Inheritance

C++ Object Oriented Programming
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Object-Oriented Analysis

- An object-orientated design provides a more **natural** and **systematic** framework for specifying and designing a programming solution.
- Program designs are almost always based on the **program specification**, i.e. a document describing the exact requirements a program is expected to achieve.

- Four phases of the object-oriented analysis process:
  - The identification of objects from the program specification.
  - The identification of the attributes and behaviours of these objects.
  - The identification of any super-classes.
  - The specification of the behaviours of the identified classes.

Inheritance

- The distinction between an "object-**based** language" and an "object-**oriented** language" is the ability to support inheritance (or derivation).
- Composition/aggregation and inheritance are the most important two ways to construct object **hierarchies**.
- In the **OOA** process, after objects are identified from the problem domain and attributes and behaviors are modeled with classes in the analysis process, the next important phase is the identification of super-classes in the problem domain
- In the language level, a super-class defines the attributes and behaviors that are common to all its sub-classes.

Base class		**Derived class**
Super-class	vs.	**Sub-class**
Parent class		**Child class**

Basic Inheritance

The Basic Problem: Extension

- Imagine you have a class for describing students

```
class Student {
public:
   Student();
   ~Student();
   void setData(char *name, int age);
   int getAge() const;
   const char *getName() const;
private:
   char *m_name;
   int m_age;
};
```

```
class Student {
public:
   Student();
   ~Student();
   void setData(char *name, int age,
                int stipend);
   int getAge() const;
   const char *getName() const;
   int getStipend() const;
private:
   char *m_name;
   int m_age;
   int m_stipend;
};
```

- Want to **add fields** to handle the requirements for graduate students

What is the problem of this design?

Not Good!

- In the above design
  - **Student** becomes a general purpose class, a set of attributes and interfaces are used for undergraduate students, while another set of attributes and interfaces are used for graduate students … a form with many redundant fields
  - In the process of this change, all previously developed programs, including those implementations of the Student class and those codes that are the client programs of the Student class, have to be recompiled…. This change is global, not limited to the part you plan to add.

OCP: open-closed principle

Software entities (classes, modules, functions, etc.) should be open for extension, but closed for modification.

A Solution – Separate Classes

- No redundant members, old codes for Student need only change the name to UnderGraduate.

```
class Undergraduate {
public:
   Undergraduate();
   ~Undergraduate();
   void setData(char *name, int age);
   int getAge() const;
   const char *getName() const;
private:
   char *m_name;
   int m_age;
};
```

```
class Graduate {
public:
   Graduate();
   ~Graduate();
   void setData(char *name,
                int age, int stipend);
   int getAge() const;
   const char *getName() const;
   int getStipend() const;
private:
   char *m_name;
   int m_age;
   int m_stipend;
};
```

Why is this still a **poor solution**?

- A client program cannot treat both classes of objects in a uniform way, ex. The library circulation system wants to check which students are holding books overdue, it has to handle undergraduate and graduate students with separate pieces of codes. Also, a lot of redundancy.

Basic Inheritance in C++

- Declare a class Graduate that is derived from Student

```
class Graduate: public Student {
public:
   Graduate(char *name, int age, int stipend);
   int getStipend() const;
private:
   int m_stipend;
};
```

Student is called the base class, **Graduate** is called the derived class

new member functions

new data member

- All the data members (m_name and m_age) and most the member functions (setData(), getAge(), getName()) of class Student are automatically inherited by the Graduate class
- New member functions

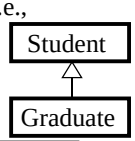
```
Graduate::Graduate(char *name, int age, int stipend) : m_stipend(stipend) {
   setData(name, age); // this is inherited from Student
}

int Graduate::getStipend() const {
   return m_stipend;
}
```

