CH08-320142

Object-oriented Programming I

OOP I

Lecture 5 & 6

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Agenda Week 3

- The `bool` data type
- More on namespaces
- The `static` keyword
- Inline methods
- The implicit pointer `this`
- The `friend` keyword
- Operator overloading
- Polymorphism
- Abstract classes
- The `virtual` keyword

C++ `bool` Data Type

- C++ introduces a basic data type for dealing with boolean variables
- Its name is `bool` and the constants `true` and `false` can be used to assign values to a `bool` variable

```
bool a = true;
```

- Usual C conventions still hold: `false` is converted to 0 and true to 1
- Every `int` not equal to 0 is converted to `true`, and 0 is converted to `false`

C++ Boolean Operators

- As not all the keyboards easily provide the keys for the C boolean operators (`&`, `|`, `^`, etc) in C++ the following operators are introduced (in the header `<ciso646>`)
  - `and`, `or`, `not`, `not_eq`, `bitand`, `and_eq`, `bitor`, `or_eq`, `xor`, `xor_eq`, `compl`

Namespaces (1)

- While developing large projects, the risk of running into a name clash is high
  - Multiple programmers could use the same names for their classes, functions, etc. At the linking stage, name collisions can arise
  - You can have the same problem when using third party developed libraries
- Solutions found in the past, consisting on appending specific prefixes, are not appealing

Namespaces (2)

- A namespace introduces a further level of code protection
- Elements belonging to the same namespace can refer to each other without any special syntax
- Elements in different namespaces can refer to each other just by using a designed syntax
  - They have to explicitly declare that they are referring to a different namespace

Creating a Namespace

- A namespace is created using the `namespace` keyword at the file level

```
namespace CPPcourse {
  void f1() { ... }
  class class1 { ... };
}
```

- Namespace declaration can be split over multiple files without creating redefinition problems
- `namespace.h`
- `namespace.cpp`

Using Names from a Namespace

Three ways:

- Import the whole namespace
  `using namespace CPPcourse;`
- Import a specific name from a namespace

```
using CPPcourse::FirstExample;
FirstExample a("Try this");
```

- Using complete name specification
  `CPPcourse::FirstExample a("Try this");`

Examples Revised

- Then in all former examples
  `using namespace std;`
  was introduced to use standard C++ classes, which are declared in the `std` namespace
- In header files we have used full name specification
  `std::string name;`
- Never use the `using` directive in a header file, use full name qualification instead
  - While writing a header file you do not know what your potential client will need in terms of namespaces

Final Remarks on Namespaces

- If a namespace's name is too "awkward" to use, it is possible to create an alias
  `namespace short = AliasForANameTooLongToBeUsed;`
- From now on we can use short instead of the alias it points to
- Namespaces can be nested
- More details in Eckel's book (chapter 10)

`static` Data Members

- A `static` data member is shared among all the instances of a class
  - It creates a sort of class variable
- It exists even if no instances are created
- Storage must be explicitly allocated outside of class definition
- Can be useful to define class constants
  - Using `const` as modifier for a data member does not yield the desired results (as class constant)
- `staticexample.cpp`

`static` Methods

- Also methods can be declared as `static`
- Static methods can access only static data members and can call only static methods
- Static methods can be called referring to an instance or to the class
  - Like `static` data members they are class methods
- `staticshapes.cpp`

When Should we Use `static`?

No general rules, but some generic indications:

- When creating class level constants
- When you devise some information which belongs to the class rather than to instances
- When a method needs to access data members but it is not logically tied to a specific instance

Inline Methods (1)

- C is well appreciated as it is an efficient language
  - The UNIX operating system relies on C
- C++ cannot give up C efficiency
- Inline methods are designed to improve the performance of C++ programs
  - No semantic alterations w.r.t. non-inline methods

Inline Methods (2)

- A method call is equivalent to a procedure call
  - Push arguments onto the stack (or register)
  - Execute a CALL-like instruction
  - Execute function/method code and then return
  - Stack cleanup
- For small methods the overhead of the call could take more time than code execution
  - Think for example of getter or setter methods, where you have just one instruction as body
  - Moreover those methods are likely to be called frequently

Inline Methods (3)

- An `inline` function is expanded in place, rather than called
  - Instead of a regular call, function code is directly inserted
- You trade off speed for size
  - No call overhead, but your code could grow as the body of the function will be copied many times
- Good candidates for being `inline` are short methods that are frequently called

Inline Methods (4)

How to create inline methods - two possibilities:

- Put the definition of the method inside the class declaration
  `inlineinside.h` `inlineinside.cpp`
- Use the keyword `inline` and write the definition outside the class declaration
  `inlineoutside.h` `inlineoutside.cpp`
  Put the `inline` function definition in the same header file where the class is declared

Inline Methods: How Do they Work?

