esipap

European School of Instrumentation
in Particle & Astroparticle Physics

C++ programming

Lecturers:

- ***Eric Chabert***
- *Eric Conte*

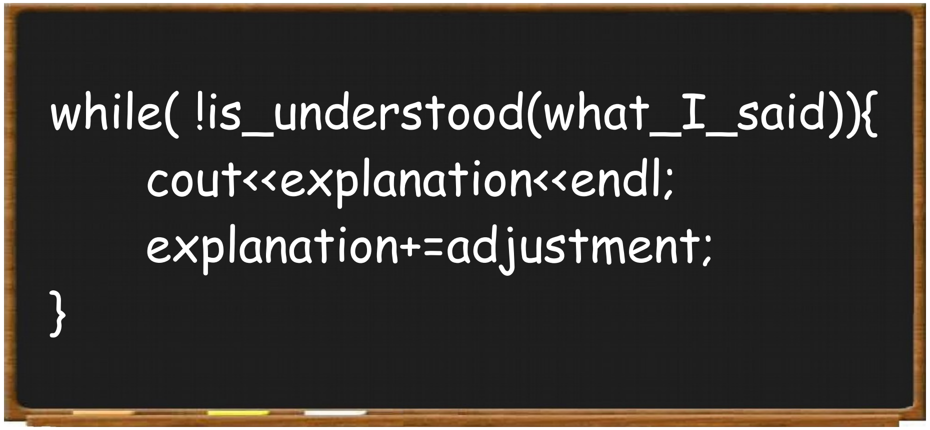
Program:

- 6 hours of lectures (& tutorials)
- 4 computing sessions (3h each)
  with an introduction to the use of

ROOT Geant 4

Goals of that course

The program has been adjusted to your level
It is the first version so it will clearly not be perfect …
.. **but** we can interact so don't hesitate to stop me & fill free to ask questions



```
while( !is_understood(what_I_said)){
      cout<<explanation<<endl;
      explanation+=adjustment;
}
```

Goals (within the limitation of 6 hours)

- (Re)inforce your knowledge & **understanding** of the basis
- Give you examples of applications
- Highlight “not well known enough” features of C++
- Give you guidance for your current & future developments
- Discuss more advanced functionalities

- ✓ *Everything will not be covered*
- ✓ *No formal lectures on ROOT or GEANT4 here*
- ✓ *It is not an advanced lecture and will not become an C++ expert*

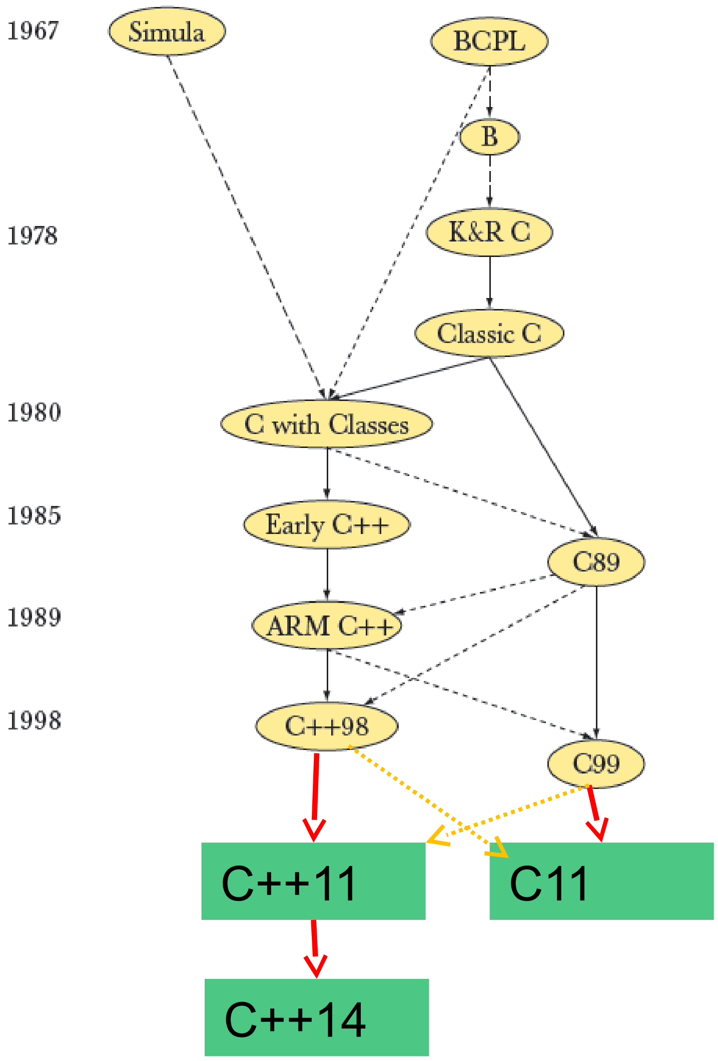
You're following a beg*in*termediate condensed lecture

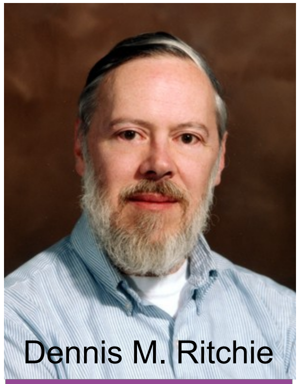
Why C++ ?

- We are looking for **scientific application** (use of numerical methods,...) and we want program to run "*fast*"
  - It cannot be an interpreted language (ex: python), but a ***compiled one***
- We have to deal with a **complex environment** and to perform well advanced tasks
  - It must be an ***oriented object*** language (ex: java, ...)
- We need a language for which *tools* already exists
  - It must have libraries (standard or not)
    - **C++ is the (*one*) answer !**

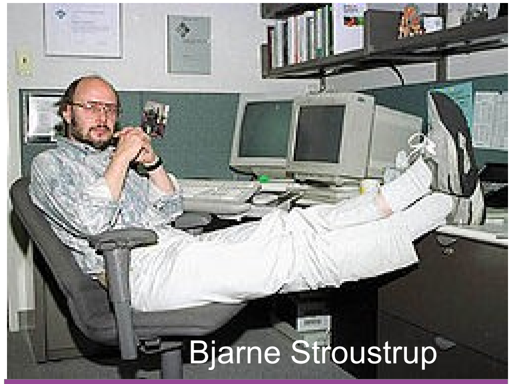
- Most of HEP collaborations use C++ for their software developments
- C++ is precisely defined by an ISO standard and is available on all OS
- *Programming concepts that you will learn using C++ can be used in other languages*

C++: a bit of history


1967 Simula BCPL
B
1978 K&R C
Classic C
1980 C with Classes
1985 Early C++
C89
1989 ARM C++
1998 C++98
C99
C++11
C11
C++14



C inventor



C++ inventor

- Both C & C++ were “born” in the Bell Labs
- C++ *almost* embed the C
- Many tasks could be done in a C/style or C++/style
- Some C/style “procedures” are be to proscribed
- C++ has a long history and is still in development
- C++ is less “*modern*” than java (91),python(93),C#(2000) …
- We will **here** discuss about **C++98** (not **C++11**)

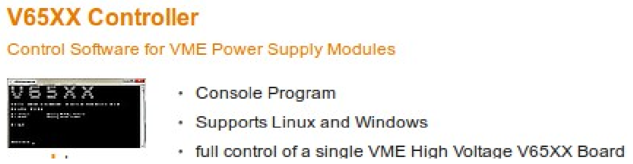
Writing a program requires many steps

- **Preparatory work**
  - Modelisation of the problem
  - Identification of the algorithms or tools to be used (does appropriate libraries exist ?)
  - Defining the specifications
  - Project management: task division/sharing ...
- **Writing the code**
  - This is not the most time consuming tasks ….
- **Compilation**
  - From simple one to more complex (use of Makefile)
  - Debugging (could be time consuming)
- **Test**
  - Test of every part & functionality of the program
  - Verification of the code protection (Crash can happen during runtime. Unexpected behavior …)
- **Optimization [optional]**
  - Could be done with respect to different quantity: cpu time, memory usage, desired precision, …
- **Utilization**
  - Private/Restrictive/Public usage ? … feedback to come ...

What is the language made of ?

- Types (*bool, int, float, char,...*)
- Expression and statements
- Selection (if/else, switch,..)
- Iteration (while,for,...)
- Functions (“intrinsic” or *user-defined*)
    - Accessible via libraries
- Containers (vector,map,..)
    - Accessible via libraries

With those ingredients, you can do a lot of things ….



V65XX Controller

Control Software for VME Power Supply Modules

- Console Program
- Supports Linux and Windows
- full control of a single VME High Voltage V65XX Board

…

“Hello world” example

Header files
Preprocessor directive

Only one “**main**”
function per executable
Return an **integer** that can used
by the system

main.cpp

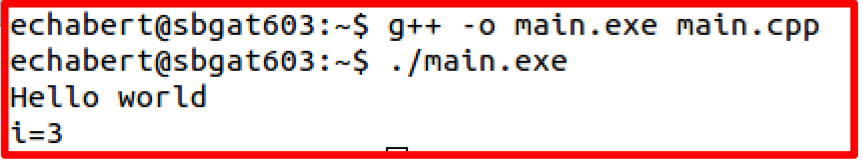
```
#include <iostream>

int main() {
  float x; //declaration
  int i=3; //declaration and affectation
  std::cout << “Hello world” <<  std::endl;
  std::cout <<”i=” << i << std::endl;
  return 0;

}
```

Type
Variable declaration
Variable affectation

Input/Output

Namespace

Terminal



```
echabert@sbgat603:~$ g++ -o main.exe main.cpp
echabert@sbgat603:~$ ./main.exe
Hello world
i=3
```

It is already a “rich” example !!

Variable and types

Several types could be accessible

- Build-in types:
  Ex: bool, int, float, double, char
- Standard library types:
  Ex:complex, string, ...
- Specific libraries:
  Ex: (Root) Float_t, TString, TH1F
- User defined types:
  your own classes

On the machine, everything is only bits filled with 0/1

“Type” is what interprets bits and give them meaning !

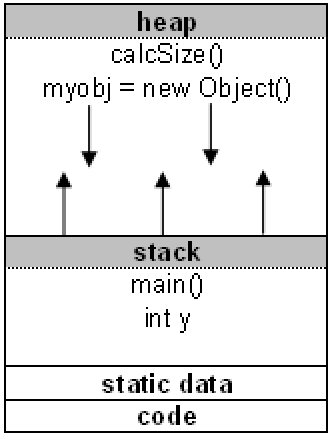
build-in type

Type representation (number of bits used) depends on the platform

Ex: *on my computer (icore7, 64 bits)*

type	content	size	range
bool	True (0) ou False (1)	8 bits	
short	Signed integer	16 bits	[-32768,32767]
int	Signed integer	32 bits	[-2147483648,2147483647]
long	Signed integer	64 bits	[-9223372036854775808,92233720368547]
float	floating-point	32 bits	de $1.4E^{-45}$ à $3.4E^{+38}$
double	floating-point	64 bits	de $4.9E^{-324}$ à $1.8E+^{308}$
char	ASCII char	8 bits	[0,255]

- Sign uses 1 bit – “unsigned” type have double possible value
- Once you “declare” a variable of a given type, you allocate memory
- Build-in type goes on the **stack**
  - fast access
  - available during the whole existence of the program



Standard library types

- String
  - “Extension” of character chains
  - Discussed later in the course

Headers:
#include <string>
#include <complex>

- complex<Scalar>
  - complex<double>
  - complex<float>
  - .. it's an example of “template class”

Types defined in other libraries

Headers:
#include <boost/cstdint.hpp>

- int_least8_t
- int_least16_t
- int_least32_t
- uint_least8_t
- uint_least16_t
- uint_least32_t
- ...

Will ensure the number of bits used on the machine (portable)

Headers:
#include <Rtypes.h>

- Int_t
- UInt_t
- Double_t
- Double32_t ….

(basic) types can be (re)defined by specific library

Comments & documentation

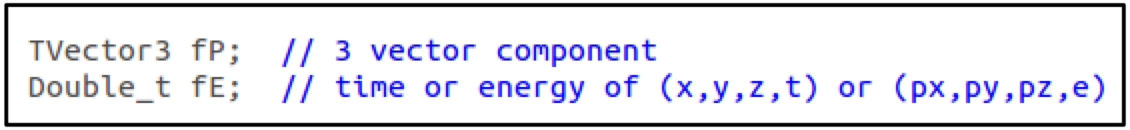
- To comment the end of a line: //

```
Instruction; //  Here starts the comment
```

- To comment a block of lines: **/* block */**

```
Instructions;
/*  The following lines are inactive
for(int i=0;i<10;i++){
        i = i*10;
}
*/
```

- Comments are **really useful**
  - Comment what variables represents (*names are not always sufficient*)
  - Comment functional block



```
TVector3 fP;   // 3 vector component
Double_t fE;   // time or energy of (x,y,z,t) or (px,py,pz,e)
```

    - Ex: reading input, computing a sum, writing an output, ...
  - Comment the program, the functions (.h), the classes (.h)
    - Explain the goals, the input, the output, the main algo ...

Commenting is not a lost of time.

It will be useful for *you* already few weeks after coding

but also for your *co-developers* or future *users* of your code !!!

Tools for documentation formatting exists, ex: doxygen

Usage of variables

- **Declaration**
  - **required**
  - Precise the type of the variable

```
int i;
```

- **Initialization**
  - **Strongly recommended**
  - Can lead to unexpected behavior otherwise
  - Declaration & Initialization can be done at once

```
i=0;
int j=10;
```

```
Float x = 103.4;
Float y = 1.034e2; //e ou E
```

- **Affectation**
- **Operations**

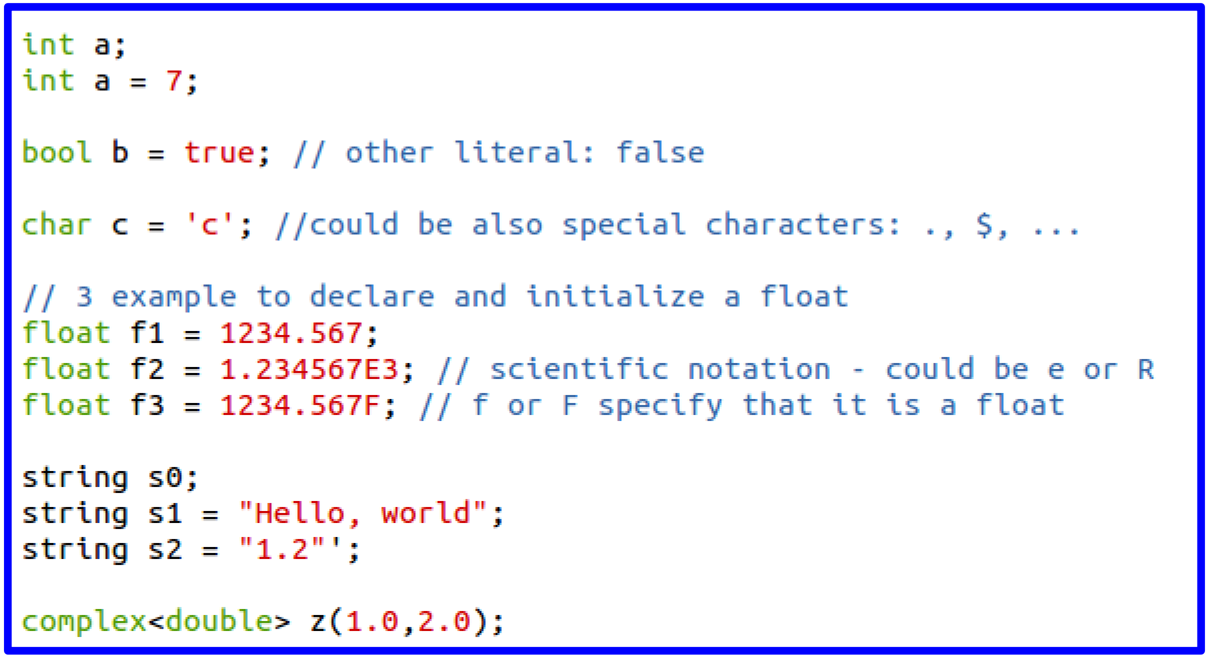
```
i=j; //affectation
i = i*2+1;
i=j**2+3*j;
```

- **Conversion**
  - Implicit (explicit)
  - Truncated numbers
  - Other features ...

```
int i=23;
short b = (short) i; //C-like
short b = i; //C-like
Short b = static_cast<short>(i); //C++ like
i= (int) 10.6; // will be truncated
Float f = 10.6;
i = static_cast<float>(f); //C++ like
```

```
float a = 3.2;
int i = 1/a;
```

Declaration and initialization (II)



```
int a;
int a = 7;

bool b = true; // other literal: false

char c = 'c'; //could be also special characters: ., $, ...

// 3 example to declare and initialize a float
float f1 = 1234.567;
float f2 = 1.234567E3; // scientific notation - could be e or R
float f3 = 1234.567F; // f or F specify that it is a float

string s0;
string s1 = "Hello, world";
string s2 = "1.2"';

complex<double> z(1.0,2.0);
```

Declaration:

- introduce a name into a **scope**
- specify a type for named object
- sometimes it includes an initialization
- a name must always be declared before being used (compilation error otherwise)

Initialization:

- Syntax depends on the type (see examples above)

Variables: operations

- Arithmetic operations
- Affectation
- Comparison operations
- Boolean operations
- Pre and post in(de)crement

Arithmetic operation	
+	addition
-	soustraction
*	multiplication
/	division
%	modulo
- (unaire)	opposed

Arithmetic/Affectation	
+=	add
-=	subtract
*=	multiply
/=	divide
%=	modulo

In/De crement	
i++	post-increment
i--	post-decrement
++i	pre-increment
--i	pre-decrement

Comparison operators	
==	equality
!=	difference
> ; >=	Greater than(or equal)
< ; <=	Lower than (or equal)

4 equivalent incrementation:

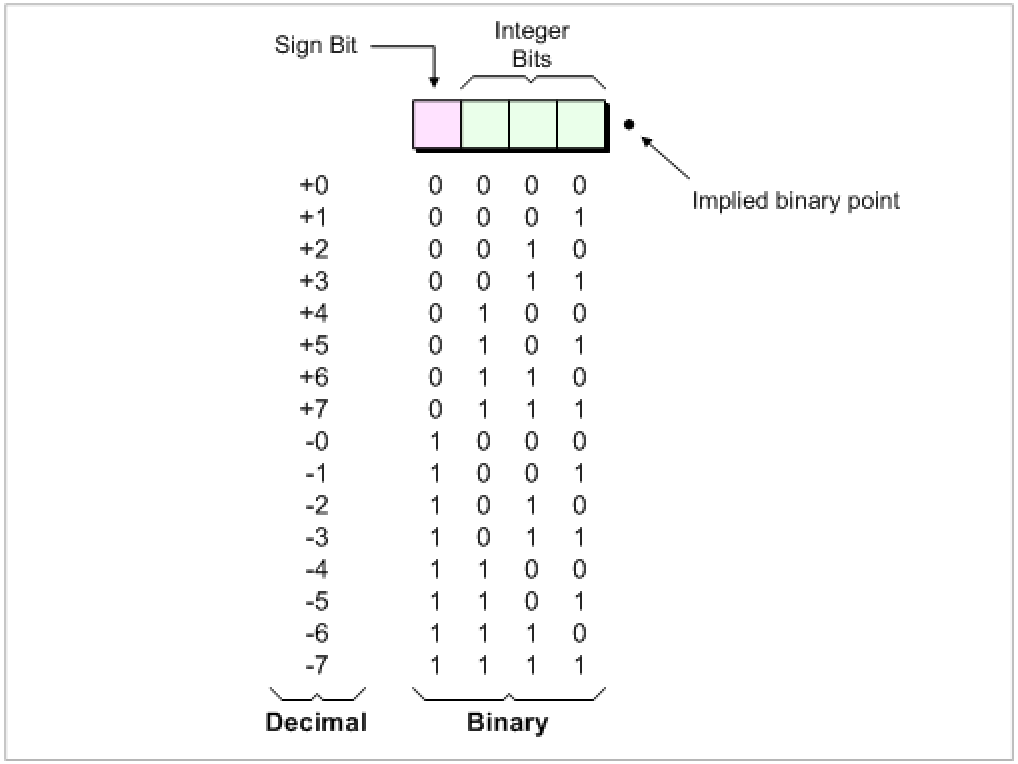
```
a=a+1;
a+=1;
a++;
++a;
```

"Concise operators" are generally better to use

a+=c ↔ a=a+c

a*=scale ↔ a=a*scale

Integer representation



Decimal	Binary			
+0	0	0	0	0
+1	0	0	0	1
+2	0	0	1	0
+3	0	0	1	1
+4	0	1	0	0
+5	0	1	0	1
+6	0	1	1	0
+7	0	1	1	1
-0	1	0	0	0
-1	1	0	0	1
-2	1	0	1	0
-3	1	0	1	1
-4	1	1	0	0
-5	1	1	0	1
-6	1	1	1	0
-7	1	1	1	1

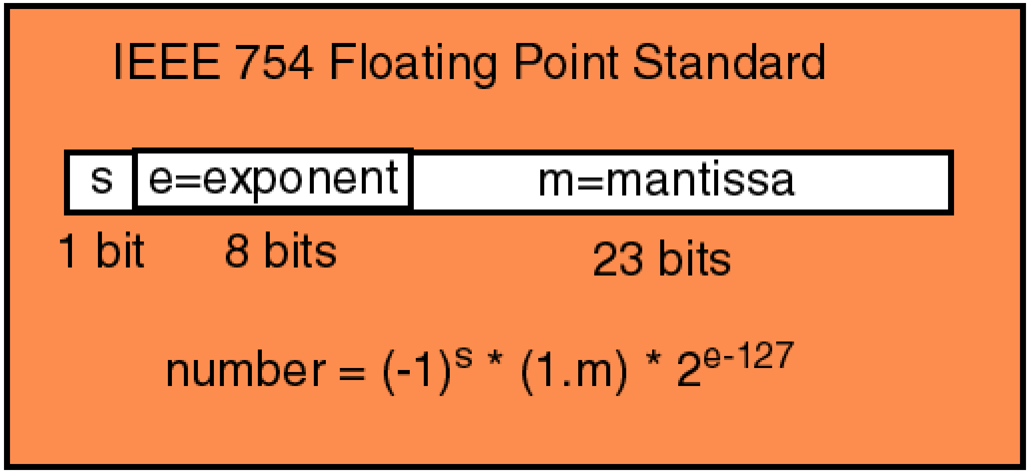
int - max value = 2^{31} - 1
unsigned int - max value = 2^{32} - 1

```
int a = 4; // coded    ...000100
a=a<<3; // coded    ...100000
cout<<"a="<<a<<endl;
a=32
```

Bitwise operators ***not only applicable to integers***	
&	AND
|	OR
^	XOR (exclusive or)
~	NOT – inversion of the bit
<<	Left shift
>>	Right shift

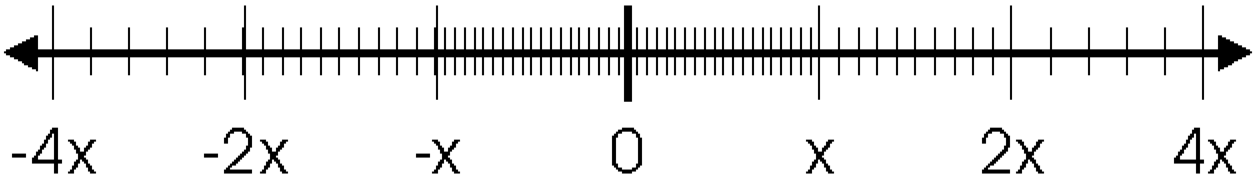
Floating Point representation

- Real (float & double) are actual mainly represented using floating point representation following the norm IEEE-754.
- Representation: $\mathbf{(-1)^s \times m \times b^{e-E}}$
    - S: sign
    - M: mantissa
    - B: base
    - E: exponent
- Reals are obviously discretely represented on computers
- Absolute precision evolve with the value of the variable



IEEE 754 Floating Point Standard

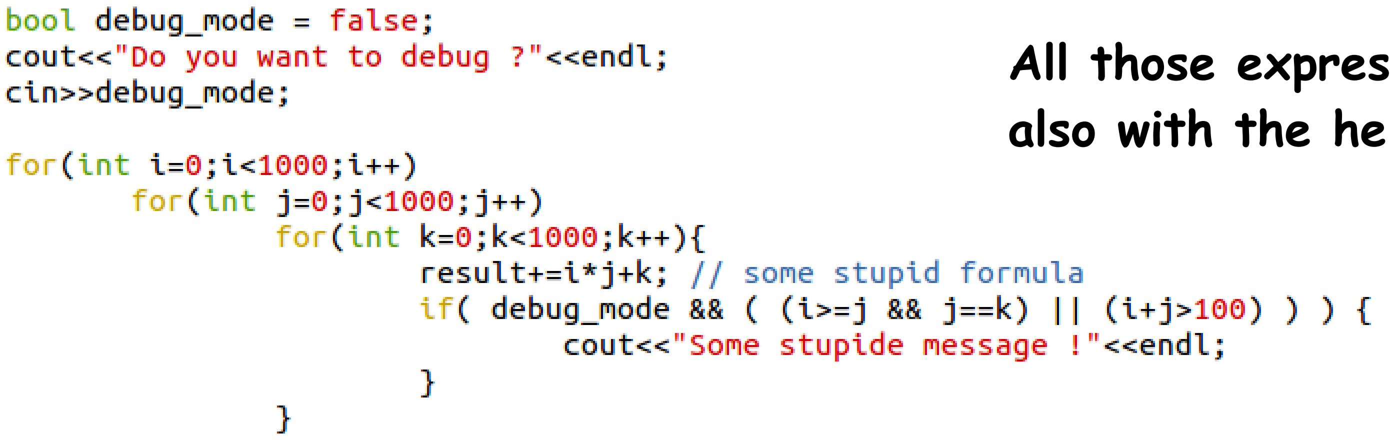
number = $(-1)^s * (1.m) * 2^{e-127}$



Expressions

Boolean type expression

Equality operators	==	equal
	!=	Not equal
Logical operators	&&	and
	||	or
	!	not
Relation operators	<	Less than
	<=	Less than or equal
	>	Greater than
	>=	Greater than or equal



```
bool debug_mode = false;
cout<<"Do you want to debug ?"<<endl;
cin>>debug_mode;

for(int i=0;i<1000;i++)
        for(int j=0;j<1000;j++)
                for(int k=0;k<1000;k++){
                        result+=i*j+k; // some stupid formula
                        if( debug_mode && ( (i>=j && j==k) || (i+j>100) ) ) {
                                cout<<"Some stupide message !"<<endl;
                        }
                }
```

All those expressions can be combined also with the help of ()

Precision & numerical uncertainty

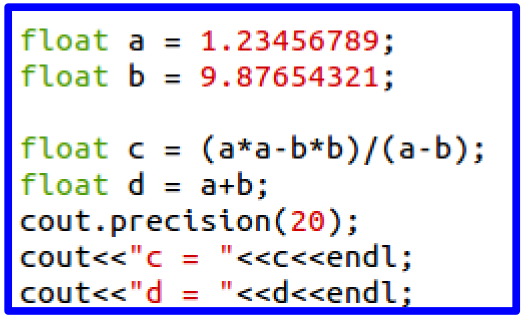
- Representation
  - The value you could want to represent might not be represented (*approximation*)

```
Float a = 1;
Float b = 3;
Float c = a/b
cout<<"c="<<c<<endl;
c=3.3333333333333315e-01
```

- Truncation
  - The result of a computation involving two well defined represented numbers can lead to a truncated number
- "Reduced" variable (close to 1)
  - This is equivalent to performance a change of variable with dimensionless variable
  - Subtraction of two variables having big difference will lead to a high uncertainty
- Expressions being analytically equal will not necessarily give the same numerical results
  - First step before implementing

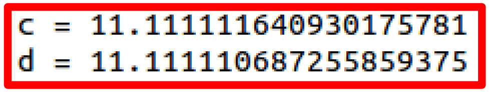
    a formula is to choose the

    the ***better*** expression (lowest uncert.)



```
float a = 1.23456789;
float b = 9.87654321;

float c = (a*a-b*b)/(a-b);
float d = a+b;
cout.precision(20);
cout<<"c = "<<c<<endl;
cout<<"d = "<<d<<endl;
```

$(a^2-b^2)/(a-b)\,!\!=(a+b)$?



```
c = 11.111116409301757781
d = 11.11110687255859375
```

Precision & numerical uncertainty

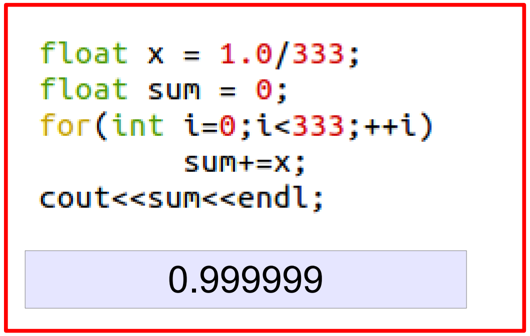
Precautions & tests:

- **Division by zero**:
  - *will lead to a crash – test the denominator first*
- **Division of integer**
  - Ex: float a = 1/3; // a = 0 !! - *at least numerator of denominator should be an float*
- **Equality test of reals**
  - It might be better to test a small difference ε between the two variables (truncature pb)

Stl offers tools to perform test on numbers

- **Isinf** // test for infinite
- **Isnan** // NAN = Not A Number
  // all combinations of bits doesn't represent a number (float/double)
- ...

Simple examples

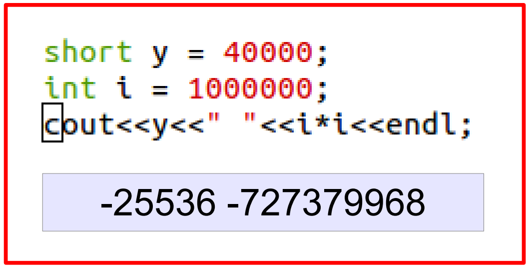


```
float x = 1.0/333;
float sum = 0;
for(int i=0;i<333;++i)
        sum+=x;
cout<<sum<<endl;
```

```
0.999999
```

Floating-point numbers are approximation of real numbers

➨ Can lead to **numerical errors** (quantification?)



