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Structure of a program

Probably the best way to start learning a programming language is by writing a program. Therefore, here is our first program:

```
1  // my first program in C++
2
3  #include <iostream>
4  using namespace std;
5
6  int main ()
7  {
8    cout << "Hello World!";
9    return 0;
10 }
```

```
Hello World!
```

The first panel (in light blue) shows the source code for our first program. The second one (in light gray) shows the result of the program once compiled and executed. To the left, the grey numbers represent the line numbers - these are not part of the program, and are shown here merely for informational purposes.

The way to edit and compile a program depends on the compiler you are using. Depending on whether it has a Development Interface or not and on its version. Consult the compilers section and the manual or help included with your compiler if you have doubts on how to compile a C++ console program.

The previous program is the typical program that programmer apprentices write for the first time, and its result is the printing on screen of the "Hello World!" sentence. It is one of the simplest programs that can be written in C++, but it already contains the fundamental components that every C++ program has. We are going to look line by line at the code we have just written:

`// my first program in C++`
: This is a comment line. All lines beginning with two slash signs (`//`) are considered comments and do not have any effect on the behavior of the program. The programmer can use them to include short explanations or observations within the source code itself. In this case, the line is a brief description of what our program is.

`#include <iostream>`
: Lines beginning with a hash sign (#) are directives for the preprocessor. They are not regular code lines with expressions but indications for the compiler's preprocessor. In this case the directive `#include <iostream>` tells the preprocessor to include the iostream standard file. This specific file (iostream) includes the declarations of the basic standard input-output library in C++, and it is included because its functionality is going to be used later in the program.

`using namespace std;`
: All the elements of the standard C++ library are declared within what is called a namespace, the namespace with the name *std*. So in order to access its functionality we declare with this expression that we will be using these entities. This line is very frequent in C++ programs that use the standard library, and in fact it will be included in most of the source codes included in these tutorials.

`int main ()`
: This line corresponds to the beginning of the definition of the main function. The main function is the point by where all C++ programs start their execution, independently of its location within the source code. It does not matter whether there are other functions with other names defined before or after it - the instructions contained within this function's definition will always be the first ones to be executed in any C++ program. For that same reason, it is essential that all C++ programs have a *main* function.

  The word `main` is followed in the code by a pair of parentheses (`()`). That is because it is a function declaration: In C++, what differentiates a function declaration from other types of expressions are these parentheses that follow its name. Optionally, these parentheses may enclose a list of parameters within them.

  Right after these parentheses we can find the body of the main function enclosed in braces (`{}`). What is contained within these braces is what the function does when it is executed.

`cout << "Hello World!";`
: This line is a C++ statement. A statement is a simple or compound expression that can actually produce some effect. In fact, this statement performs the only action that generates a visible effect in our first program.

  `cout` is the name of the standard output stream in C++, and the meaning of the entire statement is to insert a sequence of characters (in this case the `Hello World` sequence of characters) into the standard output stream (*cout*, which usually corresponds to the screen).

cout is declared in the *iostream* standard file within the *std* namespace, so that's why we needed to include that specific file and to declare that we were going to use this specific namespace earlier in our code.

Notice that the statement ends with a semicolon character (`;`). This character is used to mark the end of the statement and in fact it must be included at the end of all expression statements in all C++ programs (one of the most common syntax errors is indeed to forget to include some semicolon after a statement).

`return 0;`

The return statement causes the main function to finish. return may be followed by a return code (in our example is followed by the return code with a value of zero). A return code of *0* for the *main* function is generally interpreted as the program worked as expected without any errors during its execution. This is the most usual way to end a C++ console program.

You may have noticed that not all the lines of this program perform actions when the code is executed. There were lines containing only comments (those beginning by `//`). There were lines with directives for the compiler's preprocessor (those beginning by #). Then there were lines that began the declaration of a function (in this case, the main function) and, finally lines with statements (like the insertion into *cout*), which were all included within the block delimited by the braces (`{}`) of the main function.

The program has been structured in different lines in order to be more readable, but in C++, we do not have strict rules on how to separate instructions in different lines. For example, instead of

```
1 int main ()
2 {
3   cout << " Hello World!";
4   return 0;
5 }
```

We could have written:

```
int main () { cout << "Hello World!"; return 0; }
```

All in just one line and this would have had exactly the same meaning as the previous code.

In C++, the separation between statements is specified with an ending semicolon (`;`) at the end of each one, so the separation in different code lines does not matter at all for this purpose. We can write many statements per line or write a single statement that takes many code lines. The division of code in different lines serves only to make it more legible and schematic for the humans that may read it.

Let us add an additional instruction to our first program:

```
1  // my second program in C++
2
3  #include <iostream>
4
5  using namespace std;
6
7  int main ()
8  {
9    cout << "Hello World! ";
10   cout << "I'm a C++ program";
11   return 0;
12 }
```

```
Hello World! I'm a C++ program
```

In this case, we performed two insertions into cout in two different statements. Once again, the separation in different lines of code has been done just to give greater readability to the program, since *main* could have been perfectly valid defined this way:

```
int main () { cout << " Hello World! "; cout << " I'm a C++ program "; return 0; }
```

We were also free to divide the code into more lines if we considered it more convenient:

```
1 int main ()
2 {
3   cout <<
4     "Hello World!";
5   cout
6     << "I'm a C++ program";
7   return 0;
8 }
```

And the result would again have been exactly the same as in the previous examples.

Preprocessor directives (those that begin by #) are out of this general rule since they are not statements. They are lines read and processed by the preprocessor and do not produce any code by themselves. Preprocessor directives must be specified in their own line and do not have to end with a semicolon (;).

Comments

Comments are parts of the source code disregarded by the compiler. They simply do nothing. Their purpose is only to allow the programmer to insert notes or descriptions embedded within the source code.

C++ supports two ways to insert comments:

```
1 // line comment
2 /* block comment */
```

The first of them, known as line comment, discards everything from where the pair of slash signs (//) is found up to the end of that same line. The second one, known as block comment, discards everything between the /* characters and the first appearance of the */ characters, with the possibility of including more than one line.
We are going to add comments to our second program:

```
1  /* my second program in C++
2     with more comments */
3
4  #include <iostream>
5  using namespace std;
6
7  int main ()
8  {
9    cout << "Hello World! ";     // prints Hello World!
10   cout << "I'm a C++ program"; // prints I'm a C++ program
11   return 0;
12 }
```

```
Hello World! I'm a C++ program
```

If you include comments within the source code of your programs without using the comment characters combinations //, /* or */, the compiler will take them as if they were C++ expressions, most likely causing one or several error messages when you compile it.

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Variables. Data Types.

The usefulness of the *"Hello World"* programs shown in the previous section is quite questionable. We had to write several lines of code, compile them, and then execute the resulting program just to obtain a simple sentence written on the screen as result. It certainly would have been much faster to type the output sentence by ourselves. However, programming is not limited only to printing simple texts on the screen. In order to go a little further on and to become able to write programs that perform useful tasks that really save us work we need to introduce the concept of *variable*.

Let us think that I ask you to retain the number 5 in your mental memory, and then I ask you to memorize also the number 2 at the same time. You have just stored two different values in your memory. Now, if I ask you to add 1 to the first number I said, you should be retaining the numbers 6 (that is 5+1) and 2 in your memory. Values that we could now -for example- subtract and obtain 4 as result.

The whole process that you have just done with your mental memory is a simile of what a computer can do with two variables. The same process can be expressed in C++ with the following instruction set:

```
1 a = 5;
2 b = 2;
3 a = a + 1;
4 result = a - b;
```

Obviously, this is a very simple example since we have only used two small integer values, but consider that your computer can store millions of numbers like these at the same time and conduct sophisticated mathematical operations with them.

Therefore, we can define a *variable* as a portion of memory to store a determined value.

Each variable needs an identifier that distinguishes it from the others. For example, in the previous code the *variable identifiers* were `a`, `b` and `result`, but we could have called the variables any names we wanted to invent, as long as they were valid identifiers.