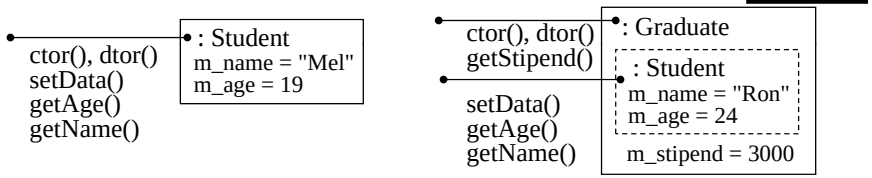

Basic Inheritance (cont'd)

- **Usages**:

```
Student student;
student.setData("Mel", 19);
Graduate gradStudent("Ron", 24, 3000);
```

Note: A Graduate object **is a** Student object because a Graduate object provides the complete set of **interface** functions of a Student object, i.e., they looks the same from the outside.






```
cout << student.getName() << " is " << student.getAge()
     << " years old undergraduate student\n";
cout << gradStudent.getName() << " is  " << gradStudent.getAge()
     << " years old and has a stipend of " << gradStudent.getStipend()
     << " dollars.\n";
```


Basic Inheritance (cont'd)

- This would be illegal

```
int Graduate::getStipend() const {
   if (m_age > 30)
      return 0;
   return m_stipend;
}
```

- Private data member of the base class is implicitly declared/defined but is still kept private from its derived class. (the boundary of base class is maintained)
- This is legal

```
int Graduate::getStipend() const {
   if (getAge() > 30)
      return 0;
   return m_stipend;
}
```

- **Back to OCP**: Did you extend the functionality of the class Student? Did you edit student.h or student.cpp?

Protected Data and Functions

- Can we give the derived class access to "private" data of base class?

```
class Student {
public:
   Student();
   ~Student();
   void setData(char *name, int age);
   int getAge() const;
   const char *getName() const;
protected:
   char *m_name;
   int m_age;
};
```

- Who can access protected fields?
  - base class and friends of base class
  - derived class and friends of derived classes

- The following is now legal

```
int Graduate::getStipend() const {
   if (m_age > 30)
      return 0;
   return m_stipend;
}
```

Note: the encapsulation perimeter is enlarged a great deal with "protected" in your design

Basic Inheritance (cont'd)

- Most of the member functions of the base class are implicitly inherited by the derived class except
  - The constructor (including copy ctor)
  - The assignment operator
  - The destructor
- They are synthesized by the complier again if not explicitly defined. The synthesized ctor, dtor, and assignment operator would chain automatically to the function defined in the base class.

Inheritance and Constructors

- Rewrite Student using constructor

```
class Student {
public:
   Student(char *name, int age);
   ~Student();
   void setData(char *name, int age);
   int getAge() const;
   const char *getName() const;
private:
   char *m_name;
   int m_age;
};
```

- In this case, the constructor for Graduate fails

```
Graduate::Graduate(char *name, int age, int stipend) : m_stipend(stipend) {
   setData(name, age); // this is inherited from Student
}
```

error C2512: 'Student' : no appropriate default constructor available

- Why??

```
Graduate::Graduate(char *name, int age, int stipend)
            : Student(), m_stipend(stipend) {
   setData(name, age); // this is inherited from Student
}
```

chaining

Compiler insert this automatically

Inheritance and Ctors (cont'd)

- In this case, the correct form of the constructor for Graduate is

```
Graduate::Graduate(char *name, int age, int stipend)
            : Student(name, age), m_stipend(stipend) {
   setData(name, age); // setData() is inherited from Student
}

Student::Student(char *name, int age) : m_age(age) {
   m_name = new char[strlen(name)+1];
   strcpy(m_name, name);
}
```

- You cannot initialize base class members directly in the initialization list even if they are public or protected, i.e.

```
Graduate::Graduate(char *name, int age, int stipend)
            : m_age(age), m_stipend(stipend)
```

error C2614: 'Graduate' : illegal member initialization: 'm_age' is not a base or member

- Base class guarantee

  The base class will be fully constructed before the body of the derived class constructor is entered

Copy Constructor

- Copy constructor is also a constructor. Member objects and base class **must** be initialized through **initialization list**

- For example:

```
class Derived: public Base {
public:
   …
   Derived(Derived &src);
   …
private:
   Component m_obj;
};

Derived::Derived(Derived &src): Base(src), m_obj(src.m_obj) {
   …
}
```

Compiler adds **Base()** invocation automatically

Note:

```
Derived::Derived(Derived &src):
      m_obj(src.m_obj)
{
   …
}
```

If you do not define a copy ctor, the compiler would generate one exactly like this.