- When the compiler finds the definition of an inline method it stores its signature and its code in its symbol table
- When it finds a call to an inline method it checks type correctness and replaces/copies the code
  - C preprocessor macros offered similar advantages, but no type checking was enforced
    - Nasty to find bugs which could be generated
    - Preprocessor macros have no concept of scoping

Inline Methods: Final Remarks

- Not everything declared as `inline` by the programmer will necessarily be inlined by the compiler (inline is just a hint)
  - If a method includes loops it is unlikely that it will be expanded
- Defining inline methods outside class declaration increases code readability
- Multiple inclusions of headers with inline methods will not result in redefinition problems

The Implicit Pointer `this`

- The reserved keyword `this` is a pointer to the current instance of a class
- `this` is silently passed by the compiler as an argument to every method call
  - Except of course to static methods. Why?
- `thisexample.cpp`
- Will be very useful when implementing overloaded operators

`friend` Functions

It is possible to "break" the protection mechanism, i.e., to let a class or a function access non-public data members of a class

- Is this needed? Sometimes yes, if getting through the getter and setter methods becomes difficult to manage
- We will see that this will be very important while redefining operators
- Be aware: when using `friend` elements, you break the information hiding mechanism
- Do not misuse it

`friend`: How to Create

- In the class declaration, declare a "method" with the `friend` modifier
  - That indicates a function which can access class data members
  - The function has to be defined later, but remember that it is not a method
  - `friendexample.cpp`
- It is also possible to create `friend` classes, i.e., classes which can access private data of other classes

Linking (1)

- While developing non-trivial projects, it is useful to split the code into multiple files
  - For example, each class could be coded in a separate couple of files (i.e., the header and the implementation file)
- The compiler takes an implementation source file and produces an object file
  - An object file is something "almost ready to be executed", but with dangling external references

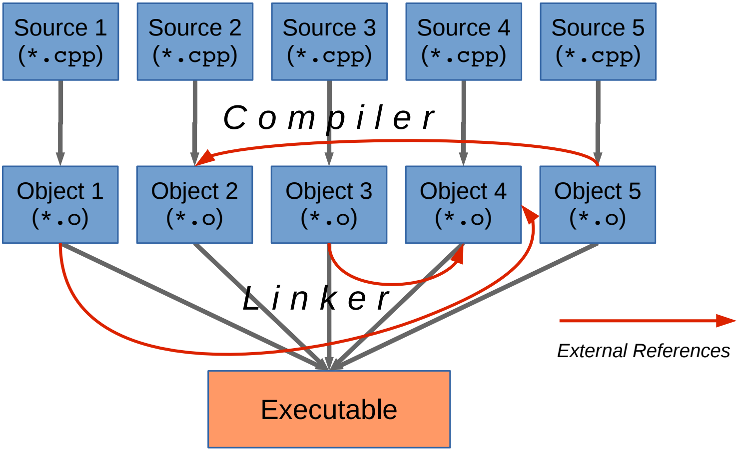
Linking (2)

- To compile a source file, the compiler needs only the declaration of the classes used
  - Thus you include only header files
- This needs only the names and the types because of checking the correctness of calls, declaration, etc.
- If a source file refers to something declared but not defined, a dangling link is introduced

Linking (3)

- When building the executable, the linker puts together multiple object files and produces one single executable
- While putting them together, it tries to resolve dangling references
- If it finds multiple definitions of the same entity, a linker error is raised
  - Which one should it use?

Linking (4)


Source 1 (*.cpp)
Source 2 (*.cpp)
Source 3 (*.cpp)
Source 4 (*.cpp)
Source 5 (*.cpp)
Compiler
Object 1 (*.o)
Object 2 (*.o)
Object 3 (*.o)
Object 4 (*.o)
Object 5 (*.o)
Linker
External References
Executable

Function Overloading

```
#include <iostream>
using namespace std;
int division(int dividend, int divisor)
{
  return dividend/divisor;
}
float division(float dividend, float divisor)
{
  return dividend/divisor;
}
int main()
{
  int ia = 10;
  int ib = 3;
  float fa = 10.0;
  float fb = 3.0;
  cout << division(ia, ib) << endl;
  cout << division(fa, fb) << endl;
  return 0;
}
```