Identifiers

A *valid identifier* is a sequence of one or more letters, digits or underscore characters (_). Neither spaces nor punctuation marks or symbols can be part of an identifier. Only letters, digits and single underscore characters are valid. In addition, variable identifiers always have to begin with a letter. They can also begin with an underline character (_), but in some cases these may be reserved for compiler specific keywords or external identifiers, as well as identifiers containing two successive underscore characters anywhere. In no case can they begin with a digit.

Another rule that you have to consider when inventing your own identifiers is that they cannot match any keyword of the C++ language nor your compiler's specific ones, which are *reserved keywords*. The standard reserved keywords are:

```
asm, auto, bool, break, case, catch, char, class, const, const_cast, continue, default, delete, do,
double, dynamic_cast, else, enum, explicit, export, extern, false, float, for, friend, goto, if,
inline, int, long, mutable, namespace, new, operator, private, protected, public, register,
reinterpret_cast, return, short, signed, sizeof, static, static_cast, struct, switch, template, this,
throw, true, try, typedef, typeid, typename, union, unsigned, using, virtual, void, volatile,
wchar_t, while
```

Additionally, alternative representations for some operators cannot be used as identifiers since they are reserved words under some circumstances:

```
and, and_eq, bitand, bitor, compl, not, not_eq, or, or_eq, xor, xor_eq
```

Your compiler may also include some additional specific reserved keywords.

Very important: The C++ language is a *"case sensitive"* language. That means that an identifier written in capital letters is not equivalent to another one with the same name but written in small letters. Thus, for example, the `RESULT` variable is not the same as the `result` variable or the `Result` variable. These are three different variable identifiers.

Fundamental data types

When programming, we store the variables in our computer's memory, but the computer has to know what kind of data we want to store in them, since it is not going to occupy the same amount of memory to store a simple number than to store a single letter or a large number, and they are not going to be interpreted the same way.

The memory in our computers is organized in bytes. A byte is the minimum amount of memory that we can manage in C++. A byte can store a relatively small amount of data: one single character or a small integer (generally an integer between 0 and 255). In addition, the computer can manipulate more complex data types that come from grouping several bytes, such as long numbers or non-integer numbers.

Next you have a summary of the basic fundamental data types in C++, as well as the range of values that can be represented with each one:

Name	Description	Size*	Range*
`char`	Character or small integer.	1byte	signed: -128 to 127 unsigned: 0 to 255
`short int` (`short`)	Short Integer.	2bytes	signed: -32768 to 32767 unsigned: 0 to 65535
`int`	Integer.	4bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
`long int` (`long`)	Long integer.	4bytes	signed: -2147483648 to 2147483647 unsigned: 0 to 4294967295
`bool`	Boolean value. It can take one of two values: true or false.	1byte	`true` or `false`
`float`	Floating point number.	4bytes	+/- 3.4e +/- 38 (~7 digits)
`double`	Double precision floating point number.	8bytes	+/- 1.7e +/- 308 (~15 digits)
`long double`	Long double precision floating point number.	8bytes	+/- 1.7e +/- 308 (~15 digits)
`wchar_t`	Wide character.	2 *or* 4 bytes	1 wide character

* The values of the columns *Size* and *Range* depend on the system the program is compiled for. The values shown above are those found on most 32-bit systems. But for other systems, the general specification is that `int` has the natural size suggested by the system architecture (one *"word"*) and the four integer types `char`, `short`, `int` and `long` must each one be at least as large as the one preceding it, with `char` being always one byte in size. The same applies to the floating point types `float`, `double` and `long double`, where each one must provide at least as much precision as the preceding one.

Declaration of variables

In order to use a variable in C++, we must first declare it specifying which data type we want it to be. The syntax to declare a new variable is to write the specifier of the desired data type (like int, bool, float...) followed by a valid variable identifier. For example:

```
1 int a;
2 float mynumber;
```

These are two valid declarations of variables. The first one declares a variable of type *int* with the identifier *a*. The second one declares a variable of type *float* with the identifier *mynumber*. Once declared, the variables *a* and *mynumber* can be used within the rest of their scope in the program.

If you are going to declare more than one variable of the same type, you can declare all of them in a single statement by separating their identifiers with commas. For example:

```
int a, b, c;
```

This declares three variables (*a*, *b* and *c*), all of them of type *int*, and has exactly the same meaning as:

```
1 int a;
2 int b;
3 int c;
```

The integer data types *char*, *short*, *long* and *int* can be either signed or unsigned depending on the range of numbers needed to be represented. Signed types can represent both positive and negative values, whereas unsigned types can only represent positive values (and zero). This can be specified by using either the specifier *signed* or the specifier *unsigned* before the type name. For example:

```
1 unsigned short int NumberOfSisters;
2 signed int MyAccountBalance;
```

By default, if we do not specify either *signed* or *unsigned* most compiler settings will assume the type to be signed, therefore instead of the second declaration above we could have written:

```
int MyAccountBalance;
```

with exactly the same meaning (with or without the keyword `signed`)

An exception to this general rule is the *char* type, which exists by itself and is considered a different fundamental data type from *signed char* and *unsigned char*, thought to store characters. You should use either `signed` or `unsigned` if you intend to store numerical values in a *char*-sized variable.

`short` and `long` can be used alone as type specifiers. In this case, they refer to their respective integer fundamental types: `short` is equivalent to `short int` and `long` is equivalent to `long int`. The following two variable declarations are equivalent:

```
short Year;
short int Year;
```

Finally, `signed` and `unsigned` may also be used as standalone type specifiers, meaning the same as `signed int` and `unsigned int` respectively. The following two declarations are equivalent:

```
unsigned NextYear;
unsigned int NextYear;
```

To see what variable declarations look like in action within a program, we are going to see the C++ code of the example about your mental memory proposed at the beginning of this section:

```
// operating with variables

#include <iostream>
using namespace std;

int main ()
{
  // declaring variables:
  int a, b;
  int result;

  // process:
  a = 5;
  b = 2;
  a = a + 1;
  result = a - b;

  // print out the result:
  cout << result;

  // terminate the program:
  return 0;
}
```

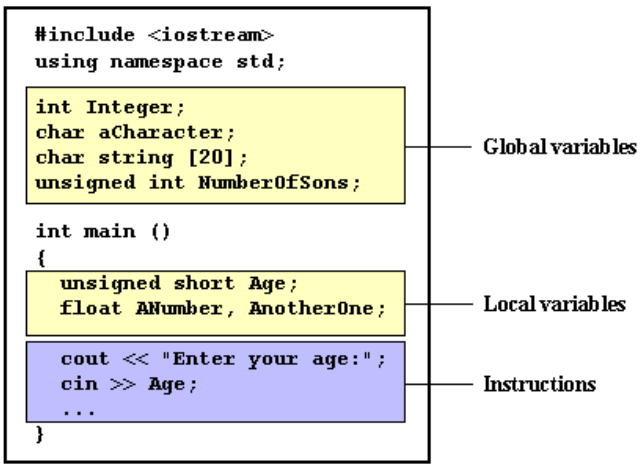
```
4
```

Do not worry if something else than the variable declarations themselves looks a bit strange to you. You will see the rest in detail in coming sections.

Scope of variables

All the variables that we intend to use in a program must have been declared with its type specifier in an earlier point in the code, like we did in the previous code at the beginning of the body of the function main when we declared that *a*, *b*, and *result* were of type *int*.

A variable can be either of global or local scope. A global variable is a variable declared in the main body of the source code, outside all functions, while a local variable is one declared within the body of a function or a block.



Global variables can be referred from anywhere in the code, even inside functions, whenever it is after its declaration.

The scope of local variables is limited to the block enclosed in braces ({}) where they are declared. For example, if they are declared at the beginning of the body of a function (like in function *main*) their scope is between its declaration point and the end of that function. In the example above, this means that if another function existed in addition to *main*, the local variables declared in *main* could not be accessed from the other function and vice versa.

