C++ programming language

Object-oriented programming (OOP)

Classes and objects in C++

Defining classes

Object creation/destruction

Operator overloading

Rule of three

Object-Oriented Programming

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Overview

1. C++ programming language
2. Object-oriented programming (OOP)
3. Classes and objects in C++
4. Defining classes
5. Object creation/destruction
6. Operator overloading
7. Rule of three
8. Static and friend elements

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Rule of three

C++ programming language I

- C++ was initially created by Bjarne Stroustrup and first standardized in 1998.
- The C++ standard evolves: https://isocpp.org/. The current standard is C++14 (a new one will be produced this year - C++17).
- C programs are valid C++ programs.

"C makes it easy to shoot yourself in the foot; C++ makes it harder, but when you do it blows your whole leg off". (Bjarne Stroustrup)

C++ programming language II

In addition to the facilities provided by C, C++ provides:

- additional data types (bool, reference);
- classes;
- templates;
- exceptions;
- namespaces;
- operator overloading;
- function name overloading;
- free store management operators;
- additional library facilities.

I/O Library

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Rule of three

- The C++ I/O operations are defined in the header ¡iostream¿.
- cin - corresponds to the standard input (stdin).
- cout - corresponds to the standard output (stdout).
- The writing operation is achieved using the *insertion operator* $<<$.
- The reading operation is achieved using the *extraction operator* $>>$.

References in C++ I

- A *reference variable* or *reference* is an *alias* or an *alternate name* for a variable (for the same memory location).
- They are particularly useful for function parameter passing by reference (changes inside the functions are reflected after the function finishes).
- A reference has the same memory address as the original variable.
- A const reference does not allow the modification of a variable.

References in C++ II

- References are similar to pointers, however there are the following notable differences:
  - A reference must be initialized when it is declared. (On the other hand, pointers can be declared and not initialized or initialized with NULL or nullptr.)
  - Once stablished to a variable, a reference cannot be changed to reference another variable. (A pointer can be made to point to a different variable than the one it was initialized with).
  - There is no need to use neither dereferencing operator (*), nor the address operator (&) with references.

DEMO

References. (*Lecture3_C++*).

Variable initialization

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Rule of three

- Initialize variables using the curly brackets {} (C++ uniform initialization): `int a{2};`
- The auto specifier specifies that the type of the variable that is being declared will be automatically deduced from its initializer.
- auto is useful for:
  - avoiding writing long typenames;
  - avoiding repetitions;
  - getting the correct type (and no implicit conversions).

DEMO

References. (*Lecture3_C++*).

Namespaces

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Rule of three

- Namespaces provide a method for grouping items together, for preventing name conflicts and for organizing code.
- A namespace is a declarative region that provides a scope to the identifiers inside it.
- A namespace can contain functions, variables, classes.
- The elements inside a namespace are accesible only by using:
  - the fully qualified name (including the **scope resolution operator ::**).
  - a using directive. This directive **should not** be used in header files!

DEMO

Namespaces. (*Lecture3_C++*).

Ranged-based for loop

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Rule of three

- Is a more readable equivalent for the *for loop*, for iterating a container.

DEMO

Ranged-based for loop. (*Lecture3_C++*).

Object-oriented programming I

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Rule of three

- Allows programmers to think in terms of the structure of the problem.
- The problem is decomposed into a set of objects.
- Objects interact with each other to solve the problem.
- New types of objects are created to model elements from the problem space.
- The objects in the programming sense are designed to be closely related to the real world objects.

Object-oriented programming II

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Operator overloading

Rule of three

- First, the objects must be identified.
- Objects' internals (attributes) and behaviour (actions) must be defined.
- The manner in which the objects interact must be described (functions).
- OOP includes and combines the advantages of modularity and reusability.

Object-oriented programming III

Primary OOP features

- **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.

Real world objects

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Rule of three

- they all have: a *state* (what characterises them) and a *behaviour* (what they can do).

Software objects

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Rule of three

- are conceptually similar to real world objects;
- the *state* - is stored in *fields* (data/attributes);
- the *behaviour* - is exposed through *methods* (functions).

