

## Remind of C/C++ basic elements

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## The “main” function

The execution of a C++ program starts with the `main` function

- all C++ programs have **one and only one** `main` function
- it executes operations, calls other functions, creates objects...
- instructions are terminated by a semicolon ;
- it returns an integer (typically 0 to indicate no errors)

```
...
int main() {
    ...
    return 0;
}
```

Programs are (usually) splitted in several files:  
“translation units”

```
c++ -Wall -o exec_name file_list
```

## Data types

- signed integers: `int`, `short`, `long`, `long long`
- unsigned integers: `unsigned int`, ...
- enumerators: `enum` (improved in C++11: `enum class`)
- floating point: `float`, `double`, `long double`
- characters: `char`
- C-strings: `char*/char[]` (terminated by `'\0'`)
- logicals: `bool` (or also `int`, 0 for false)

### All variables must be “declared” before their usage

- names are case-sensitive:  
Energy is not the same as energy
- they can be initialized: `int i=3;`
- several variables can be declared in one line: `int i, j;`
- they can be made unmodifiable: `const float x=3.14;`
- they are (usually) visible inside the “scope” (`{}`) where they're declared

## Automatic type determination

### C++11 only

- In declarations with initialization the type could be deduced by the right member.
- A variable can be “declared” having the same type of another one.

```
int f(double x) {  
    return 2*round(x);  
}  
  
int main() {  
    auto i=f(3.7);  
    decltype(i) j;  
    j=i*i;  
    std::cout << i << " " << j << std::endl;  
    return 0;  
}
```

## Compile-time constants

C++11 only

An unmodifiable object known at compile time  
can be declared `constexpr`.

```
constexpr int f(int i, int j) {  
    return i*j;  
}  
  
int main() {  
    constexpr int i=3;  
    int j;  
    std::cin >> j;  
    std::cout << i*j << std::endl;  
    constexpr int k=f(i,5);  
    std::cout << k << std::endl;  
    return 0;  
}
```

# Operations

- “unary” operators:  $-x$  ,  $j--$  ,  $++l$  , ...
- “binary” operators:  $a+b$  ,  $x-y$  ,  $i*j$  ,  $p<q$  , ...
- “ternary” operators:  $x?a:b$
- other operators:
  - `()` : function call
  - `new` , `delete` : create and destroy
  - ...
  - `sizeof(...)` : variable size (in bytes)

There's a defined **precedence** and **associativity** table:

- e.g. in  $a+b*c$  the multiplications is executed before the sum
- but it can be overridden by using parentheses:  $(a+b)*c$  .

The expressions evaluation order is NOT defined:

$k = (i+3) * (++i)$  ; is undefined

## Flux control

- **Conditional** statements:
  - `if (expr) stat:`  
it evaluates `expr`, if it's true it executes `stat`.
- **Loop** statements:
  - `for (exp1;exp2;exp3) stat :`  
it evaluates `exp1`,  
then it evaluates `exp2`,  
if it's true it executes `stat` and then `exp3`,  
then it evaluates `exp2` again and so on.
  - `while (expr) stat:`  
it evaluates `expr`, if it's true it executes `stat`,  
it evaluates `expr` again and so on.
  - `do stat while (expr):`  
it executes `stat` and then it evaluates `expr`,  
if it's true it executes `stat` again and so on.
  - `continue` and `break` instructions to alter the cycle
- **Choice** statements:
  - `switch (int_expr) { list_of_cases }`

## Comments

Comments can (must) be included in programs!

The compiler ignores anything that:

- follows a `//` until the end of the line,
- is comprised between a `/*` and a `*/`

```
...
int main() {
    ... // an one-line comment
    /* a comment
       written over
       several lines */
    ...
    return 0;
}
```

## Mathematical operators

Decreasing priority:

- ++ , -- : pre/post increment and decrement
- \* , / , % : multiplication, division, modulus
- + , - : addition and subtraction
- < , > , <= , >= , == , != : relations
- = , \*= , /= , %= , += , -= : assignment