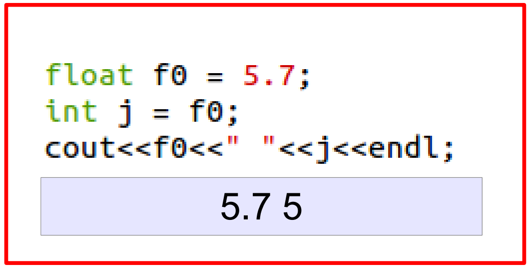
```
short y = 40000;
int i = 1000000;
cout<<y<<" "<<i*i<<endl;
```

```
-25536 -727379968
```

Integer types represent integer up to a certain limit

➨ **Overflow problem**

Integer and real numbers are infinite while the number of bits to represent is definitively finite !
Remember this while applying numerical methods



```
float f0 = 5.7;
int j = f0;
cout<<f0<<" "<<j<<endl;
```

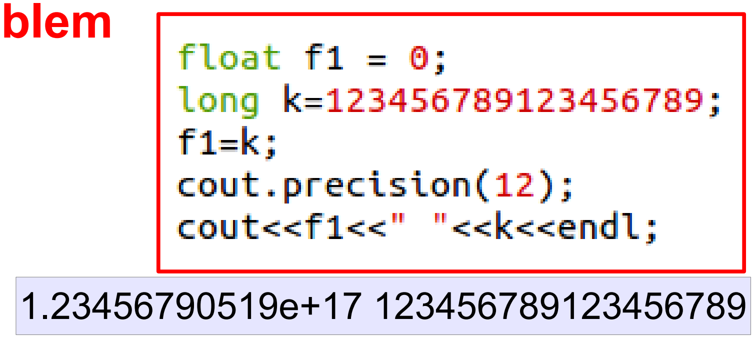
```
5.7 5
```

Implicit conversion float to integer

➨ **truncature problem**

Lost of precision for large integer values

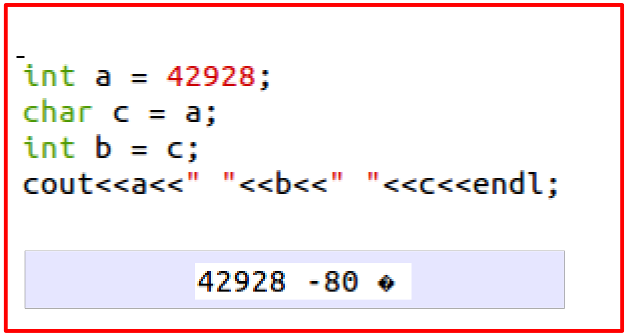
➨ **troncature problem**



```
float f1 = 0;
long k=123456789123456789;
f1=k;
cout.precision(12);
cout<<f1<<" "<<k<<endl;
```

```
1.23456790519e+17 123456789123456789
```

Type-safety violation

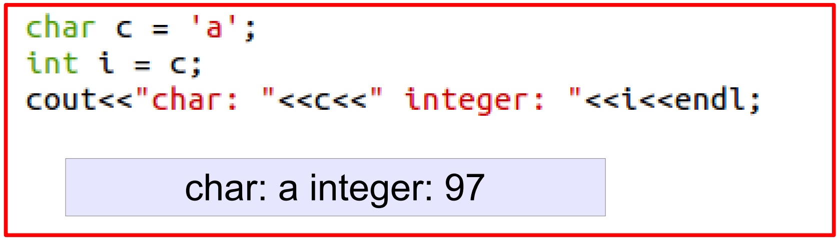


```
int a = 42928;
char c = a;
int b = c;
cout<<a<<" "<<b<<" "<<c<<endl;
```

```
42928 -80 ◆
```

C++ doesn't prevent you from trying to put a large value into a small variable (though a compiler may warm)

- **Implicit narrowing**



```
char c = 'a';
int i = c;
cout<<"char: "<<c<<" integer: "<<i<<endl;
```

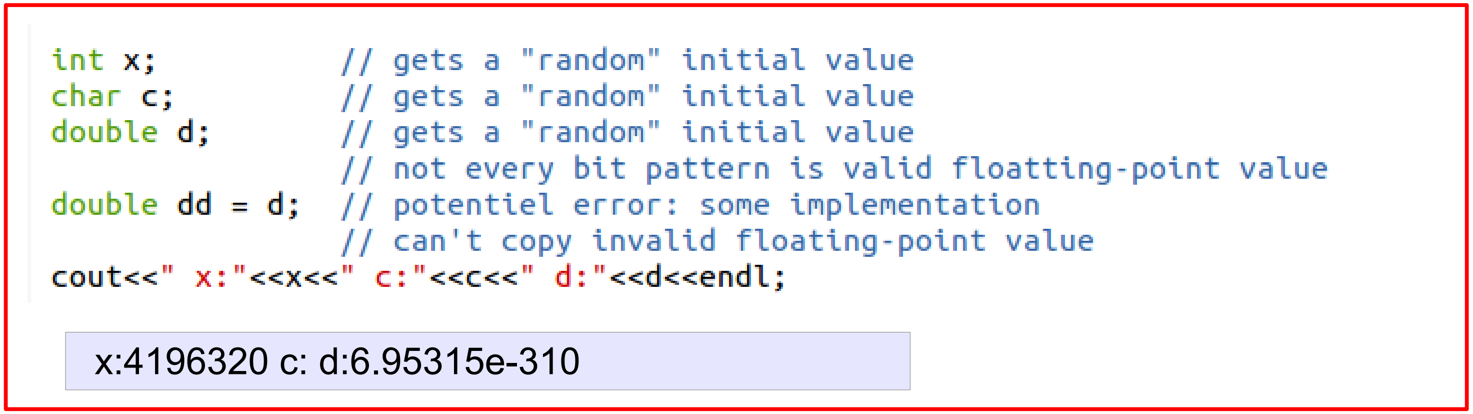
```
char: a integer: 97
```

In memory, everything is just bits: **01100001**

Type is what gives meaning to bits:

01100001 is the **char** 'a'

01100001 is the **integer** 97



```
int x;          // gets a "random" initial value
char c;         // gets a "random" initial value
double d;       // gets a "random" initial value
                // not every bit pattern is valid floatting-point value
double dd = d;  // potentiel error: some implementation
                // can't copy invalid floating-point value
cout<<" x:"<<x<<" c:"<<c<<" d:"<<d<<endl;
```

```
x:4196320 c: d:6.95315e-310
```

- **Always initialize your variable !!**
- **Valid exception**: input variable

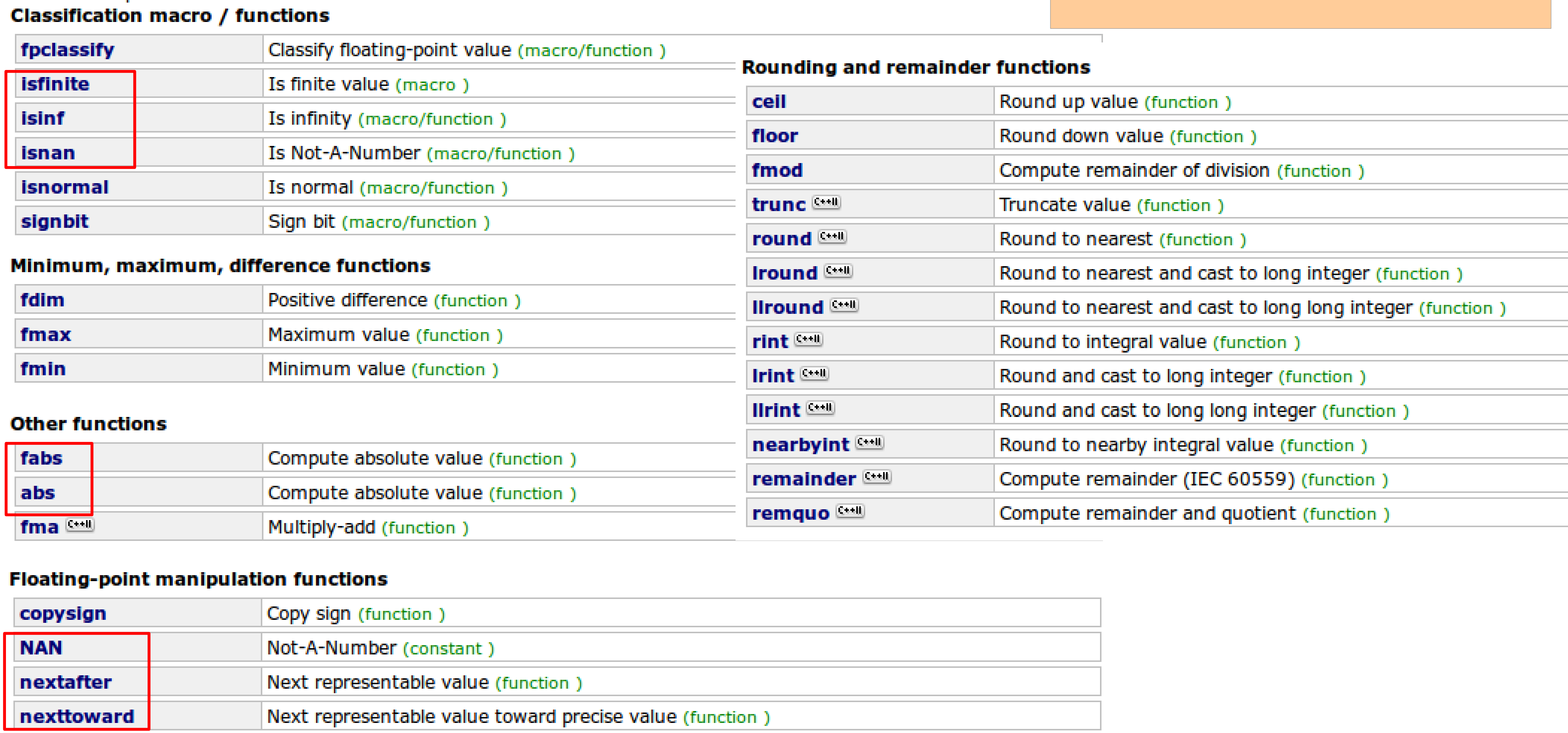
STL: Standard Template Library

- C++ offers a very useful library than can be used: STL
- It offers solutions in various aspects:
  - Defining containers
  - Providing algorithms
  - Input/Output
  - More details later in the course
- Most of the “tools” (variables, functions, classes,...) are defined in the **namespace** std
- To give access to those functionalities, one need to include file
  - Ex: #include <iostream>
- To use it, one need to specify the namespace
  - Ex: std::cout
  - Or using namespace std; and then cout (no need to precise the namespace)

Numerics: standard functions

There are already a lot of "tools" in the STL that can helps you in your implementation (and tests)

Headers:
#include <cmath>



Classification macro / functions

fpclassify	Classify floating-point value (macro/function)
isfinite	Is finite value (macro)
isinf	Is infinity (macro/function)
isnan	Is Not-A-Number (macro/function)
isnormal	Is normal (macro/function)
signbit	Sign bit (macro/function)

Minimum, maximum, difference functions

fdim	Positive difference (function)
fmax	Maximum value (function)
fmin	Minimum value (function)

Other functions

fabs	Compute absolute value (function)
abs	Compute absolute value (function)
fma C++11	Multiply-add (function)

Rounding and remainder functions

ceil	Round up value (function)
floor	Round down value (function)
fmod	Compute remainder of division (function)
trunc C++11	Truncate value (function)
round C++11	Round to nearest (function)
lround C++11	Round to nearest and cast to long integer (function)
llround C++11	Round to nearest and cast to long long integer (function)
rint C++11	Round to integral value (function)
lrint C++11	Round and cast to long integer (function)
llrint C++11	Round and cast to long long integer (function)
nearbyint C++11	Round to nearby integral value (function)
remainder C++11	Compute remainder (IEC 60559) (function)
remquo C++11	Compute remainder and quotient (function)

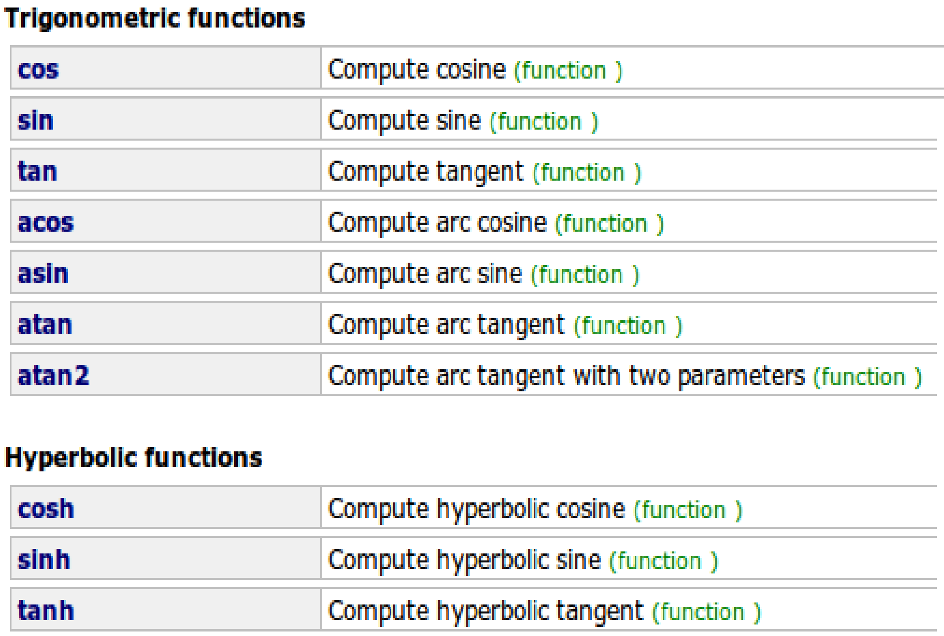
Floating-point manipulation functions

copysign	Copy sign (function)
NAN	Not-A-Number (constant)
nextafter	Next representable value (function)
nexttoward	Next representable value toward precise value (function)

From http://www.cplusplus.com/reference/cmath/

Mathematical libraries: standard functions

Headers:
#include <cmath>

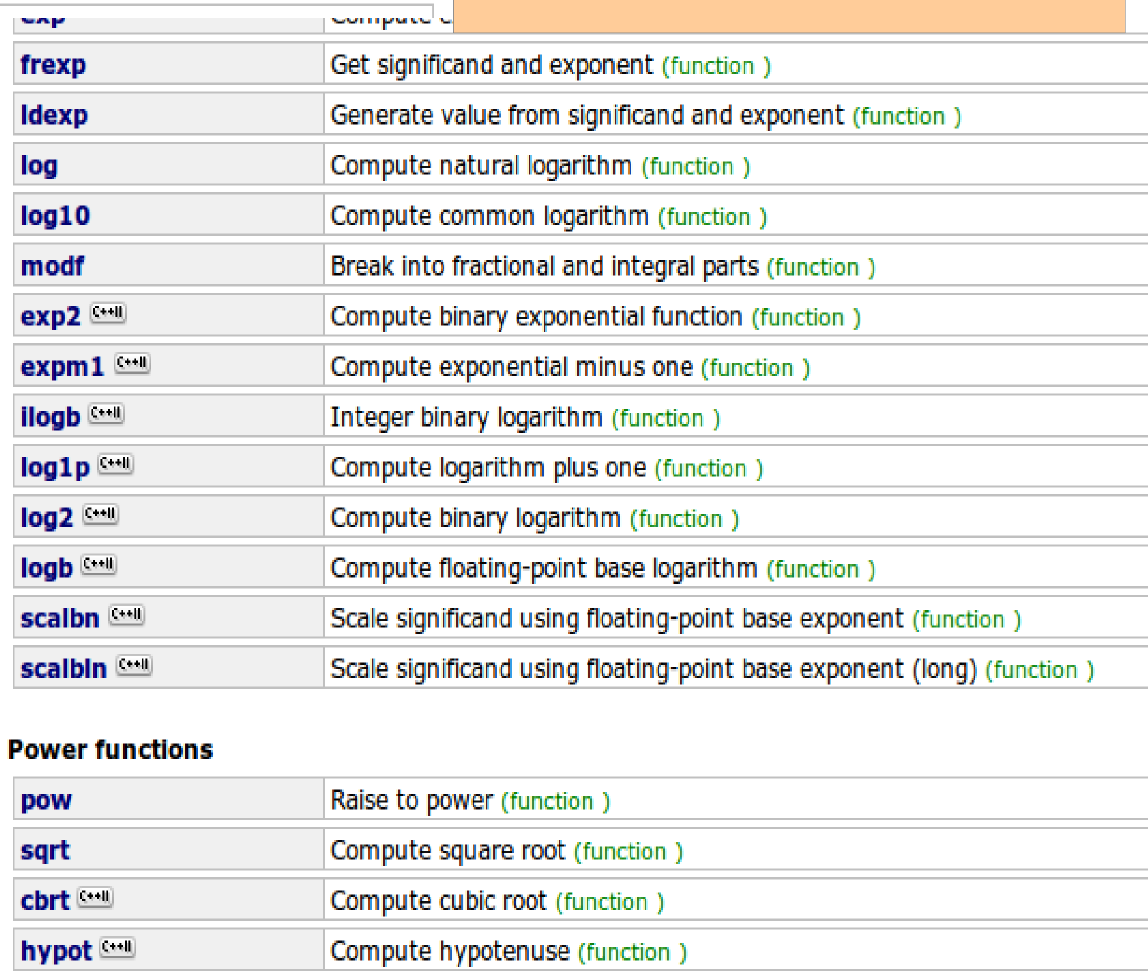


Trigonometric functions

cos	Compute cosine (function)
sin	Compute sine (function)
tan	Compute tangent (function)
acos	Compute arc cosine (function)
asin	Compute arc sine (function)
atan	Compute arc tangent (function)
atan2	Compute arc tangent with two parameters (function)

Hyperbolic functions

cosh	Compute hyperbolic cosine (function)
sinh	Compute hyperbolic sine (function)
tanh	Compute hyperbolic tangent (function)



frexp	Get significand and exponent (function)
ldexp	Generate value from significand and exponent (function)
log	Compute natural logarithm (function)
log10	Compute common logarithm (function)
modf	Break into fractional and integral parts (function)
exp2 C++11	Compute binary exponential function (function)
expm1 C++11	Compute exponential minus one (function)
ilogb C++11	Integer binary logarithm (function)
log1p C++11	Compute logarithm plus one (function)
log2 C++11	Compute binary logarithm (function)
logb C++11	Compute floating-point base logarithm (function)
scalbn C++11	Scale significand using floating-point base exponent (function)
scalbln C++11	Scale significand using floating-point base exponent (long) (function)

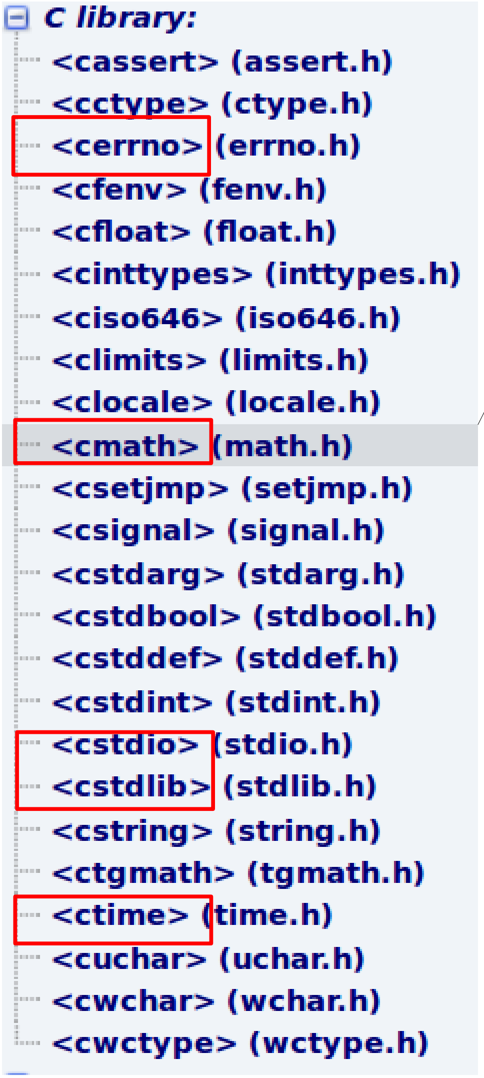
Power functions

pow	Raise to power (function)
sqrt	Compute square root (function)
cbrt C++11	Compute cubic root (function)
hypot C++11	Compute hypotenuse (function)

You've certainly already used some of them.
Other are less well know but might be useful for you in a future project ...

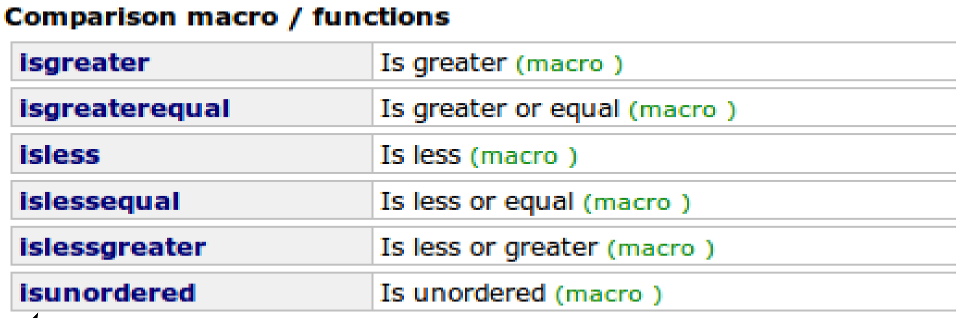
Do not reinvent the wheel !

*A lot of things are already available in the **stl***



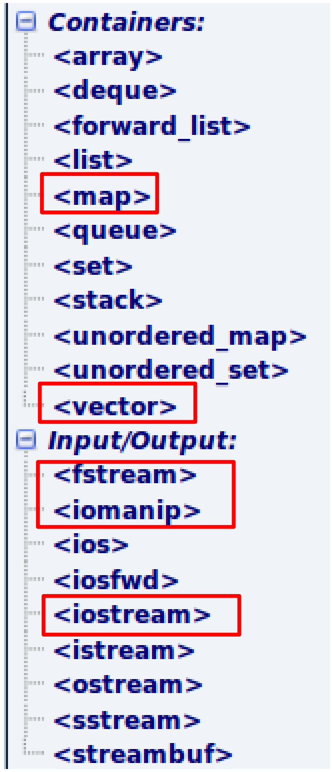
C library:

- <cassert> (assert.h)
- <cctype> (ctype.h)
- <cerrno> (errno.h)
- <cfenv> (fenv.h)
- <cfloat> (float.h)
- <cinttypes> (inttypes.h)
- <ciso646> (iso646.h)
- <climits> (limits.h)
- <clocale> (locale.h)
- <cmath> (math.h)
- <csetjmp> (setjmp.h)
- <csignal> (signal.h)
- <cstdarg> (stdarg.h)
- <cstdbool> (stdbool.h)
- <cstddef> (stddef.h)
- <cstdint> (stdint.h)
- <cstdio> (stdio.h)
- <cstdlib> (stdlib.h)
- <cstring> (string.h)
- <ctgmath> (tgmath.h)
- <ctime> (time.h)
- <cuchar> (uchar.h)
- <cwchar> (wchar.h)
- <cwctype> (wctype.h)



Comparison macro / functions

isgreater	Is greater (macro)
isgreaterequal	Is greater or equal (macro)
isless	Is less (macro)
islessequal	Is less or equal (macro)
islessgreater	Is less or greater (macro)
isunordered	Is unordered (macro)

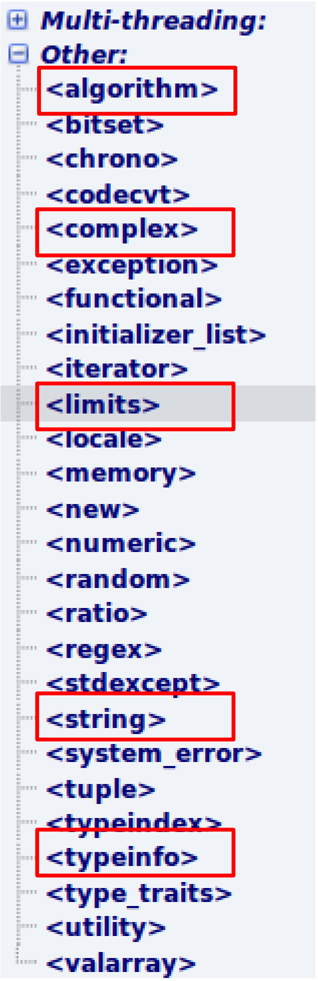


Containers:

- <array>
- <deque>
- <forward_list>
- <list>
- <map>
- <queue>
- <set>
- <stack>
- <unordered_map>
- <unordered_set>
- <vector>

Input/Output:

- <fstream>
- <iomanip>
- <ios>
- <iosfwd>
- <iostream>
- <istream>
- <ostream>
- <sstream>
- <streambuf>



Multi-threading:

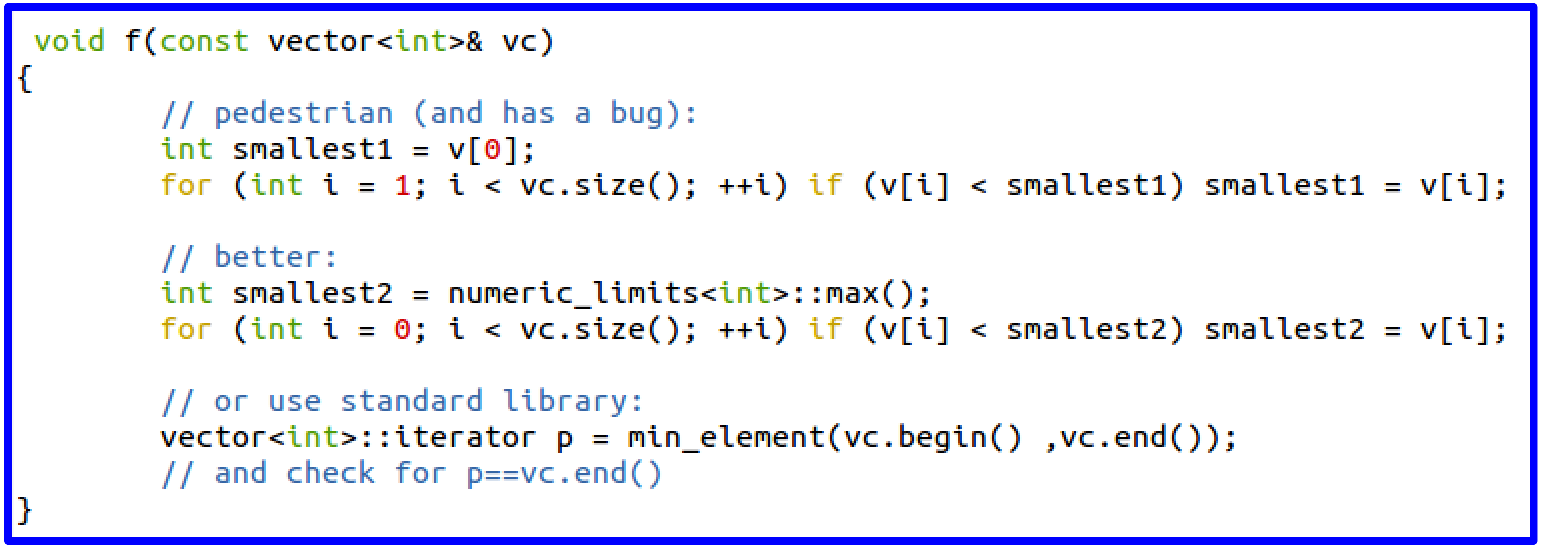
Other:

- <algorithm>
- <bitset>
- <chrono>
- <codecvt>
- <complex>
- <exception>
- <functional>
- <initializer_list>
- <iterator>
- <limits>
- <locale>
- <memory>
- <new>
- <numeric>
- <random>
- <ratio>
- <regex>
- <stdexcept>
- <string>
- <system_error>
- <tuple>
- <typeindex>
- <typeinfo>
- <type_traits>
- <utility>
- <valarray>

A simple example

Let's consider the problem of looking to the smallest element of a std::vector

#include <vector>



```
 void f(const vector<int>& vc)
{
        // pedestrian (and has a bug):
        int smallest1 = v[0];
        for (int i = 1; i < vc.size(); ++i) if (v[i] < smallest1) smallest1 = v[i];

        // better:
        int smallest2 = numeric_limits<int>::max();
        for (int i = 0; i < vc.size(); ++i) if (v[i] < smallest2) smallest2 = v[i];

        // or use standard library:
        vector<int>::iterator p = min_element(vc.begin() ,vc.end());
        // and check for p==vc.end()
}
```

#include <limit>

#include <algorithm>

A lot of "common problems" have been treated and implemented by more experimented C++ developer that you:

Why won't we use their tools ?

Once you have a project, first check on the existing tools (lib) if a solution have been already developed.

If yes, it will let you know time to concentrate on the specificity of your current project and also time to analyze your results !

Const variables

It is not a good idea to have “magic numbers”, “hardcoded values”.
When reviewing your codes, you should change them (better to be done at first implementation)

Many possibilities:

- The value is a *parameter*:
  - user can change it (cin, file, ...)

```
Int nof_channels = 0;
cout<<”Enter the number of channel:”<<endl;
cin>>nof_channels;
```

- The value is redefining by a macro alias:

```
#define NOF_CHANNELS 12
```

- The value can be a constant !

```
const int nof_channels = 12;
```

  - Initialization should come with definition
  - The value is protected and could not be changed later on the program
  - Attempts to change the value will lead to compilation error

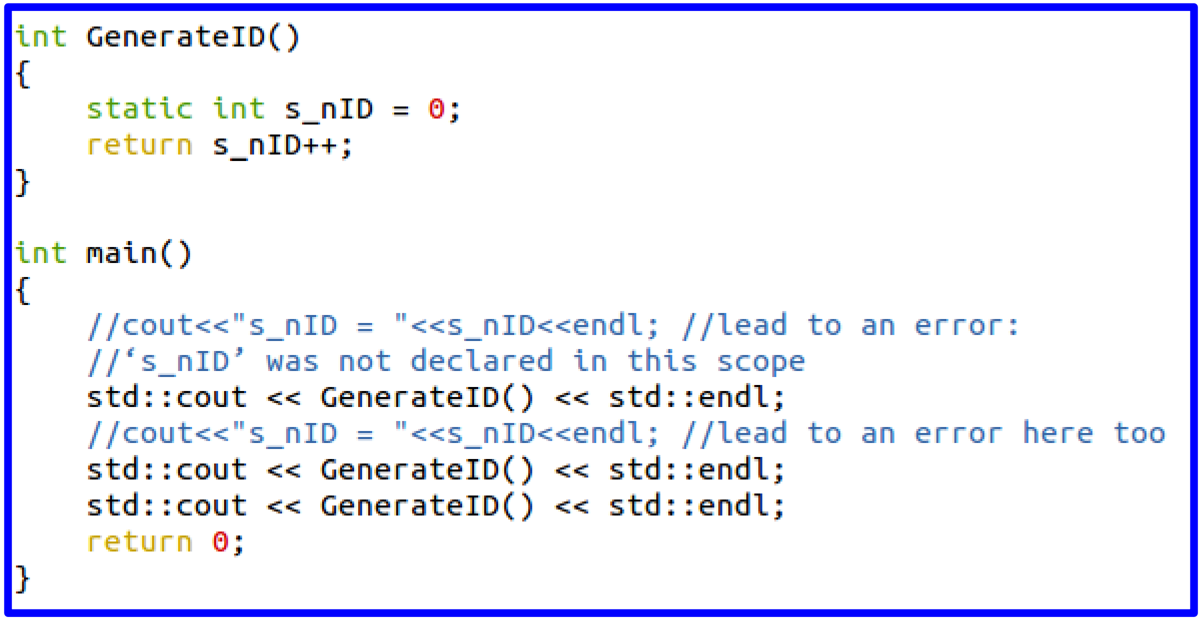
It is useful to define as const variables many kind of variables:

- mathematical/physical constants: π, G, ε_0
- constants variables of your software: *number of channels, ...*

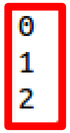
It helps for the **meaning**: *12 doesn't mean anything while nof_channels does !*
It avoid numerical **problems**:having dependent on the number of digits: 3.14!=3.14159265

Static variable

- **Static variables** keep their values and are not destroyed even after they go out of scope
  - Can be useful for incrementation by example



```
int GenerateID()
{
    static int s_nID = 0;
    return s_nID++;
}

int main()
{
    //cout<<"s_nID = "<<s_nID<<endl; //lead to an error:
    //‘s_nID’ was not declared in this scope
    std::cout << GenerateID() << std::endl;
    //cout<<"s_nID = "<<s_nID<<endl; //lead to an error here too
    std::cout << GenerateID() << std::endl;
    std::cout << GenerateID() << std::endl;
    return 0;
}
```



```
0
1
2
```

Coding rules: name of variables

- C++ Rules:
  - starts with a letter
  - *only* contains letters,digits, underscores
  - cannot use *keywords* names (if, int, ...)

