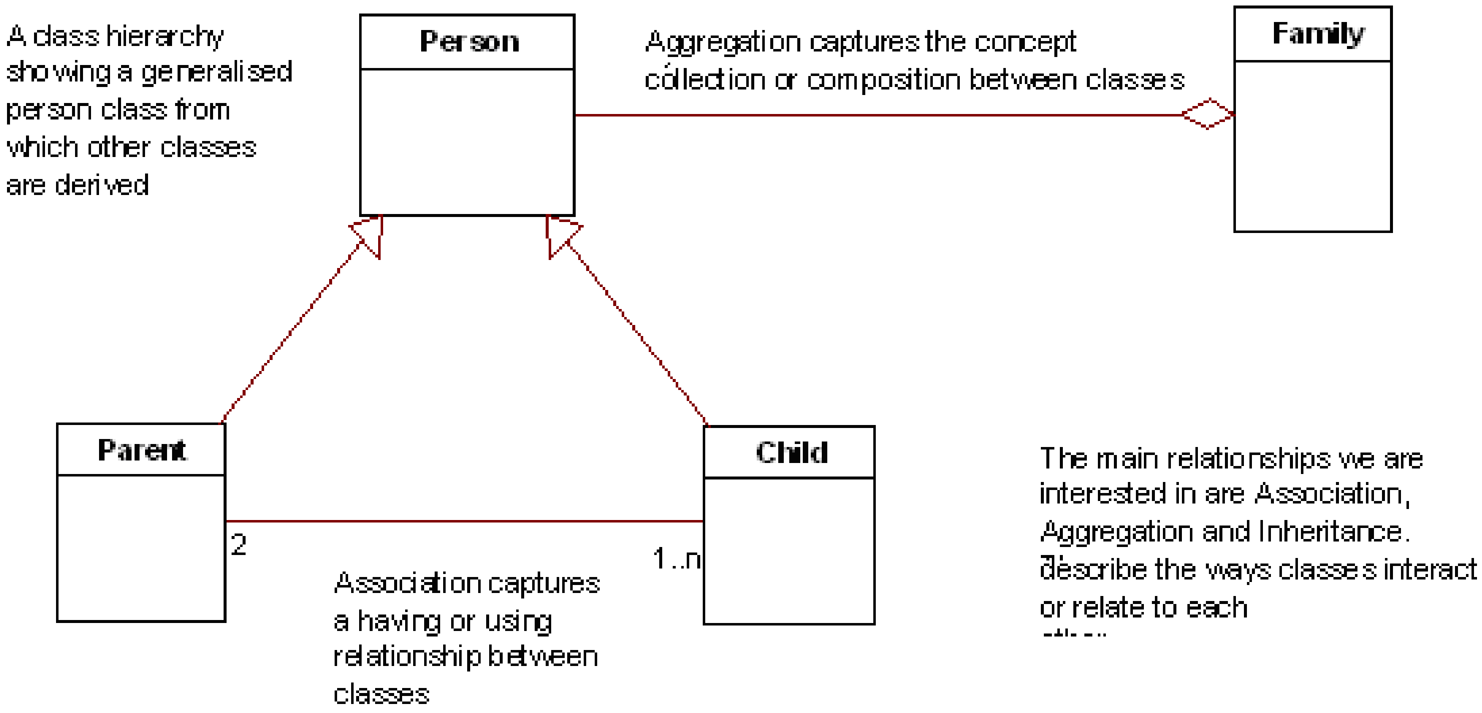


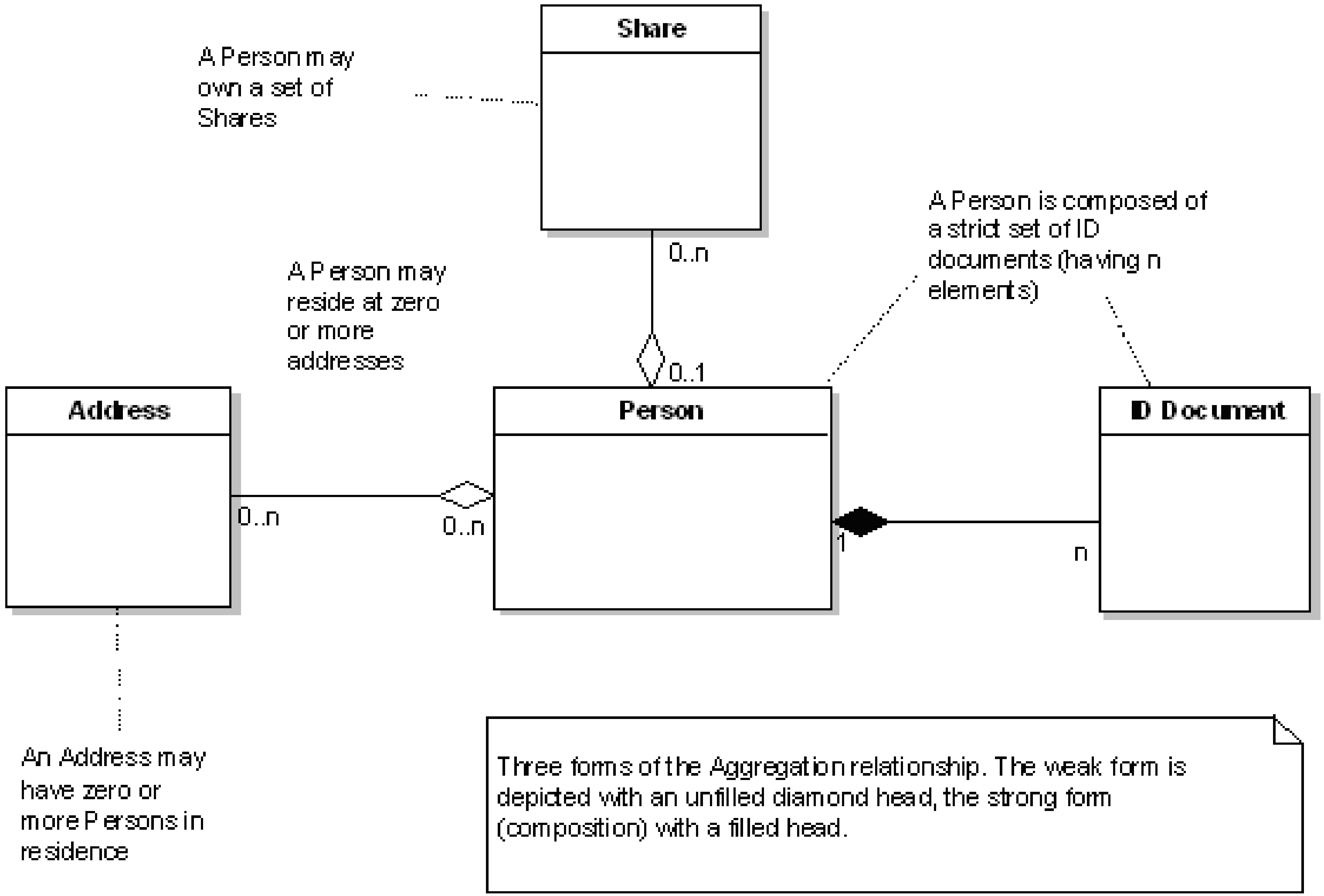
# Class Diagram



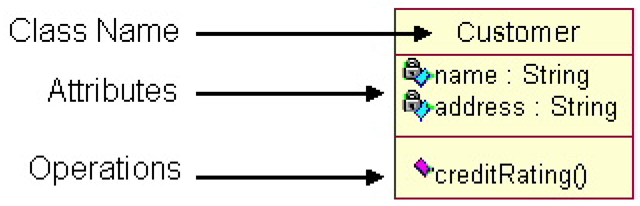
