Object-Oriented Programming

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Overview

Primary OOP features

- **Encapsulation**: grouping related data and functions together as objects and defining an interface to those objects.
- **Inheritance**: allowing code to be reused between related types.
- **Polymorphism**: allowing an object to be one of several types, and determining at runtime how to "process" it, based on its type.

Polymorphism I

Definitions

- Polymorphism is the property of an entity to react differently depending on its type.
- Polymorphism is the property that allows different entities to behave in different ways to the same action.
- Polymorphism allows different objects to respond in different ways to the same message.
- Polymorphism - Greek meaning: "having multiple forms".

Polymorphism II

- Usually, polymorphism occurs in situations when one has classes related by inheritance.
- A call to a member function will cause the execution of a different code, depending on the type of object that invokes the function.
- The code to be executed is determined dynamically, at run time.
- The decision is based on the actual object.

Polymorphism III

? In the code below, why are we allowed to write: *Animal* a2 = &p1;* ?

```
Animal a1("black", 20);
Penguin p1("black and white", 7, "Magellanic");
Animal* a2 = &p1;
cout<<a2->toString(); //which toString function?
    The one from the class Animal, or the one
   from the class Penguin?
```

Static binding

- The choice of which function to call is made at compile time.
- The object *a2* is declared as a pointer to Animal $\Rightarrow$ at compile-time it is decided that the function *Animal::toString()* will be called.
- Static binding is also called **early binding**.

Dynamic binding I

- In the presented case, the behaviour we expect is a call to the function *Penguin::toString()*.
- At runtime, the actual type of the object is determined.
- The decision of using *Animal::toString()* or *Penguin::toString()* should be taken only after determining the actual type of the object $\Rightarrow$ at runtime.
- This is **dynamic binding**: take the correct decision of which function body to execute, according to the actual type of the object.

Dynamic binding II

- Dynamic binding is also called **late binding**.
- When a message is sent to an object, the code being called in not determined until runtime.
- Dynamic binding **only works with non-value types**: references and pointers.
- In C++, dynamic binding is achieved using virtual functions.

Virtual methods I

Declaration

virtual function_signature

- If a function is declared virtual **in a base class** and then overriden in a derived class ⇒ dynamic binding is enabled.
- The actual function that is called depends on the content of the pointer (or reference).
- The function becomes polymorphic by being designed virtual.

Virtual methods II

- The function in the derived class that is overriding the function in the base class can use the override specifier to ensure that the function is overriding a virtual function from the base class.
- override is an identifier with a special meaning when used after member function declarators and otherwise, it is not a reserved keyword.

DEMO

Polymorphic function *toString* (Animal - Penguin, Dog) (*Lecture6_demo_virtual_functions*).

C++ mechanism I

- In memory, for an object with no virtual functions, only its own data is stored.
- Member functions or pointers to them are **not** stored in the object. They are stored in a code memory section, and are known to the compiler.
- When a member function is called, the pointer to the current object (this) is passed as an invisible parameter so the functions know on which object to operate when they are called.

C++ mechanism II

- Things are different when virtual functions come into play.

- In the case of a derived class with virtual functions, the compiler creates a table of function addresses called the **virtual table** - a static array set up by the compiler at compile time.

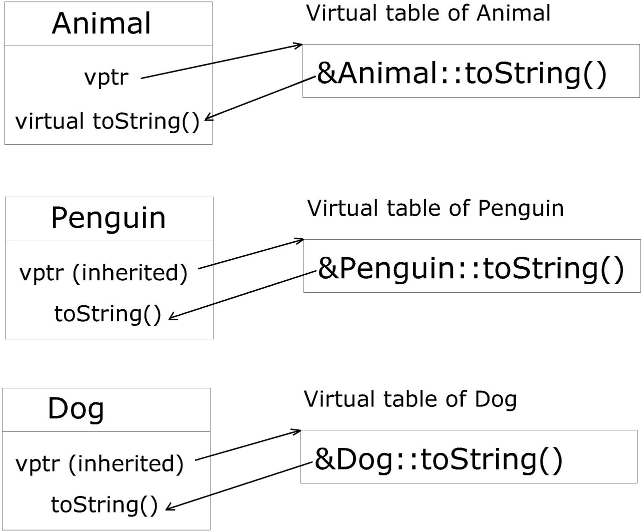
- Every class that uses virtual functions (or is derived from a class that uses virtual functions) will have its own virtual table.