### Care needed!

- The result of the **division between integers** is an integer
- **Equality and assignment** operators are similar but different

```
int i=4, j=5;
float x=i/j; // x=0
float y=i*1.0/j;
           // y=0.8
```

```
int i=7, j=9, k=0;
if(i==j)k+=1; // false
if(i=j )k+=2; // true
           // k=2
```

## Logical and bitwise operators

Logical - Decreasing priority:

- & : bitwise and
- ^ : bitwise exclusive or
- | : bitwise or
- && : logical and
- || : logical or
- &= , ^= , |= : bitwise assignment

Bitwise - Decreasing priority:

- << , >> : bitwise shift left/right
- <<= , >>= : bitwise shift assignment

Expressions evaluation ends when the result is known:

```
in if ( ((i*i) < 0) && ((j+=2) < 10) ) . . . ;
      j is NOT incremented.
```

## Assignment operators

### Assignment operators are also expressions

- The value of the expression is given by the left-side after the assignment
- Assignments can be used inside complex operations

```
int i=3;
int j;
float x=5.7/(j=i);
// now both "i" and "j" are 3
// and "x" is 5.7/3=1.9
```

## Type conversions

Variables are **converted** to other types implicitly when needed, but some control is sometime necessary (e.g. `x=i*1.0/j`):

“type cast”

Explicit conversions between an `int i` and a `float x`:

- C-style casts: `i=(int)x` or `i=int(x)`
  - not always clear what they do
  - difficult to find across the code
- C++-style casts: `i=static_cast<int>(x)`

C++ has 3 other types of casts, they will be seen later

## Type synonyms

An existing type (e.g. `float`) can be given an additional name with a `typedef` declaration

```
typedef float number;  
number x=5.1;  
number y=6.7;  
number z=x+y;  
std::cout << z << std::endl;
```

- A set of variables can be declared with a common type that can be changed by **modifying just one line**.
- Short names can be defined for **complex types** (to be seen later).

## User-defined functions

Blocks of code can be isolated into “functions”:

- a function takes a list of “arguments”,
- a function returns one value, or none (“void”),
- a function must be “declared” before being used.

```
int f(int x, float y);  
int main() {  
    int i=2;  
    float z=3.4;  
    int j=f(i, z);  
    return 0;  
}
```

A function can be “defined” after being used, or even in another “translation unit” (i.e. another file): only the declaration must be present before the usage

## Executable build

- “compilation”: each source file is compiled to machine instructions
- “linking”: the instructions in all files are linked together and any instruction to interact with the operating system is added
  - both steps can be executed in one go:  
`c++ -o exe file1.cc file2.cc`
  - the second step can be skipped:  
`c++ -c file1.c file2.c`
  - the files created in the first step can be given as input to the second step: `c++ -o exe file1.o file2.o`
- A function can be declared many times, and must be defined exactly once.
- Otherwise an “undefined reference” or “multiple definition” error arises.

This check is performed at linking time.

# Recursion

C/C++ allow a function to call itself: “recursive” calls

- At each call all the function local variables are created and initialized.
- Some condition must occur for the function to return without calling itself.
- Example: function to compute  $n!$

$$n! = \begin{cases} 1 & \text{if } n = 0 \\ (n-1)!n & \text{if } n > 0 \end{cases}$$

```
unsigned int fact(unsigned int n) {  
    if(n) return n*fact(n-1);  
    return 1;  
}
```

## inline functions

By declaring a function `inline` the compiler is instructed to replicate the code across the program (if possible):

- there's no function call/return overhead,
- larger executables are produced,
- the function declaration is not sufficient.

```
inline int iabs(int i) {  
    return (i>0?i:-i);  
}
```

- Inlining is not possible for recursive functions.
- The program size increase could vanish the benefit.
- The compiler can ignore the indication.

## Functions arguments

Function arguments are passed “by value”, i.e. each variable is copied to a local one, inside the function scope:

- the function can modify that copy,
- the function cannot modify the variable in the calling function,
- the copy is destroyed when the function ends.

The return value is copied back to the calling function.