Are forbidden:
- _x
- 12x
- Time.Acquisition@CERN
- My Variable
- ...

- Recommendations
  - Choose meaningful names
    - Avoid confusing abbreviations and acronyms
    - Use conventions (i,j,k as loop indexes by example)
  - Avoid overly long names

the_number_of_channels // *too long*
nof_channels // *shorter and meaningful*
Nofc; // *what does it mean ??*

  - You could define your own rules (or the own of your team)
    - Use of capital letters, underscore
    - Examples
      - ROOT class names starts with a “T” (ex:**T**Graph)
      - variable with a “f” (ex: **f**Entries)
      - Accessors starts with “Get” (ex: histo->**Get**Xaxis())

Instructions

Selection (if/else)

```
if( test){
     Instructions1;
}
elsif(test2){ // optional
     Instructions2;
}
else{
     Instructions3;
} // brackets not needed if
  // there is only one line

Ex: if(a>b) max=a;
     else max=b;
```

Condensed syntax

```
 test ? Inst1: Inst2 ;

Ex: (a>b)? max=a: max=b;
```

Loop: for

```
for(initialize,condition,increment){
     instructions;
}
Initialize: ex: int i=0;
Condition: ex: i<10
Increment: ex: i++ (i=0 at it. 1)
                ++i (i=1 at it. 1)
```

For is used when the number of Iterations is well defined

(ex: summation of all elements of an array/vector)

Loop: while

```
while(condition){
     Instructions;
}
```

While is mandatory when the number of Iterations is not know before running time

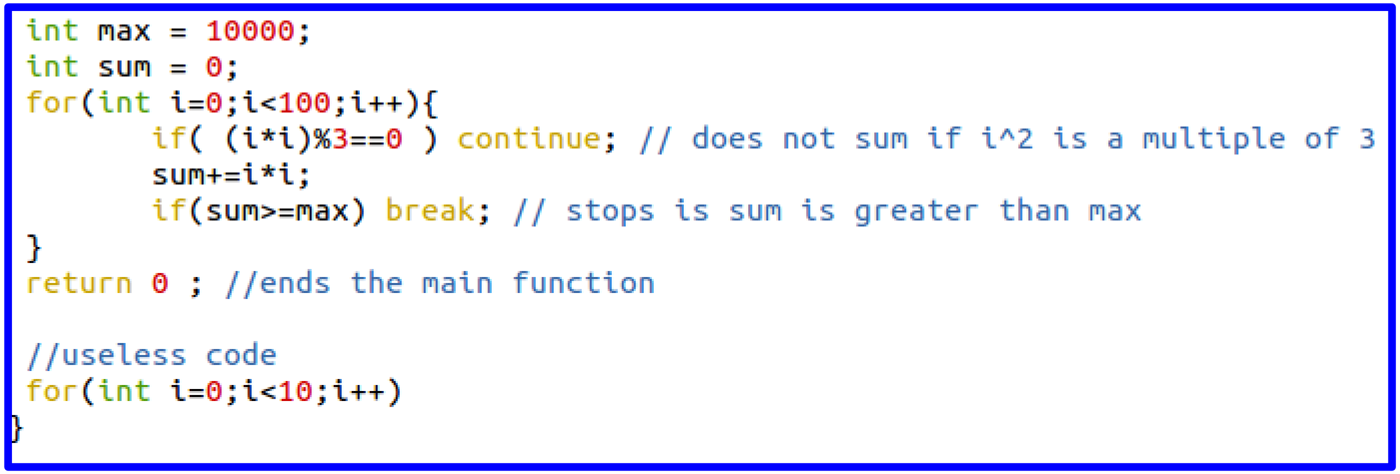
(ex: minimization problem)

```
do{
     Instructions;
}
while(condition)
```

Ensure that instructions are run at least once

Control commands

- Break
  - Allow to stop a loop
- Continue
  - Allow to bypass a section of code
  - Used in loops to go directly to next iteration
- Return
  - Ends a function (Ex: main)
  - Can be followed by a variable

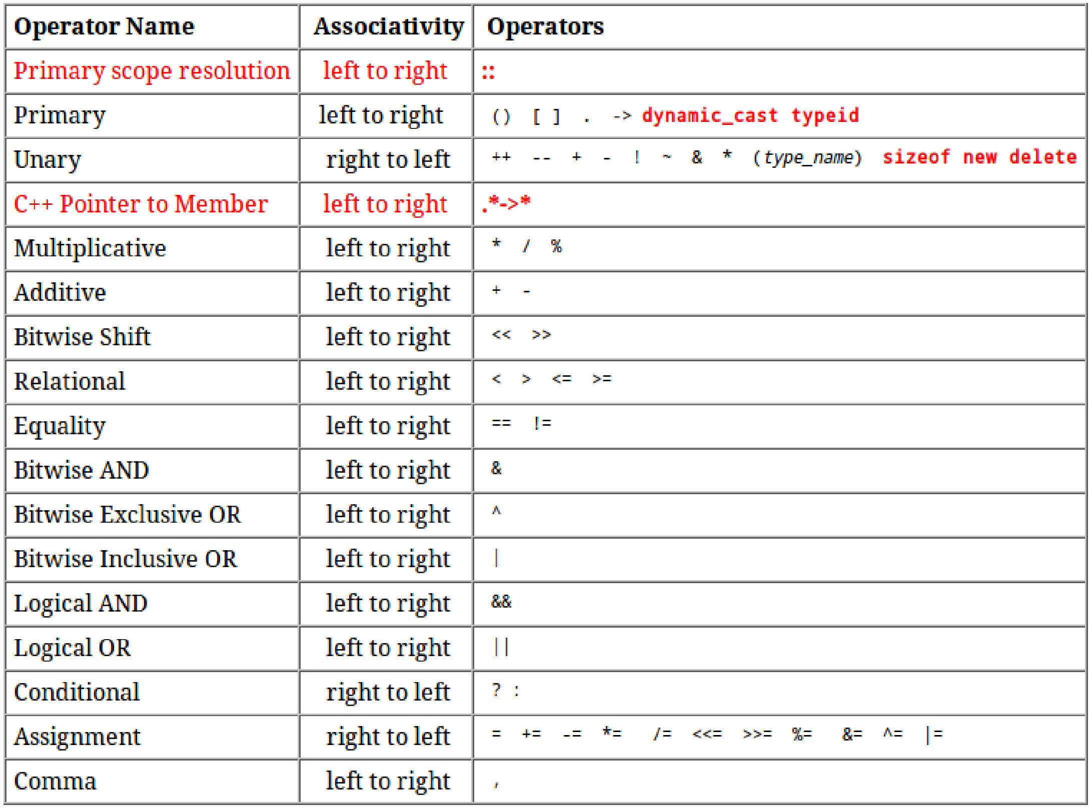


```
int max = 10000;
int sum = 0;
for(int i=0;i<100;i++){
        if( (i*i)%3==0 ) continue; // does not sum if i^2 is a multiple of 3
        sum+=i*i;
        if(sum>=max) break; // stops is sum is greater than max
}
return 0 ; //ends the main function

//useless code
for(int i=0;i<10;i++)
}
```

Precedence and associativity

- Operator precedence determines which operator will be performed first in a group of operators with different precedences
  - Ex: *5+3*2 computed as 5+(3*2) = 11 ant not (5+3)*2 = 16*
- The operator associativity rules define the order in which adjacent operators with the same precedence level are evaluated
  - 8-3-2 computed as (8-3)-2=3 and not 8-(3-2)=7

Max priority



Operator Name	Associativity	Operators
Primary scope resolution	left to right	::
Primary	left to right	() [ ] . -> dynamic_cast typeid
Unary	right to left	++ -- + - ! ~ & * (*type_name*) sizeof new delete
C++ Pointer to Member	left to right	.*->*
Multiplicative	left to right	* / %
Additive	left to right	+ -
Bitwise Shift	left to right	<< >>
Relational	left to right	< > <= >=
Equality	left to right	== !=
Bitwise AND	left to right	&
Bitwise Exclusive OR	left to right	^
Bitwise Inclusive OR	left to right	|
Logical AND	left to right	&&
Logical OR	left to right	||
Conditional	right to left	? :
Assignment	right to left	= += -= *= /= <<= >>= %= &= ^= |=
Comma	left to right	,

- To ensure that you're calculus will be performed as you expected, you can always add **parentheses**.
- Nevertheless it is better to not “overload” you code with unnecessary ()

From http://n.ethz.ch/~werdemic/download/week3/C++%20Precedence.html

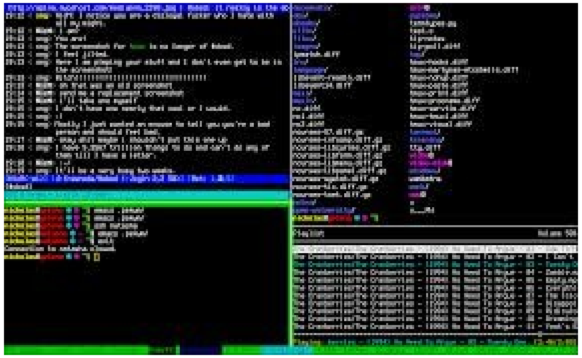
Input/Output

INPUT:

- Keyboard (***default***)
- Files
- Data base
- Other input device
- Other programs
- Other part of a program

Code

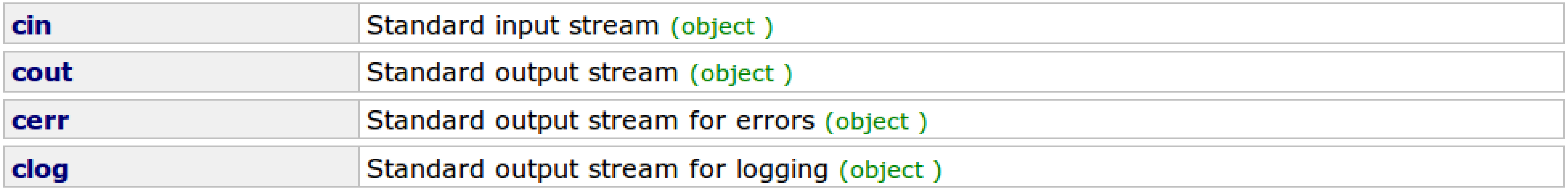
Make some **computation** partially based on the input (if any) and produce an output !



OUTPUT:

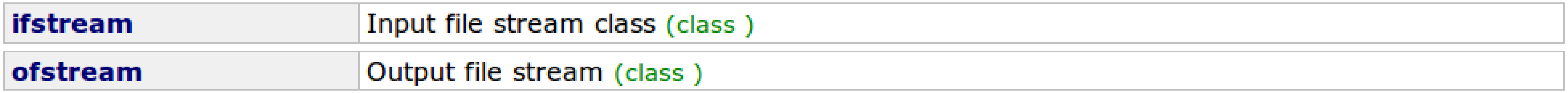
- Screen (***default***)
- Files
- Data base
- Other input device
- Other programs
- Other part of a program

Input and Output



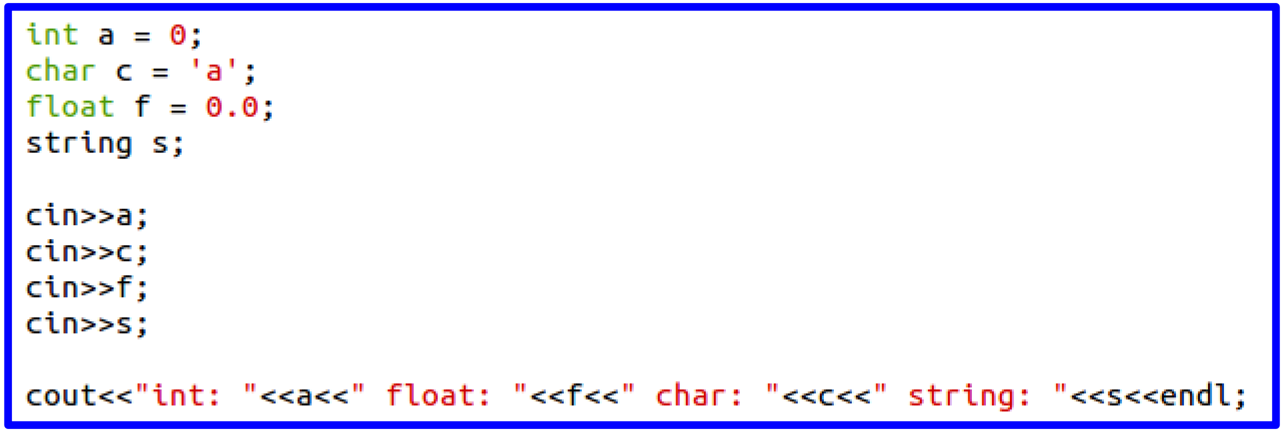
cin	Standard input stream (object)
cout	Standard output stream (object)
cerr	Standard output stream for errors (object)
clog	Standard output stream for logging (object)

```
./prog.exe   > log.stdout        # redirect only cout streams
./prog.exe 1> log.stdout        # idem

./prog.exe 2>log.stderr          #redirect cerr streams
./prog.exe 2>/dev/null          #avoid having cerr streams on screen or in a fil e
./prog.exe > log.txt   2>&1      # redirect cout & cerr streams
./prog.exe  &> log.txt           #idem
```



ifstream	Input file stream class (class)
ofstream	Output file stream (class)

I/O and types



```
int a = 0;
char c = 'a';
float f = 0.0;
string s;

cin>>a;
cin>>c;
cin>>f;
cin>>s;

cout<<"int: "<<a<<" float: "<<f<<" char: "<<c<<" string: "<<s<<endl;
```

Separator can be a space or a new line

Bad input can lead to errors and stop the program

- Ex: Enter a character for an integer or a float

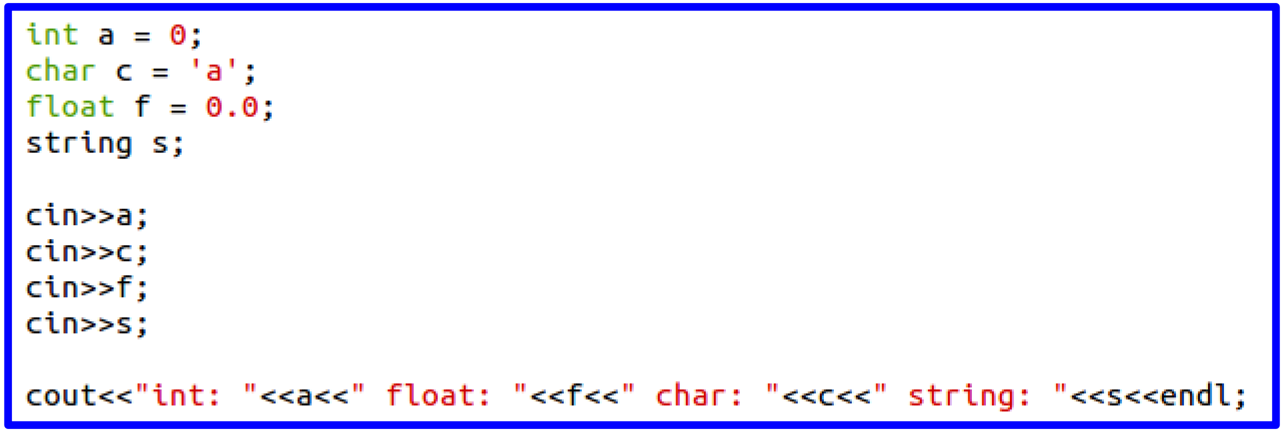
It can also lead to unexpected behaviour

- One ***should*** protect the code for this !

Correct behaviour:
Input: 1 3.4 a toto
Output: int: 1 float: 3.4 char: a string: toto
Input: 1 3.4 1 3.4
Output: int: 1 float: 3.4 char: 1 string: 3.4

“Undesired” behaviour:
Input: 1 3.4 abc toto
Output: int: 1 float: 3.4 char: a string:
Input: 1.2 a toto
Output: int: 1 float: 0.2 char: a string: toto

I/O and types



```
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char c = 'a';
float f = 0.0;
string s;

cin>>a;
cin>>c;
cin>>f;
cin>>s;

cout<<"int: "<<a<<" float: "<<f<<" char: "<<c<<" string: "<<s<<endl;
```

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Correct behaviour:

Input: 1 3.4 a toto

Output: int: 1 float: 3.4 char: a string: toto

Input: 1 3.4 1 3.4

Output: int: 1 float: 3.4 char: 1 string: 3.4

“Undesired” behaviour:

Input: 1 3.4 abc toto

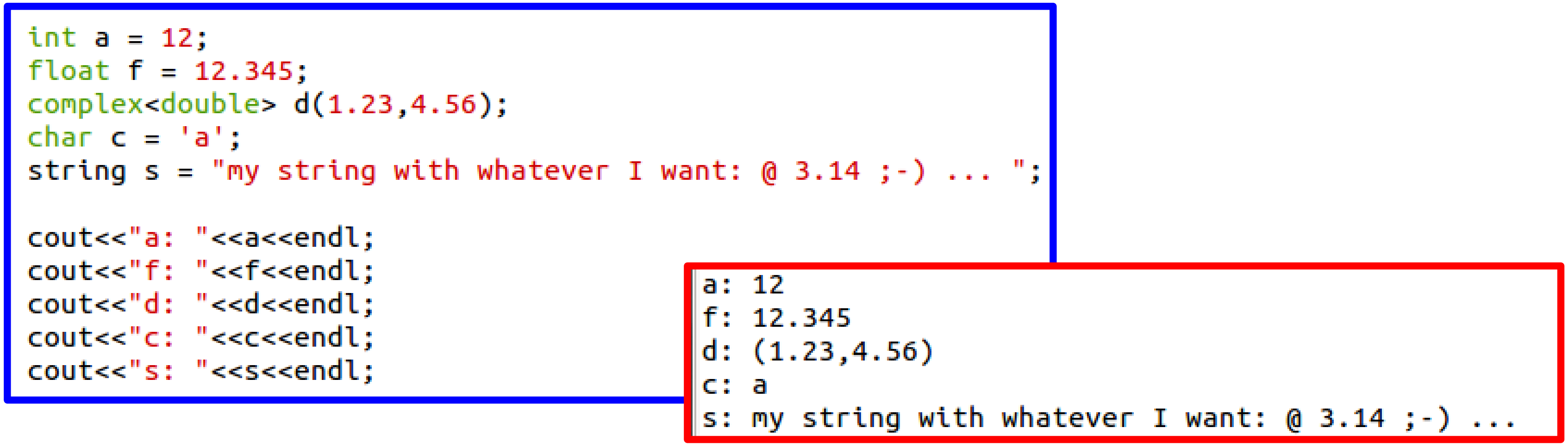
Output: int: 1 float: 3.4 char: a string:

Input: 1.2 a toto

Output: int: 1 float: 0.2 char: a string: toto

I/O types

“cout” can redirect all built-in types and some std library types (string, complex,...)

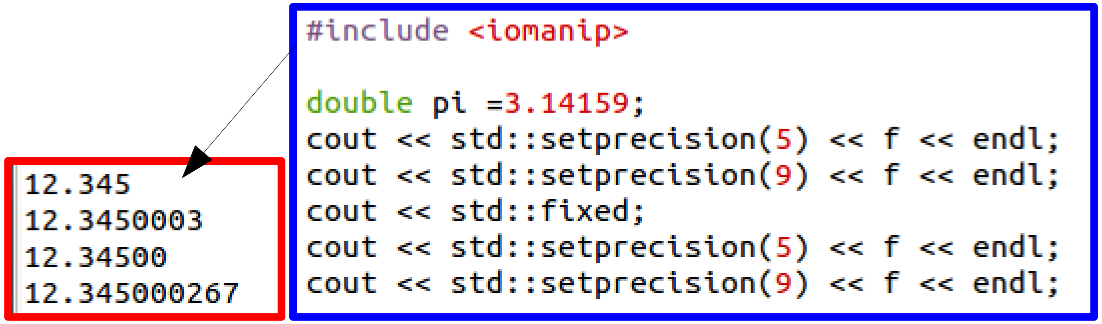


```
int a = 12;
float f = 12.345;
complex<double> d(1.23,4.56);
char c = 'a';
string s = "my string with whatever I want: @ 3.14 ;-) ... ";

cout<<"a: "<<a<<endl;
cout<<"f: "<<f<<endl;
cout<<"d: "<<d<<endl;
cout<<"c: "<<c<<endl;
cout<<"s: "<<s<<endl;
```

```
a: 12
f: 12.345
d: (1.23,4.56)
c: a
s: my string with whatever I want: @ 3.14 ;-) ...
```

<< operator can also be ***overloaded*** to any user-defined type !

- You can define the desired precision
- *Precision of the value and printing it are different things.*

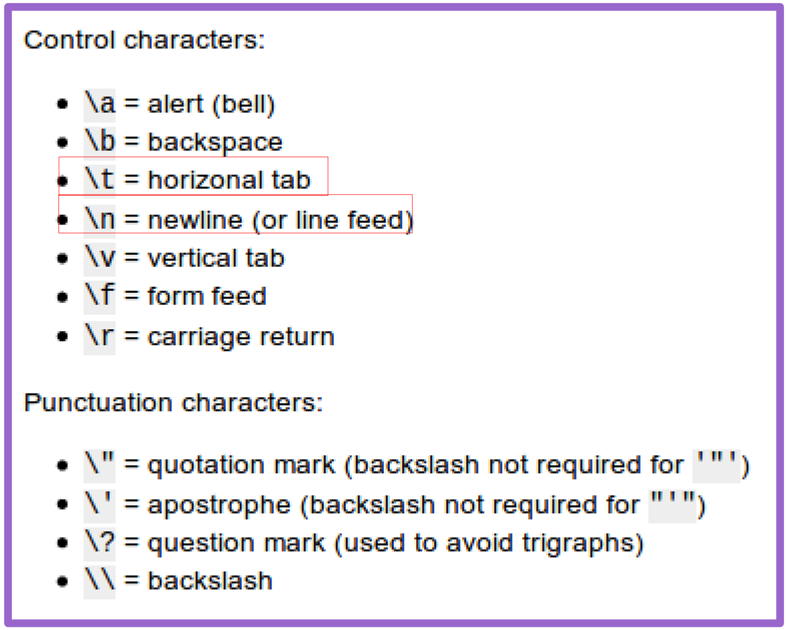


```
#include <iomanip>

double pi =3.14159;
cout << std::setprecision(5) << f << endl;
cout << std::setprecision(9) << f << endl;
cout << std::fixed;
cout << std::setprecision(5) << f << endl;
cout << std::setprecision(9) << f << endl;
```

```
12.345
12.3450003
12.34500
12.345000267
```

I/O types

List of special characters:

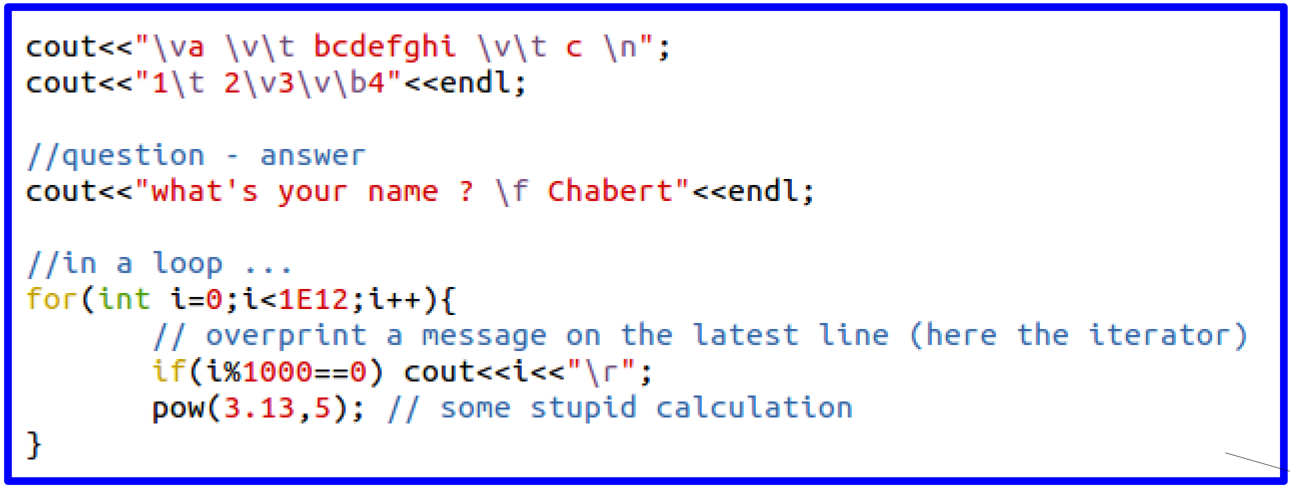


Control characters:

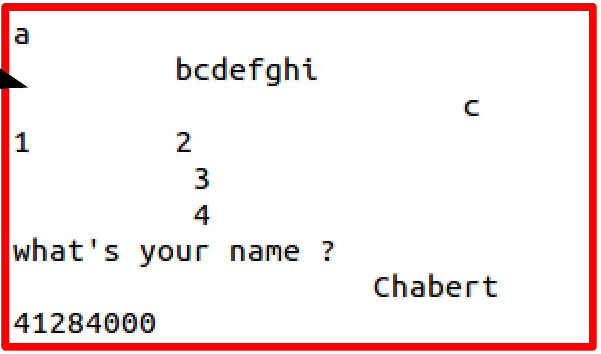
- `\a` = alert (bell)
- `\b` = backspace
- `\t` = horizonal tab
- `\n` = newline (or line feed)
- `\v` = vertical tab
- `\f` = form feed
- `\r` = carriage return

Punctuation characters:

- `\"` = quotation mark (backslash not required for `'"'`)
- `\'` = apostrophe (backslash not required for `"'"`)
- `\?` = question mark (used to avoid trigraphs)
- `\\` = backslash

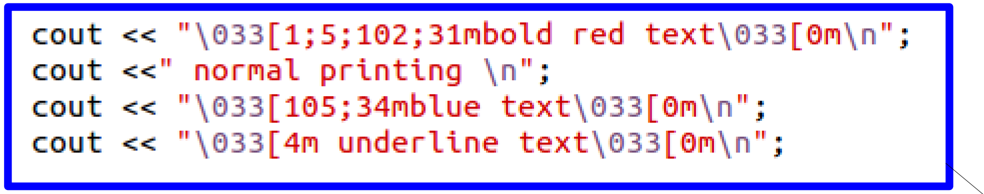


```
cout<<"\va \v\t bcdefghi \v\t c \n";
cout<<"1\t 2\v3\v\b4"<<endl;

//question - answer
cout<<"what's your name ? \f Chabert"<<endl;

//in a loop ...
for(int i=0;i<1E12;i++){
       // overprint a message on the latest line (here the iterator)
       if(i%1000==0) cout<<i<<"\r";
       pow(3.13,5); // some stupid calculation
}
```

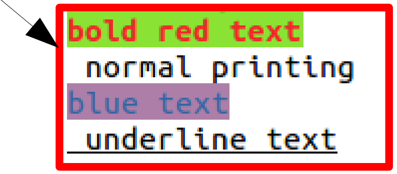


```
a
         bcdefghi
                         c
1        2
          3
          4
what's your name ?
                    Chabert
41284000
```

Go further: *Fancy cout* !

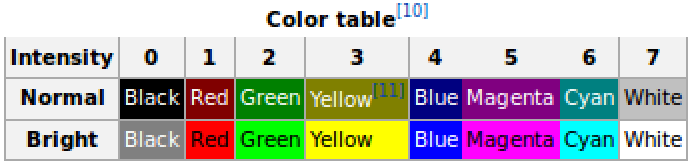


```
cout << "\033[1;5;102;31mbold red text\033[0m\n";
cout <<" normal printing \n";
cout << "\033[105;34mblue text\033[0m\n";
cout << "\033[4m underline text\033[0m\n";
```



```
bold red text
 normal printing
blue text
 underline text
```

Bold: 1
Underline: 4
Text color: 30+x
Background color: 100+x



Color table[10]

Intensity	0	1	2	3	4	5	6	7
Normal	Black	Red	Green	Yellow[11]	Blue	Magenta	Cyan	White
Bright	Black	Red	Green	Yellow	Blue	Magenta	Cyan	White

Although these features might be amazing, there are not deployed/available on all systems

This illustrates an other problem, having a **portable** code :

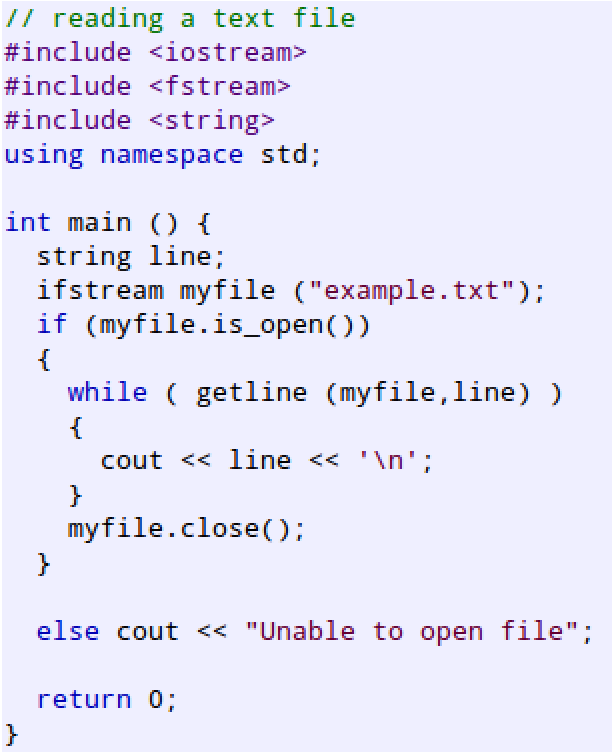
- Support on most **compilers**
- Support on most **O.S.**

This is not always a request for physicists but it depends on the case.