- Each entry in the virtual table is a function pointer that points to the most derived function accessible by the class.

C++ mechanism III

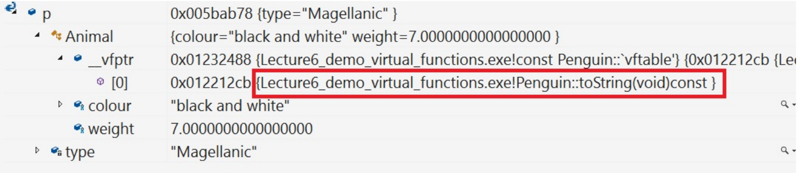
- A pointer to the virtual table (vptr) is added to the base class - and inherited by the derived classes.
- When a class object is created, the pointer to the virtual table is set to point to the virtual table for that class.
- When a call is made through a pointer or reference, the compiler generates code that dereferences the pointer to the objects virtual table and makes an indirect call using the address of a member function stored in the table.

C++ mechanism IV



C++ mechanism V


```
Animal* p = new Penguin{ "black and white",
    7, "Magellanic" };
```



C++ mechanism VI

- The virtual function mechanism works only with pointers and references, **but not** with objects.

- Calling a virtual function is slower than calling a non-virtual function:
  1. Use the vptr to access the correct virtual table.
  2. Find the correct function to call in the virtual table.
  3. Call the function.

- Declare functions as virtual only if necessary.

DEMO

Virtual functions. (*Lecture6_demo_virtual_functions*).

Virtual constructors?

- Constructors **cannot** be virtual.
- When creating an object, one must know exactly what type of object one is creating.
- Usually, the virtual table pointer is initialized in the constructor.

Virtual destructors I

- A derived class object contains data from both the base class and the derived class.
- The destructor's responsibility is to dealocate resources (memory).
- In the case of a derived class object, it is essential that both the destructor of the base class and the destructor of the derived class are called.

Virtual destructors II

- The correct destructor must be invoked based on the actual type of the object, not the type of the pointer holding the reference to the object.
- Therefore, the destructor must have a polymorphic behaviour $\Rightarrow$ the base class destructor must be virtual.

DEMO

Virtual destructor. (*Lecture6_demo_virtual_functions*).

Upcasting and downcasting I

Upcasting

- Casting an object/reference/pointer of a derived class to an object/reference/pointer of the base class.
- Casting up the hierarchy.
- Allows us treating a derived type as though it were its base type.
- Is always allowed for public inheritance, without an explicit cast, as a a derived class object has all the members of the base class (and more).

Upcasting and downcasting II

Downcasting

- Casting a base-class pointer/reference to a derived-class pointer/reference.
- Casting down the hierarchy.
- Is **not** allowed without an explicit type cast (requires explicit casting from the user). **?** Why?
- For explicit casting: static_cast, dynamic_cast.

Upcasting and downcasting III

- static_cast:
  - converts a reference/pointer to a specified type;
  - will check, at compile time, if the types are compatible (in the same inheritance hierarchy);
  - does not perform runtime checking; does not check if the object being converted is "complete" $\Rightarrow$ bad casts can lead to runtime errors.

Upcasting and downcasting IV

- dynamic_cast:
  - converts a reference/pointer to a specified type;
  - will check, at runtime, if the object can be converted and if it cannot, it returns nullptr or an error;
  - only works with pointers or references.

DEMO

Upcasting and downcasting (*Lecture6_demo_virtual_functions - upCasting() and downCasting()*).

Pure virtual functions I

- The definition of a method from a class can be omitted by making the function **pure virtual**.

Syntax

virtual function_signature =0;

- A **pure virtual** function is a function with no body.
- All the derived classes will have to define the function.

Pure virtual functions II

- The compiler will reserve a slot for the pure virtual function in the virtual table, but will not add any address in that particular slot.

- A destructor can be declared pure virtual, but if any objects of that class or any derived class are created in the program, the destructor shall be defined.

Abstract classes I

- A class containing *at least* one pure virtual function is called an **abstract class**.
- An abstract class cannot be instantiated (one cannot create objects of that type).
- There are cases in which one needs the base class only as a starting point for derived classes.
- In reality, there are penguins and dogs and koala bears, but no generic animals.

Abstract classes II

- When a class is abstract, the compiler will not allow the creation of objects of that class.