Inheritance and Destructors

- If we add a dynamically allocated string data member to Graduate to store the student's home address, then Graduate requires a destructor

```
Student::Student(char *name, int age) : m_age(age) {
   m_name = new char[strlen(name)+1];
   strcpy(m_name, name);
   cout << "In Student ctor\n";
}
```

```
Student::~Student() {
   delete[] m_name;
   cout << "In Student dtor\n";
}
```

```
Graduate::Graduate(char *name, int age, int stipend, char *address)
   : Student(name, age), m_stipend(stipend) {
   m_address = new char[strlen(address)+1];
   strcpy(m_address, address);
   cout << "In Graduate ctor\n";
}
```

```
Graduate::~Graduate() {
   delete[] m_address;
   cout << "In Graduate dtor\n";
}
```


Inheritance and Dtors (cont'd)

- What happens in main()

```
void main() {
   Graduate student("Michael", 24, 6000, " 8899 Storkes Rd.");
   cout << student.getName() << " is " << student.getAge() << " years old and "
        << "has a stipend of " <, student.getStipend() << "dollars.\n"
        << "His address is " << student.getAddress() << "\n";
}
```

The output is:

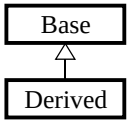
```
In Student ctor
In Graduate ctor
Michael is 24 years old and has a stipend of 6000 dollars.
His address is 8899 Storkes Rd.
In Graduate dtor
In Student dtor
```

chaining

- The compiler automatically calls each dtor when the object dies.
- The dtors are invoked in the opposite order of the ctors
  - In destructing the derived object, the base object is still in scope and functioning correctly.

Chaining of Assignment Operator

- By default, the compiler adds a "**bit-wise copy**" assignment operator for every class which you do not define an assignment operator
- If you have a class hierarchy where a class Derived inherits from a class Base. There are 4 possibilities in defining their assignment operators:



1. If both classes do not have assignment operator: both are bit-wise copy
2. If you define Base& Base::operator=(Base &) but not Derived& Derived::operator=(Derived &), then compiler synthesizes

```
Derived& Derived::operator=(Derived &rhs) {
    Base::operator=(rhs); // calling your function
        ….
    return *this;
}
```

3&4. If you define Derived& Derived::operator=(Derived &rhs) yourself, you have to call Base::operator=(rhs); in Derived::operator=(Derived) no matter it is synthesized or not; otherwise the Base part of the object would not be copied.

Layers of Inheritance

- Let us add a new type of graduate student

```
class Student {
public:
   Student(char *name, int age);
   ~Student();
   void setData(char *name, int age);
   int getAge() const;
   const char *getName() const;
private:
   char *m_name;
   int m_age;
};
```

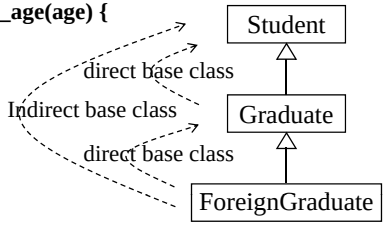
```
class ForeignGraduate: public Graduate {
public:
   ForeignGraduate(char *name, int age,
                   int stipend,
                   char *nationality);
   ~ForeignGraduate()
   const char *getNationality();
private:
   char *m_nationality;
};
```

```
class Graduate: public Student {
public:
   Graduate(char *name, int age, int stipend);
   int getStipend() const;
private:
   int m_stipend;
};
```