Files: input/output

- Input file: ifstream

#include <ifstream>



```
// reading a text file
#include <iostream>
#include <fstream>
#include <string>
using namespace std;

int main () {
  string line;
  ifstream myfile ("example.txt");
  if (myfile.is_open())
  {
    while ( getline (myfile,line) )
    {
      cout << line << '\n';
    }
    myfile.close();
  }

  else cout << "Unable to open file";

  return 0;
}
```

Reading can be performed:

- Per line: **getline()**
- Per character(s): **get()**
- Ignore characters: **ignore()**
- Read buffer: **read(), readsome()**
- Depending on a format: **operator>>**

Check state flag:

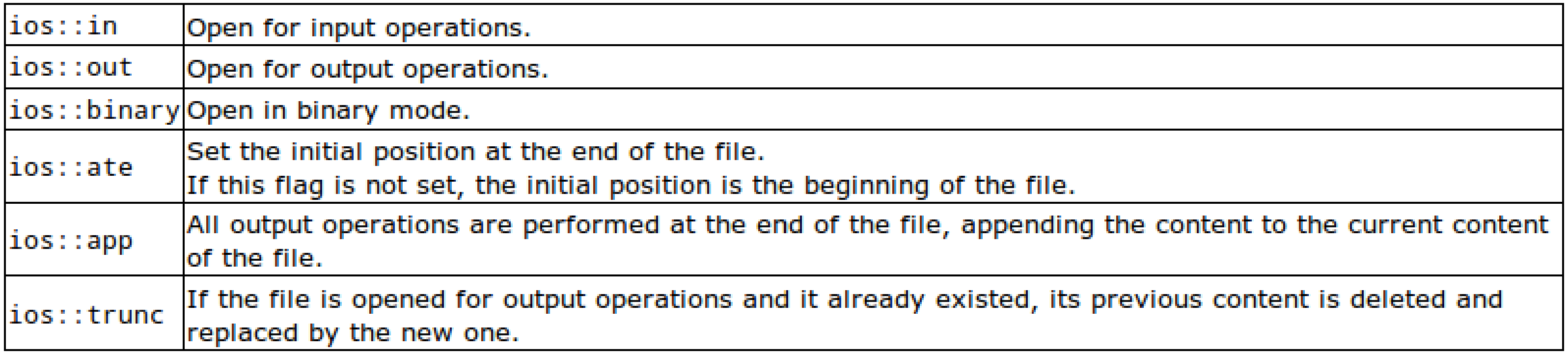
- **eof()**: check the end of file
- **good()**: state of stream is good
- **bad()**: true if a reading or writing operation fails
- **fail()**: true is bad() and if a format error happens

Many more possible options. Check documentation !

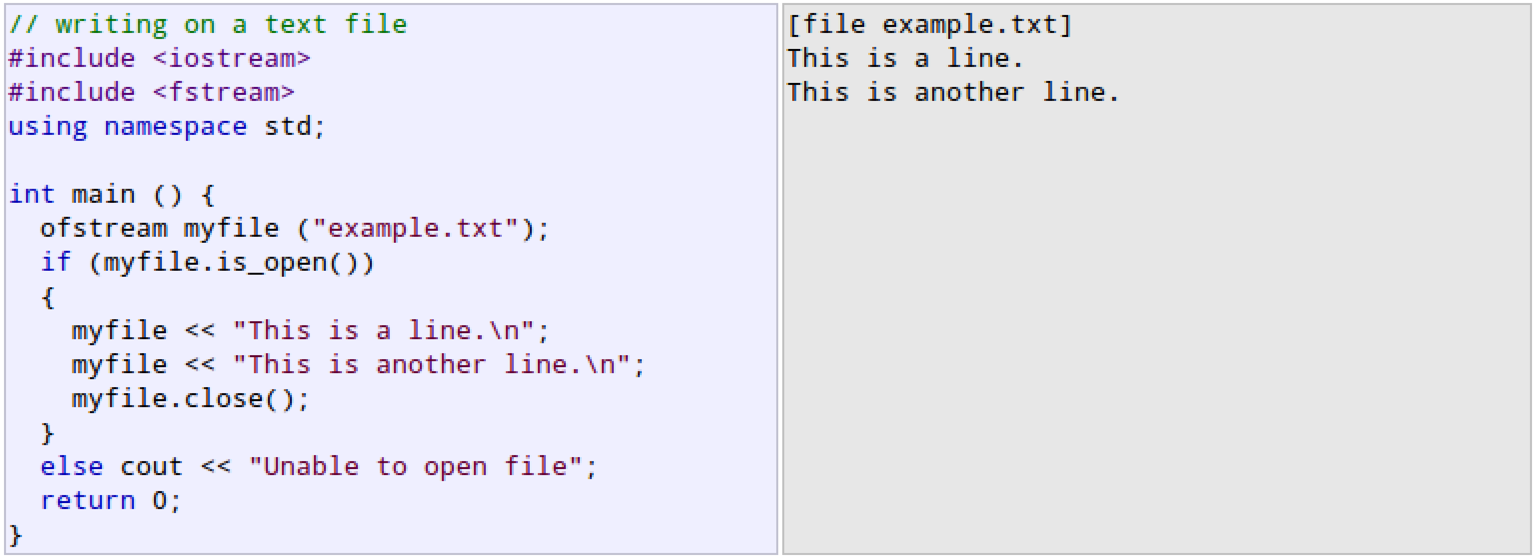
Files: input/output

- Output file: ofstream **#include <ofstream>**

Opening modes:



`ios::in`	Open for input operations.
`ios::out`	Open for output operations.
`ios::binary`	Open in binary mode.
`ios::ate`	Set the initial position at the end of the file. If this flag is not set, the initial position is the beginning of the file.
`ios::app`	All output operations are performed at the end of the file, appending the content to the current content of the file.
`ios::trunc`	If the file is opened for output operations and it already existed, its previous content is deleted and replaced by the new one.



```cpp
// writing on a text file
#include <iostream>
#include <fstream>
using namespace std;

int main () {
  ofstream myfile ("example.txt");
  if (myfile.is_open())
  {
    myfile << "This is a line.\n";
    myfile << "This is another line.\n";
    myfile.close();
  }
  else cout << "Unable to open file";
  return 0;
}
```

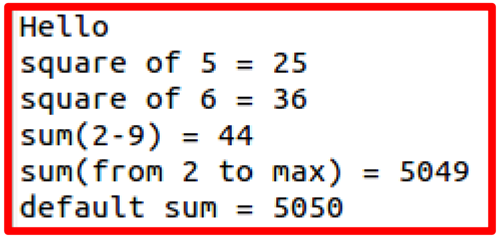
```
[file example.txt]
This is a line.
This is another line.
```

Functions

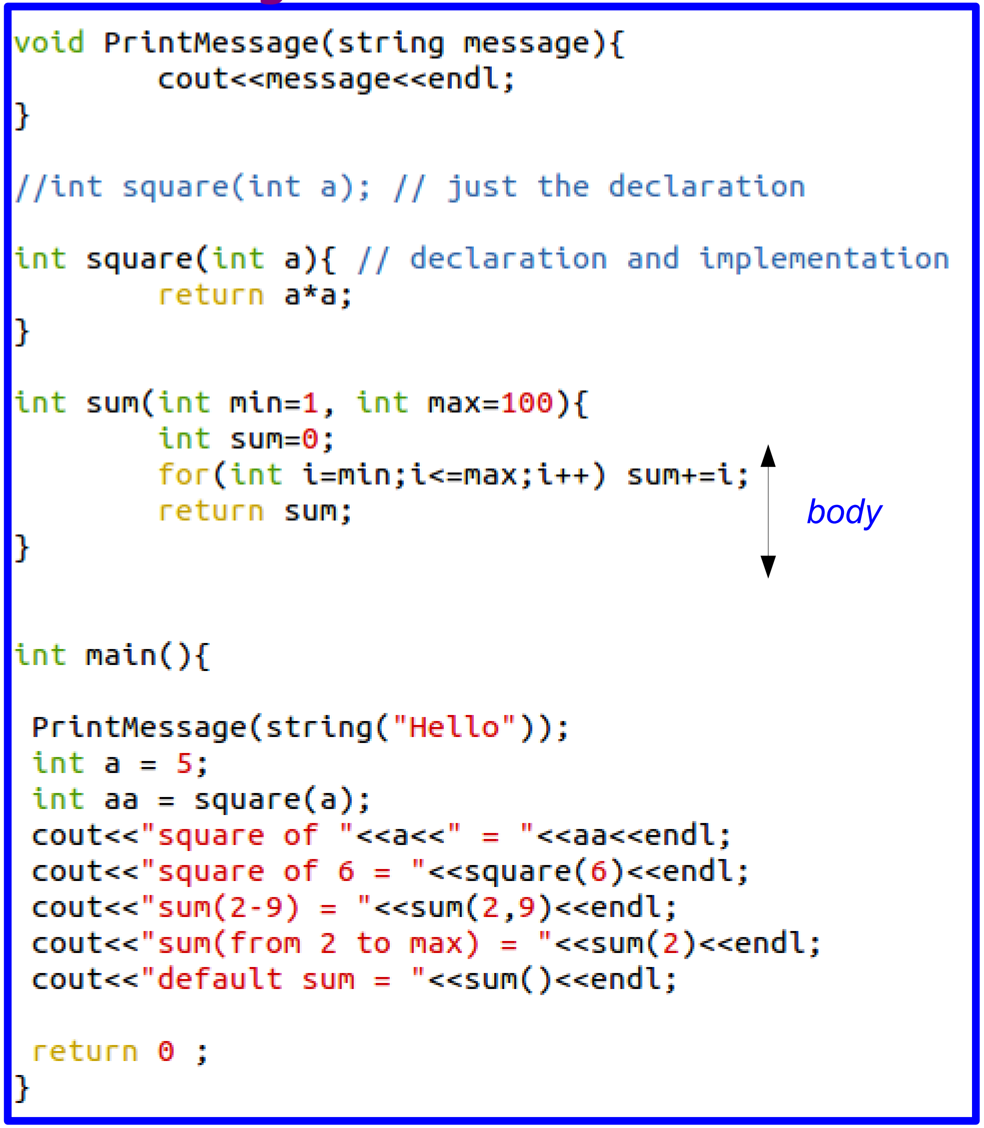
Functions represent/implement computations/algorithms

- Return type (int, void)
  - Return **one** variable at maximum
  - **Void** means don't return a value
  - Type can be an user-defined class
- Name
- “Arguments” or “parameters”
  - (last) parameters can have default value
- Body

  (in the definition)



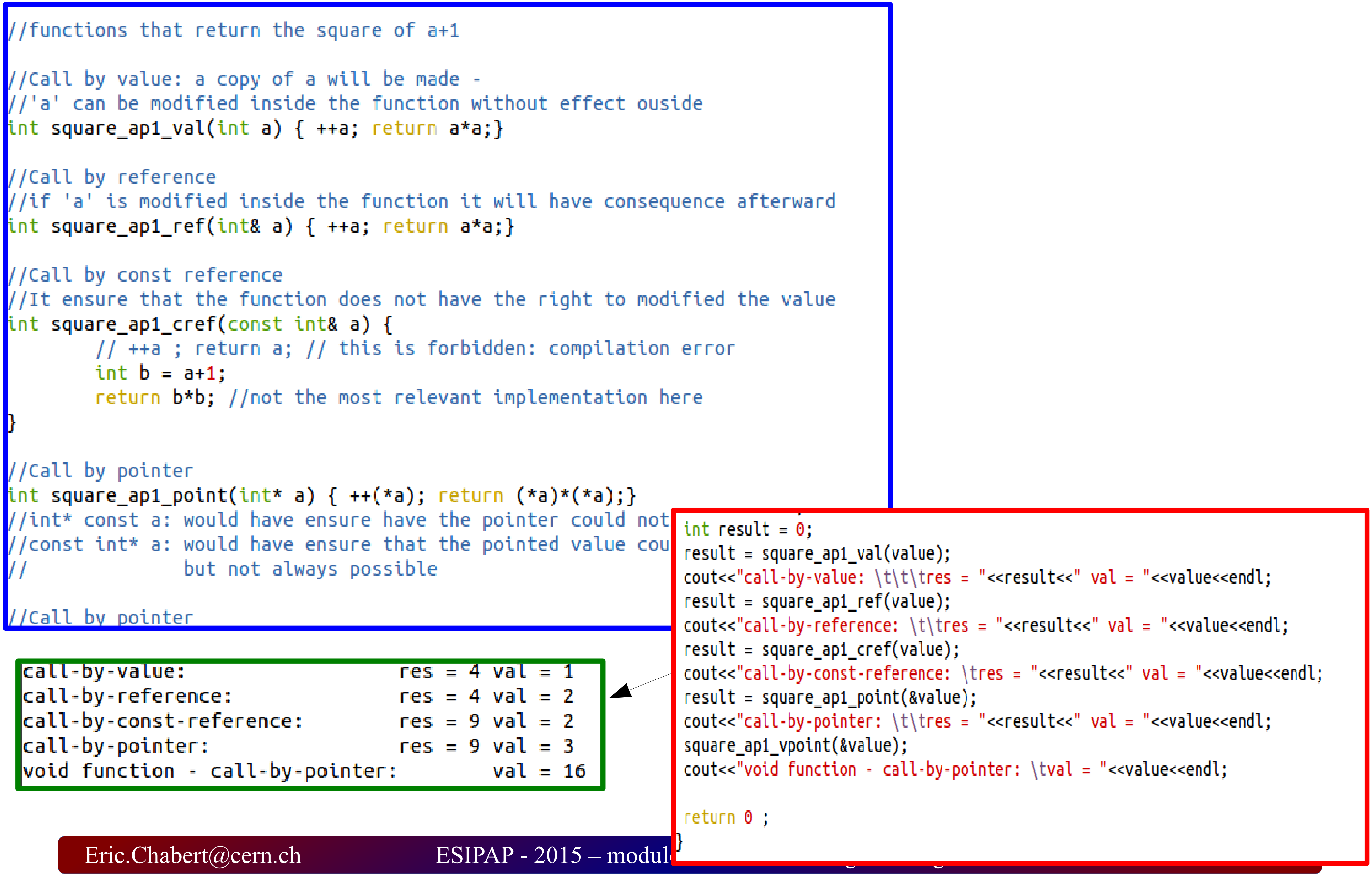
```
Hello
square of 5 = 25
square of 6 = 36
sum(2-9) = 44
sum(from 2 to max) = 5049
default sum = 5050
```



```
void PrintMessage(string message){
        cout<<message<<endl;
}

//int square(int a); // just the declaration

int square(int a){ // declaration and implementation
        return a*a;
}

int sum(int min=1, int max=100){
        int sum=0;
        for(int i=min;i<=max;i++) sum+=i;
        return sum;
}


int main(){

 PrintMessage(string("Hello"));
 int a = 5;
 int aa = square(a);
 cout<<"square of "<<a<<" = "<<aa<<endl;
 cout<<"square of 6 = "<<square(6)<<endl;
 cout<<"sum(2-9) = "<<sum(2,9)<<endl;
 cout<<"sum(from 2 to max) = "<<sum(2)<<endl;
 cout<<"default sum = "<<sum()<<endl;

 return 0 ;
}
```

Possibility to declare many functions with the same name in the same scope if they have different arguments (number,type)

Function: call by value, ref, …



```cpp
//functions that return the square of a+1

//Call by value: a copy of a will be made -
//'a' can be modified inside the function without effect ouside
int square_ap1_val(int a) { ++a; return a*a;}

//Call by reference
//if 'a' is modified inside the function it will have consequence afterward
int square_ap1_ref(int& a) { ++a; return a*a;}

//Call by const reference
//It ensure that the function does not have the right to modified the value
int square_ap1_cref(const int& a) {
        // ++a ; return a; // this is forbidden: compilation error
        int b = a+1;
        return b*b; //not the most relevant implementation here
}

//Call by pointer
int square_ap1_point(int* a) { ++(*a); return (*a)*(*a);}
//int* const a: would have ensure have the pointer could not
//const int* a: would have ensure that the pointed value cou
//              but not always possible

//Call by pointer
```

```cpp
int result = 0;
result = square_ap1_val(value);
cout<<"call-by-value: \t\t\tres = "<<result<<" val = "<<value<<endl;
result = square_ap1_ref(value);
cout<<"call-by-reference: \t\tres = "<<result<<" val = "<<value<<endl;
result = square_ap1_cref(value);
cout<<"call-by-const-reference: \tres = "<<result<<" val = "<<value<<endl;
result = square_ap1_point(&value);
cout<<"call-by-pointer: \t\tres = "<<result<<" val = "<<value<<endl;
square_ap1_vpoint(&value);
cout<<"void function - call-by-pointer: \tval = "<<value<<endl;

return 0 ;
}
```

```
call-by-value:                      res = 4 val = 1
call-by-reference:                  res = 4 val = 2
call-by-const-reference:            res = 9 val = 2
call-by-pointer:                    res = 9 val = 3
void function - call-by-pointer:            val = 16
```

Functions: guidance for arguments

- Use call-by-value for small objects only
- Use call-by const-reference for large objects
- Return a result rather than modify an object through a reference argument
- Use call-by reference only when you have to
  - Ex: case of multiples outputs
- Be careful with the use of pointers
  - Take care of deletion
  - Modification of the pointer
  - Modification of the pointed value

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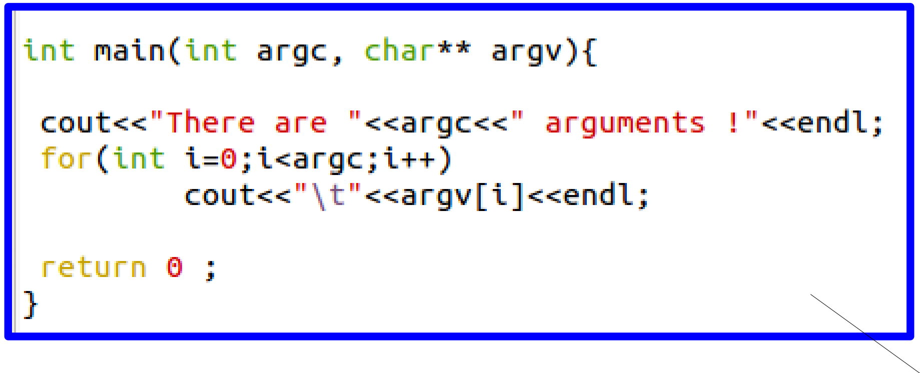
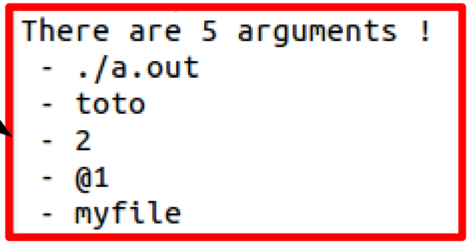
int main(int argc,char** argv)

- It might be convenient to “transmit” information to the program from the command line
- It avoid to recompile the code to change its execution
- It might avoid to read configuration file



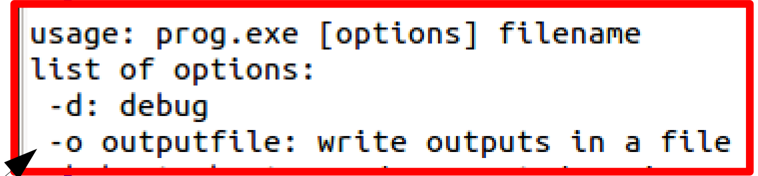
```
int main(int argc, char** argv){

 cout<<"There are "<<argc<<" arguments !"<<endl;
 for(int i=0;i<argc;i++)
         cout<<"\t"<<argv[i]<<endl;

 return 0 ;
}
```



```
There are 5 arguments !
 - ./a.out
 - toto
 - 2
 - @1
 - myfile
```

int main(int argc,char** argv)

```
void help(){
        cout<<"usage: prog.exe [options] filename"<<endl;
        cout<<"list of options:"<<endl;
        cout<<" -d: debug"<<endl;
        cout<<" -o outputfile: write outputs in a file"<<endl;
}

bool ReadArguments(int argc, char** argv, bool debug, string ifilename, string ofilename){
        for(int i=1;i<argc;i++){
                cout<<argv[i]<<endl;
                if(string(argv[i])==string("-d")) {
                        debug = true;
                }
                else if(string(argv[i])==string("-o")){
                        if(i<argc-1){
                                ofilename = argv[i+1];
                                cout<<ofilename<<endl;
                                ++i;
                        }
                        else cerr<<"outfilename is missing"<<endl;
                }
                else {
                        ifilename = string(argv[i]);
                }
        }
        if(ifilename==string()) return true;
        else return false;
}

int main(int argc, char** argv){

 if(argc==1){
        help();
        return 1;
 }
 string ifilename;
 string ofilename;
 bool debug = false;
 if(!ReadArguments(argc,argv,debug,ifilename,ofilename)) return 2;

 //instructions ...

 return 0 ;
}
```

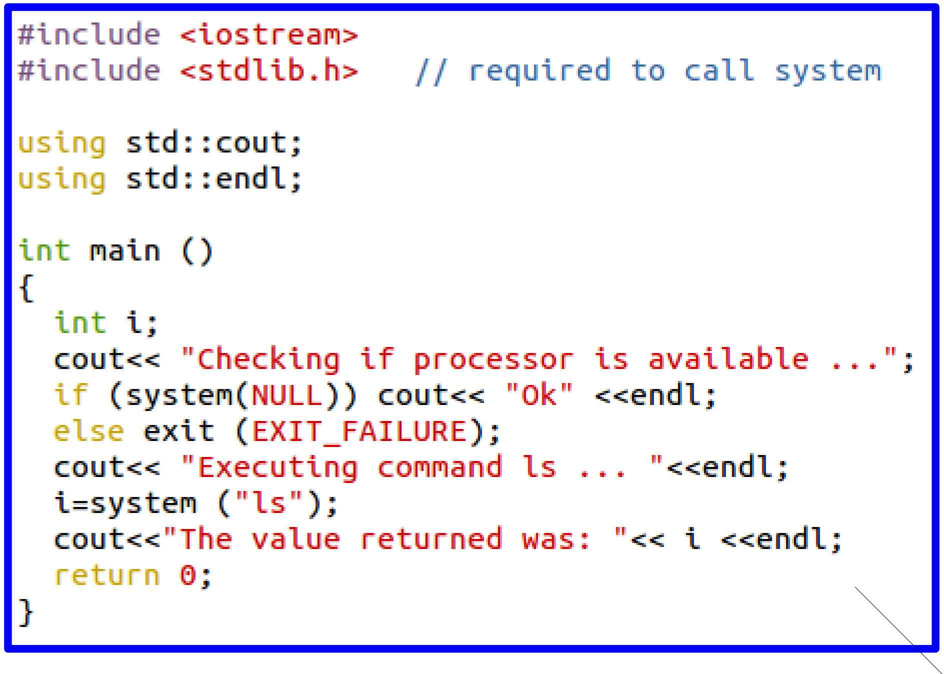


```
usage: prog.exe [options] filename
list of options:
 -d: debug
 -o outputfile: write outputs in a file
```

```
./prog.exe -d -o ofile.txt ifile.txt
```

Call system

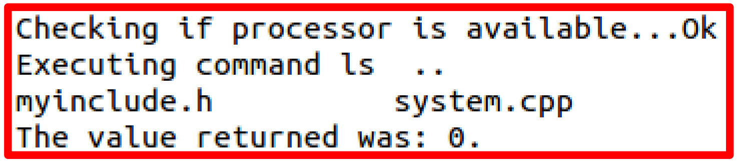
- Invokes the command processor
- **Warning**: *the command called is system/library dependent* !
- Possibility to parse the output value BUT not the output of the command



```
#include <iostream>
#include <stdlib.h>    // required to call system

using std::cout;
using std::endl;

int main ()
{
  int i;
  cout<< "Checking if processor is available ...";
  if (system(NULL)) cout<< "Ok" <<endl;
  else exit (EXIT_FAILURE);
  cout<< "Executing command ls ... "<<endl;
  i=system ("ls");
  cout<<"The value returned was: "<< i <<endl;
  return 0;
}
```

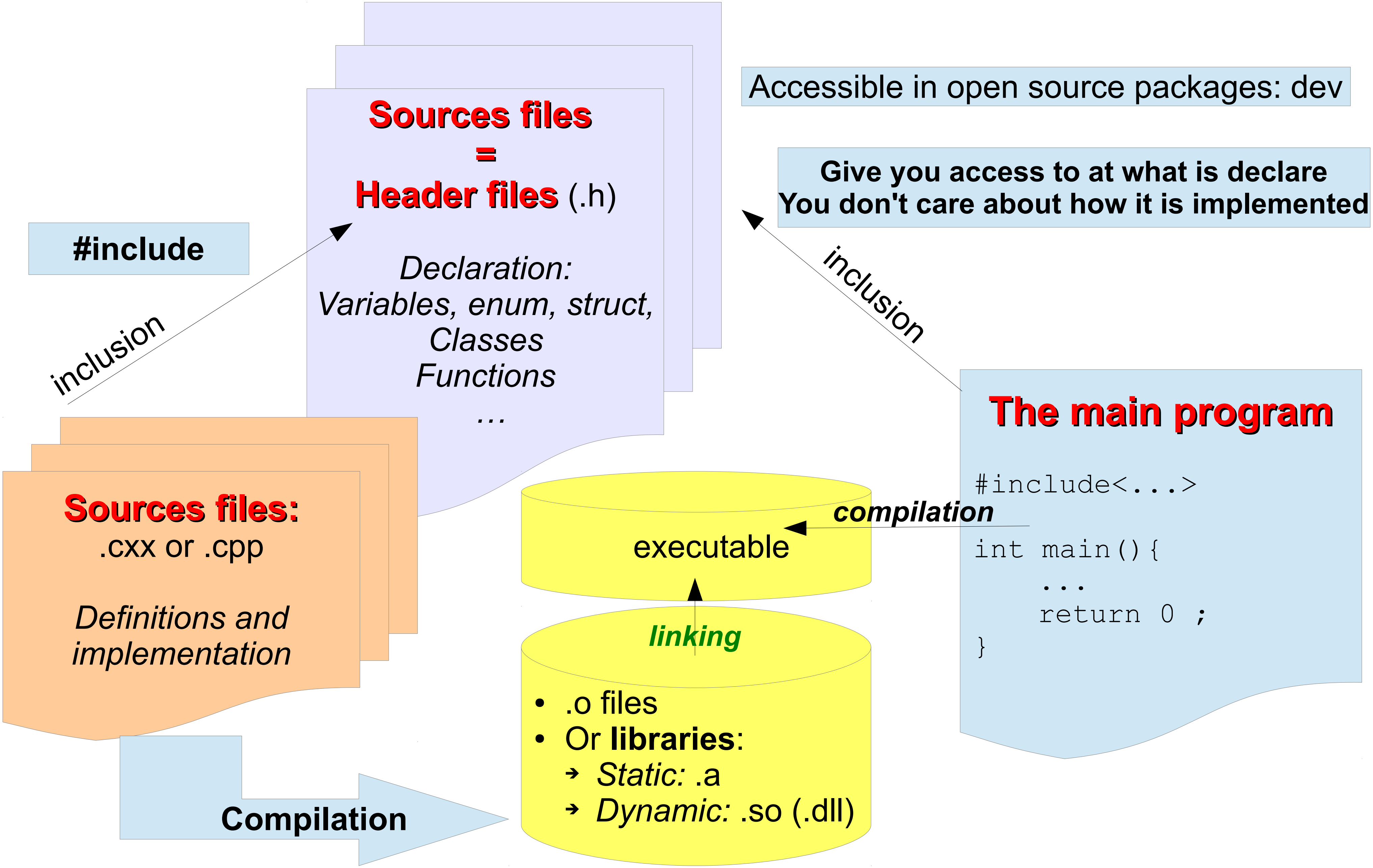
Could be convenient for many applications:

- Compile generated latex code
- Manipulation of files/folders
- ...



```
Checking if processor is available...Ok
Executing command ls  ..
myinclude.h          system.cpp
The value returned was: 0.
```

Compilation chain



Accessible in open source packages: dev

Give you access to at what is declare
You don't care about how it is implemented

#include

inclusion

Sources files
=
Header files (.h)

Declaration:
Variables, enum, struct,
Classes
Functions
…

inclusion

The main program

```
#include<...>
int main(){
    ...
    return 0 ;
}
```

compilation

executable

linking

- .o files
- Or **libraries**:
  - *Static:* .a
  - *Dynamic:* .so (.dll)

Sources files:
.cxx or .cpp

Definitions and
implementation

Compilation

Compilation chain

Example of one class (class.h & class.cpp file) and a main program (main.cpp)

1 step compilation

```
g++ class.cpp main.cpp -o main.exe
```

class.cpp will be recompiled even if only main.cpp changed

2 steps compilation

```
g++ -c class.cpp
g++ class.o main.cpp -o main.exe
```

First line can be omitted if only main.cpp changed

2 steps compilation + use of libToto.so

```
g++ -c class.cpp
g++ -I headerDir -L libDir -lToto class.o main.cpp -o main.exe
```

Toto.h is in headerDir
libToto.so is in libDir
LibDir might be in $LD_LIBRARY_PATH

Compilation chain

2 steps compilation + use of ROOT lib.

```
g++ -c class.cpp `root-config --cflags --glibs`
g++  class.o main.cpp -o main.exe `root-config --cflags --glibs`
```

“3 steps” compilation with shared library

```
g++ -c class.cpp # do the same for other classes
g++ -fPIC  -shared class.cpp -o libPerso.so
g++  main.cpp -o main.exe -L libPersoDir -lPerso
```

To know the symbols inside .so

```
nm -s --demangle libPoint.so
```

To list shared library dependencies:

```
ldd main.exe
```

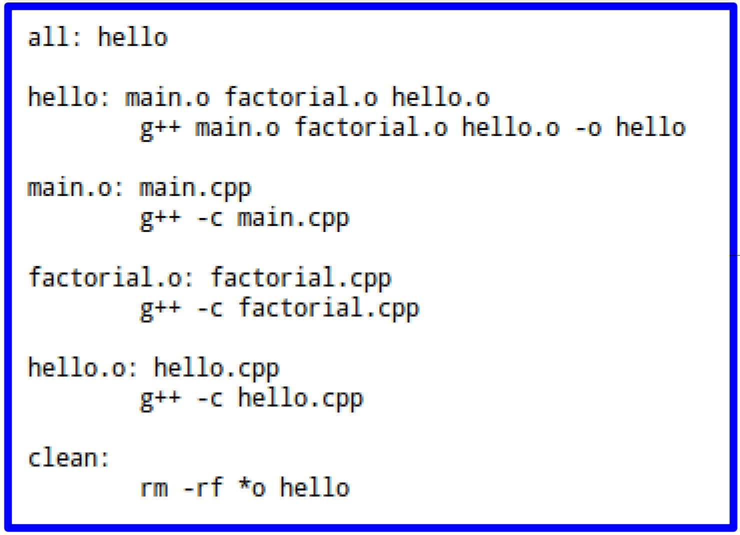
Few compilation options

- Previously listed
  - -o *outputfile*
- Warning options
  - -Wall: combination of many warnings …
  - -Wfloat-equal ….
- Debugging options
  - -g: produce debugging info that could be used by the debugger program ***GDB***
- Optimization options: *following options are needed to speed-up execution time*
  - *WARNING: by default compiler try to reduce compilation time*
  - -01 (space/speed tradoff) -O2 (speed opt.) -O3 (inline,regist.) -Os (-02 + code size reduction)
- Linker options:
  - -L lib*dir* -l*library*   -shared (to create .so)
- Compilation report:

  -ftime-report -fmem-report
- Preprocessor options
- ...

