

Polymorphism

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

Polymorphism

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Overview

Polymorphism

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

1 Polymorphism

2 Static and dynamic binding

3 Virtual methods

4 Upcasting and downcasting

5 Abstract classes

Primary OOP features

Polymorphism

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- **Abstraction:** separating an object's *specification* from its *implementation*.
- **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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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.

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes



Figure source: <https://www.youtube.com/watch?v=ng98qapa4Sw>

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

? 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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

Dynamic binding I

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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 ⇒ at runtime.
- This is **dynamic binding**: take the decision of which function body to execute according to the actual type of the object.

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

Declaration

`virtual function_signature`

- If a function is declared **virtual** in a **base class** and then overriden in a derived class \Rightarrow 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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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_polymorphism*).

C++ mechanism I

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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 on when they are called.

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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.

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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 object's virtual table and makes an indirect call using the address of a member function stored in the table.

C++ mechanism IV

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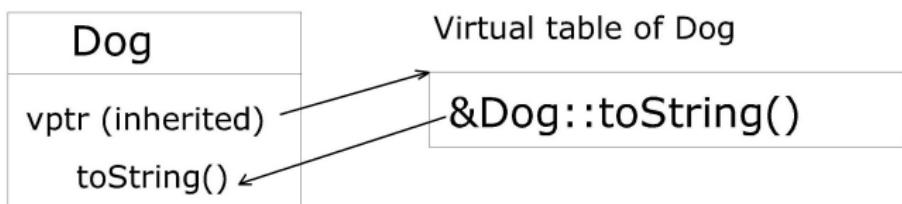
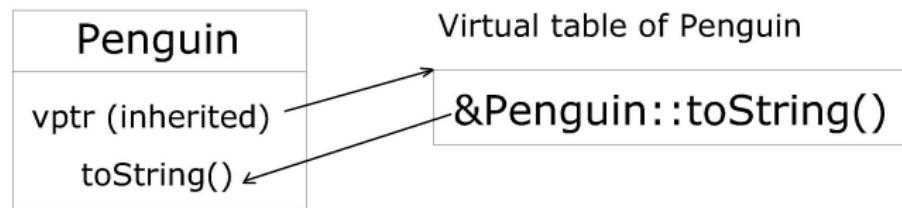
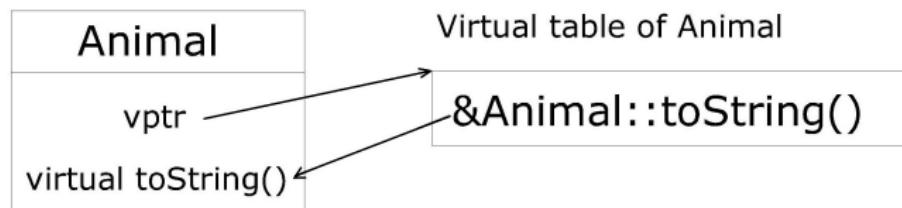
Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes



C++ mechanism V

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

• p	0x005bab78 {type="Magellanic" }
↳ Animal	{colour="black and white" weight=7.000000000000000 }
↳ _vptr	0x01232488 {Lecture6_demo_virtual_functions.exe!const Penguin::`vtable'}
↳ [0]	0x012212cb {Lecture6_demo_virtual_functions.exe!Penguin::toString(void)const }
↳ colour	"black and white"
↳ weight	7.000000000000000
↳ type	"Magellanic"

C++ mechanism VI

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- The virtual function mechanism works only with pointers and references, **but not** with value-types (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. (*Lecture_6_polymorphism*).

Virtual constructors?

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- A derived class object contains data from both the base class and the derived class.
- The destructor's responsibility is to deallocate 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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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
⇒ the base class destructor must be **virtual**.

DEMO

Virtual destructor. (*Lecture_6_polymorphism*).

Upcasting and downcasting I

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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 derived class object has all the members of the base class (and more).

Upcasting and downcasting II

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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`.

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

• `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" ⇒ bad casts can lead to runtime errors.