Operator Overloading (1)

- Overloaded operators allow a different syntax for function/method calls
- Operator overloading allows the programmer to use language operators for user defined data type. For example

```
Car first, second, third;
...
third = first + second;
```

  what this could mean is left to the programmer
- New operators cannot be introduced

Operator Overloading (2)

- It is possible to overload operators only for user defined data types
  - Thus it is not possible to alter the meaning of the + operator between `int`s, `float`s, and so on
    - C code should compile with C++ compilers without changing its functionality
- Overloading an operator should help the reader of the program and not the programmer
  - You can define an operator + between two instances of a salary class which subtracts them
  - Whether this makes sense or not is up to your design choices and skills

Sorting Students by Grade

With overloaded operators

```
Student *list;
...
for (i = ...)
  if (list[i] > list[j]) {
    tmp = list[i];
    list[i] = list[j];
    list[j] = tmp;
  }
...
```

Without overloaded operators

```
Student *list;
...
for (i = ...) {
  if (list[i].getGrade() >
    list[j].getGrade()) {
      ...
  }
}
...
```

Which one is “cleaner”?

Using/Calling Operators

- From the previous example it should be clear that no magic things are happening, but just a compact (and clear) syntax for method calls can be used
- Whenever the compiler finds an operator involving user defined types, it verifies if it is possible to find a proper definition
- Operators are overloaded as there can be more than just one version: $+$ between two instances of car, $+$ between an instance of car and an instance of bike, and so on
- Types help in determining the version which should be called

Operators, Methods or `friend` Functions

- To carry out their task operators need to access class data
- Then, they have to be either methods or friend functions
  - There are some guidelines
    `Student3.h` `Student3.cpp` `studentoperator.cpp`
- It is possible to overload both unary and binary operators

Overloading the = Operator

- Overloading the = operator is fundamental if your class deals with pointers as properties
- Language provided = operator performs field to field copy
- If the class has pointers, different instances end up with sharing the same memory
  - Also, there could be memory leaks
    `charbuffer.h` `charbuffer.cpp`
- The operator = must be a method and must return a reference to the class
  - This allows iterated assignments (`a=b=c;`)

Overloadable Operators

Unary Operators	Binary Operators
`+ - & ! ~`	`+ - * / % ^ & | <<`
`++ --`	`>> += -= *= /= %= ^=`
(both prefix and postfix)	`&= |= >>= <<= == !=`
`[ ] -> ( )`	`< > <= >= && || ->*`

`new` and `delete` can be overloaded as well

What Should Operators Return?

- A reference, it they modify the involved argument(s) (like =, +=, etc.)
- Return a reference to the modified object, usually by using `this`
- A new instance if they do not modify arguments, but rather use them to produce new information (like most binary operators: `+`, `-`, etc.)
- A `bool` if it is a boolean operator

Member or `friend`?

The following table proposed in the textbook can be taken as a general guideline

<table>
<tr><th>Operator</th><th>Use</th></tr>
<tr><td>Unary operators</td><td>Member</td></tr>
<tr><td>= ( ) [ ] -> ->*</td><td>Must be member</td></tr>
<tr><td>+= -= /= *= ^= &= |= %= >>= <<=</td><td>Member</td></tr>
<tr><td>Other binary operators</td><td>Friend or member</td></tr>
</table>

`complex.h` `complex.cpp` `testcomplex2.cpp`

Overloading << and >>

- For example for the `Complex` class:

```
friend ostream& operator<<(ostream& out, const Complex &z)

friend istream& operator>>(istream& in, Complex &z)
```

Polymorphism

- The last cornerstone of OOP has no correspondence in non-OOP languages
- It deals with writing code which can correctly operate even with data types unknown at compile time
- Just one additional keyword, `virtual`, which offers a wide range of applications

Starting from Upcasting

- Upcasting means that a derived class can be used wherever an ancestor class is expected
  - This because the interface of the parent is inherited
- A derived class can redefine a method, i.e., it can provide a new implementation
- `randomnonvirtual.cpp`
- `randomvirtual.cpp`

What Happens?