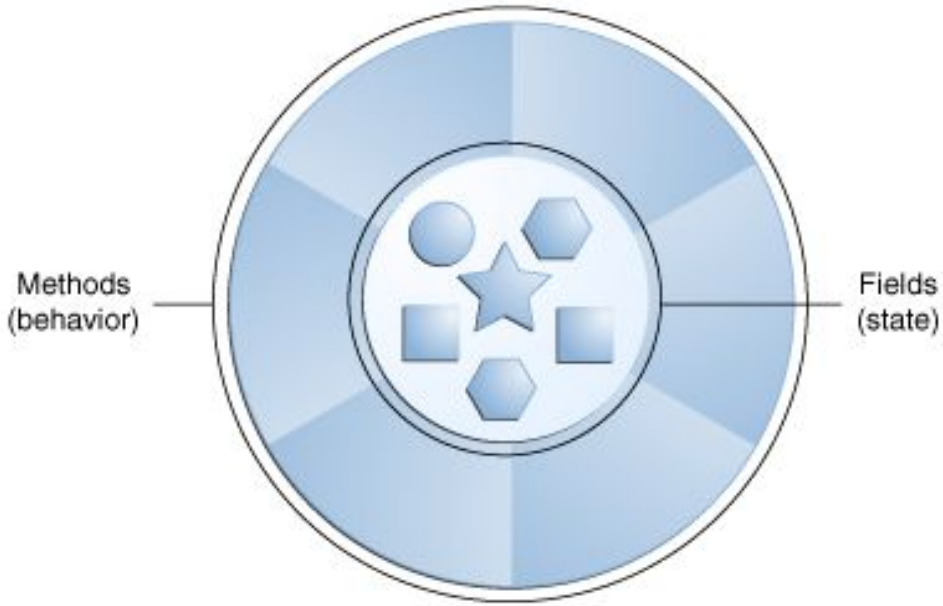

Figure source: https://docs.oracle.com/javase/tutorial/java/concepts/object.html

Classes

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Operator overloading

Rule of three

- Classes enable us to create new types.
- A class:
  - is a user defined data type;
  - is a *template/blueprint* from which individual objects are created;
  - specifies what data and what functions will be included in objects of that type.

Example - Vector in a plane (2D Vector)

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Rule of three

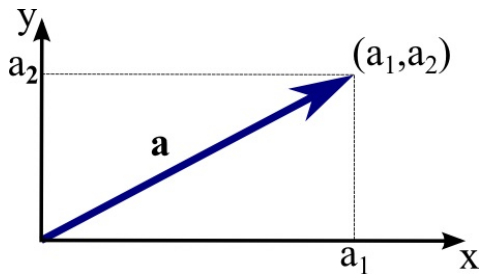

Figure source: http://mathinsight.org/vectors_cartesian_coordinates_2d_3d

- *Characteristics*: **x** and **y** coordinates/components of the 2D vector (data members).
- *Behaviour* (function members/methods):
  - 2D vectors can be added;
  - 2D vectors can be subtracted;
  - 2D vectors can be multiplied by a scalar value;
  - 2D vectors can be rotated;

Class declaration

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Operator overloading

Rule of three

A class is declared in a header file: it will contain fields and function declarations:

```
class Vector2D
{
public:
    double xCoordinate;
    double yCoordinate;

public:
    /*
        Add the given 2D vector to the current 2D vector.
        Input: v - Vector2D
        Output: v is added to the current 2D vector.
    */

    void rotate(double angle);

    /*
        Multiplies the current 2D vector with a scalar value.
        Input: scalarValue - real number
        Output: the current 2D vector is multiplied by the given value.
    */
    void multiplyByScalar(double scalarValue);

    // other methods
};
```

Method definition I

- In a separate cpp file we define the methods declared in the class.
- Use the **scope resolution operator ::** to indicate that the method is part of the class.

```
#include "Vector2D.h"
#include <cmath>

void Vector2D::add(Vector2D v)
{
    xCoordinate += v.xCoordinate;
    yCoordinate += v.yCoordinate;
}

void Vector2D::rotate(double angle)
{
    xCoordinate = xCoordinate * cos(angle) - yCoordinate * sin(angle);
    yCoordinate = xCoordinate * sin(angle) + yCoordinate * cos(angle);
}
```

Method definition II

- Methods can also be defined in the class declaration (header file).
- These are **inline methods**.
- When an inline function is called, the compiler will replace the function call with the actual code from the function.
- Inlining is best suited to short functions.