# Relationships and Identity

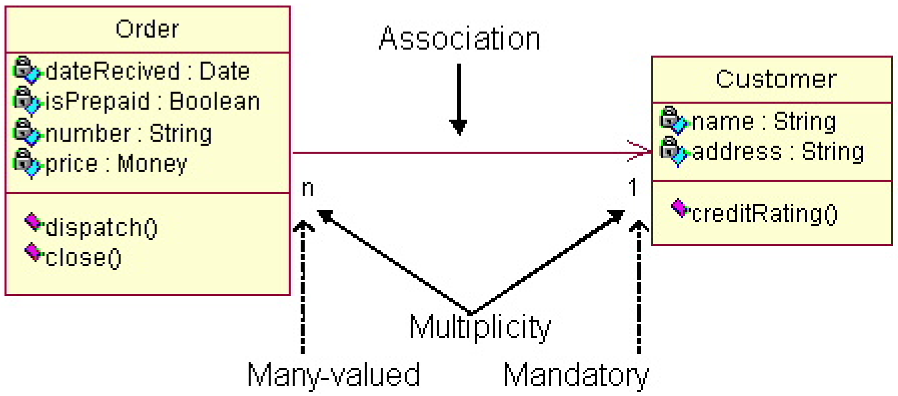
Association is a relationship between 2 classes.