- In the first example the redefinition of the method was not perceived, while in the second the expected behavior was observed
- It should be evident that at compile time there is not enough information to bind the method call to the right method to execute
  - This is called late binding

The `virtual` Keyword

- When a method is declared as `virtual`, late binding is requested
- `virtual` should be specified just in the declaration of the base class
- Late binding is inherited from there on
  - The redefinition of virtual methods is called overriding
- When dealing with virtual methods, each object carries some sort of info to make its identification possible at runtime

`virtual` and Pointers

- Be aware: the late binding feature works only if you deal with pointers to instances, and not if you directly work with instances
  - And of course, also with C++ references
- When passing objects to methods/functions, using C++ references speeds up parameters passing and enables polymorphism

The Added Value of Polymorphism

- By mean of polymorphism it is possible to write general purpose code
  - When possible, general code always deals with base classes, and calls virtual methods
- Then, the code will work even with later introduced data types (new classes)

What Should be `virtual`?

- The decision is up to the designer
  - Some languages (like Java) make all methods virtual
- Virtual method calls introduce overhead
  - Run time binding
  - Making always every method virtual is poor design
- The choice is done at the base class level
  - If a method is not virtual in the base class, it cannot be made virtual in a derived class

Abstract Classes (1)

- It should be evident that classes near to the root of the hierarchy are seldom instantiated
  - Very general but also very unspecialized
- Some classes are introduced just to define common behaviors, but are not self sufficient
  - Think of the class shape in one of the former examples
- Those classes are useful only for abstraction

Abstract Classes (2)

- Abstract classes define a set of methods to be shared by a derived class but are not yet implemented
  - Implementation will be defined in a derived class
    - Virtual mechanism plays a fundamental role
- A pure virtual method is a method declared as:
  ```
  virtual void something() = 0;
  ```
- A class having one or more pure virtual methods is abstract

Abstract Classes (3)

- Abstract classes cannot be instantiated
- Abstract classes can also include non-pure virtual methods
- Methods and functions can accept pointers to abstract classes
  - This is their main use: through virtual calls generic code is developed

Shapes Example Revised

- In the shape example the shape class has not actually represented a shape (instance), but rather collected some data common to all shapes
- Therefore, `Shape` is a good candidate to be an abstract class
  - `shapesrevised.h`
  - `shapesrevised.cpp`
  - `testshapesrevised.cpp`

Virtual Destructors?

Destructors are almost always `virtual`

- If you are manipulating objects via pointers to the base class, then the base class should define its destructor as `virtual`
- Otherwise just the base class destructor is called
- Recall that destructors are called from bottom to up
- Destructors can be pure `virtual`
  - There are some subtle details concerning this aspect (see Eckel's book, chapter 15)

Virtual Constructors?

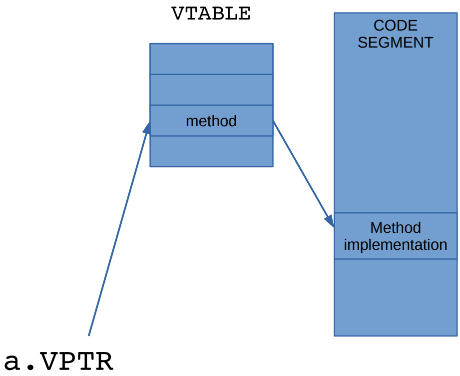
- You cannot have virtual constructors
  - Remember that constructors are called from the base to the leaves of the derivation tree
- Inside a constructor you can call a virtual method, but this will execute the local version
  - No downsearch is performed, as the assembly of the object is still being performed and elements belonging to derived classes are not guaranteed to be properly initialized

How Does Polymorphism Work?

- In order to correctly manage it, it is useful to know how polymorphism is implemented
  - For every class with virtual methods, a table is created; the table holds the address of the virtual methods (VTABLE)
  - In addition, a pointer to this table is stored inside the class; this pointer is invisible (VPTR)
  - When a virtual method is called, the pointer is used to access the table, and then from the table the address of the function is read
  - As each class with virtual elements is shaped this way, the compiler can insert the code to resolve the calls without knowing the type
  - The intermediate indirection through VTABLE is the reason for the slower performance of virtual method calls

Calls Through the Virtual Table

```
class Base {
  public:
    virtual void
      method()=0;
    // VPTR INSERTED
};
class Derived
    : public Base {
  public:
    void method() { };
    // VPTR INSERTED
};
...
Base *a= new Derived;
a->method();
```



Final Exam: Details

- At the end of the semester, scheduled by the SRO
- Final tutorial before exam will be offered by the TAs
- Programming exercises to be solved on paper
  - You have two hours to solve exercises
  - Similar to the programming assignments
  - Practice to write your programs on paper
- You do not need paper, it will be provided
- You may not use books or other documentation while taking the exam
- You may not use mobile phones, calculators or any other electronic devices