Makefile

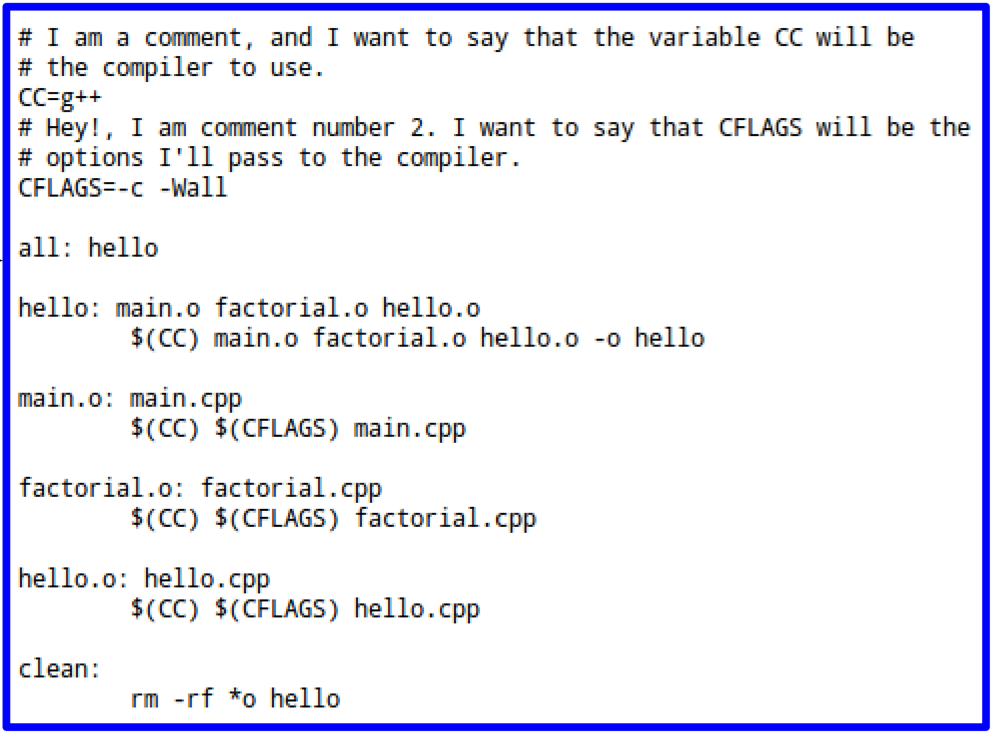
Makefile



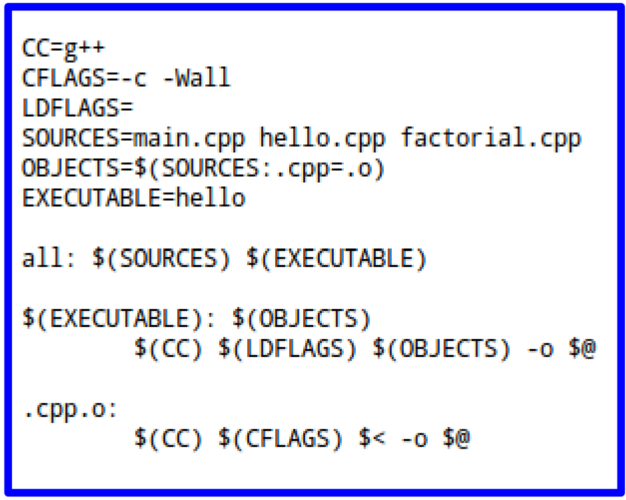
```
all: hello

hello: main.o factorial.o hello.o
        g++ main.o factorial.o hello.o -o hello

main.o: main.cpp
        g++ -c main.cpp

factorial.o: factorial.cpp
        g++ -c factorial.cpp

hello.o: hello.cpp
        g++ -c hello.cpp

clean:
        rm -rf *o hello
```

make # or make all

Using variables & comments



```
# I am a comment, and I want to say that the variable CC will be
# the compiler to use.
CC=g++
# Hey!, I am comment number 2. I want to say that CFLAGS will be the
# options I'll pass to the compiler.
CFLAGS=-c -Wall

all: hello

hello: main.o factorial.o hello.o
        $(CC) main.o factorial.o hello.o -o hello

main.o: main.cpp
        $(CC) $(CFLAGS) main.cpp

factorial.o: factorial.cpp
        $(CC) $(CFLAGS) factorial.cpp

hello.o: hello.cpp
        $(CC) $(CFLAGS) hello.cpp

clean:
        rm -rf *o hello
```



```
CC=g++
CFLAGS=-c -Wall
LDFLAGS=
SOURCES=main.cpp hello.cpp factorial.cpp
OBJECTS=$(SOURCES:.cpp=.o)
EXECUTABLE=hello

all: $(SOURCES) $(EXECUTABLE)

$(EXECUTABLE): $(OBJECTS)
        $(CC) $(LDFLAGS) $(OBJECTS) -o $@

.cpp.o:
        $(CC) $(CFLAGS) $< -o $@
```

Parallelization can be useful
for big projects

make -j NofNodes

.o files are not reproduced (compilation) if .cpp doesn't change

Scopes

- **Global scope** (accessible everywhere)
- **Class scope**
- **Local scope** (between {..}: loop, functions,...)
- **Statement scope** (in a for-statement)

```
int x;          // global variable – avoid those where you can
int y;          // another global variable
int f() {
      int x;    // local variable (Note – now there are two x’s)
      x = 7;    // local x, not the global x
      {
                int x = y; // another local x, initialized by the global y
                           // (Now there are three x’s)
                x++;                     // increment the local x in this scope
      }
}
// avoid such complicated nesting and hiding: keep it simple!
```

Remarks

- A name in a scope can be seen from within its scope and within scopes nested within that scope
- A scope keeps “things” local
  - Prevent var. and functions to interfere with outside
  - Keep names as local as possible

Namespaces

- A **namespace** is a named scope
- The syntax **::** is used to specify which **namespace** you are using and which (of many possible) objects of the same name you are referring to
  - **Ex**: You want to create your own class “string”. But it already exists …
    - std::string will refer the class implemented in the stl
    - your_name_space::string will refer to your own implementation

- How to create my namespace ?
  - You can encapsulate things (functions, classes, enums, …) as following

```
namespace Xproject{ // create a namespace called Xproject
  const double pi = 3.14159;                    // variable
  double square(double a) {return a*a;}    // function
  class X{                                             // class
      //...
  };
}
```

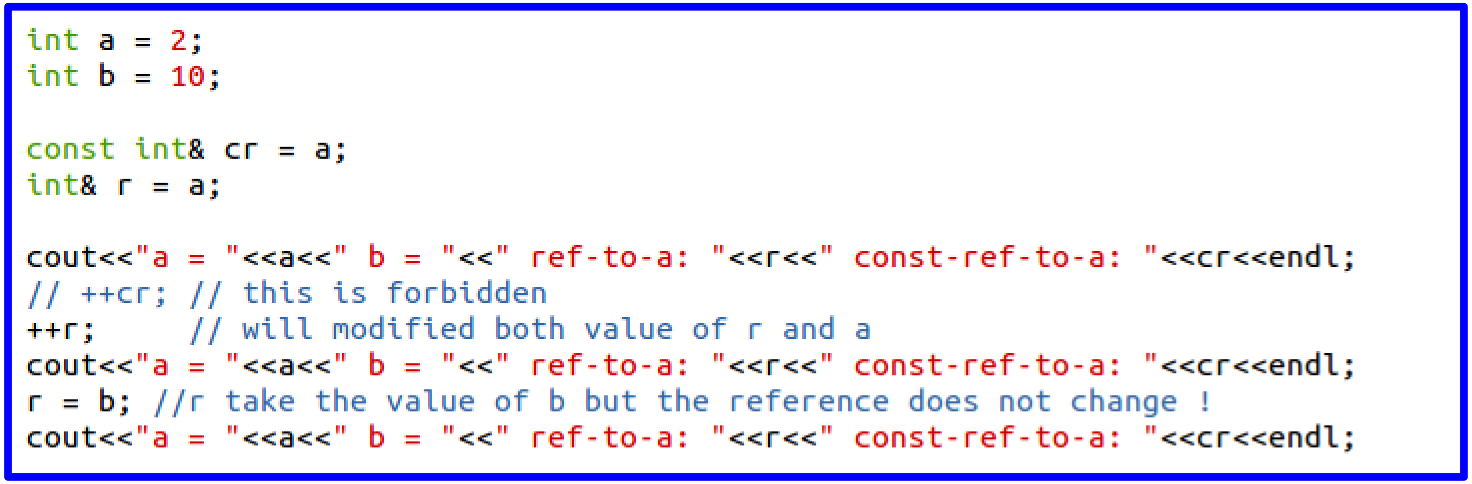
- How to avoid calling everywhere the namespace ??
  - **Ex**: using std::cout;
  - **Ex**: using namespace std;

Pointer & address

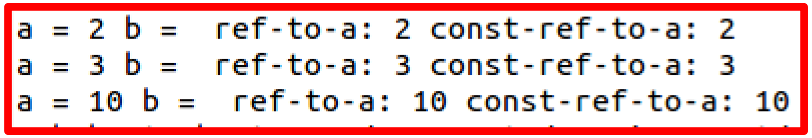
```
int a = 10;    //declare a integer
int* pa = &a;  //declare a pointer to an integer and initialize it to the adress of a
cout<<"a: "<<a<<" - its adress: " <<&a<<endl;
cout<<"pa: "<<*pa<<" - its adress: "<<pa<<endl;
cout<<"################################"<<endl<<endl;

++a;
cout<<"a: "<<a<<"\t(*pa): "<<(*pa)<<endl;
++(*pa); // once you give one (or many) pointer to a variable, nothing prevent that the value could change
cout<<"a: "<<a<<"\t(*pa): "<<(*pa)<<endl;
++pa;
cout<<"a: "<<a<<" - its adress: " <<&a<<endl;
cout<<"pa: "<<*pa<<" - its adress: "<<pa<<endl;
cout<<"################################"<<endl<<endl;


int b = 11;
int* pb;       //declare a pointer to integer which is not initialized !
const int* cpb = &b; //declarer a       pointer to an const integer
int* const pbc = &b; //declarer a const pointer to an integer
cout<<"pb: "<<*pb<<" - its adress: "<<pb<<endl;
pb = &b;
cout<<"b: "<<b<<" - its adress: " <<&b<<endl;
cout<<"pb: "<<*pb<<" - its adress: "<<pb<<endl;
cout<<"cpb: "<<*cpb<<" - its adress: "<<cpb<<endl;
//++(*cpb); // compilation error: increment of read-only location ‘* cpb’
cpb++; //allowed: the pointer is not const (the pointed value is const)
//pbc++; //compilation error: increment of read-only variable ‘pbc’
cout<<"################################"<<endl<<endl;

const int c = 12;
//int* pc = &c; // this lead to and compilation error
const int* cpc = &c; // this lead to and compilation error
cout<<"c: "<<c<<" - its adress: " <<&c<<endl;
cout<<"cpc: "<<*cpc<<" - its adress: "<<cpc<<endl;

//++c; //error - you cannot change a const variable - compilation error: increment of read-only variable ‘c’
//++(*cpc); // compilation error: increment of read-only location ‘* cpc’
```

```
a: 10 - its adress: 0x7fff772d3644
pa: 10 - its adress: 0x7fff772d3644
################################

a: 11   (*pa): 11
a: 12   (*pa): 12
a: 12 - its adress: 0x7fff772d3644
pa: 4196208 - its adress: 0x7fff772d3648
################################

pb: 1999458643 - its adress: 0x7fff772d3748
b: 11 - its adress: 0x7fff772d3648
pb: 11 - its adress: 0x7fff772d3648
cpb: 11 - its adress: 0x7fff772d3648
################################

c: 12 - its adress: 0x7fff772d364c
cpc: 12 - its adress: 0x7fff772d364c
```

Pointer & reference



```
int a = 2;
int b = 10;

const int& cr = a;
int& r = a;

cout<<"a = "<<a<<" b = "<<" ref-to-a: "<<r<<" const-ref-to-a: "<<cr<<endl;
// ++cr; // this is forbidden
++r;     // will modified both value of r and a
cout<<"a = "<<a<<" b = "<<" ref-to-a: "<<r<<" const-ref-to-a: "<<cr<<endl;
r = b; //r take the value of b but the reference does not change !
cout<<"a = "<<a<<" b = "<<" ref-to-a: "<<r<<" const-ref-to-a: "<<cr<<endl;
```



```
a = 2 b =  ref-to-a: 2 const-ref-to-a: 2
a = 3 b =  ref-to-a: 3 const-ref-to-a: 3
a = 10 b =  ref-to-a: 10 const-ref-to-a: 10
```

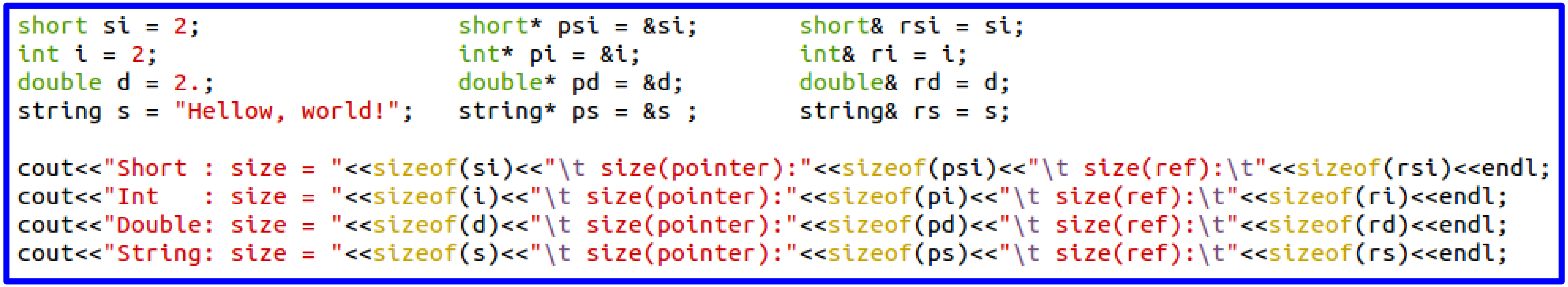
- You can't modify an object through a const reference
- You can't make a reference refer to another object after initialization (difference from a pointer)

Pointer & reference

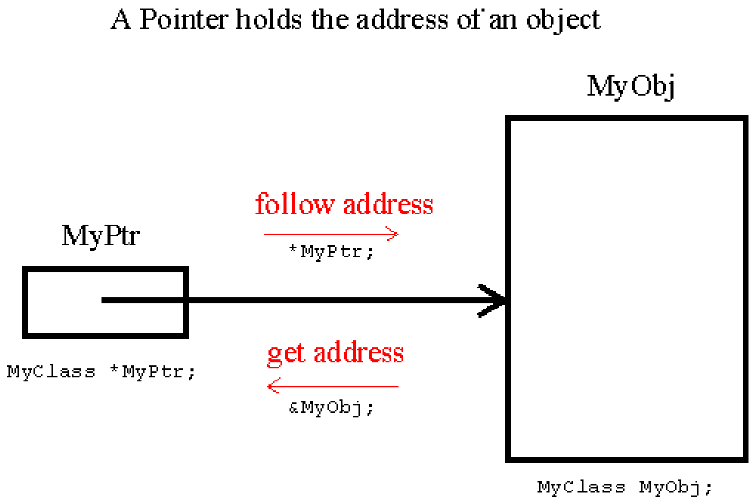
	Pointer	Reference
Must be initialized	no	yes
Can be null (=0)	yes	no
Can change the “pointed” variable	yes	no
Can change the value of the “pointed” variable	yes (no if type* const)	yes (no if const type &
Can delete the memory	yes	no

There shall be no references to references, no arrays of references, and no pointers to references.

Pointer & reference: Memory

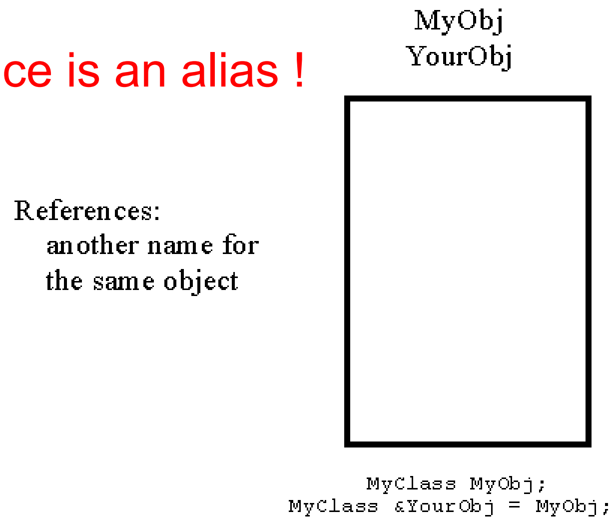


```
short si = 2;                    short* psi = &si;        short& rsi = si;
int i = 2;                       int* pi = &i;            int& ri = i;
double d = 2.;                   double* pd = &d;         double& rd = d;
string s = "Hellow, world!";     string* ps = &s ;        string& rs = s;

cout<<"Short : size = "<<sizeof(si)<<"\t size(pointer):"<<sizeof(psi)<<"\t size(ref):\t"<<sizeof(rsi)<<endl;
cout<<"Int   : size = "<<sizeof(i)<<"\t size(pointer):"<<sizeof(pi)<<"\t size(ref):\t"<<sizeof(ri)<<endl;
cout<<"Double: size = "<<sizeof(d)<<"\t size(pointer):"<<sizeof(pd)<<"\t size(ref):\t"<<sizeof(rd)<<endl;
cout<<"String: size = "<<sizeof(s)<<"\t size(pointer):"<<sizeof(ps)<<"\t size(ref):\t"<<sizeof(rs)<<endl;
```



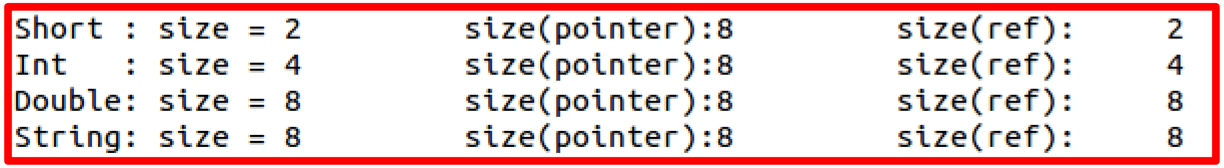
A Pointer holds the address of an object

Reference is an alias !



References:
another name for
the same object

the size in memory of a pointer depends on the platform where the program runs



```
Short : size = 2          size(pointer):8          size(ref):      2
Int   : size = 4          size(pointer):8          size(ref):      4
Double: size = 8          size(pointer):8          size(ref):      8
String: size = 8          size(pointer):8          size(ref):      8
```

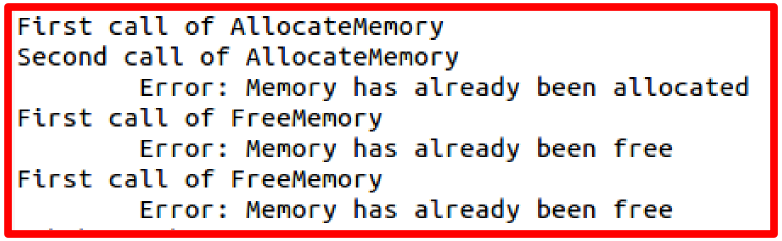
Test on pointer

- It is always safer to test is a pointer is not null before accessing the pointed variable !
- Could be useful to not allocate and delete twice memory (see example below)

```
void AllocateMemory(int*& array, int size){
	if(array==0){ // or array==NULL
		array = new int[size];
		for(int i=0;i<size;i++) array[i] = 0;
	}
	else cerr<<"\tError: Memory has already been allocated"<<endl;
	return;
}

void FreeMemory(int*& array){
	if(!array){
		delete[] array;
		array = 0;
	}
	else cerr<<"\tError: Memory has already been free"<<endl;
}

int main(){

 int* array = 0;

 cout<<"First call of AllocateMemory"<<endl;
 AllocateMemory(array,10);
 cout<<"Second call of AllocateMemory"<<endl;
 AllocateMemory(array,5);

 cout<<"First call of FreeMemory"<<endl;
 FreeMemory(array);
 cout<<"First call of FreeMemory"<<endl;
 FreeMemory(array);

 return 0 ;
}
```

Tests on pointers:

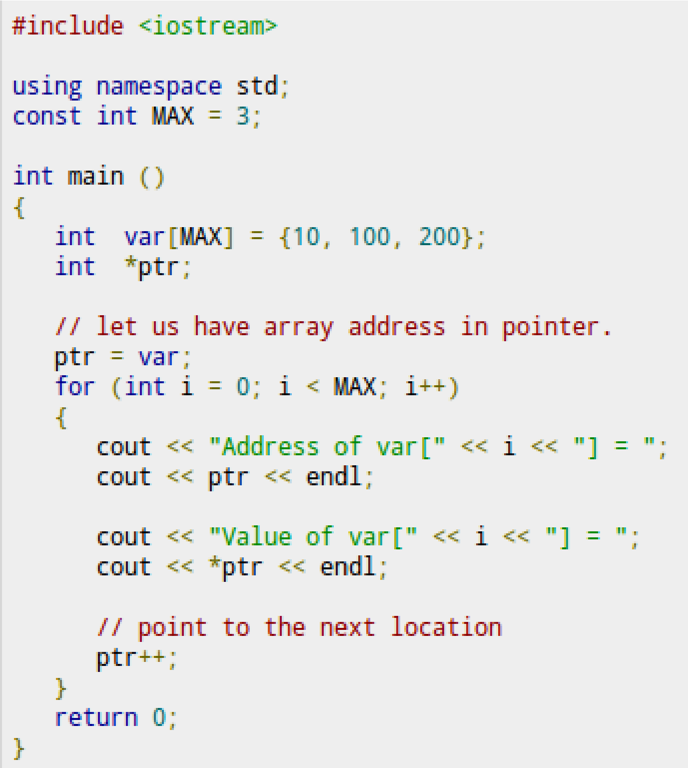
- Pointer==0
- !Pointer



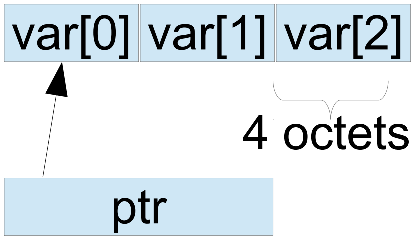
```
First call of AllocateMemory
Second call of AllocateMemory
        Error: Memory has already been allocated
First call of FreeMemory
        Error: Memory has already been free
First call of FreeMemory
        Error: Memory has already been free
```

Arithmetic of pointers

- Several operators are also defined for pointers: **++, --**
- It will allow you to change the address and by consequence the pointed “object”
- The result of those operations are not guaranteed and protection have to be written
- The operation depends on the kind of object type used

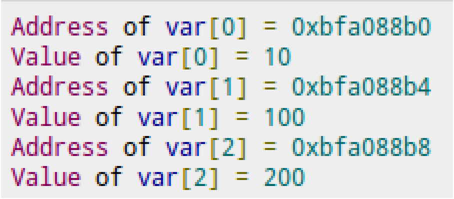


```
#include <iostream>

using namespace std;
const int MAX = 3;

int main ()
{
   int  var[MAX] = {10, 100, 200};
   int  *ptr;

   // let us have array address in pointer.
   ptr = var;
   for (int i = 0; i < MAX; i++)
   {
      cout << "Address of var[" << i << "] = ";
      cout << ptr << endl;

      cout << "Value of var[" << i << "] = ";
      cout << *ptr << endl;

      // point to the next location
      ptr++;
   }
   return 0;
}
```



int* ptr;
++ptr move by 4 octets

double* ptr;
++ptr move by 8 octets

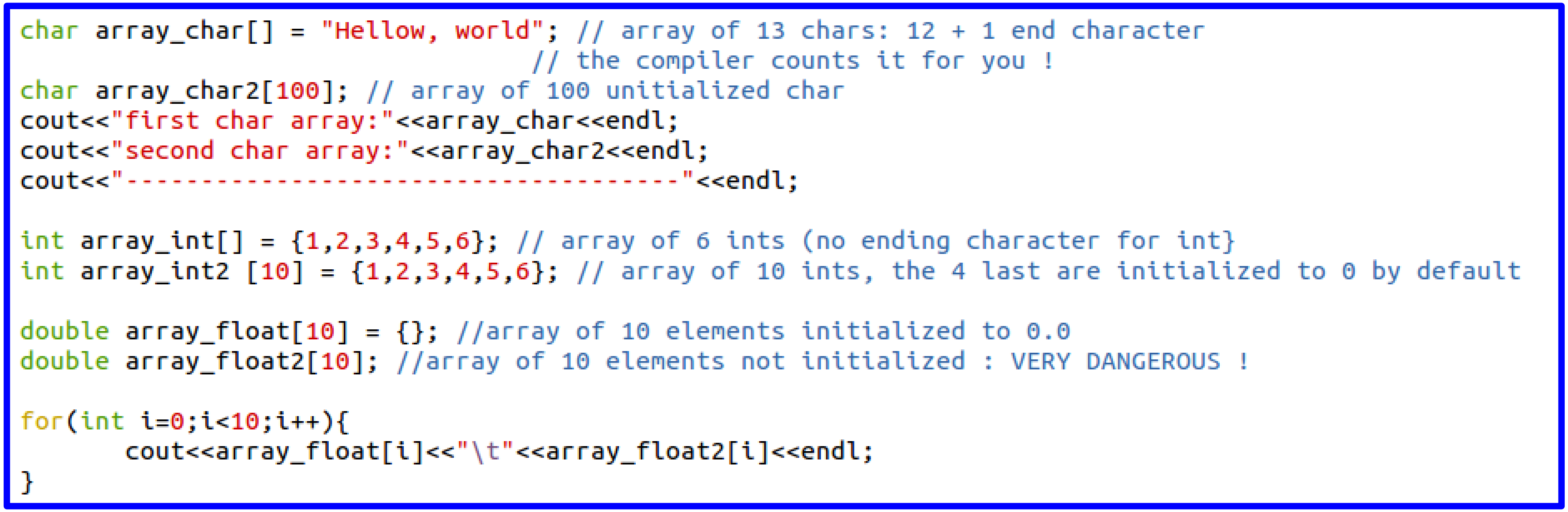


```
Address of var[0] = 0xbfa088b0
Value of var[0] = 10
Address of var[1] = 0xbfa088b4
Value of var[1] = 100
Address of var[2] = 0xbfa088b8
Value of var[2] = 200
```

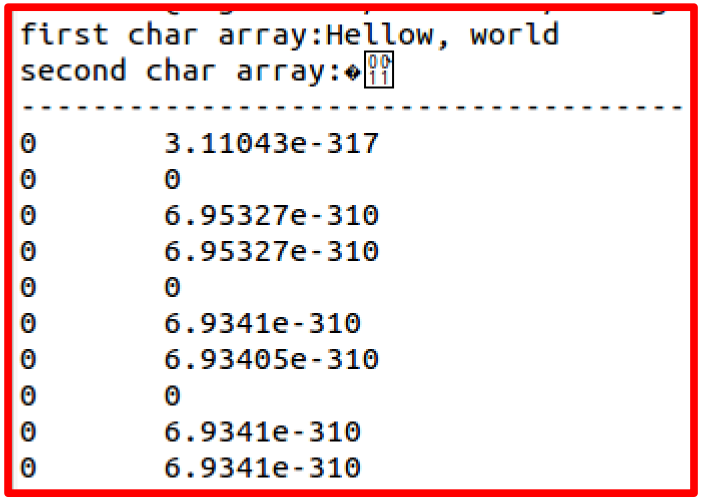
Arrays

- It's all that C has – It's mainly used in many C++ packages
- Array don't know their own size
  - Often use their size as an arguments in functions
- Access to elements
  - First element has index 0. **Ex**: tab[0]
- Avoid arrays whenever you can:
  - largest source of bug in C and (unnecessarily in C++)
  - among the largest source of security violations:
    - Possibility to access non declared memory (runtime error or unexpected behavior)

Arrays: initialization



```
char array_char[] = "Hellow, world"; // array of 13 chars: 12 + 1 end character
                                  // the compiler counts it for you !
char array_char2[100]; // array of 100 unitialized char
cout<<"first char array:"<<array_char<<endl;
cout<<"second char array:"<<array_char2<<endl;
cout<<"-------------------------------------"<<endl;

int array_int[] = {1,2,3,4,5,6}; // array of 6 ints (no ending character for int}
int array_int2 [10] = {1,2,3,4,5,6}; // array of 10 ints, the 4 last are initialized to 0 by default

double array_float[10] = {}; //array of 10 elements initialized to 0.0
double array_float2[10]; //array of 10 elements not initialized : VERY DANGEROUS !

for(int i=0;i<10;i++){
       cout<<array_float[i]<<"\t"<<array_float2[i]<<endl;
}
```

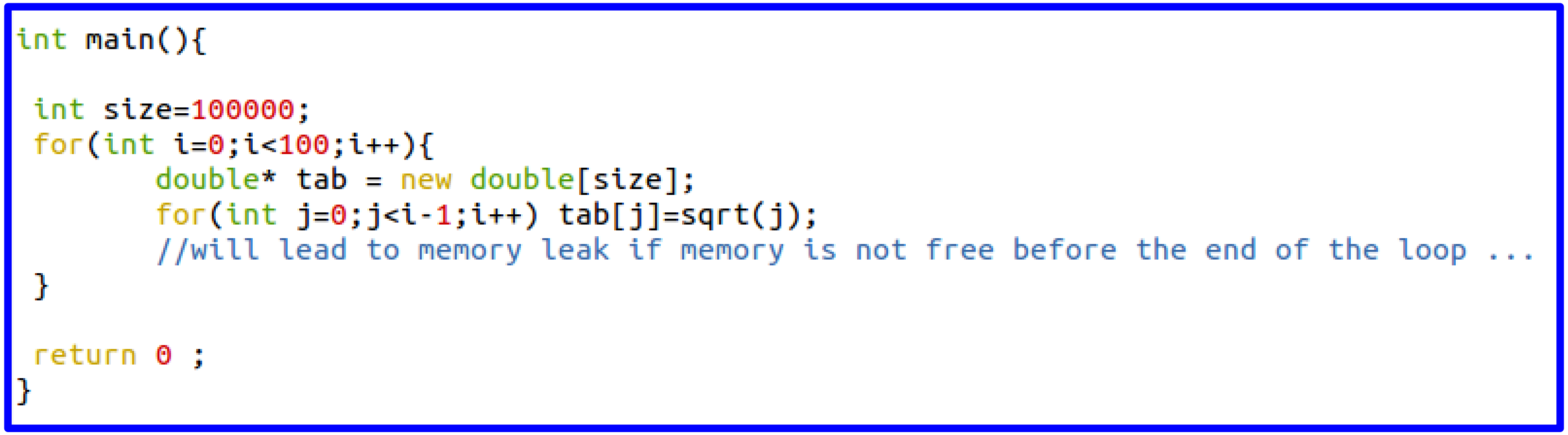


```
first char array:Hellow, world
second char array:�
-------------------------------------
0       3.11043e-317
0       0
0       6.95327e-310
0       6.95327e-310
0       0
0       6.9341e-310
0       6.93405e-310
0       0
0       6.9341e-310
0       6.9341e-310
```

It is safer to ***always*** initialize the arrays !