### C++ specific: function “overloading”

A function name is “overloaded” when several functions exist with the same name but different argument number and/or types

## Default arguments

Default values can be provided:

- they're set in the function declaration,
- if an argument has a default value, all the following ones must have one.

```
int f(int i, int j=1, int k=2);
int main() {
    int n=12;
    int m=23;
    int l=f(n,m);
    // equivalent to
    // int l=f(n,m,2);
}
```

## main function arguments

The “main” function has its arguments, too:

- the first one is an integer, equal to the number of “words” in the command line, i.e. the number of arguments plus one,
- the second is an array of C-strings, corresponding to those words.

```
int main(int argc, char* argv[]) {
    std::cout << argv[0]
               << " called with arguments:";

    int iarg;
    for(iarg=1; iarg<argc; ++iarg)
        std::cout << ( iarg > 1 ? ", " : " " )
                  << argv[iarg];

    std::cout << std::endl;
    return 0;
}
```

## Predefined functions

Some functions are “predefined”, i.e. they’re already available

### Mathematical functions (in `math.h`):

- `sqrt(double)` , `pow(double, double)`
- `sin(double)` , `acos(double)` , ...
- `atan2(double, double)`
- `exp(double)` , `log(double)`
- `fabs(double)` : **abs. value**
- `lround(double)` , `llround(double)` : **rounding**

**Add a trailing “l” to use with long doubles**

---

### Utility functions (in `stdlib.h`):

- `random()` : **random int**  
**between 0 and  $2^{31} - 1$  (`RAND_MAX`≡`0x7fffffff`)**
- `srand(unsigned int)` : **set the seed for the random generation**
- `exit(int)` : **stop the execution immediately**

## Pointers

The “pointer” to a variable (or an object) is its memory address:

- it's declared by adding a “\*” to the variable type,
- it can be obtained by mean of the operator “&” ,
- it can be changed to contain the address of another variable (of the same type),
- the variable or object content can be obtained back by mean of the operator “\*” ,
- dereferencing an invalid pointer can produce a fatal error,
- a null pointer (=0) is always invalid (`nullptr` in C++11).

```
int i=12;
int j=23;
int* p=&i; // "p" is the address of "i"
std::cout << *p << std::endl;
*p=24; // "i" is now 24
p=&j; // "p" is now the address of "j"
std::cout << i << " " << *p << std::endl;
```

## Pointers declaration pitfalls

- A pointer can be declared in two ways (different “styles” but identical effects):

```
int* p; // "p" is an "int*"
int *p; // "*p" is an "int"
```

- When several variables are declared in one line, a pitfall may arise:

```
int* p, q;
// "p" is a pointer to int, "q" is an int
```

- Each pointer must be declared with its “\*”

```
int* p, *q;
// both "p" and "q" are pointers to int
int *p, *q;
// both "p" and "q" are pointers to int
int p, *q;
// "p" is an int, "q" is a pointer to int
```

# Arrays

Arrays are sets of variables of the same type:

- they're declared by adding a “[N]” (where “N” is an integer) to the variable name, eventually initialized with a list,
- their elements are stored in contiguous memory locations and accessed by adding a “[i]”, where  $0 \leq i \leq N-1$ .

```
int i[12];
int k[12]={7,6,5,4,3,2,1,0,11,10,9,8};
int j;
for(j=0;j<12;++j)i[j]=2*j;
for(j=0;j<12;++j)std::cout << j << " "
    << i[j] << " " << k[j] << std::endl;
```

- Arrays are quite similar to pointers.
- `int* p=i;` is the pointer to the first element:  
`*p ≡ i[0]` , `*(p+n) ≡ i[n]` , `p+n ≡ &i[n]`
- Strings are arrays of `chars`, with a `'\0'` as last element.

## Range for

C++11 only

A loop can be executed over array elements

```
int i[12];  
int k=0;  
for (int& j: i) j=2*k++;  
for (int j: i) std::cout << j << " ";  
std::cout << std::endl;
```

## Initializer lists

### Prevention of “narrowing”

Initializer lists can be used also for “simple” variables.

```
int i={23};  
int j={43.1}; // ERROR:  
                // conversion of float to int  
                // ("narrowing")
```

### C++11 only

The “=” can be removed  
(uniform with other initializers)

```
int i{23};  
int j[3]{14,25,37};
```

## References

A “reference” can be seen as a new name for an existing variable or object:

- it's declared by adding a & to the variable type,
- the referred variable must be specified in the declaration,
- contrary to pointers, it cannot be changed to refer to a different variable.

```
int i=12;
int& j=i; // "j" is a reference to "i"
std::cout << j << std::endl;
j=24; // "i" is now 24
std::cout << i << std::endl;
```

- They're useful in passing or retrieving variables to/from functions.
- Actually they're pointers, with the “\*” embedded.