Initialization of variables

When declaring a regular local variable, its value is by default undetermined. But you may want a variable to store a concrete value at the same moment that it is declared. In order to do that, you can initialize the variable. There are two ways to do this in C++:

The first one, known as *c-like initialization*, is done by appending an equal sign followed by the value to which the variable will be initialized:

```
type identifier = initial_value ;
```

For example, if we want to declare an *int* variable called *a* initialized with a value of 0 at the moment in which it is declared, we could write:

```
int a = 0;
```

The other way to initialize variables, known as *constructor initialization*, is done by enclosing the initial value between parentheses (()):

```
type identifier (initial_value) ;
```

For example:

```
int a (0);
```

Both ways of initializing variables are valid and equivalent in C++.

```
1  // initialization of variables
2
3  #include <iostream>
4  using namespace std;
5
6  int main ()
7  {
8    int a=5;               // initial value = 5
9    int b(2);              // initial value = 2
10   int result;            // initial value undetermined
11
12   a = a + 3;
13   result = a - b;
14   cout << result;
15
16   return 0;
17 }
```

```
6
```

Introduction to strings

Variables that can store non-numerical values that are longer than one single character are known as strings.

The C++ language library provides support for strings through the standard `string` class. This is not a fundamental type, but it behaves in a similar way as fundamental types do in its most basic usage.

A first difference with fundamental data types is that in order to declare and use objects (variables) of this type we need to include an additional header file in our source code: `<string>` and have access to the `std` namespace (which we already had in all our previous programs thanks to the `using namespace` statement).

```
// my first string
#include <iostream>
#include <string>
using namespace std;

int main ()
{
  string mystring = "This is a string";
  cout << mystring;
  return 0;
}
```

```
This is a string
```

As you may see in the previous example, strings can be initialized with any valid string literal just like numerical type variables can be initialized to any valid numerical literal. Both initialization formats are valid with strings:

```
string mystring = "This is a string";
string mystring ("This is a string");
```

Strings can also perform all the other basic operations that fundamental data types can, like being declared without an initial value and being assigned values during execution:

```
// my first string
#include <iostream>
#include <string>
using namespace std;

int main ()
{
  string mystring;
  mystring = "This is the initial string content";
  cout << mystring << endl;
  mystring = "This is a different string content";
  cout << mystring << endl;
  return 0;
}

```

```
This is the initial string content
This is a different string content
```

For more details on C++ strings, you can have a look at the string class reference.

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Control Structures

A program is usually not limited to a linear sequence of instructions. During its process it may bifurcate, repeat code or take decisions. For that purpose, C++ provides control structures that serve to specify what has to be done by our program, when and under which circumstances.

With the introduction of control structures we are going to have to introduce a new concept: the *compound-statement* or *block*. A block is a group of statements which are separated by semicolons (;) like all C++ statements, but grouped together in a block enclosed in braces: `{ }`:

```
{ statement1; statement2; statement3; }
```

Most of the control structures that we will see in this section require a generic statement as part of its syntax. A statement can be either a simple statement (a simple instruction ending with a semicolon) or a compound statement (several instructions grouped in a block), like the one just described. In the case that we want the statement to be a simple statement, we do not need to enclose it in braces (`{}`). But in the case that we want the statement to be a compound statement it must be enclosed between braces (`{}`), forming a block.

Conditional structure: if and else

The `if` keyword is used to execute a statement or block only if a condition is fulfilled. Its form is:

```
if (condition) statement
```

Where `condition` is the expression that is being evaluated. If this condition is true, `statement` is executed. If it is false, `statement` is ignored (not executed) and the program continues right after this conditional structure.
For example, the following code fragment prints `x is 100` only if the value stored in the `x` variable is indeed `100`:

```
1 if (x == 100)
2   cout << "x is 100";
```

If we want more than a single statement to be executed in case that the condition is true we can specify a block using braces `{ }`:

```
1 if (x == 100)
2 {
3    cout << "x is ";
4    cout << x;
5 }
```

We can additionally specify what we want to happen if the condition is not fulfilled by using the keyword `else`. Its form used in conjunction with `if` is:

```
if (condition) statement1 else statement2
```

For example:

```
1 if (x == 100)
2   cout << "x is 100";
3 else
4   cout << "x is not 100";
```

prints on the screen `x is 100` if indeed `x` has a value of `100`, but if it has not -and only if not- it prints out `x is not 100`.

The `if + else` structures can be concatenated with the intention of verifying a range of values. The following example shows its use telling if the value currently stored in `x` is positive, negative or none of them (i.e. zero):

```
1 if (x > 0)
2   cout << "x is positive";
3 else if (x < 0)
```

```
  cout << "x is negative";
else
  cout << "x is 0";
```

Remember that in case that we want more than a single statement to be executed, we must group them in a block by enclosing them in braces `{ }`.

Iteration structures (loops)

Loops have as purpose to repeat a statement a certain number of times or while a condition is fulfilled.

The while loop

Its format is:

```
while (expression) statement
```

and its functionality is simply to repeat statement while the condition set in expression is true.
For example, we are going to make a program to countdown using a while-loop:

```
// custom countdown using while

#include <iostream>
using namespace std;

int main ()
{
  int n;
  cout << "Enter the starting number > ";
  cin >> n;

  while (n>0) {
    cout << n << ", ";
    --n;
  }

  cout << "FIRE!\n";
  return 0;
}
```

```
Enter the starting number > 8
8, 7, 6, 5, 4, 3, 2, 1, FIRE!
```

When the program starts the user is prompted to insert a starting number for the countdown. Then the `while` loop begins, if the value entered by the user fulfills the condition `n>0` (that `n` is greater than zero) the block that follows the condition will be executed and repeated while the condition (`n>0`) remains being true.

The whole process of the previous program can be interpreted according to the following script (beginning in main):

1. User assigns a value to `n`
2. The while condition is checked (`n>0`). At this point there are two possibilities:
   * condition is true: statement is executed (to step 3)
   * condition is false: ignore statement and continue after it (to step 5)
3. Execute statement:
   `cout << n << ", ";`
   `--n;`
   (prints the value of `n` on the screen and decreases `n` by `1`)
4. End of block. Return automatically to step 2
5. Continue the program right after the block: print FIRE! and end program.

When creating a while-loop, we must always consider that it has to end at some point, therefore we must provide within the block some method to force the condition to become false at some point, otherwise the loop will continue looping forever. In this case we have included `--n;` that decreases the value of the variable that is being evaluated in the condition (`n`) by one - this will eventually make the condition (`n>0`) to become false after a certain number of loop iterations: to be more specific, when `n` becomes `0`, that is where our while-loop and our countdown end.

Of course this is such a simple action for our computer that the whole countdown is performed instantly without any practical delay between numbers.

The do-while loop

Its format is:

```
do statement while (condition);
```

Its functionality is exactly the same as the while loop, except that `condition` in the do-while loop is evaluated after the execution of statement instead of before, granting at least one execution of `statement` even if `condition` is never fulfilled. For example, the following example program echoes any number you enter until you enter `0`.

```
// number echoer

#include <iostream>
using namespace std;

int main ()
{
  unsigned long n;
  do {
    cout << "Enter number (0 to end): ";
    cin >> n;
    cout << "You entered: " << n << "\n";
  } while (n != 0);
  return 0;
}
```

```
Enter number (0 to end): 12345
You entered: 12345
Enter number (0 to end): 160277
You entered: 160277
Enter number (0 to end): 0
You entered: 0
```

The do-while loop is usually used when the condition that has to determine the end of the loop is determined **within** the loop statement itself, like in the previous case, where the user input within the block is what is used to determine if the loop has to end. In fact if you never enter the value `0` in the previous example you can be prompted for more numbers forever.

The for loop

Its format is:

```
for (initialization; condition; increase) statement;
```

and its main function is to repeat `statement` while `condition` remains true, like the while loop. But in addition, the `for` loop provides specific locations to contain an `initialization` statement and an `increase` statement. So this loop is specially designed to perform a repetitive action with a counter which is initialized and increased on each iteration.