Layers of Inheritance (cont'd)

- **ctor of Student**

```
Student::Student(char *name, int age) : m_age(age) {
   m_name = new char[strlen(name)+1];
   strcpy(m_name, name);
}
```



- **ctor of Graduate invokes the ctor of its direct base class - Student**

```
Graduate::Graduate(char *name, int age, int stipend)
   : Student(name, age), m_stipend(stipend) {
}
```

- **ctor of ForeignGraduate invokes the ctor of its direct base class - Graduate**

```
ForeignGraduate::ForeignGraduate(char *name,
            int age, int stipend, char *nationality)
      : Graduate(name, age, stipend) {
   m_nationality = new char[strlen(nationality)+1];
   strcpy(m_nationality, nationality);
}
```


Behavior Changing (Hiding)

- In the previous example, suppose we would like to have a display() member function in the Student class that shows the details of a Student object on the screen, ex.

```
void Student::display() const {
   cout << m_name << " is " << m_age << "years old.\n";
}
```

- The Graduate class **automatically inherits this member function**. However, the output of this function for a Graduate object is in a way short of many important data.
- We would like to **redefine this function** in the derived class – Graduate, such that it will show the stipend and address together.

```
void Graduate::display() const {   // masks the inherited version of display()
   cout << getName() << " is " << getAge() << " years old.\n";
   cout << "He has a stipend of " << m_stipend << " dollars.\n";
   cout << "His address is " << m_address << ".\n";
}
```

- Note: **function signature** is exactly the same as in the base class.

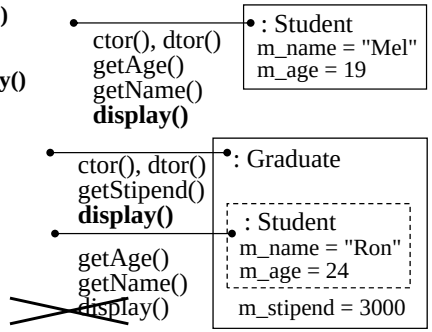
Behavior Changing (cont'd)

- Example **usage** of the previous design:

```
Student student1("Alice", 20);
Graduate student2("Michael", 24, 6000, "8899 Storkes Rd.");

student1.display();   // Student::display()
cout << "\n";
student2.display();   // Graduate::display()
```

Output:

```
Alice is 20 years old.
Michael is 24 years old.
He has a stipend of 6000 dollars.
His address is 8899 Storke Rd.
```



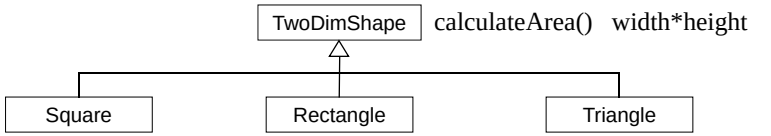
- Note: display() interface usually can enhance the encapsulation, replacing the functionality of trivial accessor functions

Behavior Changing (cont'd)

- Avoid the **redundancy** of the common code, **Student::display()**, in the inherited version of display(), **Graduate::display()**, by

```
void Graduate::display() const // masks the inherited version of display() {
   Student::display(); // invoke the inherited codes
   cout << "He has a stipend of " << m_stipend << " dollars.\n";
   cout << "His address is " << m_address << ".\n";
}
```