Array: dynamical allocation

Possible memory leak ….

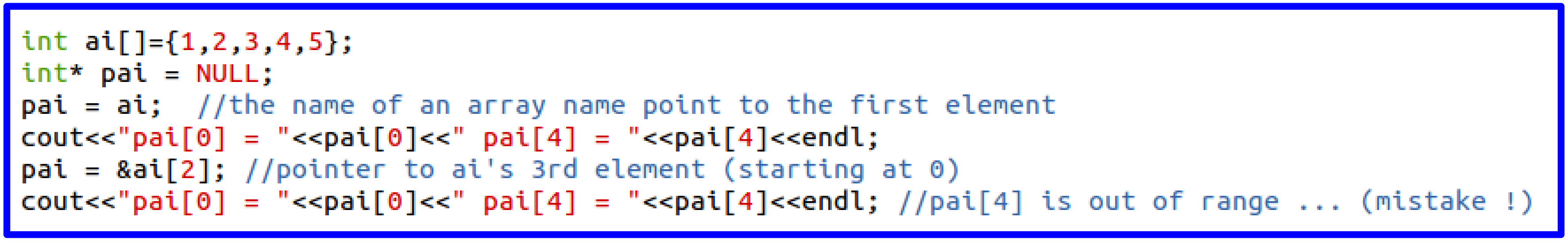


```
int main(){

 int size=100000;
 for(int i=0;i<100;i++){
        double* tab = new double[size];
        for(int j=0;j<i-1;i++) tab[j]=sqrt(j);
        //will lead to memory leak if memory is not free before the end of the loop ...
 }

 return 0 ;
}
```

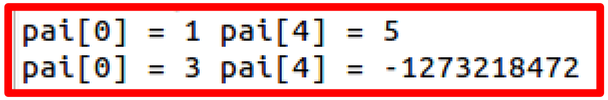
Always free memory:

- ***when it will be not used anymore***
- ***when you still have access to the pointer !***
- ***when you are "owner" of the 'memory' (pb of double free)***

Array and pointer



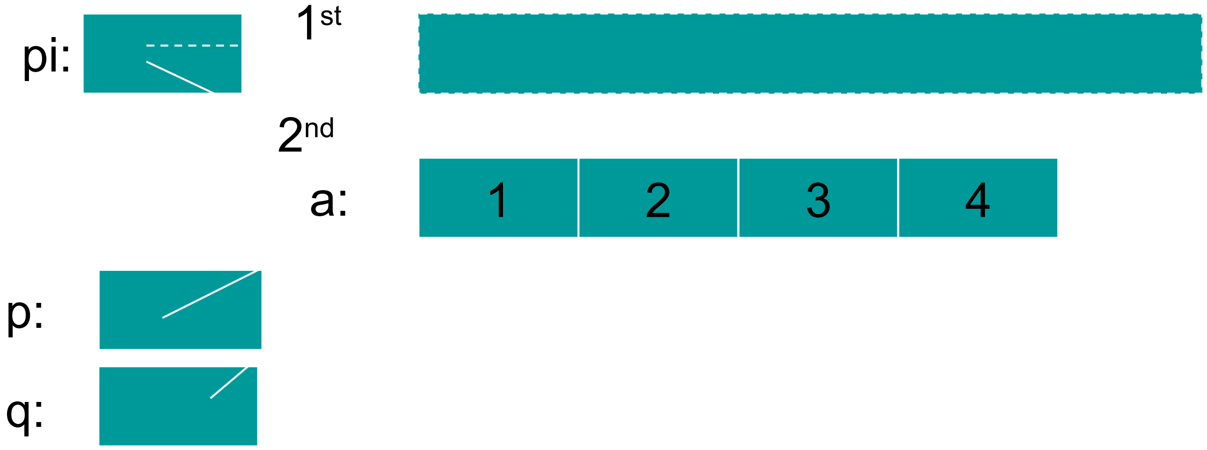
```
int ai[]={1,2,3,4,5};
int* pai = NULL;
pai = ai;  //the name of an array name point to the first element
cout<<"pai[0] = "<<pai[0]<<" pai[4] = "<<pai[4]<<endl;
pai = &ai[2]; //pointer to ai's 3rd element (starting at 0)
cout<<"pai[0] = "<<pai[0]<<" pai[4] = "<<pai[4]<<endl; //pai[4] is out of range ... (mistake !)
```



```
pai[0] = 1 pai[4] = 5
pai[0] = 3 pai[4] = -1273218472
```

Array and pointer

```
void f(int pi[ ])  // equivalent to void f(int* pi)
 {
    int a[ ] = { 1, 2, 3, 4 };
    int b[ ] = a;   // error: copy isn’t defined for arrays
    b = pi;         // error: copy isn’t defined for arrays. Think of a
                    // (non-argument) array name as an immutable pointer
    pi = a;         // ok: but it doesn’t copy: pi now points to a’s first element
                    // Is this a memory leak? (maybe)
    int* p = a;     // p points to the first element of a
    int* q = pi;    // q points to the first element of a
}
```



from B. Stroustrup slides

Array and pointers

```
char* f()
{
    char ch[20];
    char* p = &ch[90];
    // …
    *p = 'a';              // we don’t know what this’ll overwrite
    char* q;               // forgot to initialize
    *q = 'b';              // we don’t know what this’ll overwrite
    return &ch[10];        // oops: ch disappears upon return from f()
                           // (an infamous “dangling pointer”)
}

void g()
{
    char* pp = f();
    // …
    *pp = 'c';        // we don’t know what this’ll overwrite
                      // (f’s ch is gone for good after the return from f)
}
```

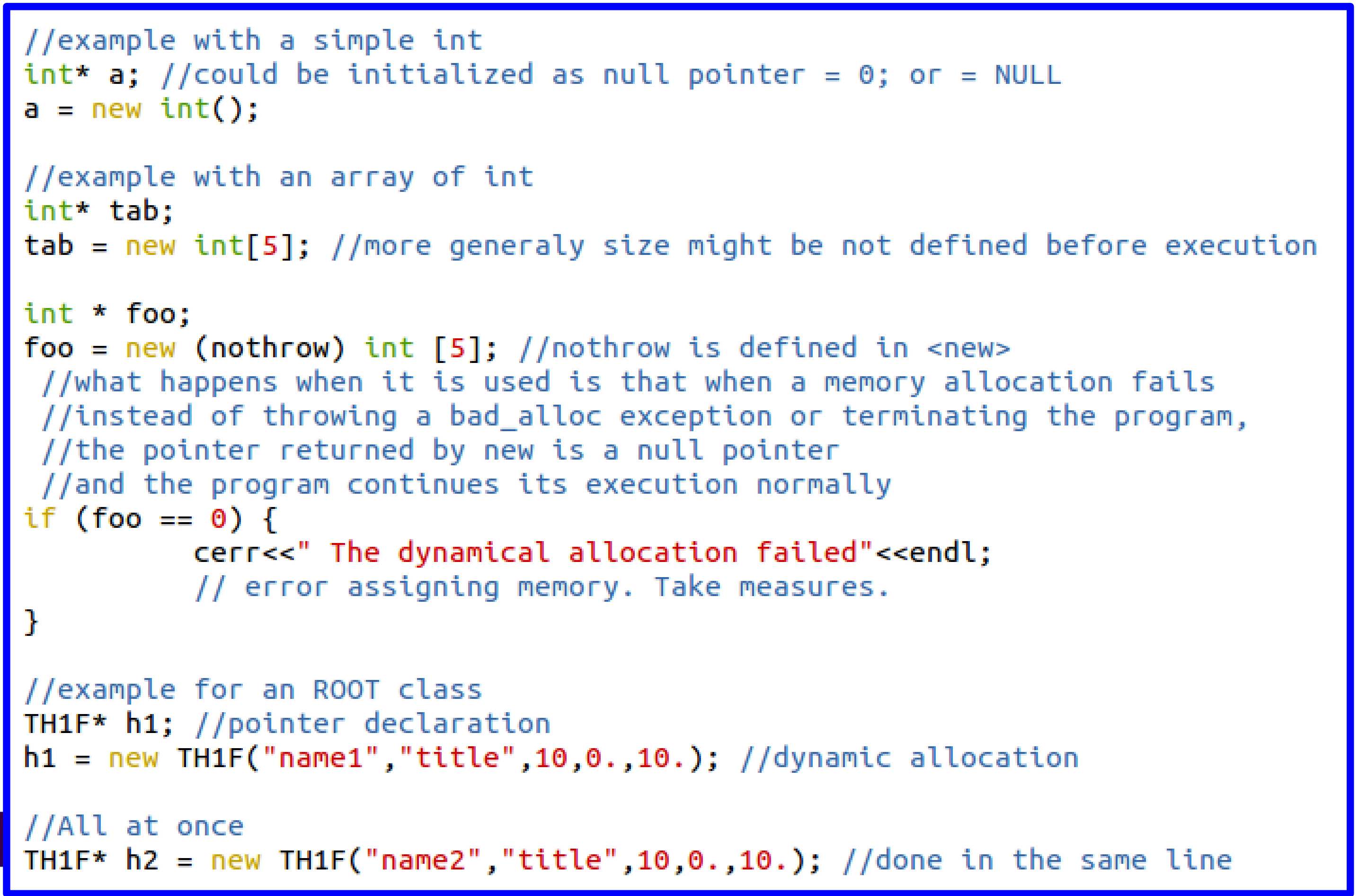
from B. Stroustrup slides

```
void f(int n, int* pai, int* pai2, int*& rpai, int*& rpai2){
  char ac[20]; //local array - "lives" untile the end of the scope (end of the function) - on stack
  int ai[n]; //local array - size is known at execution time (was leading to error in the past)
  int* ai2 = new int[n]; // this works - dynamical allocation - BUT memory will not be deallocated at the end of the function

  for(int i=0;i<n;i++){
        ai[i] = i+1;
        ai2[i] = i+1;
  }
  pai = ai;
  rpai = ai;
  pai2 = ai2;
  rpai2 = ai2;
  cout<<"### In function f: "<<endl;
  cout<<"pointer adress (pai):"<<pai<<endl;
  cout<<"pointer adress (pai2):"<<pai2<<endl;
  cout<<"pointer adress (rpai):"<<pai<<endl;
  cout<<"pointer adress (rpai2):"<<pai2<<endl;
  cout<<"#################################"<<endl;
}


int main(){

 char ac0[10] = {}; //global array - "lives" until the end of the program - in "static storage".
 int max = 100;
 int ai[max]; // allocated - not initialized
 int* ai2 = new int[max]; //equivalent here

 int* pai = NULL; // assign a NULL pointer
 int* pai2 = 0;   // does the same thing
 int* rpai = NULL; // assign a NULL pointer
 int* rpai2 = 0;   // does the same thing
 f(13,pai,pai2,rpai,rpai2);
 cout<<"### In main: "<<endl;
 cout<<"pointer adress (pai):"<<pai<<endl;
 cout<<"pointer adress (pai2):"<<pai2<<endl;
 cout<<"pointer adress (rpai):"<<rpai<<endl;
 cout<<"pointer adress (rpai2):"<<rpai2<<endl;
 cout<<"### access to elements: "<<endl;
 cout<<"rpai[0]:"<<rpai[0]<<endl;
 cout<<"rpai[1]:"<<rpai[1]<<endl;
 cout<<"rpai2[0]:"<<rpai2[0]<<endl;
 cout<<"rpai2[1]:"<<rpai2[1]<<endl;
 cout<<"pai[0]:"<<pai[0]<<endl;

 return 0 ;
}
```

```
### In function f:
pointer adress (pai):0x7fffb2f34dc0
pointer adress (pai2):0x246c1b0
pointer adress (rpai):0x7fffb2f34dc0
pointer adress (rpai2):0x246c1b0
#################################
### In main:
pointer adress (pai):0
pointer adress (pai2):0
pointer adress (rpai):0x7fffb2f34dc0
pointer adress (rpai2):0x246c1b0
### access to elements:
rpai[0]:38191536
rpai[1]:0
rpai2[0]:1
rpai2[1]:2
Erreur de segmentation (core dumped)
```

Dynamic allocation

- In some application, all memory needs cannot be determined before program execution by defining the variables needed.
- In that case, it is determined during runtime.
    - **Ex**: depends on user input(s), depends on the result of a calculus, ...
- Operators **new** and **new[]**
    - build-in types
    - Classes (lib/user)



```
//example with a simple int
int* a; //could be initialized as null pointer = 0; or = NULL
a = new int();

//example with an array of int
int* tab;
tab = new int[5]; //more generaly size might be not defined before execution

int * foo;
foo = new (nothrow) int [5]; //nothrow is defined in <new>
 //what happens when it is used is that when a memory allocation fails
 //instead of throwing a bad_alloc exception or terminating the program,
 //the pointer returned by new is a null pointer
 //and the program continues its execution normally
if (foo == 0) {
          cerr<<" The dynamical allocation failed"<<endl;
          // error assigning memory. Take measures.
}

//example for an ROOT class
TH1F* h1; //pointer declaration
h1 = new TH1F("name1","title",10,0.,10.); //dynamic allocation

//All at once
TH1F* h2 = new TH1F("name2","title",10,0.,10.); //done in the same line
```

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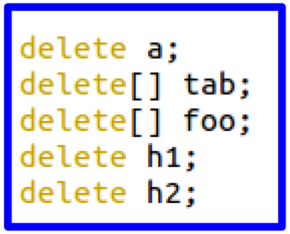
Delete: free memory

- in most cases, memory allocated dynamically is only needed during specific periods of time within a program; once it is no longer needed, it can be freed so that the memory becomes available again for other requests of dynamic memory.
- This operation should be performed when variable is still in the scope
  - End of a loop or function
  - In the destructor of a class (if memory has been allocated in the constr.)
  - At the end of a program
- Operators delete
  - **delete**: delete a single element in memory
  - **delete[]**: delete an array of elements
- Pointer is not null after delete
  - You could do it yourself to ensure future test on pointers
- You can't delete twice memory: double free exception
  - If you have 2 pointers on the same element, make sure that only one of them will be deleted



```
delete a;
delete[] tab;
delete[] foo;
delete h1;
delete h2;
```

std::vector

- Vector in C++ supersedes array defined in C
  - There are still a lot of applications using arrays rather than std::vector

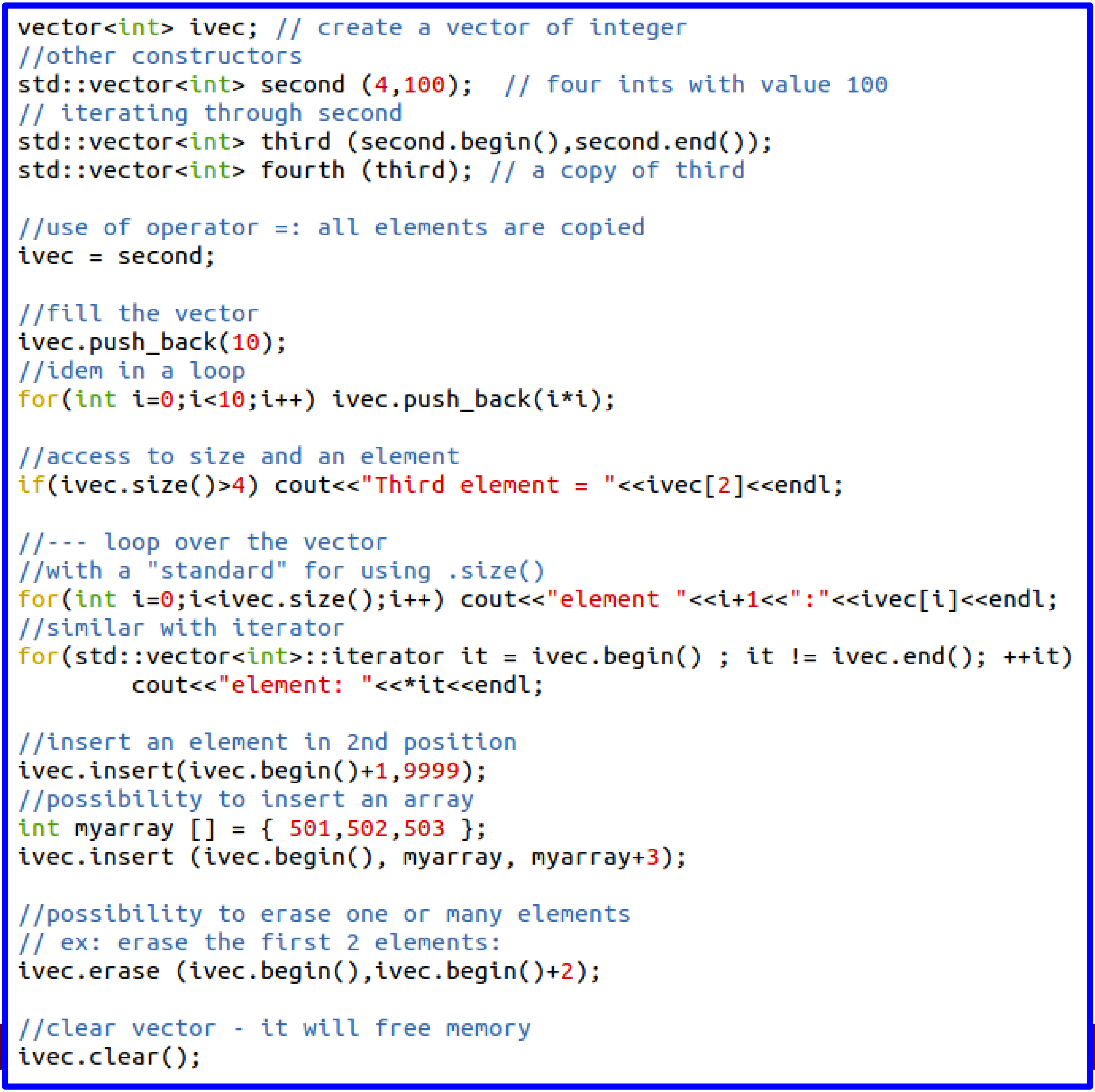
- It properly deals with dynamic memory

- When vector is destructed, all its elements are deleted

- **Important**: the size of the vector is one of the data member of a std::vector (contrary to an C array)

- Size is not fixed. Can be changed during program execution !

std::vector



```
vector<int> ivec; // create a vector of integer
//other constructors
std::vector<int> second (4,100);  // four ints with value 100
// iterating through second
std::vector<int> third (second.begin(),second.end());
std::vector<int> fourth (third); // a copy of third

//use of operator =: all elements are copied
ivec = second;

//fill the vector
ivec.push_back(10);
//idem in a loop
for(int i=0;i<10;i++) ivec.push_back(i*i);

//access to size and an element
if(ivec.size()>4) cout<<"Third element = "<<ivec[2]<<endl;

//--- loop over the vector
//with a "standard" for using .size()
for(int i=0;i<ivec.size();i++) cout<<"element "<<i+1<<":"<<ivec[i]<<endl;
//similar with iterator
for(std::vector<int>::iterator it = ivec.begin() ; it != ivec.end(); ++it)
        cout<<"element: "<<*it<<endl;

//insert an element in 2nd position
ivec.insert(ivec.begin()+1,9999);
//possibility to insert an array
int myarray [] = { 501,502,503 };
ivec.insert (ivec.begin(), myarray, myarray+3);

//possibility to erase one or many elements
// ex: erase the first 2 elements:
ivec.erase (ivec.begin(),ivec.begin()+2);

//clear vector - it will free memory
ivec.clear();
```

Ex: vector – pointer – delete

```
vector glob(10);                    // global vector – "lives" forever

vector* some_fct(int n)
{
    vector v(n);                    // local vector – "lives" until the end of scope
    vector* p = new vector(n);      // free-store vector – "lives"  until we delete it
    // …
    return p;
}

void f()
{
    vector* pp = some_fct(17);
    // …
    delete pp;      // deallocate the free-store vector allocated in some_fct()
}
```

- it's easy to forget to delete free-store allocated objects
  - so avoid **new/delete** when you can

from B. Stroustrup slides

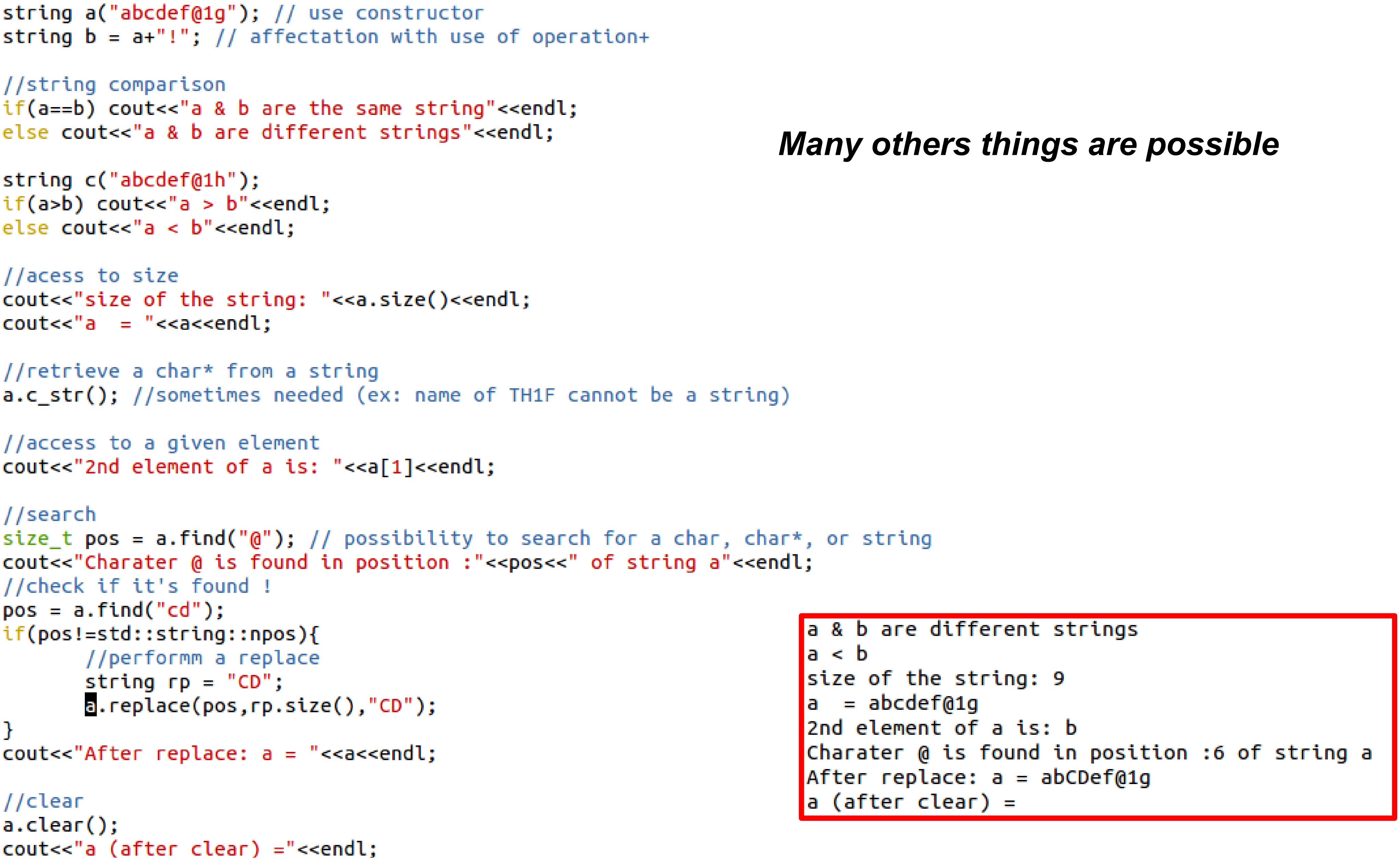
std::string

- **std::string** is a class that deals with character chains

- It "*supersedes*" char* (*inherited from C*)

- Many operations are easily possible
  - Access to size
  - Find a element
  - Retrieve a sub-string
  - Replace elements
  - Swap elements
  - ...

string



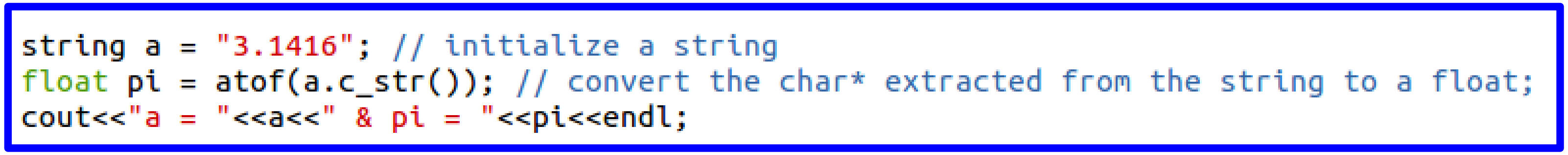
```
string a("abcdef@1g"); // use constructor
string b = a+"!"; // affectation with use of operation+

//string comparison
if(a==b) cout<<"a & b are the same string"<<endl;
else cout<<"a & b are different strings"<<endl;

string c("abcdef@1h");
if(a>b) cout<<"a > b"<<endl;
else cout<<"a < b"<<endl;

//acess to size
cout<<"size of the string: "<<a.size()<<endl;
cout<<"a  = "<<a<<endl;

//retrieve a char* from a string
a.c_str(); //sometimes needed (ex: name of TH1F cannot be a string)

//access to a given element
cout<<"2nd element of a is: "<<a[1]<<endl;

//search
size_t pos = a.find("@"); // possibility to search for a char, char*, or string
cout<<"Charater @ is found in position :"<<pos<<" of string a"<<endl;
//check if it's found !
pos = a.find("cd");
if(pos!=std::string::npos){
        //performm a replace
        string rp = "CD";
        a.replace(pos,rp.size(),"CD");
}
cout<<"After replace: a = "<<a<<endl;

//clear
a.clear();
cout<<"a (after clear) ="<<endl;
```

Many others things are possible

```
a & b are different strings
a < b
size of the string: 9
a  = abcdef@1g
2nd element of a is: b
Charater @ is found in position :6 of string a
After replace: a = abCDef@1g
a (after clear) =
```

Int/float ↔ char* conversion

- Char* to number conversion : **#include<stdlib.h>**
  - **Atof**: convert char* to float
  - **Atoi**: convert char* to int



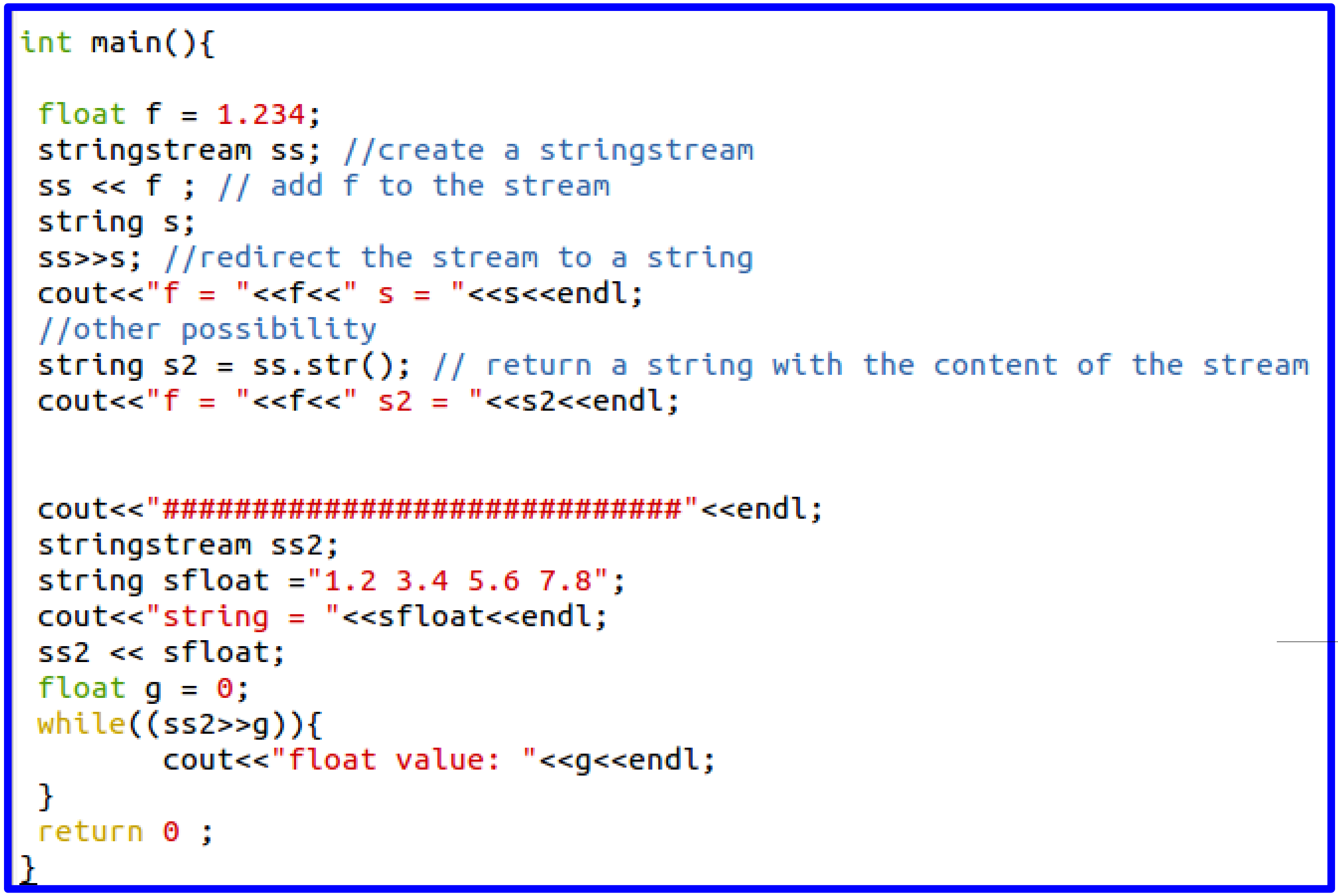
```
string a = "3.1416"; // initialize a string
float pi = atof(a.c_str()); // convert the char* extracted from the string to a float;
cout<<"a = "<<a<<" & pi = "<<pi<<endl;
```

```
a = 3.1416 & pi = 3.1416
```

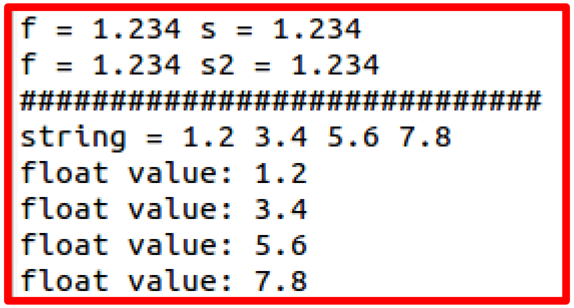
  - This is a common problem
  - Above solution is coming from C, but we can used C++ tools (next slide)

stringstream and conversion

#include <sstream>



```
int main(){

 float f = 1.234;
 stringstream ss; //create a stringstream
 ss << f ; // add f to the stream
 string s;
 ss>>s; //redirect the stream to a string
 cout<<"f = "<<f<<" s = "<<s<<endl;
 //other possibility
 string s2 = ss.str(); // return a string with the content of the stream
 cout<<"f = "<<f<<" s2 = "<<s2<<endl;


 cout<<"#############################"<<endl;
 stringstream ss2;
 string sfloat ="1.2 3.4 5.6 7.8";
 cout<<"string = "<<sfloat<<endl;
 ss2 << sfloat;
 float g = 0;
 while((ss2>>g)){
        cout<<"float value: "<<g<<endl;
 }
 return 0 ;
}
```



```
f = 1.234 s = 1.234
f = 1.234 s2 = 1.234
#############################
string = 1.2 3.4 5.6 7.8
float value: 1.2
float value: 3.4
float value: 5.6
float value: 7.8
```

Preprocessor

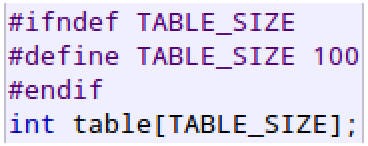
Preprocessor directives are preceded by # (*only a single line*)
No use of semicolon to end the directive
The preprocessor examines the code before the compilation

#define *identifier replacement* (#undefine)

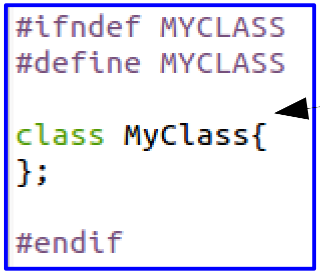
- It only replaces any occurrence of identifier
- Define a value
- Define function macros with parameters
- #undefine: ends the definition (could be used before changing the def.)