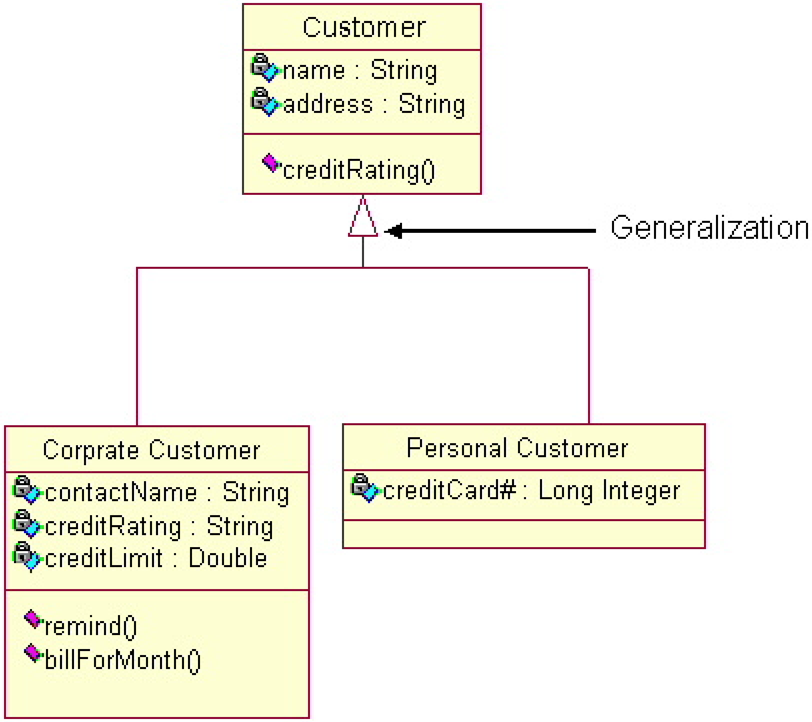


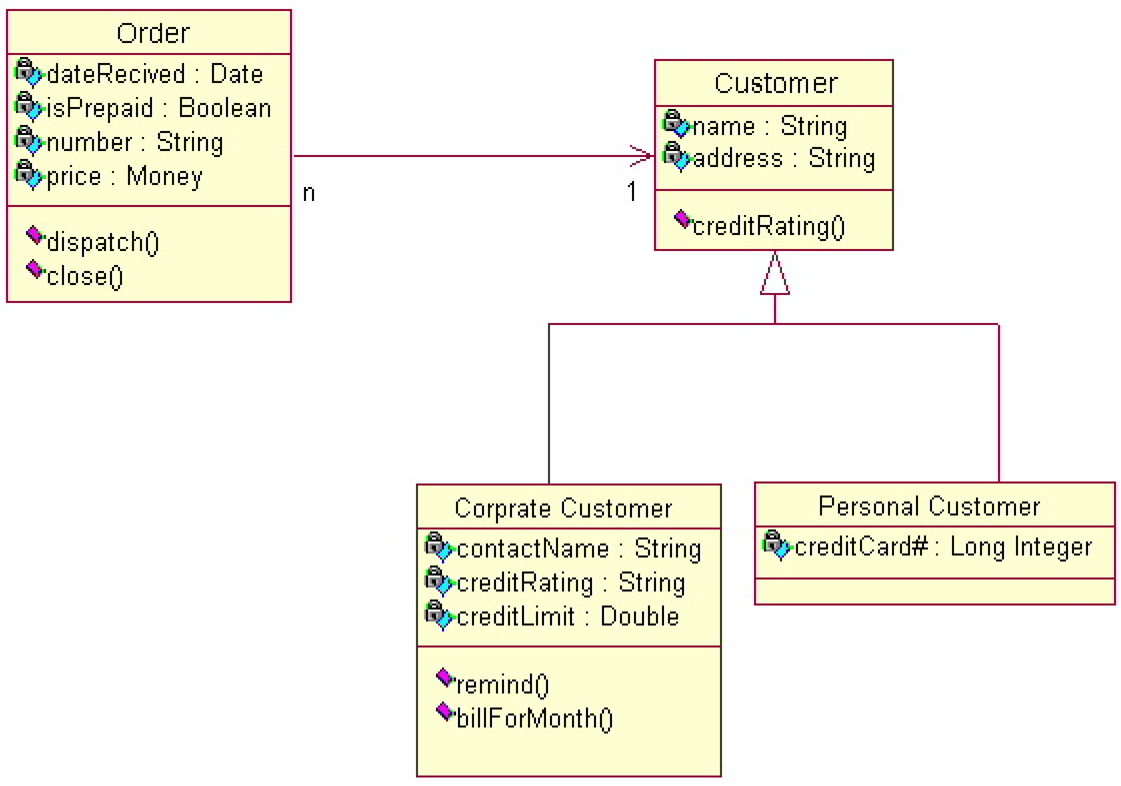

Share
A Person may own a set of Shares
0..n
0..1
A Person may reside at zero or more addresses
A Person is composed of a strict set of ID documents (having n elements)
Address
Person
ID Document
0..n
0..n
1
n
An Address may have zero or more Persons in residence
Three forms of the Aggregation relationship. The weak form is depicted with an unfilled diamond head, the strong form (composition) with a filled head.

# Class diagram




Customer
name : String
address : String
creditRating()
Generalization
Corprate Customer
contactName : String
creditRating : String
creditLimit : Double
remind()
billForMonth()
Personal Customer
creditCard# : Long Integer


Order
dateRecived : Date
isPrepaid : Boolean
number : String
price : Money