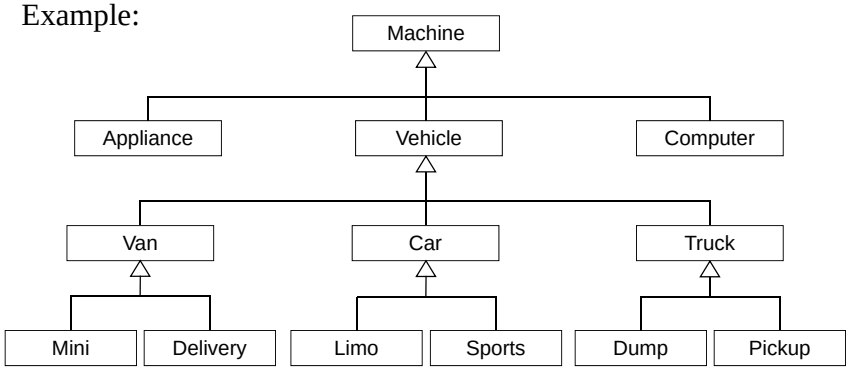
- The functions defined in the base class are OK for most derived classes. Only some of them need to be changed in the derived classes. Ex.



Class Hierarchy

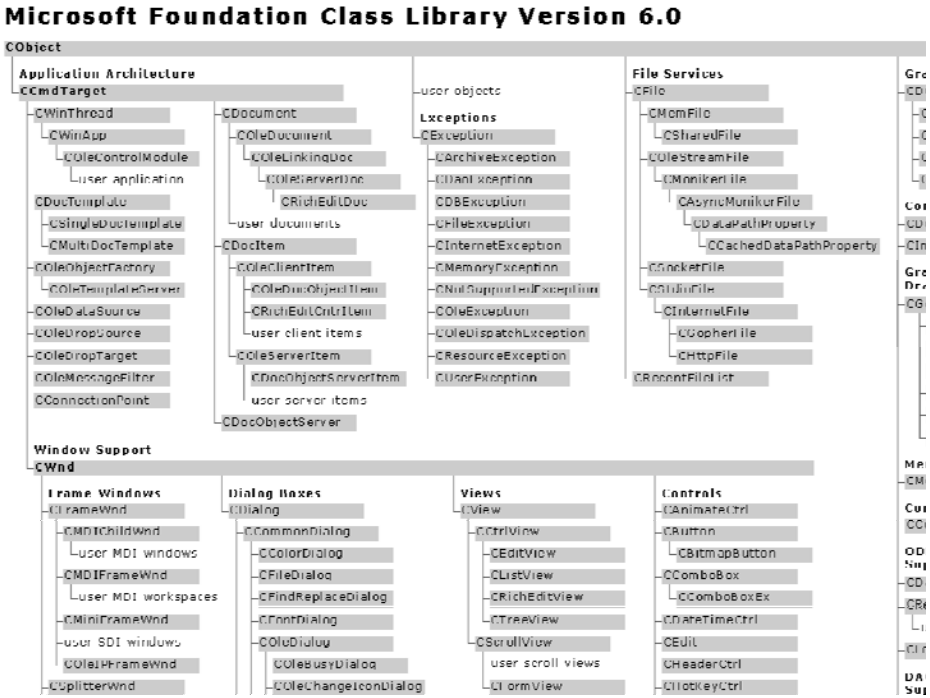
- sub-class super-class relationship can lead to a **class hierarchy** or **inheritance hierarchy**.

Example:



Real-World Examples Of Inheritance

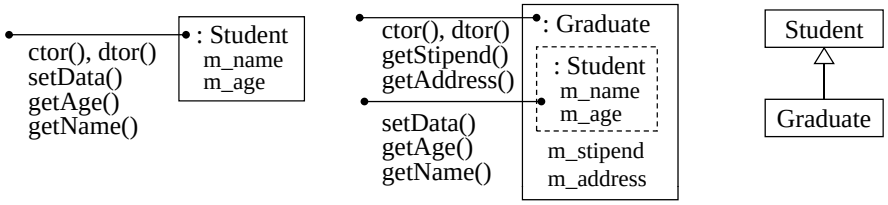
- Microsoft Foundation Class Version 6.0
  - A tree-style class hierarchy
- Java Class Library
- …



Inheritance Design

Exploring Solutions to Inheritance

- The University database program



- We would like to add a class Faculty, whose attributes include

m_name
m_age
m_address — **room # and building id of the office**
m_rank

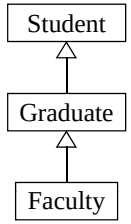
Note that there is no stipend.