Access modifiers I

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Rule of three

- Access modifiers define where the classes fields and methods can be accessed from.
- **public** fields/methods can be accessed from anywhere.
- **private** fields/methods can only be accessed within the class (and from friend functions).
- **protected** fields/methods can only be accessed within the class or from child/derived classes.
- The default access mode for classes if **private**.
- **?** Why control access to class members?

Access modifiers II

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Rule of three

- Getters can be used to allow read-only access (from outside the class) to private fields.
- Setters can be used to modify private fields (from outside the class).

```
double getXCoordinate() { return this->xCoordinate; }
double getYCoordinate() { return this->yCoordinate; }
```

- **this** - a pointer to the current instance.
- **this** pointer is implicitly passed to every method, to have a reference to the current instance.
- It is useful if there is a method parameter that has the same name as a class field.
- **?** Why use $this \rightarrow xCoordinate$ instead of $this.xCoordinate$?

The use of **const**

- const can be used to indicate that an object should not be changed;

```
Vector2D(const Vector2D& v);
```

- the **const** restrictions are verified at compile time;
- const can be used in a method to indicate that it is not changing the state of the object; in this case, const is part of the function's signature.
- a *non-const* method cannot be called for a **const** object.

```
double getXCoordinate() const { return this->xCoordinate; }
double getYCoordinate() const { return this->yCoordinate; }
```

DEMO

Const methods. (*Lecture3_demo2*).

Object declaration and initialization I

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Defining classes

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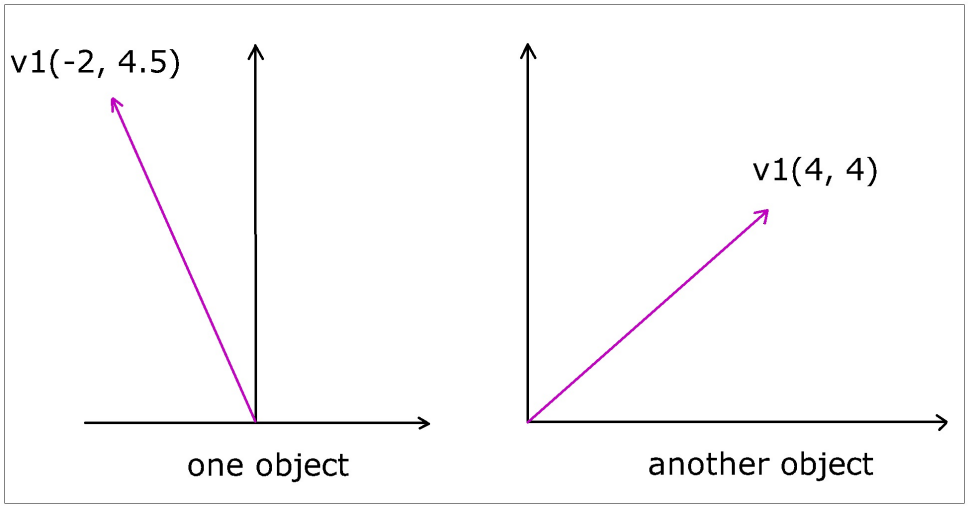
Operator overloading

Rule of three

- The template/blueprint (data type) for 2D vectors is created $\Rightarrow$ objects can be created with this template.
- An **object** is an *instance* of a class, a particular value of the defined type.
- Different instances can have different sets of values in their fields.



Object declaration and initialization II

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Object creation/destruction

Operator overloading

Rule of three

Object declaration

<class_name> <identifier>;

- Memory is allocated to store the object (store every attribute value).
- Object values should be initialized.