dispatch()
close()
n
1
Customer
name : String
address : String
creditRating()
Corprate Customer
contactName : String
creditRating : String
creditLimit : Double
remind()
billForMonth()
Personal Customer
creditCard# : Long Integer

# Object diagram

- Although we design and define classes, in a live application classes are not directly used, but instances or objects of these classes are used for executing the business logic. A pictorial representation of the relationships between these instantiated classes at any point of time (called objects) is called an "Object diagram."
- It looks very similar to a class diagram, and uses the similar notations to denote relationships.

Object name: class

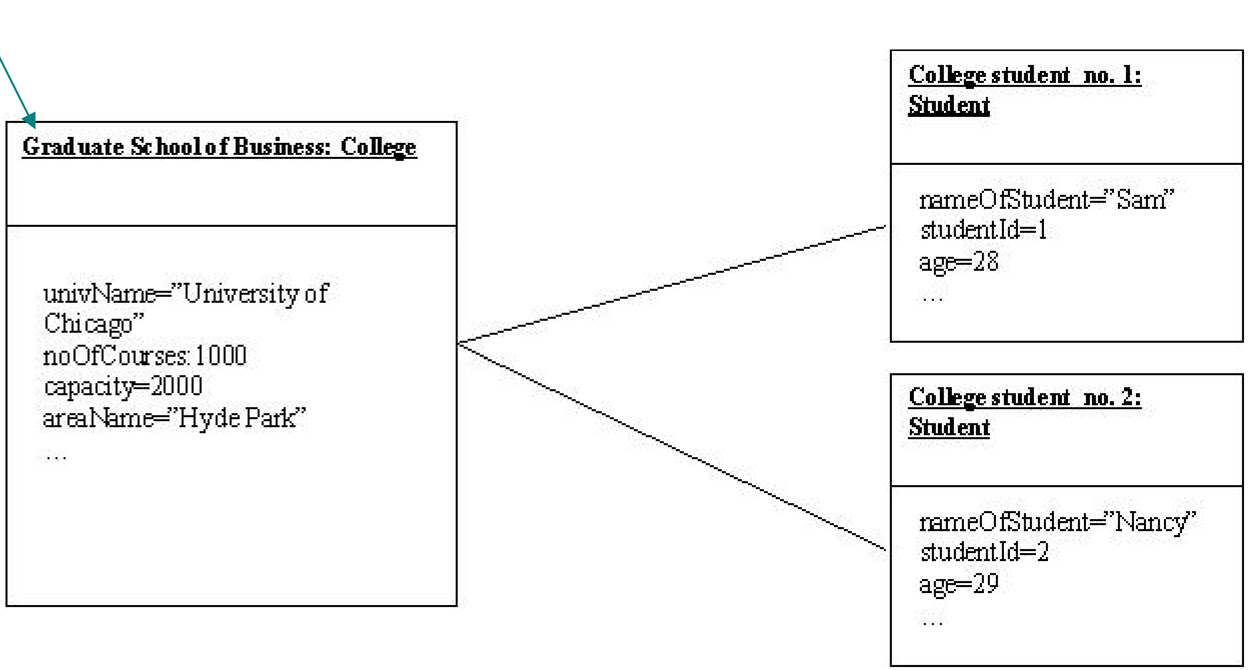



Figure: An object diagram for the College-Student class diagram