- Should Faculty be derived from Student or Graduate or none of both?
- Let us first try inheriting Faculty from Graduate since the two groups have so much data in common

Exploring Solutions (cont'd)

- Deriving Faculty from Graduate makes a very efficient reuse of codes

```
class Faculty: public Graduate {
public:
   Faculty(char *name, int age, char *address, char *rank);
   ~Faculty();
   const char *getRank() const;
private:
   char *m_rank;
};
```



- We are forced to ignore Graduate::m_stipend in ctor

```
Faculty::Faculty(char *name, int age, char *address, char *rank)
            : Graduate(name, age, 0, address) {
   m_rank = new char[strlen(rank)+1];
   strcpy(m_rank, rank);
}
```

Zero is a dummy value for the stipend

- However, the client can still do this

```
Faculty prof("Lin", 40, "#2 Bei-Ning", "Associate Professor");
cout << prof.getStipend();
```

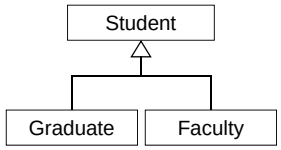
You can spare a data member but cannot turn off an interface of the base class.

This is NOT a good solution!

Another Possible Solution

- How about deriving Faculty from Student because Faculty requires all of the data from Student

```
class Faculty: public Student {
public:
   Faculty(char *name, int age, char *address, char *rank);
   ~Faculty();
   const char *getRank() const;
   const char *getAddress() const;
private:
   char *m_address;
   char *m_rank;
};
```

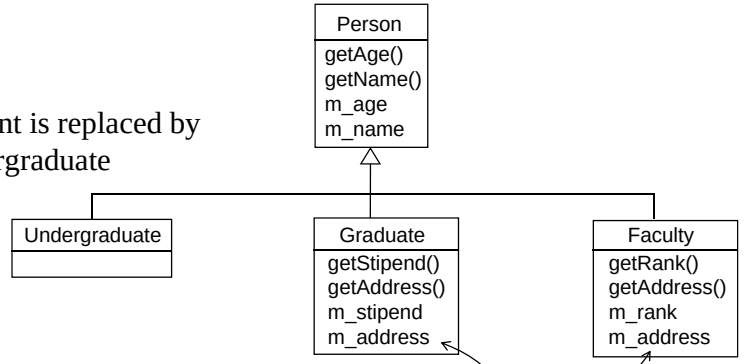


- What is the problem now?
  - ⋆ Faculty duplicates some codes in Graduate: m_address related
  - ⋆ What happens if Student adds a field for "undergraduate advisor"?
  - ⋆ The problem is that Faculty is intrinsically **not** a Student.

"Inheritance SHOULD **NOT** be designed based on solely implementation considerations – eg. code reuse."

A Better Design

- Create a **Person** class and put everything common to all people in that class, all other classes are derived from this class.



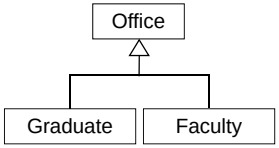
- Student is replaced by Undergraduate
- Should we eliminate UnderGraduate and use only Person in its place?

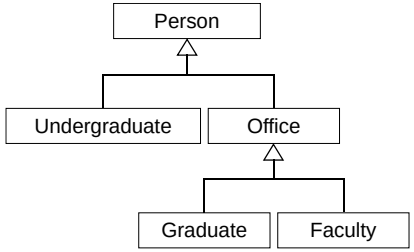
Is there any redundancy?

- Should Graduate be derived from Undergraduate?

Adding an Office Class

- Codes related to address could be merged into a single copy. How about encapsulating all data related to the address in the **Office** class?
- Anyone who needs an office can then **inherit** from Office.
- But Graduate and Faculty still need to inherit name and age categories so this design forces us to this inheritance





Bad design!! Problematic!!?