Conditional inclusions

- #ifdef
- #endif
- #if #else #elif



```
#ifndef TABLE_SIZE
#define TABLE_SIZE 100
#endif
int table[TABLE_SIZE];
```



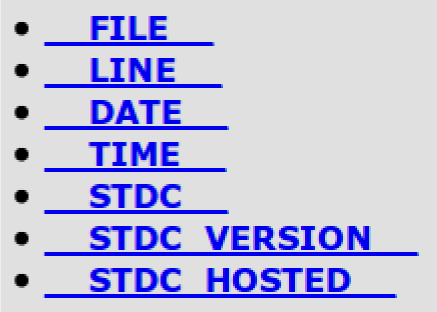
```
#ifndef MYCLASS
#define MYCLASS

class MyClass{
};

#endif
```

Avoid multiple file inclusion

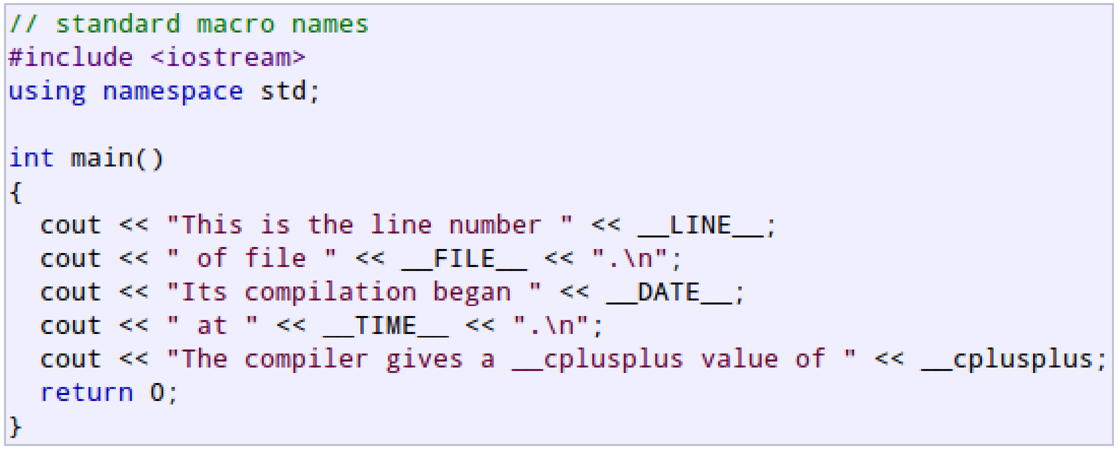
#include
#include <header>: provided by the installed libraries (stl,...)
#include “file.h”: could be everywhere not only the installed packages

Preprocessor: predefined macros

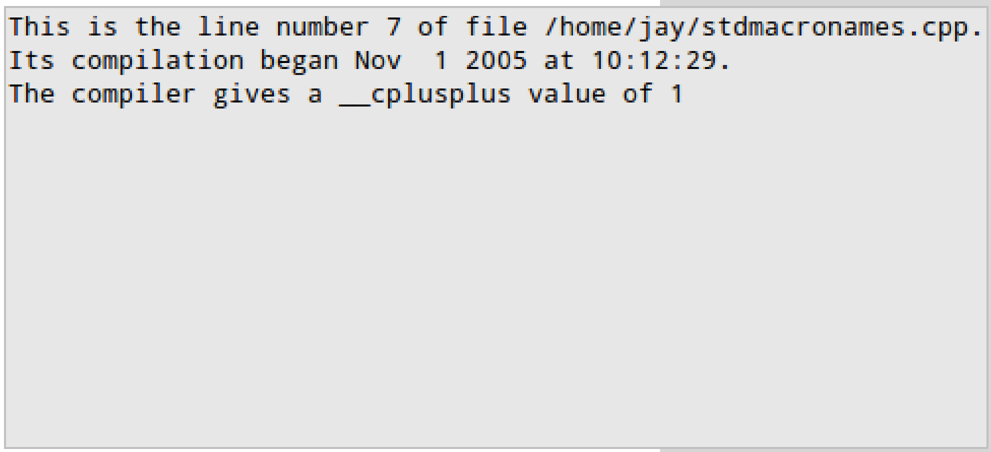
Predefined macro names



- __FILE__
- __LINE__
- __DATE__
- __TIME__
- __STDC__
- __STDC_VERSION__
- __STDC_HOSTED__



```
// standard macro names
#include <iostream>
using namespace std;

int main()
{
  cout << "This is the line number " << __LINE__;
  cout << " of file " << __FILE__ << ".\n";
  cout << "Its compilation began " << __DATE__;
  cout << " at " << __TIME__ << ".\n";
  cout << "The compiler gives a __cplusplus value of " << __cplusplus;
  return 0;
}
```

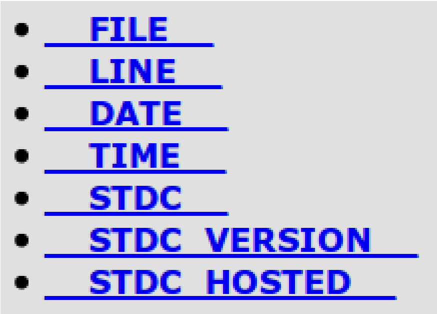


```
This is the line number 7 of file /home/jay/stdmacronames.cpp.
Its compilation began Nov  1 2005 at 10:12:29.
The compiler gives a __cplusplus value of 1
```

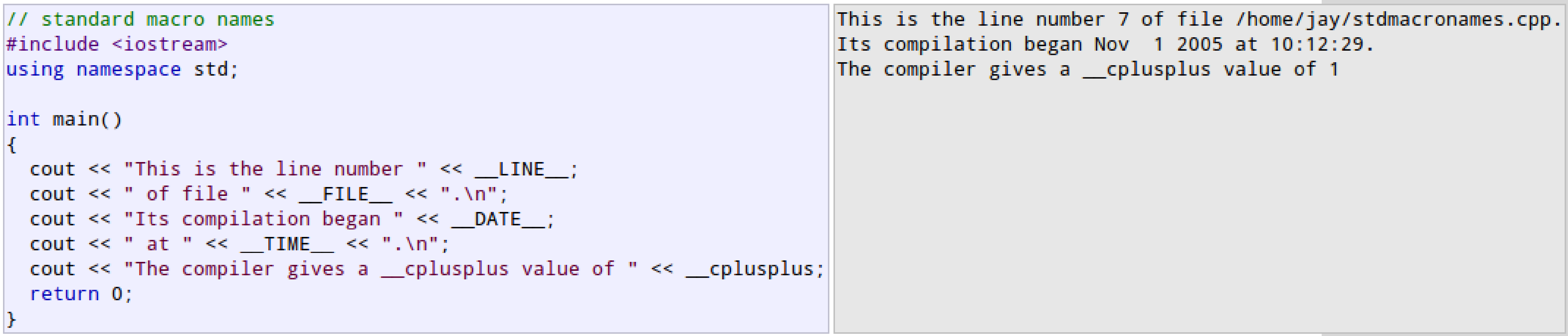
Those macro might be useful for **exception** and **error tracking**

Preprocessor: predefined macros

Predefined macro names



- `__FILE__`
- `__LINE__`
- `__DATE__`
- `__TIME__`
- `__STDC__`
- `__STDC_VERSION__`
- `__STDC_HOSTED__`



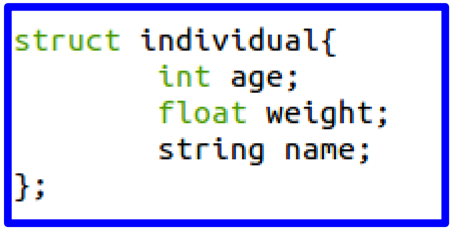
```cpp
// standard macro names
#include <iostream>
using namespace std;

int main()
{
  cout << "This is the line number " << __LINE__;
  cout << " of file " << __FILE__ << ".\n";
  cout << "Its compilation began " << __DATE__;
  cout << " at " << __TIME__ << ".\n";
  cout << "The compiler gives a __cplusplus value of " << __cplusplus;
  return 0;
}
```

```
This is the line number 7 of file /home/jay/stdmacronames.cpp.
Its compilation began Nov  1 2005 at 10:12:29.
The compiler gives a __cplusplus value of 1
```

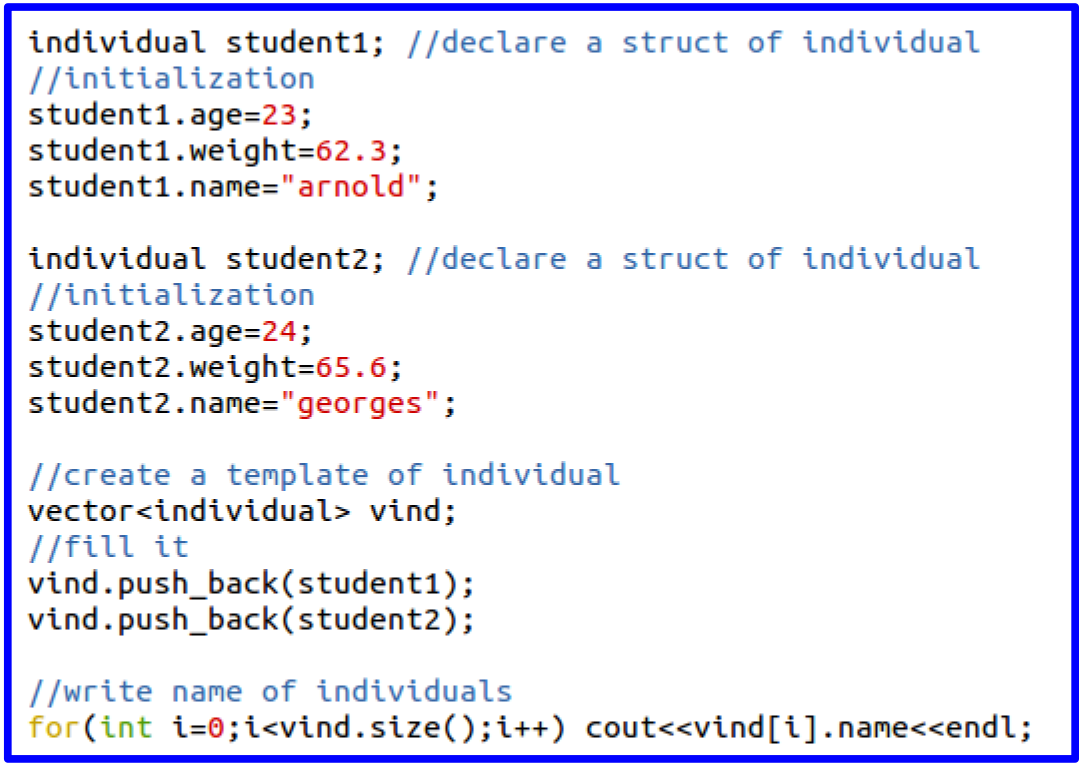
Those macro might be useful for **exception** and **error tracking**

Struct

A **struct** is a group of data elements grouped together under one name.
These data elements, known as members, can have different types and different lengths



```
struct individual{
        int age;
        float weight;
        string name;
};
```



```
individual student1; //declare a struct of individual
//initialization
student1.age=23;
student1.weight=62.3;
student1.name="arnold";

individual student2; //declare a struct of individual
//initialization
student2.age=24;
student2.weight=65.6;
student2.name="georges";

//create a template of individual
vector<individual> vind;
//fill it
vind.push_back(student1);
vind.push_back(student2);

//write name of individuals
for(int i=0;i<vind.size();i++) cout<<vind[i].name<<endl;
```

Oriented Object

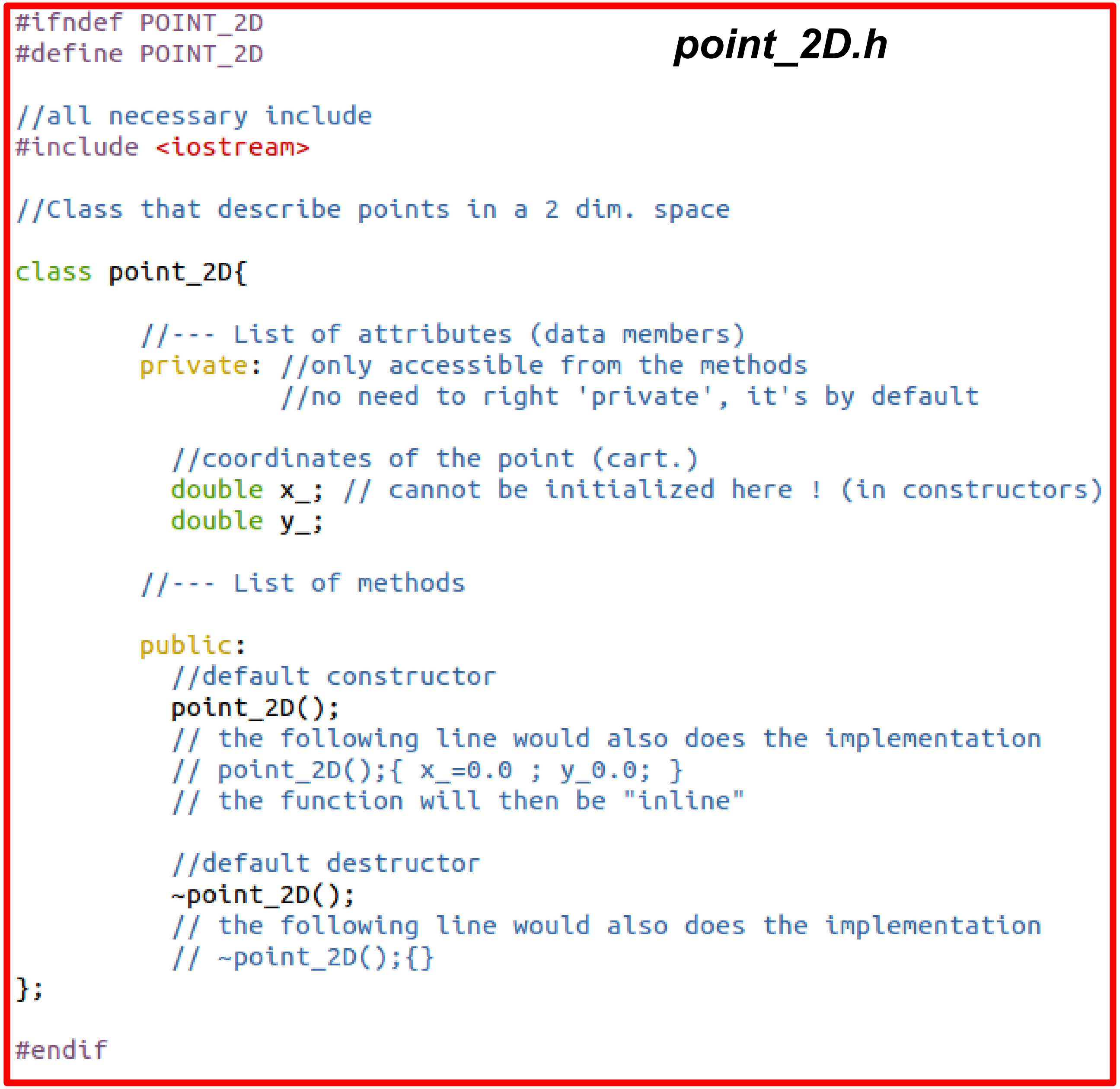
- What is an object ? (Ex: vehicle)
  - Defined by its properties (**Ex**: *number of wheels, ...*)
  - Defined by its actions (**Ex**: *driving, honking,..*)
  - Objects can interact (**Ex**: blinking)
  - We can have many objects of the same **type (***instances***)**
  - We can have different category of object “inheriting” from the same mother category (**Ex**: *motorcycle, car, bus, truck …*)
  - Object can interact with object from another category (**Ex**: *driver, ...*)
- Definition of an object is already an “abstract concept”
- Oriented Object Programming is a powerful tool that allows things that might be difficult to implement with a procedural language

Class

- Represent directly a “concept” in a program
  - Ex: vector, matrix, string, picture, histogram, particle, detector,...
- It is a user-defined type that specifies how objects of its type can be created and used (and deleted)
- Classes are key building blocks for large programs

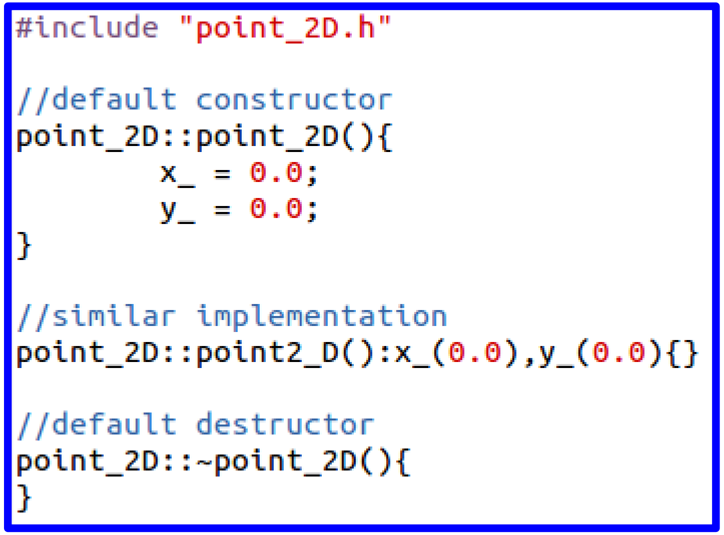
Minimal class

point_2D.h



```
#ifndef POINT_2D
#define POINT_2D

//all necessary include
#include <iostream>

//Class that describe points in a 2 dim. space

class point_2D{

        //--- List of attributes (data members)
        private: //only accessible from the methods
                 //no need to right 'private', it's by default

          //coordinates of the point (cart.)
          double x_; // cannot be initialized here ! (in constructors)
          double y_;

        //--- List of methods

        public:
          //default constructor
          point_2D();
          // the following line would also does the implementation
          // point_2D();{ x_=0.0 ; y_0.0; }
          // the function will then be "inline"

          //default destructor
          ~point_2D();
          // the following line would also does the implementation
          // ~point_2D();{}
};

#endif
```

point_2D.cpp



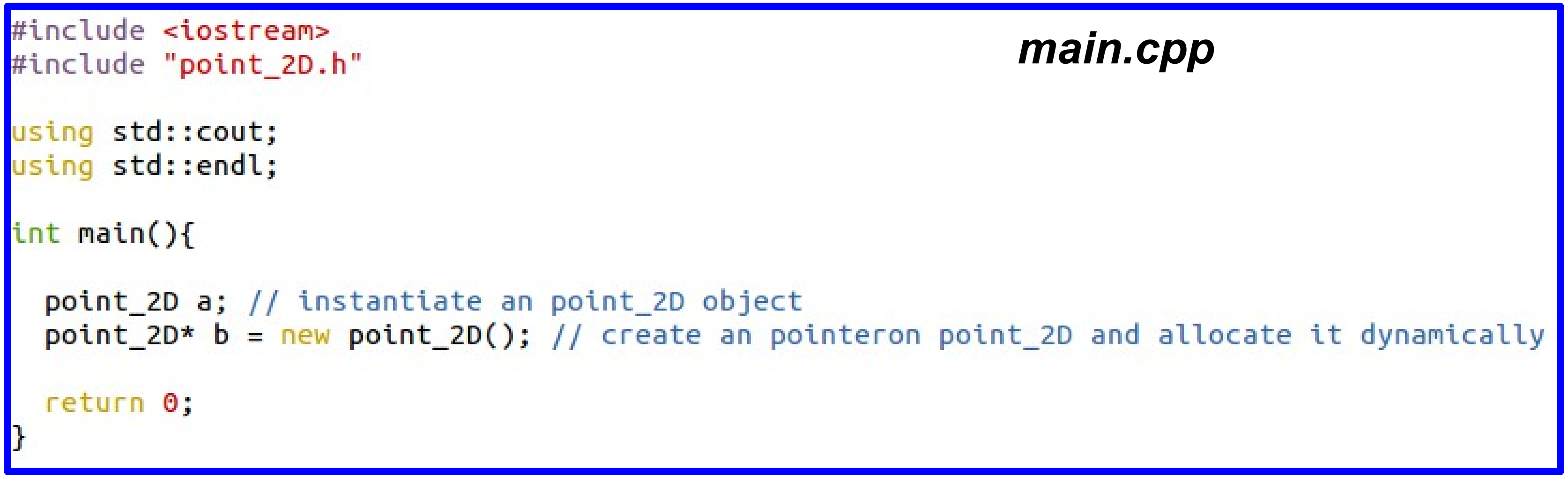
```
#include "point_2D.h"

//default constructor
point_2D::point_2D(){
        x_ = 0.0;
        y_ = 0.0;
}

//similar implementation
point_2D::point2_D():x_(0.0),y_(0.0){}

//default destructor
point_2D::~point_2D(){
}
```

Minimal class

Compilation:

#creating a point_2D.o (compiled code)
g++ -c point_2D.cpp

#creating an executable
g++ -I. -o main.exe point_2D.o main.cpp
-I. Is needed to be able to access point_2D.h
-o is needed if you want to specify the name of your executable (a.out by default)
code is “linked” to point_2D.o

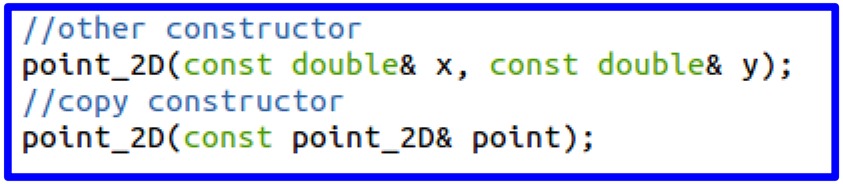


main.cpp

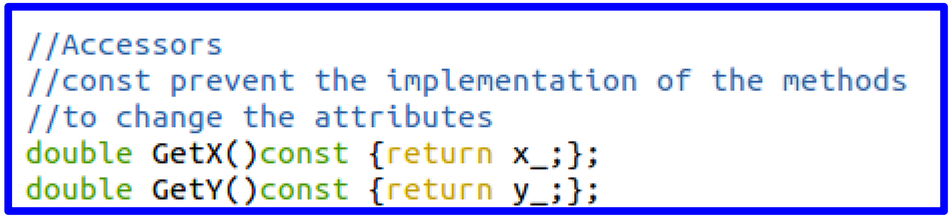
```
#include <iostream>
#include "point_2D.h"

using std::cout;
using std::endl;

int main(){

  point_2D a; // instantiate an point_2D object
  point_2D* b = new point_2D(); // create an pointeron point_2D and allocate it dynamically

  return 0;
}
```

constructor & copy constructor

point_2D.h

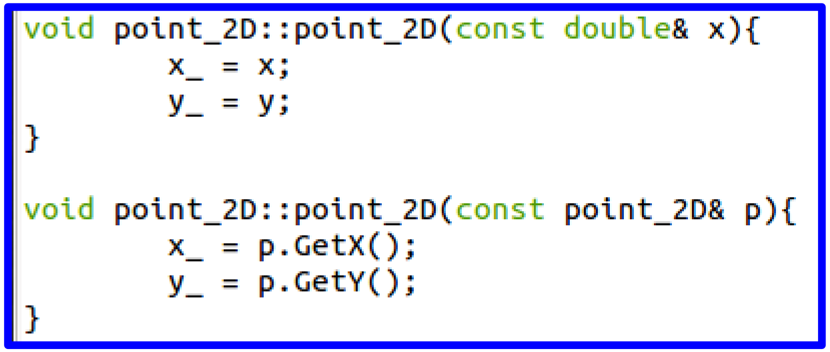


```
//other constructor
point_2D(const double& x, const double& y);
//copy constructor
point_2D(const point_2D& point);
```



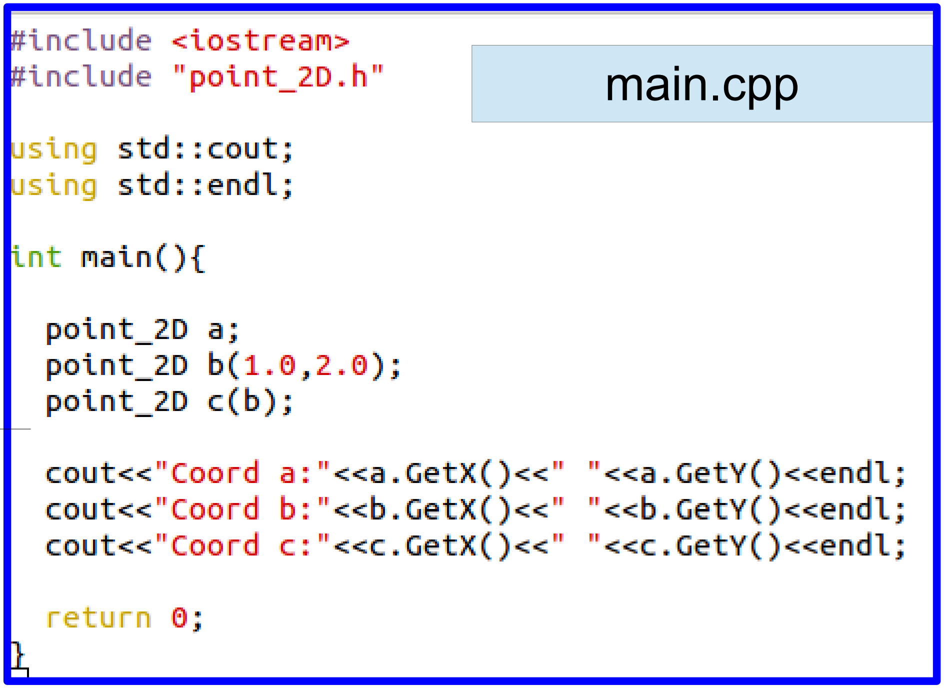
```
//Accessors
//const prevent the implementation of the methods
//to change the attributes
double GetX()const {return x_;};
double GetY()const {return y_;};
```

point_2D.cpp

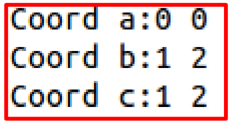


```
void point_2D::point_2D(const double& x){
        x_ = x;
        y_ = y;
}

void point_2D::point_2D(const point_2D& p){
        x_ = p.GetX();
        y_ = p.GetY();
}
```

main.cpp



```
#include <iostream>
#include "point_2D.h"

using std::cout;
using std::endl;

int main(){

  point_2D a;
  point_2D b(1.0,2.0);
  point_2D c(b);

  cout<<"Coord a:"<<a.GetX()<<"  "<<a.GetY()<<endl;
  cout<<"Coord b:"<<b.GetX()<<"  "<<b.GetY()<<endl;
  cout<<"Coord c:"<<c.GetX()<<"  "<<c.GetY()<<endl;

  return 0;
}
```



```
Coord a:0 0
Coord b:1 2
Coord c:1 2
```

Operators overload

Mathematical operators

- +,-,*,/,%
- +=,-=,*=,/=,%=

point_2D.h

```
//overloading the operator +
//first argument should not be const as it will be changed
point_2D operator+(point_2D& a);
//overloading the operator +=
point_2D operator+=(const point_2D& a);
```

point_2D.cpp

```
//overloading the operator +
point_2D point_2D::operator+(point_2D& a){
        point_2D c ; // call the default construcor
        //additionne the value of X and Y
        c.SetX(GetX()+a.GetX());
        c.SetY(GetY()+a.GetY());
        return c;
}

//overloading the operator +=
point_2D point_2D::operator+=(point_2D const& a){
        //directly modify the data members x_ & y_
        x_ += a.GetX();
        y_ += a.GetY();
        return *this; //'this' is pointer to the current instance of the class
}
```

main.cpp

```
point_2D a;
point_2D b(1.0,2.0);
a+=b;

point_2D c;
c=a+b;
```

Operators overload

Comparison:

- == , !=
- >, >=,<,<=

point_2D.h

```
//-- Comparison operators
bool operator==(const point_2D& a) const;
bool operator!=(const point_2D& a) const;
```

point_2D.cpp

```
//overloading the operation ==
bool point_2D::operator==(const point_2D& a) const{
        //compare both x & y value
        if (GetX() == a.GetY() && GetY() == a.GetY()) return true;
        return false;
}

bool point_2D::operator!=(const point_2D& a) const{
        //we can reuse the already defined operator ==
        if(*this==a) return false;
        return true;
}
```

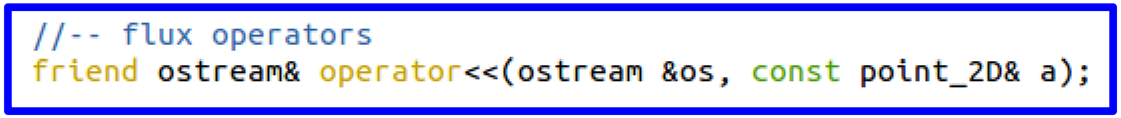
main.cpp

```
point_2D a;
point_2D b(1.0,2.0);

if(a==b) cout<<"Equality: OK"<<endl;
else cout<<"Equality: NO"<<endl;
if(a!=b) cout<<"Difference: OK"<<endl;
else cout<<"Difference: NO"<<endl;
```

Operators overload

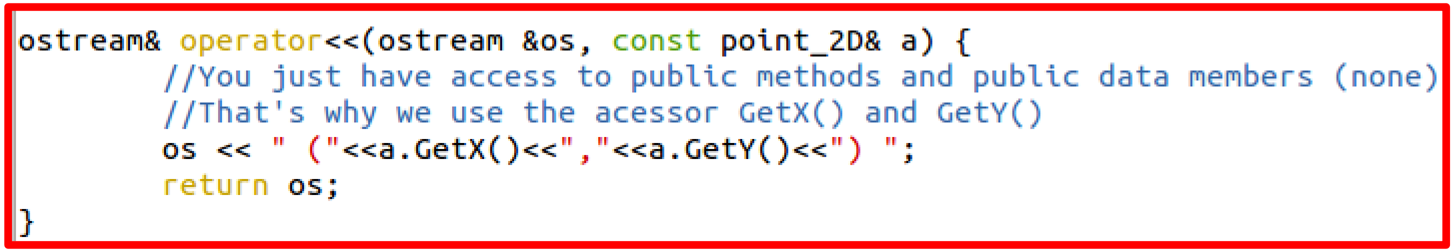
Flux operators: <<, >>

point_2D.h



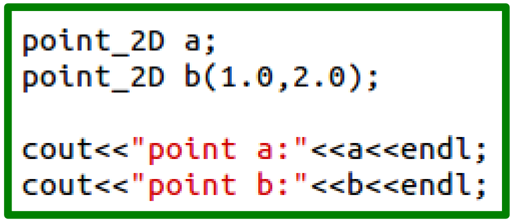
```
//-- flux operators
friend ostream& operator<<(ostream &os, const point_2D& a);
```

point_2D.cpp



```
ostream& operator<<(ostream &os, const point_2D& a) {
        //You just have access to public methods and public data members (none)
        //That's why we use the acessor GetX() and GetY()
        os << " ("<<a.GetX()<<","<<a.GetY()<<") ";
        return os;
}
```

main.cpp



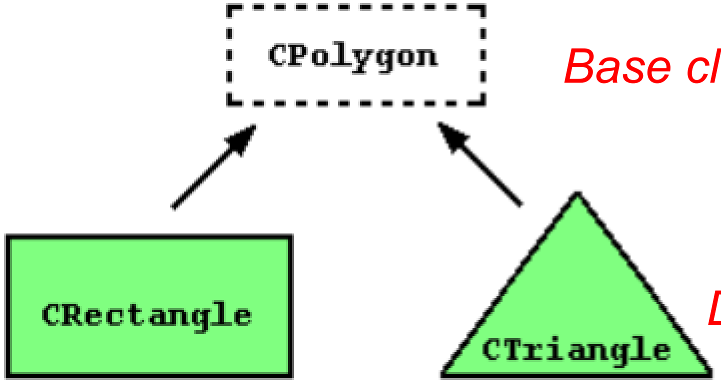
```
point_2D a;
point_2D b(1.0,2.0);

cout<<"point a:"<<a<<endl;
cout<<"point b:"<<b<<endl;
```

Pointer & classes

- Pointer "*this*": pointer to the current instance of the class
- Pointers to other classes:
  - Take care to the construction, copy constructor & destructor

Inheritance

Example from http://www.cplusplus.com



Base class

Derived classes

Rectangle & triangle have common properties
They are both polygons.