It works in the following way:

1. `initialization` is executed. Generally it is an initial value setting for a counter variable. This is executed only once.
2. `condition` is checked. If it is true the loop continues, otherwise the loop ends and `statement` is skipped (not executed).
3. `statement` is executed. As usual, it can be either a single statement or a block enclosed in braces `{ }`.
4. finally, whatever is specified in the `increase` field is executed and the loop gets back to step 2.

Here is an example of countdown using a for loop:

```
// countdown using a for loop
#include <iostream>
using namespace std;
int main ()
{
  for (int n=10; n>0; n--) {
    cout << n << ", ";
  }
  cout << "FIRE!\n";
  return 0;
}
```

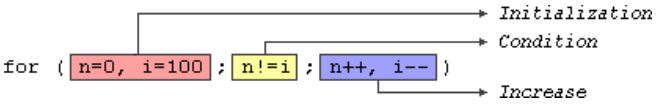
```
10, 9, 8, 7, 6, 5, 4, 3, 2, 1, FIRE!
```

The `initialization` and `increase` fields are optional. They can remain empty, but in all cases the semicolon signs between them must be written. For example we could write: `for (;n<10;)` if we wanted to specify no initialization and no increase; or `for (;n<10;n++)` if we wanted to include an increase field but no initialization (maybe because the variable was already initialized before).

Optionally, using the comma operator (`,`) we can specify more than one expression in any of the fields included in a `for` loop, like in `initialization`, for example. The comma operator (`,`) is an expression separator, it serves to separate more than one expression where only one is generally expected. For example, suppose that we wanted to initialize more than one variable in our loop:

```
for ( n=0, i=100 ; n!=i ; n++, i-- )
{
   // whatever here...
}
```

This loop will execute for 50 times if neither n or i are modified within the loop:



n starts with a value of 0, and i with 100, the condition is n!=i (that n is not equal to i). Because n is increased by one and i decreased by one, the loop's condition will become false after the 50th loop, when both n and i will be equal to 50.

Jump statements.

The break statement

Using break we can leave a loop even if the condition for its end is not fulfilled. It can be used to end an infinite loop, or to force it to end before its natural end. For example, we are going to stop the count down before its natural end (maybe because of an engine check failure?):

```
1  // break loop example
2
3  #include <iostream>
4  using namespace std;
5
6  int main ()
7  {
8    int n;
9    for (n=10; n>0; n--)
10   {
11     cout << n << ", ";
12     if (n==3)
13     {
14       cout << "countdown aborted!";
15       break;
16     }
17   }
18   return 0;
19 }
```

```
10, 9, 8, 7, 6, 5, 4, 3, countdown aborted!
```

The continue statement

The continue statement causes the program to skip the rest of the loop in the current iteration as if the end of the statement block had been reached, causing it to jump to the start of the following iteration. For example, we are going to skip the number 5 in our countdown:

```
1  // continue loop example
2  #include <iostream>
3  using namespace std;
4
5  int main ()
6  {
7    for (int n=10; n>0; n--) {
8      if (n==5) continue;
9      cout << n << ", ";
10   }
11   cout << "FIRE!\n";
12   return 0;
13 }
```

```
10, 9, 8, 7, 6, 4, 3, 2, 1, FIRE!
```

The goto statement

goto allows to make an absolute jump to another point in the program. You should use this feature with caution since its execution causes an unconditional jump ignoring any type of nesting limitations.
The destination point is identified by a label, which is then used as an argument for the goto statement. A label is made of a valid identifier followed by a colon (:).

Generally speaking, this instruction has no concrete use in structured or object oriented programming aside from those that low-level programming fans may find for it. For example, here is our countdown loop using goto:

```
1  // goto loop example
2
3  #include <iostream>
4  using namespace std;
5
```

```
10, 9, 8, 7, 6, 5, 4, 3, 2, 1, FIRE!
```

```
6  int main ()
7  {
8    int n=10;
9    loop:
10   cout << n << ", ";
11   n--;
12   if (n>0) goto loop;
13   cout << "FIRE!\n";
14   return 0;
15 }
```

The exit function

`exit` is a function defined in the `cstdlib` library.

The purpose of `exit` is to terminate the current program with a specific exit code. Its prototype is:

```
void exit (int exitcode);
```

The `exitcode` is used by some operating systems and may be used by calling programs. By convention, an exit code of `0` means that the program finished normally and any other value means that some error or unexpected results happened.

The selective structure: switch.

The syntax of the switch statement is a bit peculiar. Its objective is to check several possible constant values for an expression. Something similar to what we did at the beginning of this section with the concatenation of several `if` and `else if` instructions. Its form is the following:

```
switch (expression)
{
  case constant1:
     group of statements 1;
     break;
  case constant2:
     group of statements 2;
     break;
  .
  .
  .
  default:
     default group of statements
}
```

It works in the following way: switch evaluates `expression` and checks if it is equivalent to `constant1`, if it is, it executes `group of statements 1` until it finds the `break` statement. When it finds this `break` statement the program jumps to the end of the `switch` selective structure.

If expression was not equal to `constant1` it will be checked against `constant2`. If it is equal to this, it will execute `group of statements 2` until a break keyword is found, and then will jump to the end of the `switch` selective structure.

Finally, if the value of `expression` did not match any of the previously specified constants (you can include as many `case` labels as values you want to check), the program will execute the statements included after the `default:` label, if it exists (since it is optional).

Both of the following code fragments have the same behavior:

switch example	if-else equivalent

`switch (x) {`
`  case 1:`
`  cout << "x is 1";`
`  break;`
`  case 2:`
`  cout << "x is 2";`
`  break;`
`  default:`
`  cout << "value of x unknown";`
`  }`
	`if (x == 1) {`
	`  cout << "x is 1";`
	`  }`
	`else if (x == 2) {`
	`  cout << "x is 2";`
	`  }`
	`else {`
	`  cout << "value of x unknown";`
	`  }`

The `switch` statement is a bit peculiar within the C++ language because it uses labels instead of blocks. This forces us to put `break` statements after the group of statements that we want to be executed for a specific condition. Otherwise the remainder statements -including those corresponding to other labels- will also be executed until the end of the `switch` selective block or a `break` statement is reached.

For example, if we did not include a `break` statement after the first group for case one, the program will not automatically jump to the end of the `switch` selective block and it would continue executing the rest of statements until it reaches either a `break` instruction or the end of the `switch` selective block. This makes it unnecessary to include braces `{ }` surrounding the statements for each of the cases, and it can also be useful to execute the same block of instructions for different possible values for the expression being evaluated. For example:

```
switch (x) {
  case 1:
  case 2:
  case 3:
    cout << "x is 1, 2 or 3";
    break;
  default:
    cout << "x is not 1, 2 nor 3";
  }
```

Notice that switch can only be used to compare an expression against constants. Therefore we cannot put variables as labels (for example `case n:` where `n` is a variable) or ranges (`case (1..3):`) because they are not valid C++ constants.

If you need to check ranges or values that are not constants, use a concatenation of `if` and `else if` statements.

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Classes (I)

A *class* is an expanded concept of a data structure: instead of holding only data, it can hold both data and functions.

An *object* is an instantiation of a class. In terms of variables, a class would be the type, and an object would be the variable.

Classes are generally declared using the keyword `class`, with the following format:

```
class class_name {
  access_specifier_1:
    member1;
  access_specifier_2:
    member2;
  ...
  } object_names;
```

Where `class_name` is a valid identifier for the class, `object_names` is an optional list of names for objects of this class. The body of the declaration can contain members, that can be either data or function declarations, and optionally access specifiers.

All is very similar to the declaration on data structures, except that we can now include also functions and members, but also this new thing called *access specifier*. An access specifier is one of the following three keywords: `private`, `public` or `protected`. These specifiers modify the access rights that the members following them acquire:

- `private` members of a class are accessible only from within other members of the same class or from their *friends*.
- `protected` members are accessible from members of their same class and from their friends, but also from members of their derived classes.
- Finally, `public` members are accessible from anywhere where the object is visible.