What's wrong?

- **If the Office has a clean() method, The Faculty automatically has a clean() method. What does it mean?**
- **What if a faculty has two offices?**

Code for Office Solution

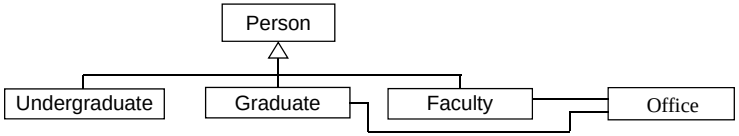
```
class Office: public Person {
public:
   Office(char *name, int age, char address);
   ~Office()
   const char *getAddress() const;
private:
   char *m_address;
};
```

Poor design!!
Problematic!!?

```
class Graduate: public Office {
public:
   Graduate(char *name, int age, int stipend, char *address);
   int getStipend() const;
private:
   int m_stipend;
};
class Faculty: public Office {
public:
   Faculty(char *name, int age, char *address, char *rank);
   ~Faculty();
   const char *getRank() const;
private:
   char *m_rank;
};
```


Final Solution

- Back to our original inheritance design (good design)



- Instead of having Graduate and Faculty inherit from Office, we store an Office object within each classes
- The office class exists separately, without involving any inheritance
- Codes:

```
class Office {
public:
   Office(char *address);
   ~Office();
   const char *getAddress() const;
private:
   char *m_address;
};
```


Final Solution (cont'd)

```
class Graduate: public Person {
public:
   Graduate(char *name, int age, int stipend, char *address);
   int getStipend() const;
   const char* getAddress() const;
private:
   int m_stipend;
   Office m_office;
};
```

delegation

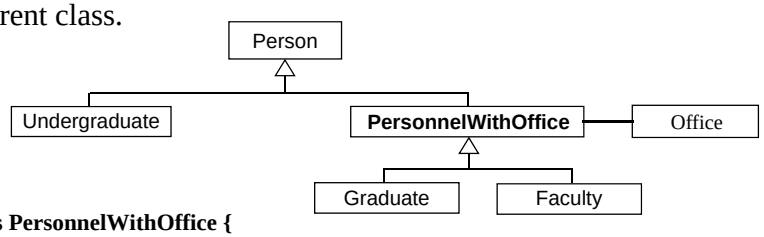
```
const char* Graduate::
      getAddress() const {
   return m_office.getAddress();
}
```

```
class Faculty: public Person
{
public:
   Faculty(char *name, int age, char *address, char *rank);
   ~Faculty();
   const char* getAddress() const;
   const char *getRank() const;
private:
   char *m_rank;
   Office m_office;
};
```

- Note: the data part m_office in Graduate and Faculty is replicated. However, the code to handle address is reduced to a single copy, i.e. Office::getAddress(). If we want to maintain a single object for the same office, we can use pointer or reference to implement m_office.

Further Abstraction

- When the relationships between Graduate or Faculty objects and other objects are common, we can model their relationships within a parent class.



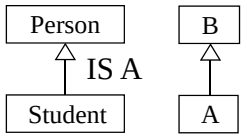

```
class PersonnelWithOffice {
public:
   const char *getAddress() const;
private:
   Office m_office;
};
```

Note: in the above class diagram, each Graduate object or Faculty object has an association with an Office object

- If there could be several offices for a certain personnel, the private member could be a container, ex. vector<Office> m_offices;

Design Rules for Inheritance

- **Primary guide**: Class A should only be derived from Class B if Class A **is a** type of Class B
  - A student **is a** person

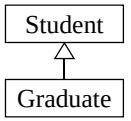


Liskov substitution Principle (LSP)

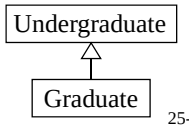
This def is formal but still abstract!! Difficult to follow!