DEMO

Class creation and object initialization. (*Lecture3_demo2*).

Initialization - Constructors I

A constructor

- is a special function that is called automatically when an instance of a class is declared;
- does not return anything;
- **must always** have exactly the same name as the class;
- may have 0 or more parameters; a constructor with no parameters is called a **default constructor**.
- is generally public.

Initialization - Constructors II

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Defining classes

Object creation/destruction

Operator overloading

Rule of three

- It is impossible to create an object without a constructor being called.
- A class must have at least one constructor function (if you dont declare one, an implicit constructor is automatically created).

Default constructors I

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Object creation/destruction

Operator overloading

Rule of three

A default constructor

- can be invoked with no arguments;
- has no arguments or
- defaults all its arguments.
- **?** Can a class have more than one default constructor? How?
- A class should have only one default constructor. **?** Why?

DEMO

Default constructors. (*Lecture3_demo2*).

Default constructors II

- When making an array of objects, the default constructor is invoked on each element.
- The compiler automatically generates a default constructor if none is available.
- Defining *any* user defined constructor will prevent the compiler from implicitly declaring a default constructor.

Constructors with parameters

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Classes and objects in C++

Defining classes

Object creation/destruction

Operator overloading

Rule of three

- A class can have multiple constructors (constructors can be overloaded), with different number of parameters and/or parameters of different types.

Member initialization

- insert a colon (:) before the constructor's body and then a list of initializations for class members:

```
Vector2D::Vector2D(double x, double y) : xCoordinate{x}, yCoordinate{y} {}
```

Copy constructors I

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Operator overloading

Rule of three

- Copy constructors are invoked when a copy of the current object is needed:
  - when assigning one class instance to another;
  - when passing object as arguments (pass by value);
  - when returning a value from a function.
- The input parameter must be a (const) reference to an object of the same type.

```
Vector2D(const Vector2D& v);
```

Copy constructors II

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Defining classes

Object creation/destruction

Operator overloading

Rule of three

- The compiler automatically generates a copy constructor if none is defined.
- The automatically generated copy constructor simply copies the contents of the original into the new object (byte by byte copy) $\Rightarrow$ shallow copies for pointer variables.
- **If the class has pointer variables and has some dynamic memory allocations, then one must explicitly create a copy constructor.** Why **?**

DEMO

Copy constructors. (*Lecture3_demo2*).

Destructors I

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Operator overloading

Rule of three

- A destructor is a special member function called when the class instance is deallocated:
  - if the instance was dynamically allocated (with new) - the destructor is called when delete is called.
  - if the instance was statically allocated - the destructor is called when it goes out of scope.
- The destructor must have the same name as the class, prefixed with tilde($\sim$).
- It does not return anything and does not have any parameters.

Destructors II

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Operator overloading

Rule of three

- **If the class has pointer variables and has some dynamic memory allocations, then one must explicitly create a destructor.**

DEMO

Destructors. (*Lecture3_demo2*).

Allocating and deallocating instances

- new - can be used to allocate a class instance on the heap.
- delete - must be used for deallocation.

DEMO

Dynamic allocation and deallocation of objects. (*Lecture3_demo2*).

Constructors and destructors invocation

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Object creation/destruction

Operator overloading

Rule of three

Constructors are invoked:

- when a new stack-allocated variable is declared;
- if we allocate instance using new (on the heap);
- when a copy of the instance is required (copy constructor):
  - assignment;
  - argument passing by value;
  - return an object from a function (by value).

The destructor is invoked:

- when delete is used to deallocate an instance allocated with new;
- when an instance allocated on the stack goes out of scope.

Operator overloading I

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Operator overloading

Rule of three

- The built-in operators available in C++ can be overloaded for user-defined types.
- Operator overloading makes the program easier to write, read and understand.
- It is just another way of calling a function.
- Almost all operators can be overloaded; see http://www.tutorialspoint.com/cplusplus/cpp_overloading.htm for the list of overloadable/non-overloadable operators.