By default, all members of a class declared with the `class` keyword have private access for all its members. Therefore, any member that is declared before one other class specifier automatically has private access. For example:

```
1 class CRectangle {
2     int x, y;
3   public:
4     void set_values (int,int);
5     int area (void);
6   } rect;
```

Declares a class (i.e., a type) called `CRectangle` and an object (i.e., a variable) of this class called `rect`. This class contains four members: two data members of type `int` (member `x` and member `y`) with private access (because private is the default access level) and two member functions with public access: `set_values()` and `area()`, of which for now we have only included their declaration, not their definition.

Notice the difference between the class name and the object name: In the previous example, `CRectangle` was the class name (i.e., the type), whereas `rect` was an object of type `CRectangle`. It is the same relationship `int` and `a` have in the following declaration:

```
int a;
```

where `int` is the type name (the class) and `a` is the variable name (the object).

After the previous declarations of `CRectangle` and `rect`, we can refer within the body of the program to any of the public members of the object `rect` as if they were normal functions or normal variables, just by putting the object's name followed by a dot (`.`) and then the name of the member. All very similar to what we did with plain data structures before. For example:

```
1 rect.set_values (3,4);
2 myarea = rect.area();
```

The only members of rect that we cannot access from the body of our program outside the class are `x` and `y`, since they have private access and they can only be referred from within other members of that same class.

Here is the complete example of class CRectangle:

```
// classes example
#include <iostream>
using namespace std;

class CRectangle {
    int x, y;
  public:
    void set_values (int,int);
    int area () {return (x*y);}
};

void CRectangle::set_values (int a, int b) {
  x = a;
  y = b;
}

int main () {
  CRectangle rect;
  rect.set_values (3,4);
  cout << "area: " << rect.area();
  return 0;
}
```

```
area: 12
```

The most important new thing in this code is the operator of scope (`::`, two colons) included in the definition of `set_values()`. It is used to define a member of a class from outside the class definition itself.

You may notice that the definition of the member function `area()` has been included directly within the definition of the `CRectangle` class given its extreme simplicity, whereas `set_values()` has only its prototype declared within the class, but its definition is outside it. In this outside definition, we must use the operator of scope (`::`) to specify that we are defining a function that is a member of the class `CRectangle` and not a regular global function.

The scope operator (`::`) specifies the class to which the member being declared belongs, granting exactly the same scope properties as if this function definition was directly included within the class definition. For example, in the function `set_values()` of the previous code, we have been able to use the variables `x` and `y`, which are private members of class `CRectangle`, which means they are only accessible from other members of their class.

The only difference between defining a class member function completely within its class or to include only the prototype and later its definition, is that in the first case the function will automatically be considered an inline member function by the compiler, while in the second it will be a normal (not-inline) class member function, which in fact supposes no difference in behavior.

Members `x` and `y` have private access (remember that if nothing else is said, all members of a class defined with keyword class have private access). By declaring them private we deny access to them from anywhere outside the class. This makes sense, since we have already defined a member function to set values for those members within the object: the member function `set_values()`. Therefore, the rest of the program does not need to have direct access to them. Perhaps in a so simple example as this, it is difficult to see any utility in protecting those two variables, but in greater projects it may be very important that values cannot be modified in an unexpected way (unexpected from the point of view of the object).

One of the greater advantages of a class is that, as any other type, we can declare several objects of it. For example, following with the previous example of class `CRectangle`, we could have declared the object `rectb` in addition to the object `rect`:

```
// example: one class, two objects
#include <iostream>
using namespace std;

class CRectangle {
    int x, y;
  public:
    void set_values (int,int);
    int area () {return (x*y);}
};

void CRectangle::set_values (int a, int b) {
  x = a;
  y = b;
}

int main () {
  CRectangle rect, rectb;
```

```
rect area: 12
rectb area: 30
```

```
  rect.set_values (3,4);
  rectb.set_values (5,6);
  cout << "rect area: " << rect.area() << endl;
  cout << "rectb area: " << rectb.area() << endl;
  return 0;
}
```

In this concrete case, the class (type of the objects) to which we are talking about is `CRectangle`, of which there are two instances or objects: `rect` and `rectb`. Each one of them has its own member variables and member functions.

Notice that the call to `rect.area()` does not give the same result as the call to `rectb.area()`. This is because each object of class CRectangle has its own variables `x` and `y`, as they, in some way, have also their own function members `set_value()` and `area()` that each uses its object's own variables to operate.

That is the basic concept of *object-oriented programming*: Data and functions are both members of the object. We no longer use sets of global variables that we pass from one function to another as parameters, but instead we handle objects that have their own data and functions embedded as members. Notice that we have not had to give any parameters in any of the calls to `rect.area` or `rectb.area`. Those member functions directly used the data members of their respective objects `rect` and `rectb`.

Constructors and destructors

Objects generally need to initialize variables or assign dynamic memory during their process of creation to become operative and to avoid returning unexpected values during their execution. For example, what would happen if in the previous example we called the member function `area()` before having called function `set_values()`? Probably we would have gotten an undetermined result since the members `x` and `y` would have never been assigned a value.

In order to avoid that, a class can include a special function called `constructor`, which is automatically called whenever a new object of this class is created. This constructor function must have the same name as the class, and cannot have any return type; not even `void`.

We are going to implement `CRectangle` including a constructor:

```
// example: class constructor
#include <iostream>
using namespace std;

class CRectangle {
    int width, height;
  public:
    CRectangle (int,int);
    int area () {return (width*height);}
};

CRectangle::CRectangle (int a, int b) {
  width = a;
  height = b;
}

int main () {
  CRectangle rect (3,4);
  CRectangle rectb (5,6);
  cout << "rect area: " << rect.area() << endl;
  cout << "rectb area: " << rectb.area() << endl;
  return 0;
}
```

```
rect area: 12
rectb area: 30
```

As you can see, the result of this example is identical to the previous one. But now we have removed the member function `set_values()`, and have included instead a constructor that performs a similar action: it initializes the values of `width` and `height` with the parameters that are passed to it.

Notice how these arguments are passed to the constructor at the moment at which the objects of this class are created:

```
CRectangle rect (3,4);
CRectangle rectb (5,6);
```

Constructors cannot be called explicitly as if they were regular member functions. They are only executed when a new object of that class is created.

You can also see how neither the constructor prototype declaration (within the class) nor the latter constructor definition include a return value; not even `void`.

The *destructor* fulfills the opposite functionality. It is automatically called when an object is destroyed, either because

its scope of existence has finished (for example, if it was defined as a local object within a function and the function ends) or because it is an object dynamically assigned and it is released using the operator delete.

The destructor must have the same name as the class, but preceded with a tilde sign (~) and it must also return no value.

The use of destructors is especially suitable when an object assigns dynamic memory during its lifetime and at the moment of being destroyed we want to release the memory that the object was allocated.

```
// example on constructors and destructors
#include <iostream>
using namespace std;

class CRectangle {
    int *width, *height;
  public:
    CRectangle (int,int);
    ~CRectangle ();
    int area () {return (*width * *height);}
};

CRectangle::CRectangle (int a, int b) {
  width = new int;
  height = new int;
  *width = a;
  *height = b;
}

CRectangle::~CRectangle () {
  delete width;
  delete height;
}

int main () {
  CRectangle rect (3,4), rectb (5,6);
  cout << "rect area: " << rect.area() << endl;
  cout << "rectb area: " << rectb.area() << endl;
  return 0;
}
```

```
rect area: 12
rectb area: 30
```

Overloading Constructors

Like any other function, a constructor can also be overloaded with more than one function that have the same name but different types or number of parameters. Remember that for overloaded functions the compiler will call the one whose parameters match the arguments used in the function call. In the case of constructors, which are automatically called when an object is created, the one executed is the one that matches the arguments passed on the object declaration:

```
// overloading class constructors
#include <iostream>
using namespace std;

class CRectangle {
    int width, height;
  public:
    CRectangle ();
    CRectangle (int,int);
    int area (void) {return (width*height);}
};

CRectangle::CRectangle () {
  width = 5;
  height = 5;
}

CRectangle::CRectangle (int a, int b) {
  width = a;
  height = b;
}

int main () {
  CRectangle rect (3,4);
  CRectangle rectb;
  cout << "rect area: " << rect.area() << endl;
  cout << "rectb area: " << rectb.area() << endl;
  return 0;
}
```

```
rect area: 12
rectb area: 25
```

In this case, `rectb` was declared without any arguments, so it has been initialized with the constructor that has no parameters, which initializes both `width` and `height` with a value of 5.