  - Inheritance is called an IS-A relationship
  - What we mean by "is-a" in programming is "**substitutability**".
  - Eg. Can an object of type Student be used in whatever place of an object of type Person? This is described in terms of their interfaces (the promises and requirements), instead of their implementations. If yes, Student can inherit Person.
- Inheritance should be "natural"
  - The second case is a bad inheritance even if Undergraduate is internally identical to Student.

Proper inheritance

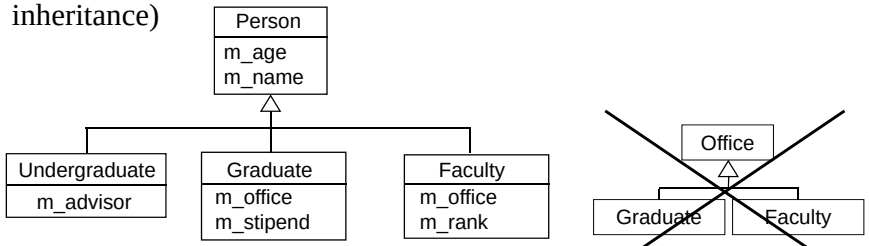


Improper inheritance

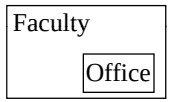


Design Rules (cont'd)

- **Common code and data** between classes can be shared by creating a base class (one of the two primary benefits we can get from inheritance)



- Never violate the primary objectives for the sake of code sharing!
- Bad cases of inheritance (improper inheritances) are often cured through composition (containment / aggregation)



This is referred to as the HAS-A relationship.

It operates in the form of delegation.

Dubious Examples of Inheritance

- Taken from Deitel & Deitel, C: How to program, p. 736

```
class Point {
public:
   Point(double x=0, double y=0);
protected:
   double x, y;
};
class Circle: public Point {
public:
   Circle(double x=0, double y=0, double radius=0);
   void display() const;
private:
   double radius;
};
```

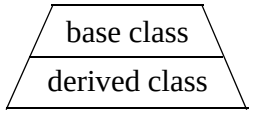
```
void Circle::display() {
   cout << "Center = " << c.x << ", " << c.y
        << "]; Radius = " << radius;
}
```

- Design rationale: A point is a type of circle, with common data, when the radius of a circle is approaching zero. ... Purely mathematical!
- Critiques: A circle is not a point. Instead, a circle has a point corresponding to its center. Substitutability: Can a circle be used as a point in constructing the four corners of a rectangle? Can a circle be used as the center of another circle?

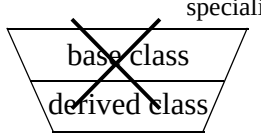
Some Other Dubious Examples

- Ex 1: A stack derived from a linked list What are the problems?
  - This stack can then be operated as a linked list, the mechanism of a stack would be completely broken.
  - If you try to turn off the insert()/delete() interface that could manipulate entries in any order, you basically make the Stack class different from the LinkList base class in terms of operations. **Client codes break!** A Stack **IS-NOT** a LinkList.
- Ex 2: A file pathname class derived from a string class

  note: a pathname IS indeed implemented by a string, but it is a special string that cannot be longer than 32 characters
- **Design rule**: The derived class **extends** the base class, not the other way around.



specialization



Points to Consider

To design a **Shape** inheritance hierarchy

- What are the **common operations** you want to perform on all Shapes
- What other kinds of Shapes might you use in your application? (Triangle, Circle, Polygon, Ellipse, Square, Rectangle Rhombus, Pentagon, …) Circle-Ellipse Square-Rectangle
- Why do you need a Rectangle class as the base class of a Square?
- Can a Square substitute for a Rectangle?
- A Rhombus is four-sided, like a Rectangle, so should Rectangle derive from Rhombus?
- Should you have a base class for all four-sided objects?
- Should you have another base class for all five-sided objects?
- Should you have a general base class for polygons with the number of sides as an attribute?
- Will your program perform geometric searches to identify objects?

Summary