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- **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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

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Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- Remember *MemoryRepository* and *FileRepository* in 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

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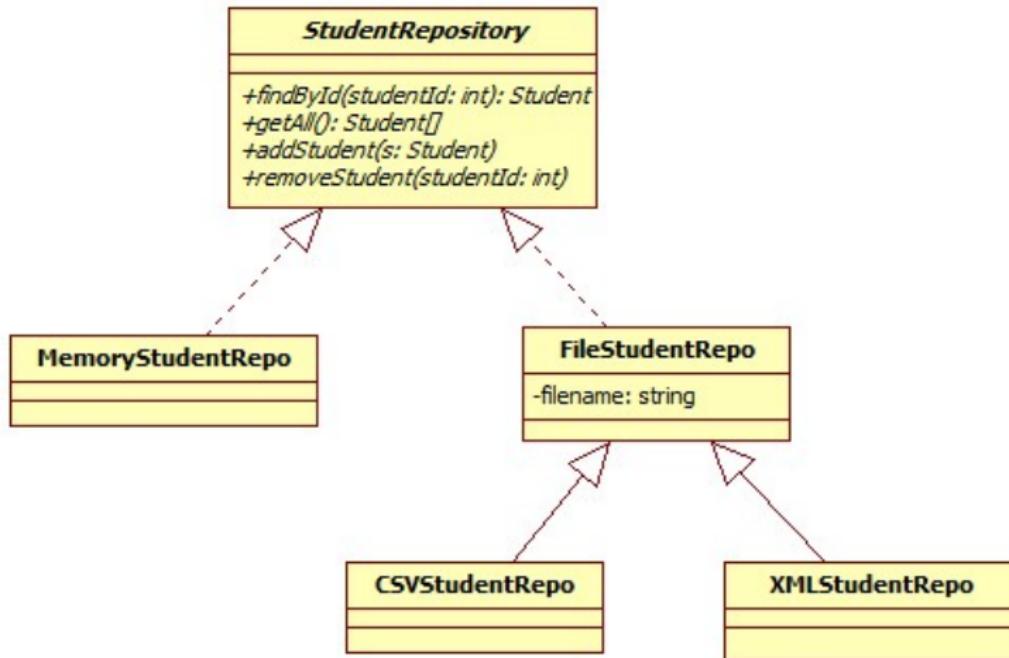
Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes



Example - pure abstract class I

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Polymorphism

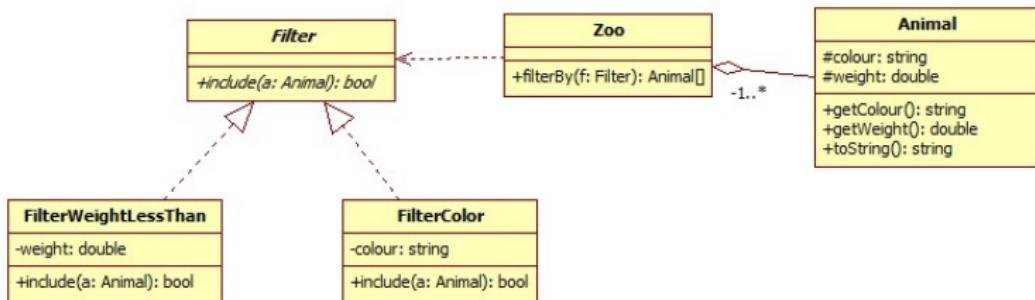
Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- **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

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

DEMO

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

Exercise I

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

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

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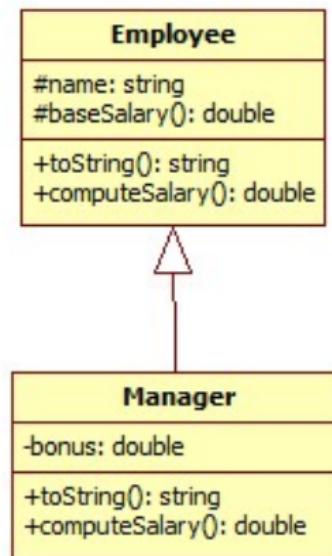
Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes



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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- 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 IV

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- Write a test program that creates several employees (both regular employees and managers), add all the employees into a list (vector).
- Create a function that for a list of employees will print out the proper name and salaries for all the employees, using the values returned by the **toString** and **computeSalary** methods.

Inheritance and polymorphism - benefits

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Polymorphism

Static and
dynamic
binding

Virtual
methods

Upcasting and
downcasting

Abstract
classes

- code reuse:

- derived classes inherit from the base class;
- code duplication is avoided ⇒ better maintenance, evolution, understanding.

- extensibility:

- generic code;
- new functionalities can be added without modifying the existing code;
- extension points are provided for further evolution.