Important: Notice how if we declare a new object and we want to use its default constructor (the one without parameters), we do not include parentheses `()`:

```
CRectangle rectb;   // right
CRectangle rectb(); // wrong!
```

Default constructor

If you do not declare any constructors in a class definition, the compiler assumes the class to have a default constructor with no arguments. Therefore, after declaring a class like this one:

```
class CExample {
  public:
    int a,b,c;
    void multiply (int n, int m) { a=n; b=m; c=a*b; }
  };
```

The compiler assumes that `CExample` has a default constructor, so you can declare objects of this class by simply declaring them without any arguments:

```
CExample ex;
```

But as soon as you declare your own constructor for a class, the compiler no longer provides an implicit default constructor. So you have to declare all objects of that class according to the constructor prototypes you defined for the class:

```
class CExample {
  public:
    int a,b,c;
    CExample (int n, int m) { a=n; b=m; };
    void multiply () { c=a*b; };
  };
```

Here we have declared a constructor that takes two parameters of type int. Therefore the following object declaration would be correct:

```
CExample ex (2,3);
```

But,

```
CExample ex;
```

Would **not** be correct, since we have declared the class to have an explicit constructor, thus replacing the default constructor.

But the compiler not only creates a default constructor for you if you do not specify your own. It provides three special member functions in total that are implicitly declared if you do not declare your own. These are the *copy constructor*, the *copy assignment operator*, and the default destructor.

The copy constructor and the copy assignment operator copy all the data contained in another object to the data members of the current object. For `CExample`, the copy constructor implicitly declared by the compiler would be something similar to:

```
CExample::CExample (const CExample& rv) {
  a=rv.a;  b=rv.b;  c=rv.c;
  }
```

Therefore, the two following object declarations would be correct:

```
CExample ex (2,3);
CExample ex2 (ex);   // copy constructor (data copied from ex)
```

Pointers to classes

It is perfectly valid to create pointers that point to classes. We simply have to consider that once declared, a class

becomes a valid type, so we can use the class name as the type for the pointer. For example:

```
CRectangle * prect;
```

is a pointer to an object of class `CRectangle`.

As it happened with data structures, in order to refer directly to a member of an object pointed by a pointer we can use the arrow operator (`->`) of indirection. Here is an example with some possible combinations:

```
// pointer to classes example
#include <iostream>
using namespace std;

class CRectangle {
    int width, height;
  public:
    void set_values (int, int);
    int area (void) {return (width * height);}
};

void CRectangle::set_values (int a, int b) {
  width = a;
  height = b;
}

int main () {
  CRectangle a, *b, *c;
  CRectangle * d = new CRectangle[2];
  b= new CRectangle;
  c= &a;
  a.set_values (1,2);
  b->set_values (3,4);
  d->set_values (5,6);
  d[1].set_values (7,8);
  cout << "a area: " << a.area() << endl;
  cout << "*b area: " << b->area() << endl;
  cout << "*c area: " << c->area() << endl;
  cout << "d[0] area: " << d[0].area() << endl;
  cout << "d[1] area: " << d[1].area() << endl;
  delete[] d;
  delete b;
  return 0;
}
```

```
a area: 2
*b area: 12
*c area: 2
d[0] area: 30
d[1] area: 56
```

Next you have a summary on how can you read some pointer and class operators (`*`, `&`, `.`, `->`, `[ ]`) that appear in the previous example:

expression	can be read as
*x	pointed by x
&x	address of x
x.y	member y of object x
x->y	member y of object pointed by x
(*x).y	member y of object pointed by x (equivalent to the previous one)
x[0]	first object pointed by x
x[1]	second object pointed by x
x[n]	(n+1)th object pointed by x

Be sure that you understand the logic under all of these expressions before proceeding with the next sections. If you have doubts, read again this section and/or consult the previous sections about pointers and data structures.

Classes defined with struct and union

Classes can be defined not only with keyword `class`, but also with keywords `struct` and `union`.

The concepts of class and data structure are so similar that both keywords (`struct` and `class`) can be used in C++ to declare classes (i.e. `struct`s can also have function members in C++, not only data members). The only difference between both is that members of classes declared with the keyword `struct` have public access by default, while members of classes declared with the keyword `class` have private access. For all other purposes both keywords are equivalent.

The concept of unions is different from that of classes declared with `struct` and `class`, since unions only store one data member at a time, but nevertheless they are also classes and can thus also hold function members. The default access in union classes is public.

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Friendship and inheritance

Friend functions

In principle, private and protected members of a class cannot be accessed from outside the same class in which they are declared. However, this rule does not affect *friends*.

Friends are functions or classes declared with the `friend` keyword.

If we want to declare an external function as friend of a class, thus allowing this function to have access to the private and protected members of this class, we do it by declaring a prototype of this external function within the class, and preceding it with the keyword `friend`:

```
// friend functions
#include <iostream>
using namespace std;

class CRectangle {
    int width, height;
  public:
    void set_values (int, int);
    int area () {return (width * height);}
    friend CRectangle duplicate (CRectangle);
};

void CRectangle::set_values (int a, int b) {
  width = a;
  height = b;
}

CRectangle duplicate (CRectangle rectparam)
{
  CRectangle rectres;
  rectres.width = rectparam.width*2;
  rectres.height = rectparam.height*2;
  return (rectres);
}

int main () {
  CRectangle rect, rectb;
  rect.set_values (2,3);
  rectb = duplicate (rect);
  cout << rectb.area();
  return 0;
}
```

```
24
```

The `duplicate` function is a friend of `CRectangle`. From within that function we have been able to access the members `width` and `height` of different objects of type `CRectangle`, which are private members. Notice that neither in the declaration of `duplicate()` nor in its later use in `main()` have we considered `duplicate` a member of class `CRectangle`. It isn't! It simply has access to its private and protected members without being a member.

The friend functions can serve, for example, to conduct operations between two different classes. Generally, the use of friend functions is out of an object-oriented programming methodology, so whenever possible it is better to use members of the same class to perform operations with them. Such as in the previous example, it would have been shorter to integrate `duplicate()` within the class `CRectangle`.

Friend classes

Just as we have the possibility to define a friend function, we can also define a class as friend of another one, granting that first class access to the protected and private members of the second one.

```
// friend class
#include <iostream>
using namespace std;

```

```
16
```

```
5  class CSquare;
6
7  class CRectangle {
8      int width, height;
9    public:
10     int area ()
11       {return (width * height);}
12     void convert (CSquare a);
13 };
14
15 class CSquare {
16   private:
17     int side;
18   public:
19     void set_side (int a)
20       {side=a;}
21     friend class CRectangle;
22 };
23
24 void CRectangle::convert (CSquare a) {
25   width = a.side;
26   height = a.side;
27 }
28
29 int main () {
30   CSquare sqr;
31   CRectangle rect;
32   sqr.set_side(4);
33   rect.convert(sqr);
34   cout << rect.area();
35   return 0;
36 }
```

In this example, we have declared `CRectangle` as a friend of `CSquare` so that `CRectangle` member functions could have access to the protected and private members of `CSquare`, more concretely to `CSquare::side`, which describes the side width of the square.