Operator overloading II

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Operator overloading

Rule of three

Definition

- Use the keyword operator followed by the symbol for the operator being defined.
- Like any other function definition, it must have parameters and a return type.

```
/*
    Overloading the + operator to add 2 2D vectors.
    Input: v - Vector2D
    Output: a 2D vector representing the sum of the current 2D vector
        and the parameter v.
*/
Vector2D operator+(const Vector2D& v);

/*
    Overloading the * operator to multiply a 2D vector with a scalar
        value.
    Input: scalarValue - double
    Output: a 2D vector representing the product of the current 2D
        vector and the given scalar value.
*/
Vector2D operator*(double scalarValue);
```

Operator overloading III

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Operator overloading

Rule of three

Using operator overloading

```
Vector2D v3 = v1 + v2;   // <=> Vector2D v3 = v1.operator+(v2);
Vector2D v4 = v1 * 3;    // <=> Vector2D v3 = v1.operator*(3);
```

? Will the following line work? Why/why not?

```
Vector2D v5 = 3 * v1;
```

DEMO

Operator overloading. (*Lecture3_demo3*).

Overloading the assignment operator (=) I

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Operator overloading

Rule of three

- The assignment operator is used to copy the values from one object to another *already existing object*.
- The compiler will generate an assignment operator, if none was defined.
  - Its default behaviour is memberwise assignment.
  - It makes shallow copies.
- **If the class has pointer variables and has some dynamic memory allocations, then one must explicitly create an assignment operator.**

Overloading the assignment operator (=) II

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Rule of three

Return value of the assignment operator

- The return value cannot be void (chain assignment $a = b = c$ would then be impossible).
- It must return a reference to the object that called the operator function.

```
Vector2D& operator=(const Vector2D& v);
```

Copy constructor vs. assignment operator

```
Vector2D v1{ -1, 1 };
Vector2D v2{2, 3};
Vector2D v7 = v1;   // copy constructor is called (a new object is
    created and data is copied into it)
Vector2D v8;
v8 = v2;        // assignment operator is called (the object already
    exists, data is copied into it)
```

Rules for operator overloading

- Overloaded operators must either be a nonstatic class member function or a global function.
- The first argument for member-function overloaded operators is always of the class type of the object for which the operator is invoked.
- Unary operators declared as member functions take no arguments; if declared as global functions, they take one argument.
- Binary operators declared as member functions take one argument; if declared as global functions, they take two arguments.
- Overloaded operators cannot have default arguments.

Source: https://msdn.microsoft.com/en-us/library/4x88tzx0.aspx

Rule of three

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Rule of three

"If a class requires a user-defined destructor, a user-defined copy constructor, or a user-defined copy assignment operator, it almost certainly requires all three." (http://en.cppreference.com/w/cpp/language/rule_of_three)

If a class is responsible to manage a resource (heap memory, file, database connection, etc) we need to define:

- copy constructor;
- assignment operator;
- destructor.

Static elements I

Static data members

- The variables declared as static are characteristic to the class, they do **not** represent object state.
- They are "global" for all objects of the class, shared by all objects.
- The reference to the variable is performed using the class name and the **scope resolution operator (::)**.

DEMO

Static elements. (*Lecture3_demo3*).

Static elements II

Static function members

- A static function member is characteristic to the class, does not depend on individual objects.
- It can be called even if no instances of the class exist.
- A static function can only access other static data members or functions, as well as functions outside the class.
- The static functions **do not** have acces to the **this** pointer.
- Static functions are accessed using the class name and the **scope resolution operator (::)**.

Friend elements I

- Friend functions are used when one wants to allow a function that is not a member of a class to access all private and protected members of the class.
- The prototype of the function must be placed inside the class, preceded by the keyword friend.

```
class Vector2D
{
// ...
public:
    // ...

    // friend function
    friend void printVectorData(const Vector2D& v);
};
```

Friend elements II

- A class can also be a friend of another class: the entire class and all its members are friend of the initial class.

```
class Vector2D
{
// ...
public:
    // ...

    // friend class
    friend class Graphics;
};

class Graphics
{
    // ...
};
```

DEMO

Friend elements. (*Lecture3_demo3*).