- An abstract class serves as a base class for a collection of related derived classes and it provides:
    - a common public interface (or pure virtual member functions);
    - any shared representation;
    - any shared member functions.

Abstract classes III

Extending an abstract class

- A concrete class that extends an abstract class inherits its public interface.
- A concrete class is expected to have instances.
- Override "abstract" functions to provide specific implementation (otherwise the derived classes will also be abstract classes).

Homogeneous containers and polymorphism

- One example of use of polymorphism is on containers holding elements of the "same type" (from the same class hierarchy).
- A message is sent to each of the objects in the container and they must respond in their specific way.

DEMO

Abstract classes. (*Lecture6_demo_abstract_classes*).

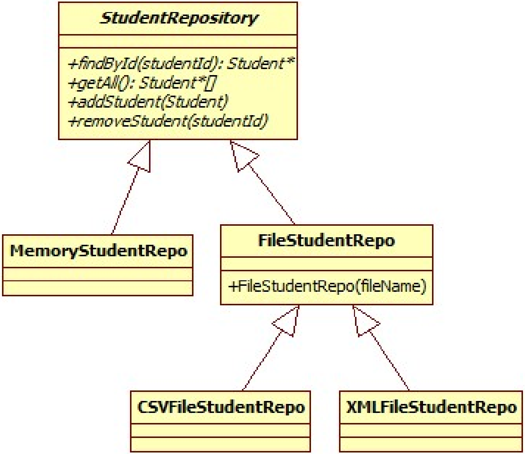
Pure abstract classes I

- A **pure abstract class** contains nothing but pure virtual methods.
- A pure abstract class is also called an **interface**.
- An interface describes the capabilities of a class without committing to a particular implementation of that class.
- The UML representation for abstract entities (functions or classes): *italic font*.

Pure abstract classes II

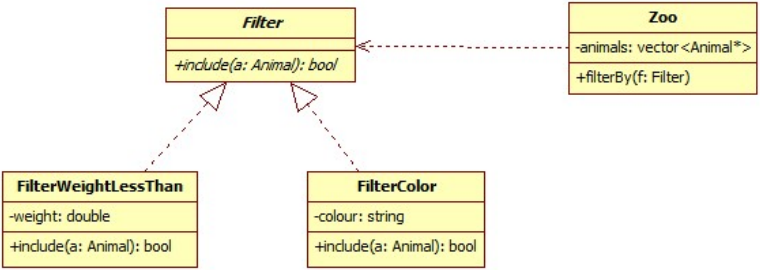
- Remember Lab5 - 10 from Fundamentals of Programming?
- We started with an in-memory repository, and added a file-based one.
- Defining an interface would allow us to use any class that implements it.

Pure abstract classes III



Example - pure abstract class I

- **Requirement**: given a list of animals, display, in turns, the animals having:
  - the weight smaller than a given value;
  - the colour equal to a given colour.



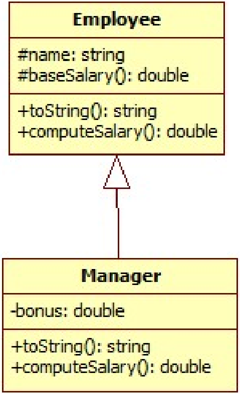
Example - pure abstract class II

DEMO

Abstract classes. (*Lecture6_demo_abstract_classes* - Filter.h and filterAnimals()).

Exercise I

Write the C++ code corresponding to the following UML class diagram related to companies and their employees.



Exercise II

- The company has several employees, some of them are managers.
- The **toString** method from Employee returns a string with the name of the employee.
- The **toString** method from Manager returns a string with the word "Manager" and the name of the employee.
- The **computeSalary** method from Employee returns the base salary.
- The **computeSalary** method from Manager returns the base salary, to which the manager bonus is added.

Exercise III

- Write a test program that creates several employees (both regular employees and managers), add all the employes into a list (vector).

- Create a function that for a list of employees will print out the proper name and salaries for all the employes, using the values returned by the **toString** and **computeSalary** methods.

Inheritance and polymorphism - benefits

- code reuse:
  - derived classes inherit from the base class;
  - code duplication is avoided $\Rightarrow$ better maintanance, evolution, understanding.
- extensibility:
  - generic code;
  - new functionalities can be added without modifying the existing code;
  - extension points are provided for further evolution.