You may also see something new at the beginning of the program: an empty declaration of class `CSquare`. This is necessary because within the declaration of `CRectangle` we refer to CSquare (as a parameter in `convert()`). The definition of `CSquare` is included later, so if we did not include a previous empty declaration for `CSquare` this class would not be visible from within the definition of `CRectangle`.

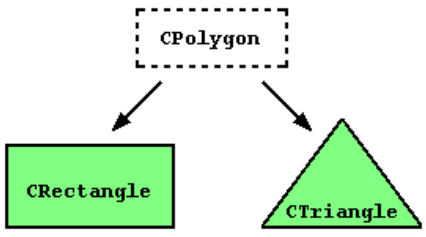
Consider that friendships are not corresponded if we do not explicitly specify so. In our example, `CRectangle` is considered as a friend class by `CSquare`, but `CRectangle` does not consider `CSquare` to be a friend, so `CRectangle` can access the protected and private members of `CSquare` but not the reverse way. Of course, we could have declared also `CSquare` as friend of `CRectangle` if we wanted to.

Another property of friendships is that they are *not transitive*: The friend of a friend is not considered to be a friend unless explicitly specified.

Inheritance between classes

A key feature of C++ classes is inheritance. Inheritance allows to create classes which are derived from other classes, so that they automatically include some of its "parent's" members, plus its own. For example, we are going to suppose that we want to declare a series of classes that describe polygons like our `CRectangle`, or like `CTriangle`. They have certain common properties, such as both can be described by means of only two sides: height and base.

This could be represented in the world of classes with a class `CPolygon` from which we would derive the two other ones: `CRectangle` and `CTriangle`.



The class `CPolygon` would contain members that are common for both types of polygon. In our case: `width` and `height`. And `CRectangle` and `CTriangle` would be its derived classes, with specific features that are different from one type of polygon to the other.

Classes that are derived from others inherit all the accessible members of the base class. That means that if a base class includes a member `A` and we derive it to another class with another member called `B`, the derived class will contain both members `A` and `B`.

In order to derive a class from another, we use a colon (`:`) in the declaration of the derived class using the following format:

```
class derived_class_name: public base_class_name
{ /*...*/ };
```

Where `derived_class_name` is the name of the derived class and `base_class_name` is the name of the class on which it is based. The `public` access specifier may be replaced by any one of the other access specifiers `protected` and `private`. This access specifier limits the most accessible level for the members inherited from the base class: The members with a more accessible level are inherited with this level instead, while the members with an equal or more restrictive access level keep their restrictive level in the derived class.

```
1  // derived classes
2  #include <iostream>
3  using namespace std;
4
5  class CPolygon {
6    protected:
7      int width, height;
8    public:
9      void set_values (int a, int b)
10       { width=a; height=b;}
11   };
12
13 class CRectangle: public CPolygon {
14   public:
15     int area ()
16       { return (width * height); }
17   };
18
19 class CTriangle: public CPolygon {
20   public:
21     int area ()
22       { return (width * height / 2); }
23   };
24
25 int main () {
26   CRectangle rect;
27   CTriangle trgl;
28   rect.set_values (4,5);
29   trgl.set_values (4,5);
30   cout << rect.area() << endl;
31   cout << trgl.area() << endl;
32   return 0;
33 }
```

```
20
10
```

The objects of the classes `CRectangle` and `CTriangle` each contain members inherited from `CPolygon`. These are: `width`, `height` and `set_values()`.

The `protected` access specifier is similar to `private`. Its only difference occurs in fact with inheritance. When a class inherits from another one, the members of the derived class can access the protected members inherited from the base class, but not its private members.

Since we wanted `width` and `height` to be accessible from members of the derived classes `CRectangle` and `CTriangle` and not only by members of `CPolygon`, we have used `protected` access instead of `private`.

We can summarize the different access types according to who can access them in the following way:

Access	public	protected	private
members of the same class	yes	yes	yes
members of derived classes	yes	yes	no
not members	yes	no	no

Where "not members" represent any access from outside the class, such as from `main()`, from another class or from a function.

In our example, the members inherited by `CRectangle` and `CTriangle` have the same access permissions as they had in their base class `CPolygon`:

```
1  CPolygon::width           // protected access
2  CRectangle::width         // protected access
3
4  CPolygon::set_values()    // public access
5  CRectangle::set_values()  // public access
```

This is because we have used the `public` keyword to define the inheritance relationship on each of the derived classes:

```
class CRectangle: public CPolygon { ... }
```

This `public` keyword after the colon (`:`) denotes the most accessible level the members inherited from the class that follows it (in this case `CPolygon`) will have. Since `public` is the most accessible level, by specifying this keyword the derived class will inherit all the members with the same levels they had in the base class.

If we specify a more restrictive access level like `protected`, all public members of the base class are inherited as protected in the derived class. Whereas if we specify the most restricting of all access levels: `private`, all the base class members are inherited as private.

For example, if `daughter` was a class derived from `mother` that we defined as:

```
class daughter: protected mother;
```

This would set `protected` as the maximum access level for the members of `daughter` that it inherited from `mother`. That is, all members that were public in `mother` would become protected in `daughter`. Of course, this would not restrict `daughter` to declare its own public members. That maximum access level is only set for the members inherited from `mother`.

If we do not explicitly specify any access level for the inheritance, the compiler assumes private for classes declared with `class` keyword and public for those declared with `struct`.

What is inherited from the base class?

In principle, a derived class inherits every member of a base class except:

- its constructor and its destructor
- its operator=() members
- its friends

Although the constructors and destructors of the base class are not inherited themselves, its default constructor (i.e., its constructor with no parameters) and its destructor are always called when a new object of a derived class is created or destroyed.

If the base class has no default constructor or you want that an overloaded constructor is called when a new derived object is created, you can specify it in each constructor definition of the derived class:

```
derived_constructor_name (parameters) : base_constructor_name (parameters) {...}
```

For example:

```
// constructors and derived classes
#include <iostream>
using namespace std;

class mother {
  public:
    mother ()
      { cout << "mother: no parameters\n"; }
    mother (int a)
      { cout << "mother: int parameter\n"; }
};

class daughter : public mother {
  public:
    daughter (int a)
      { cout << "daughter: int parameter\n\n"; }
};

class son : public mother {
  public:
    son (int a) : mother (a)
      { cout << "son: int parameter\n\n"; }
};

int main () {
  daughter cynthia (0);
  son daniel(0);

  return 0;
```

```
mother: no parameters
daughter: int parameter

mother: int parameter
son: int parameter
```

```
}
```

Notice the difference between which `mother`'s constructor is called when a new `daughter` object is created and which when it is a `son` object. The difference is because the constructor declaration of `daughter` and `son`:

```
daughter (int a)          // nothing specified: call default
son (int a) : mother (a)  // constructor specified: call this
```

Multiple inheritance

In C++ it is perfectly possible that a class inherits members from more than one class. This is done by simply separating the different base classes with commas in the derived class declaration. For example, if we had a specific class to print on screen (`COutput`) and we wanted our classes `CRectangle` and `CTriangle` to also inherit its members in addition to those of `CPolygon` we could write:

```
class CRectangle: public CPolygon, public COutput;
class CTriangle: public CPolygon, public COutput;
```

here is the complete example:

```
// multiple inheritance
#include <iostream>
using namespace std;

class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b;}
  };

class COutput {
  public:
    void output (int i);
  };

void COutput::output (int i) {
  cout << i << endl;
  }

class CRectangle: public CPolygon, public COutput {
  public:
    int area ()
      { return (width * height); }
  };

class CTriangle: public CPolygon, public COutput {
  public:
    int area ()
      { return (width * height / 2); }
  };

int main () {
  CRectangle rect;
  CTriangle trgl;
  rect.set_values (4,5);
  trgl.set_values (4,5);
  rect.output (rect.area());
  trgl.output (trgl.area());
  return 0;
}
```

```
20
10
```

Previous: **Classes (II)** Index Next: **Polymorphism**

Polymorphism

Before getting into this section, it is recommended that you have a proper understanding of pointers and class inheritance. If any of the following statements seem strange to you, you should review the indicated sections:

Statement:	Explained in:
int a::b(int c) { }	Classes
a->b	Data Structures
class a: public b { };	Friendship and inheritance

Pointers to base class

One of the key features of derived classes is that a pointer to a derived class is type-compatible with a pointer to its base class. Polymorphism is the art of taking advantage of this simple but powerful and versatile feature, that brings Object Oriented Methodologies to its full potential.