## References and pointers to `const`

A variable can be modified through a pointer or reference to it, unless a “pointer/reference to `const`” is used.

```
int i=12;
const int* p=&i; // "p" is the address of "i"
std::cout << *p << std::endl;
i=19; // allowed, "i" is not "const"
std::cout << *p << std::endl;
*p=26; // ERROR, "*p" is const
```

Only references to “`const`” and pointers to “`const`” can be defined for “`const`” variables (of course)

```
const int j=34;
int* q=&j; // ERROR, "j" is const
const int* r=&j; // allowed, "*r" is const
```

## const pointers

A pointer can be `const` itself, i.e. it cannot be changed to point to a different memory address

```
int i=12;
int const * p=&i; // "p" is a const pointer
int j=19;
p=&j; // ERROR, "p" is const
```

A pointer can be `const` itself and prevent the change of the content of the memory address it points to

```
int i=12;
const int const * p=&i;
*p=26; // ERROR, "*p" is const
int j=19;
p=&j; // ERROR, "p" is const
```

## References, pointers and function arguments

Functions pass arguments by value, but:

- arguments and/or result can be pointers, or references,
- the pointers or references are copied, actually,
- the pointed/referred variable or object can be changed,
- arguments passed as `const` reference cannot be changed.

```
float f(int& i, const float* x) {  
    i*=2;           // "i" in the client  
                  // function is modified  
    return *x*3.4; // "x" cannot be modified  
}
```

Copy by `const` reference can be used to pass functions objects that cannot be copied

## References, pointers and function return

Functions result can also be a pointer or reference, but:

- memory used for local variables is deallocated when the function returns,
- when accessed by the calling function, garbage is found,
- returning pointers and/or references to local variables lead to unpredictable results.

```
int* f(int i) {  
    int j=i*2; // local variable, destroyed  
               // when "f" returns  
    return &j; // invalid pointer returned  
}
```

Only pointer or reference to persistent objects  
can be returned

## Dynamic memory handling

Pointers are used to allocate/deallocate memory at run time (dynamically):

- variables are created/destroyed with the operators “new” and “delete”,
- dynamic variables are not bound to a scope.

```
int* i = new int(3);  
// "i" is a pointer to an int  
// whose value is "3"  
float* f = new float[12];  
// "f" is an array of 12 float  
...  
delete i;  
// "delete" destroys one single variable  
delete[] f;  
// "delete[]" destroys an array
```

## Dynamic memory pitfalls

Special care is required in dynamic variables handling

- Dynamic variables are destroyed only by a “delete” operation, or at execution end:
  - they use unrecoverable memory when all the pointers to them go out of scope (“memory leak”),
  - they must be deleted when no more necessary.
- When a variable has been deleted, the pointer to its memory location is invalid but it's still existing:
  - it cannot be de-referenced (“dangling reference”),
  - a second “delete” operation cannot be performed,
  - care is required with multiple copies of a pointer.
- Unpredictable results are obtained when “delete” is used for arrays or “delete[]” is used for single variables.
- Applying a delete or delete[] to a null pointer (=0) has no effect; a fatal error is produced with any other invalid pointer.

## Pointer and reference based type casts

By using pointers and references,  
other type casts become possible

Force the modification of a (non-const) variable  
through a pointer to const  
(unpredictable results for originally-const variables)

```
int i; // "i" is not "const"
const int* p = &i; // "*p" is "const"
*const_cast<int*>(p)=2;
```

Convert the pointer to a type to the pointer to another type,  
with no checks

```
float x = 23.45;
float* pf = &x;
int* pi = reinterpret_cast<int*>(pf);
std::cout << *pi << std::endl;
// prints "1102813594"
```

## Generic pointers

A “pointer to `void`” can contain the address of any variable or object:

- it's declared as `void*` ,
- it cannot be de-referenced,
- it cannot be used as argument for `delete` ,
- to be used a `reinterpret_cast` is needed.

```
int i;
void* p=&i;
...
std::cout << *reinterpret_cast<int*>(p)
           << std::endl;
```

## C++-style input-output

- Input and output go through “streams”, `cin` and `cout` are the standard input and output streams.
- Input and output operators are `>>` and `<<` (“bit move”).
- Input and output from/to files go through file streams.

```
#include <iostream>
#include <fstream>
int main() {
    int i;
    std::ifstream file("inputfile");
    file >> i;
    std::cout << i << std::endl;
    ...
}
```

## Loop input

- Input stream operator `>>` return value can be tested to be
  - `true` to check for successful reading,
  - `false` to check for end of file.
- End of input from keyboard can be sent with `ctrl-d`.
- To read again after an end-of-input the input stream must be reset by the function `clear()`.

```
#include <iostream>
int main() {
    int i;
    while(std::cin >> i)
        std::cout << "---> " << i << std::endl;
    std::cin.clear();
    ...
}
```

## Output formatting commands

A lot of additional commands to format the output are available, (e.g. to set the number of digits to write for numbers)

```
#include <iostream>
int main() {
    float x;
    ...
    std::cout.width(12);
    std::cout.precision(5);
    std::cout << x << std::endl;
    return 0;
}
```

## Output formatting objects

The same commands can be sent inside the output streaming

```
#include <iostream>
#include <iomanip>
int main() {
    float x;
    ...
    std::cout << std::setw(12)
               << std::setprecision(5)
               << x << std::endl;
    return 0;
}
```

## C-style input-output

C++ allows the use of plain-C I/O functions (in `stdio.h`):

- `scanf` and `printf` for input and output to/from standard; the first argument is a string setting the format
- `fscanf` and `fprintf` for input and output to/from file
- `sscanf` and `sprintf` for input and output to/from strings

```
#include <stdio.h>
int main() {
    int i;
    scanf("%d",&i); // pointer to "i" required
    printf("%d\n",i); // "\n" for new line
    return 0;
}
```

## C-style formatting

### Data type is to be specified

<code>%N.Md</code>	<b>decimal</b> int	<code>%N.Pf</code>	<b>plain</b> float
<code>%N.Mo</code>	<b>octal</b> int	<code>%N.Pe</code>	<b>exponential</b> float
<code>%N.Mx</code>	<b>hexadecimal</b> int	<code>%N.Ls</code>	char <b>string</b>
N	<b>output width</b>	M	<b>number of digits</b>
P	<b>precision</b>	L	<b>string max. length</b>
<code>%ld</code>	long	<code>%qd</code>	long long
<code>%lf</code>	double	<b>negative N : left-justify</b>	

```
printf("=%9.6d=\n", 123);  writes = 000123=
printf("=%9.3f=\n", 1.23); writes = 1.230=
```

## I/O with strings

- Read input from strings
- Write output to strings

```
// write to a string
#include <stdio.h>
int main() {
    int i;
    char s[100];
    sprintf(s, "%d\n", i);
    ...
    return 0;
}
```

```
// read from a string
#include <iostream>
#include <sstream>
int main() {
    int i;
    std::stringstream s;
    s.clear();
    s.str("12");
    s >> i;
    ...
    return 0;
}
```

## Input by line

Text input can be read “line by line”

A line of input is read by mean of the function “getline”, taking as arguments an array of `chars` and the max length (plus eventually the line-terminate character, by default ‘`\n`’)

```
#include <iostream>
int main() {
    int maxLength=1000;
    char* line=new char[maxLength];
    while(std::cin.getline(line,maxLength))
        std::cout << line << std::endl;
    return 0;
}
```

## Binary input-output

Binary files contain the variables exactly as they're stored in memory.

Binary I/O is performed with the functions “read” and “write”, taking pointers to `char` (and number of bytes) as arguments

```
#include <iostream>
#include <fstream>
int main() {
    int i;
    std::ifstream file("inputfile",
                      std::ios::binary);
    file.read(reinterpret_cast<char*>(&i),
              sizeof(i));
    std::cout << i << std::endl;
    return 0;
}
```