We are going to start by rewriting our program about the rectangle and the triangle of the previous section taking into consideration this pointer compatibility property:

```
1  // pointers to base class
2  #include <iostream>
3  using namespace std;
4
5  class CPolygon {
6    protected:
7      int width, height;
8    public:
9      void set_values (int a, int b)
10       { width=a; height=b; }
11   };
12
13 class CRectangle: public CPolygon {
14   public:
15     int area ()
16       { return (width * height); }
17   };
18
19 class CTriangle: public CPolygon {
20   public:
21     int area ()
22       { return (width * height / 2); }
23   };
24
25 int main () {
26   CRectangle rect;
27   CTriangle trgl;
28   CPolygon * ppoly1 = &rect;
29   CPolygon * ppoly2 = &trgl;
30   ppoly1->set_values (4,5);
31   ppoly2->set_values (4,5);
32   cout << rect.area() << endl;
33   cout << trgl.area() << endl;
34   return 0;
35 }
```

```
20
10
```

In function `main`, we create two pointers that point to objects of class `CPolygon` (`ppoly1` and `ppoly2`). Then we assign references to `rect` and `trgl` to these pointers, and because both are objects of classes derived from `CPolygon`, both are valid assignment operations.

The only limitation in using `*ppoly1` and `*ppoly2` instead of `rect` and `trgl` is that both `*ppoly1` and `*ppoly2` are of type `CPolygon*` and therefore we can only use these pointers to refer to the members that `CRectangle` and `CTriangle` inherit from `CPolygon`. For that reason when we call the `area()` members at the end of the program we have had to use directly the objects `rect` and `trgl` instead of the pointers `*ppoly1` and `*ppoly2`.

In order to use `area()` with the pointers to class `CPolygon`, this member should also have been declared in the class

CPolygon, and not only in its derived classes, but the problem is that CRectangle and CTriangle implement different versions of area, therefore we cannot implement it in the base class. This is when virtual members become handy:

Virtual members

A member of a class that can be redefined in its derived classes is known as a virtual member. In order to declare a member of a class as virtual, we must precede its declaration with the keyword virtual:

```
// virtual members
#include <iostream>
using namespace std;

class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area ()
      { return (0); }
  };

class CRectangle: public CPolygon {
  public:
    int area ()
      { return (width * height); }
  };

class CTriangle: public CPolygon {
  public:
    int area ()
      { return (width * height / 2); }
  };

int main () {
  CRectangle rect;
  CTriangle trgl;

  CPolygon poly;
  CPolygon * ppoly1 = &rect;
  CPolygon * ppoly2 = &trgl;
  CPolygon * ppoly3 = &poly;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly3->set_values (4,5);
  cout << ppoly1->area() << endl;
  cout << ppoly2->area() << endl;
  cout << ppoly3->area() << endl;
  return 0;
}
```

```
20
10
0
```

Now the three classes (CPolygon, CRectangle and CTriangle) have all the same members: width, height, set_values() and area().

The member function area() has been declared as virtual in the base class because it is later redefined in each derived class. You can verify if you want that if you remove this virtual keyword from the declaration of area() within CPolygon, and then you run the program the result will be 0 for the three polygons instead of 20, 10 and 0. That is because instead of calling the corresponding area() function for each object (CRectangle::area(), CTriangle::area() and CPolygon::area(), respectively), CPolygon::area() will be called in all cases since the calls are via a pointer whose type is CPolygon*.

Therefore, what the virtual keyword does is to allow a member of a derived class with the same name as one in the base class to be appropriately called from a pointer, and more precisely when the type of the pointer is a pointer to the base class but is pointing to an object of the derived class, as in the above example.

A class that declares or inherits a virtual function is called a *polymorphic class*.

Note that despite of its virtuality, we have also been able to declare an object of type CPolygon and to call its own area() function, which always returns 0.

Abstract base classes

Abstract base classes are something very similar to our CPolygon class of our previous example. The only difference is that in our previous example we have defined a valid area() function with a minimal functionality for objects that were of class CPolygon (like the object poly), whereas in an abstract base classes we could leave that area() member function without implementation at all. This is done by appending =0 (equal to zero) to the function declaration.

An abstract base CPolygon class could look like this:

```
// abstract class CPolygon
class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area () =0;
};
```

Notice how we appended `=0` to `virtual int area ()` instead of specifying an implementation for the function. This type of function is called a *pure virtual function*, and all classes that contain at least one pure virtual function are *abstract base classes*.

The main difference between an abstract base class and a regular polymorphic class is that because in abstract base classes at least one of its members lacks implementation we cannot create instances (objects) of it.

But a class that cannot instantiate objects is not totally useless. We can create pointers to it and take advantage of all its polymorphic abilities. Therefore a declaration like:

```
CPolygon poly;
```

would not be valid for the abstract base class we have just declared, because tries to instantiate an object. Nevertheless, the following pointers:

```
CPolygon * ppoly1;
CPolygon * ppoly2;
```

would be perfectly valid.

This is so for as long as `CPolygon` includes a pure virtual function and therefore it's an abstract base class. However, pointers to this abstract base class can be used to point to objects of derived classes.

Here you have the complete example:

```
// abstract base class
#include <iostream>
using namespace std;

class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
  };

class CRectangle: public CPolygon {
  public:
    int area (void)
      { return (width * height); }
  };

class CTriangle: public CPolygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  CRectangle rect;
  CTriangle trgl;
  CPolygon * ppoly1 = &rect;
  CPolygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  cout << ppoly1->area() << endl;
  cout << ppoly2->area() << endl;
  return 0;
}
```

```
20
10
```

If you review the program you will notice that we refer to objects of different but related classes using a unique type of

pointer (`CPolygon*`). This can be tremendously useful. For example, now we can create a function member of the abstract base class `CPolygon` that is able to print on screen the result of the `area()` function even though `CPolygon` itself has no implementation for this function:

```
// pure virtual members can be called
// from the abstract base class
#include <iostream>
using namespace std;

class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
    void printarea (void)
      { cout << this->area() << endl; }
  };

class CRectangle: public CPolygon {
  public:
    int area (void)
      { return (width * height); }
  };

class CTriangle: public CPolygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  CRectangle rect;
  CTriangle trgl;
  CPolygon * ppoly1 = &rect;
  CPolygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly1->printarea();
  ppoly2->printarea();
  return 0;
}
```

```
20
10
```

Virtual members and abstract classes grant C++ the polymorphic characteristics that make object-oriented programming such a useful instrument in big projects. Of course, we have seen very simple uses of these features, but these features can be applied to arrays of objects or dynamically allocated objects.

Let's end with the same example again, but this time with objects that are dynamically allocated:

```
// dynamic allocation and polymorphism
#include <iostream>
using namespace std;

class CPolygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area (void) =0;
    void printarea (void)
      { cout << this->area() << endl; }
  };

class CRectangle: public CPolygon {
  public:
    int area (void)
      { return (width * height); }
  };

class CTriangle: public CPolygon {
  public:
    int area (void)
      { return (width * height / 2); }
  };

int main () {
  CPolygon * ppoly1 = new CRectangle;
  CPolygon * ppoly2 = new CTriangle;
```

```
20
10
```

```
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly1->printarea();
  ppoly2->printarea();
  delete ppoly1;
  delete ppoly2;
  return 0;
}
```

Notice that the `ppoly` pointers:

```
CPolygon * ppoly1 = new CRectangle;
CPolygon * ppoly2 = new CTriangle;
```

are declared being of type pointer to `CPolygon` but the objects dynamically allocated have been declared having the derived class type directly.

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