Access rights

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

Rule of the "most restrictive access :

If **class Rectangle: protected Polygon**, the Public members of polygon would have been "protected" (not accessible) in Rectangle

---

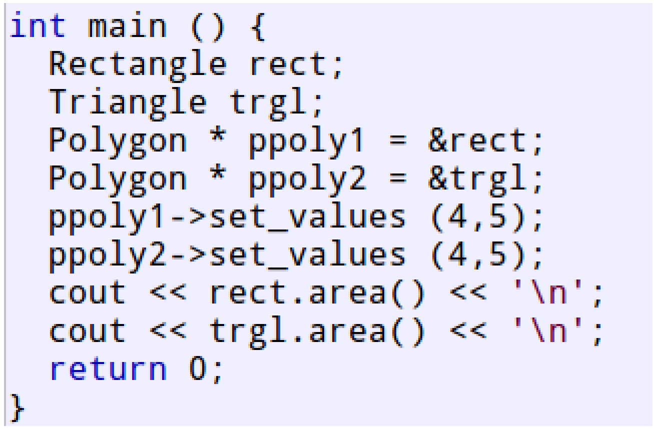
In principle, a derived class inherits every member of a base class except:

- its constructors and its destructor
- its assignment operator members (operator=)
- its friends

```
#include <iostream>
using namespace std;

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

class Rectangle: public Polygon {
  public:
    int area ()
      { return width * height; }
 };

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

int main () {
  Rectangle rect;
  Triangle trgl;
  rect.set_values (4,5);
  trgl.set_values (4,5);
  cout << rect.area() << '\n';
  cout << trgl.area() << '\n';
  return 0;
}
```

Polymorphism

- One of the key features of class inheritance 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



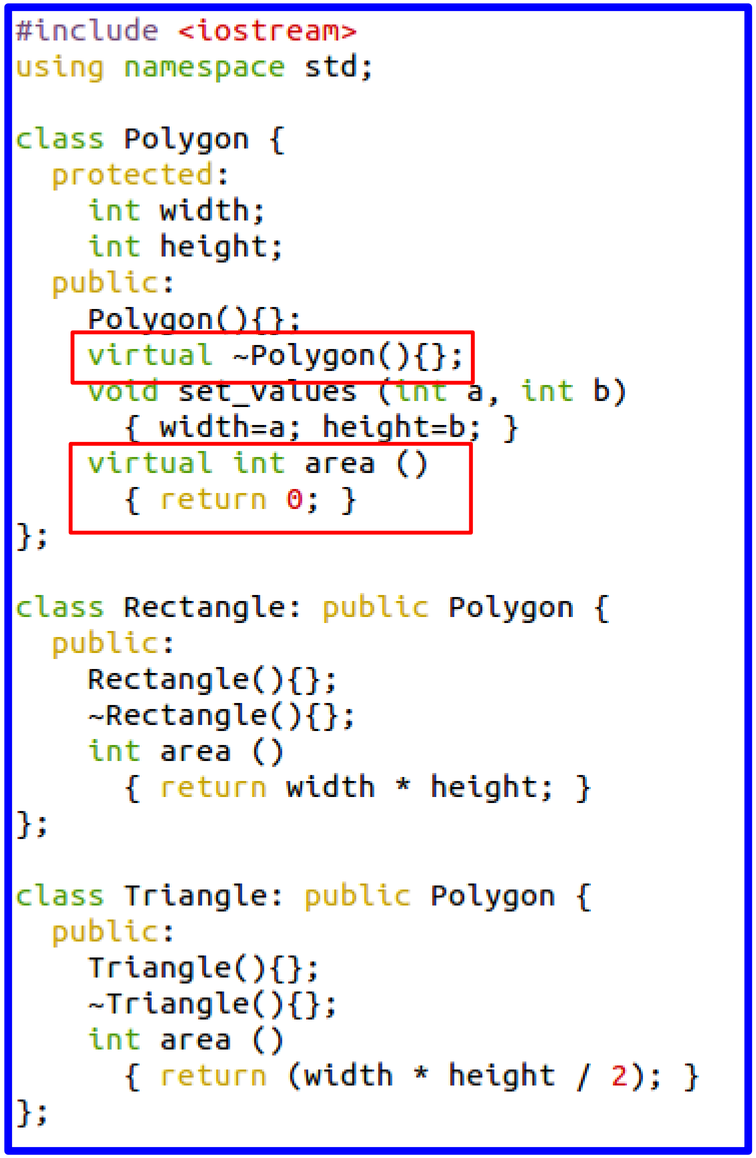
```
int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  cout << rect.area() << '\n';
  cout << trgl.area() << '\n';
  return 0;
}
```

Only members inherited from Polygon can be accessed from ppoly1 & ppoly2 and not those of the derived class

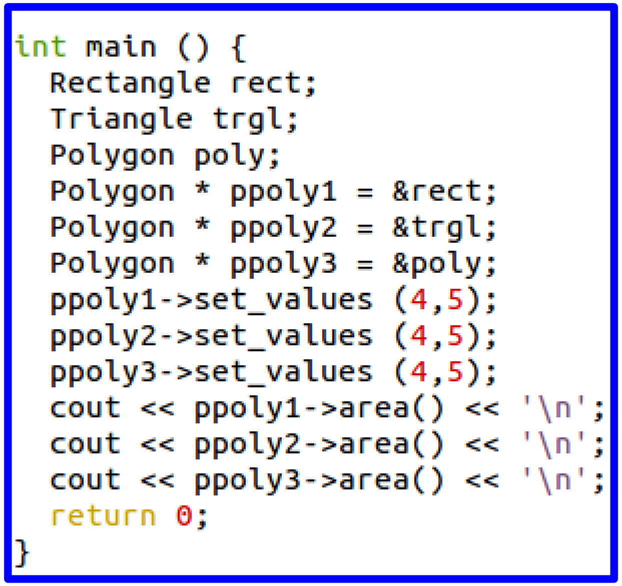
If int area() had been defined in Polygon with a different implementation from the derived class:
Rect.area() and ppoly->area() would have given different results !!

Polymorphism might be useful by example to create a vector of pointer to polygon whatever are the derived class of objects

Virtual methods



```
#include <iostream>
using namespace std;

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

class Rectangle: public Polygon {
  public:
    Rectangle(){};
    ~Rectangle(){};
    int area ()
      { return width * height; }
};

class Triangle: public Polygon {
  public:
    Triangle(){};
    ~Triangle(){};
    int area ()
      { return (width * height / 2); }
};
```



```
int main () {
  Rectangle rect;
  Triangle trgl;
  Polygon poly;
  Polygon * ppoly1 = &rect;
  Polygon * ppoly2 = &trgl;
  Polygon * ppoly3 = &poly;
  ppoly1->set_values (4,5);
  ppoly2->set_values (4,5);
  ppoly3->set_values (4,5);
  cout << ppoly1->area() << '\n';
  cout << ppoly2->area() << '\n';
  cout << ppoly3->area() << '\n';
  return 0;
}
```

```
20
10
0
```

Int area() method **can** be redefined in all derived classes ppoly1->area() refer to the method defined in Rectangle and not in Polygone !
This wouldn't have been the case if the methods would have not been virtual

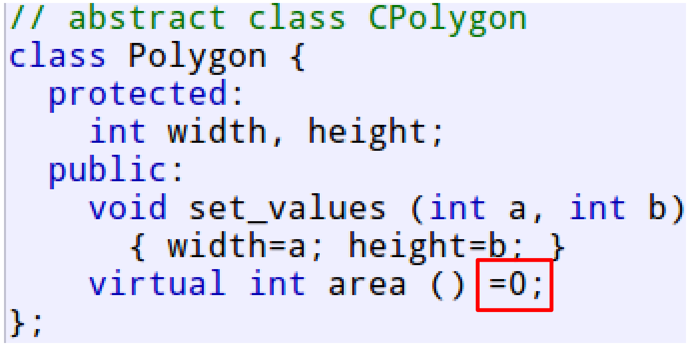
The destructor of the base class (here Polygon), should be virtual. If not, the destructor of the base class will be called but not the one of the derived class, resulting in resources leak (for memory allocated in the derived class).

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

Abstract base classes

- Can only be used for base classes allowed to have virtual member function without definition
- Those functions are called virtual functions definition is replaced by “=0”

Int area() **have** to be defined in all derived function inheriting from Polygon



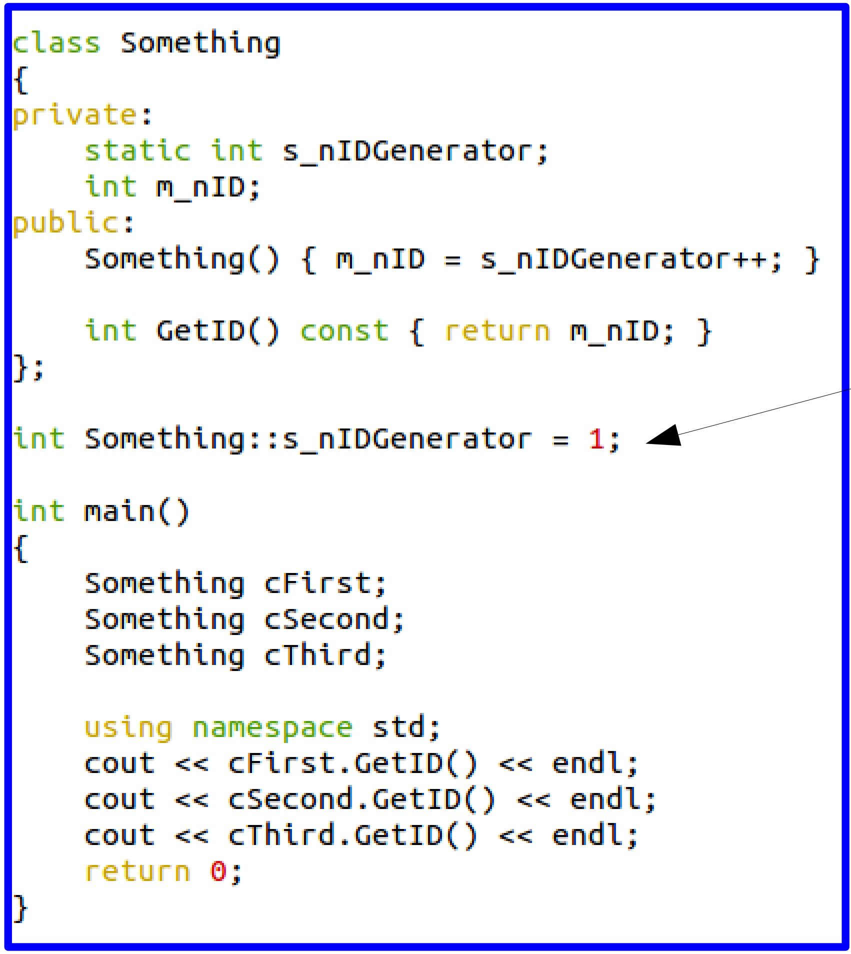
```
// abstract class CPolygon
class Polygon {
  protected:
    int width, height;
  public:
    void set_values (int a, int b)
      { width=a; height=b; }
    virtual int area () =0;
};
```

- Classes that contain at least one pure virtual function are known as abstract base classes
- Abstract base classes cannot be used to instantiate objects but pointer of abstract base class is valid !

```
Polygon mypolygon;   // not working if Polygon is abstract base class
```

Static members

- Static member variables only exist once in a program regardless of how many class objects are defined!
  - One way to think about it is that all objects of a class share the static variables.



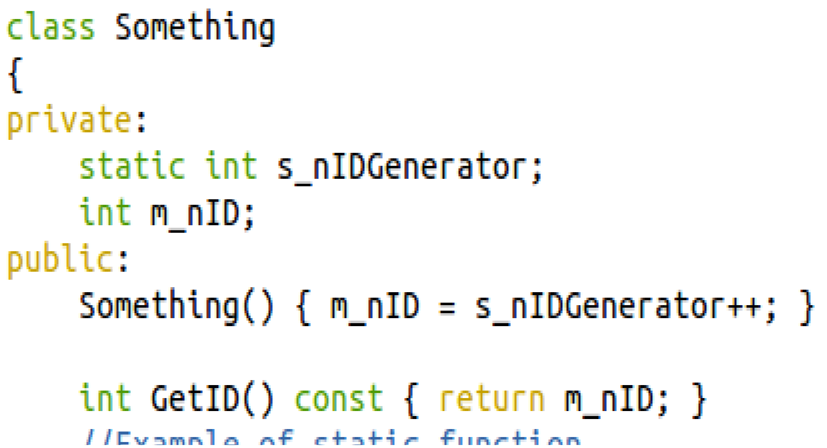
```
class Something
{
private:
    static int s_nIDGenerator;
    int m_nID;
public:
    Something() { m_nID = s_nIDGenerator++; }

    int GetID() const { return m_nID; }
};

int Something::s_nIDGenerator = 1;

int main()
{
    Something cFirst;
    Something cSecond;
    Something cThird;

    using namespace std;
    cout << cFirst.GetID() << endl;
    cout << cSecond.GetID() << endl;
    cout << cThird.GetID() << endl;
    return 0;
}
```

Initializer

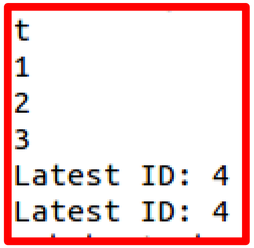
```
1
2
3
```

Static methods

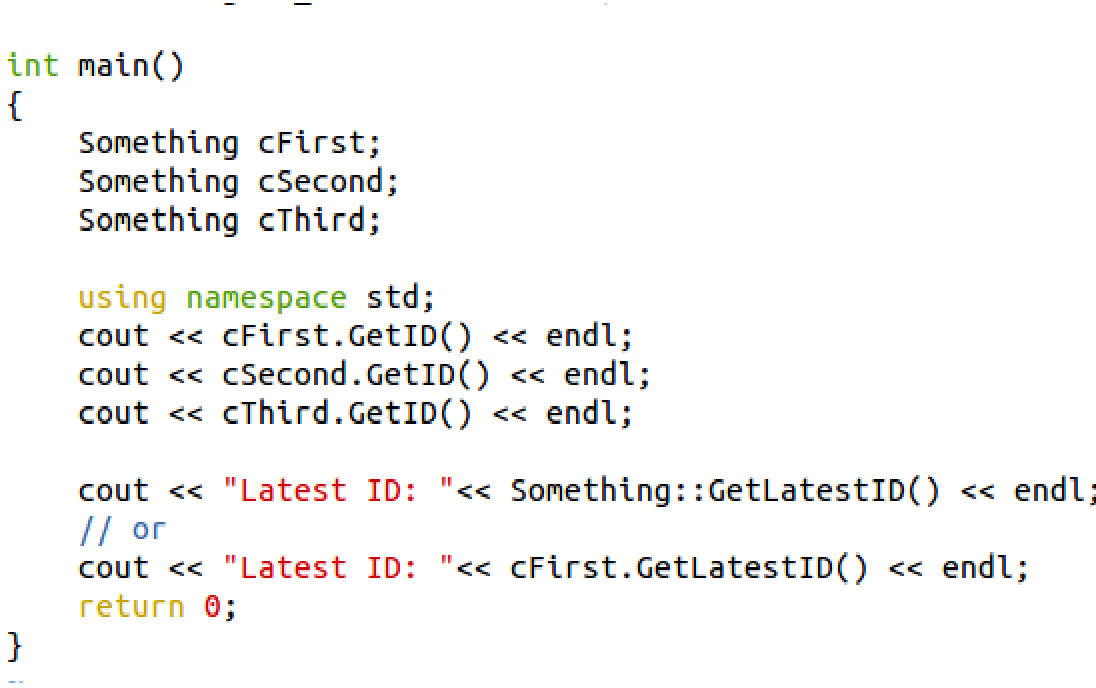
- **static methods** are not attached to a particular object, they can be called directly by using the class name and the scope operator.
- Like static member variables, they can also be called through objects of the class type, though this is not recommended
- In the implementation of those functions: access to pointer this and to non static data members is forbidden



```
class Something
{
private:
    static int s_nIDGenerator;
    int m_nID;
public:
    Something() { m_nID = s_nIDGenerator++; }

    int GetID() const { return m_nID; }
    //Example of static function
```



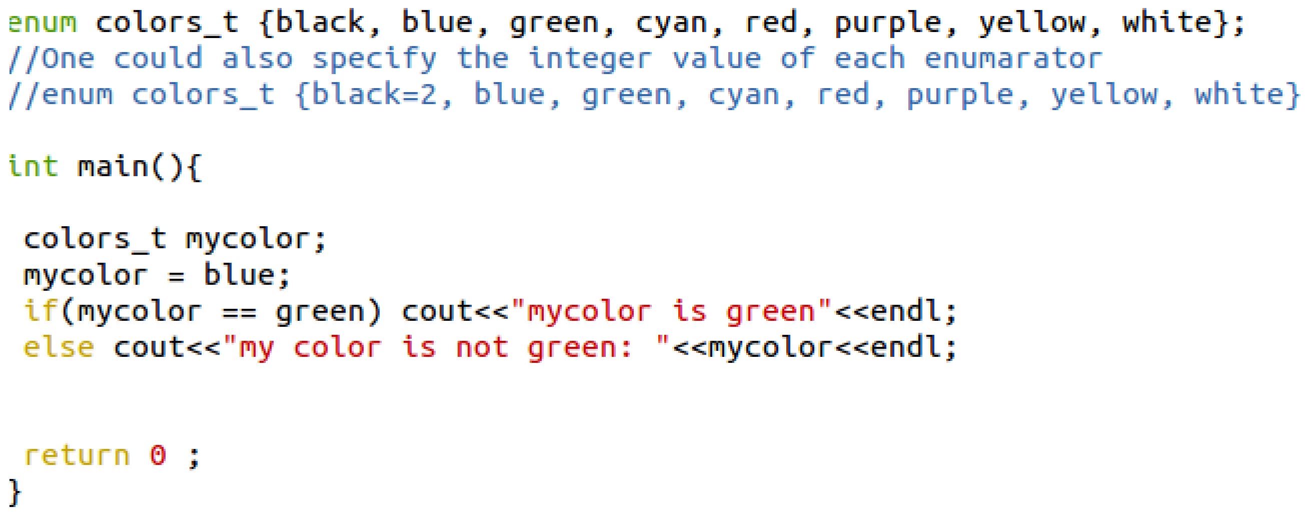
```
t
1
2
3
Latest ID: 4
Latest ID: 4
```



```
int main()
{
    Something cFirst;
    Something cSecond;
    Something cThird;

    using namespace std;
    cout << cFirst.GetID() << endl;
    cout << cSecond.GetID() << endl;
    cout << cThird.GetID() << endl;

    cout << "Latest ID: "<< Something::GetLatestID() << endl;
    // or
    cout << "Latest ID: "<< cFirst.GetLatestID() << endl;
    return 0;
}
```

enums

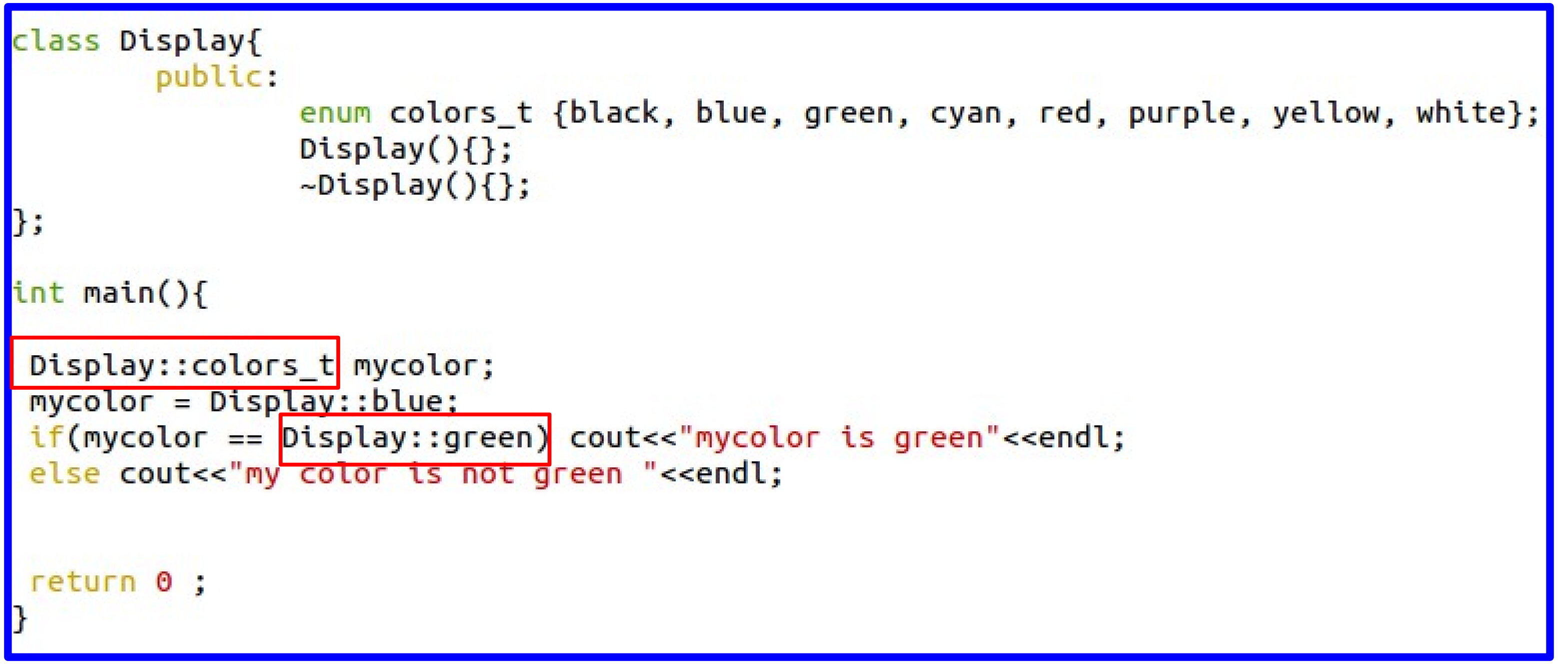
- Enumerated types are types that are defined with a set of custom identifiers (=”enumerators”), as possible values.
- Objects of these enumerated types can take any of these enumerators as value
- Value are always assigned to an integer numerical equivalent internally, of which they become an alias.
  - If it is not specified otherwise, the integer value equivalent to the first possible value is 0, the equivalent to the second is 1



```
enum colors_t {black, blue, green, cyan, red, purple, yellow, white};
//One could also specify the integer value of each enumarator
//enum colors_t {black=2, blue, green, cyan, red, purple, yellow, white}

int main(){

 colors_t mycolor;
 mycolor = blue;
 if(mycolor == green) cout<<"mycolor is green"<<endl;
 else cout<<"my color is not green: "<<mycolor<<endl;


 return 0 ;
}
```

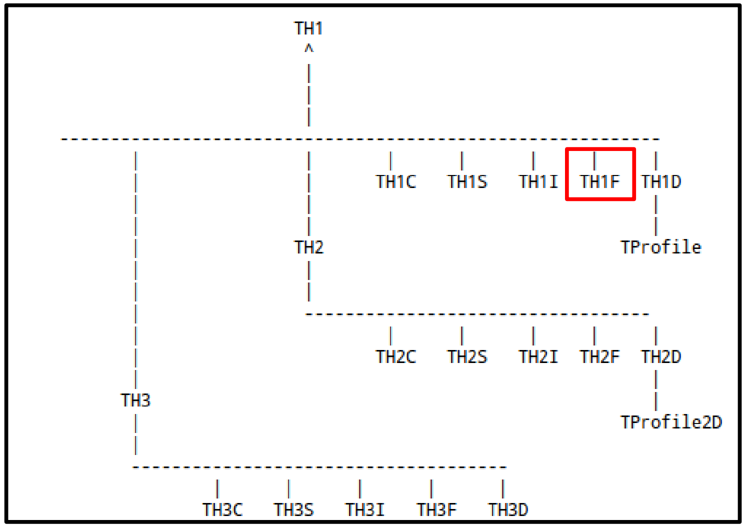
Examples of applications:
- Colors
- Months
- Gender
- ...

enums can also be defined in class

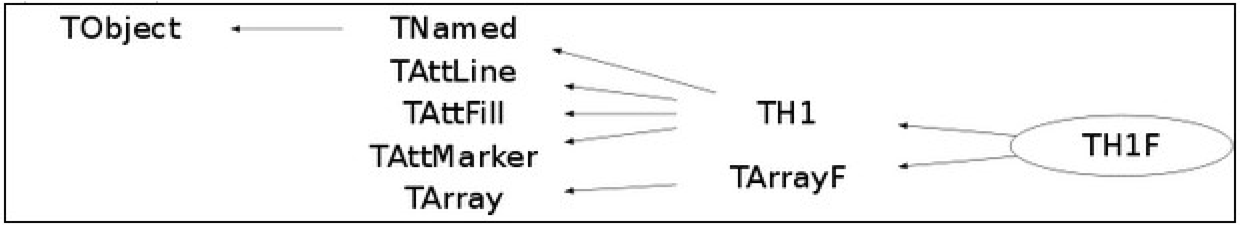


```
class Display{
        public:
                enum colors_t {black, blue, green, cyan, red, purple, yellow, white};
                Display(){};
                ~Display(){};
};

int main(){

 Display::colors_t mycolor;
 mycolor = Display::blue;
 if(mycolor == Display::green) cout<<"mycolor is green"<<endl;
 else cout<<"my color is not green "<<endl;


 return 0 ;
}
```

Example with ROOT: TH1F



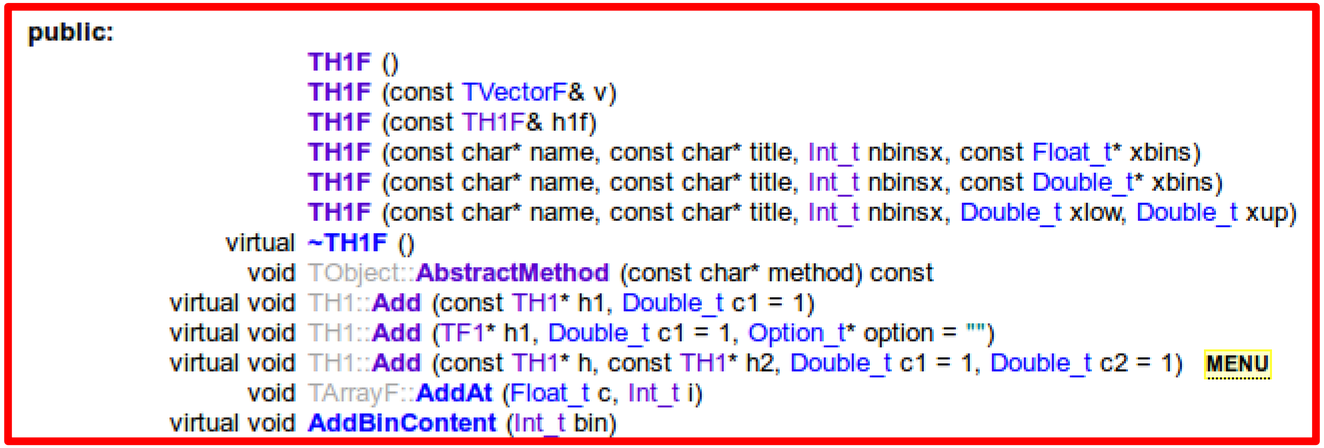
multiple **inheritance**



class TH1F: public TH1, public TArrayF

class TH1: public TNamed, public TAttLine, public TAttFill, public TAttMarker

Short **extract of the public methods ….**



```
public:
                    TH1F ()
                    TH1F (const TVectorF& v)
                    TH1F (const TH1F& h1f)
                    TH1F (const char* name, const char* title, Int_t nbinsx, const Float_t* xbins)
                    TH1F (const char* name, const char* title, Int_t nbinsx, const Double_t* xbins)
                    TH1F (const char* name, const char* title, Int_t nbinsx, Double_t xlow, Double_t xup)
            virtual ~TH1F ()
               void TObject::AbstractMethod (const char* method) const
       virtual void TH1::Add (const TH1* h1, Double_t c1 = 1)
       virtual void TH1::Add (TF1* h1, Double_t c1 = 1, Option_t* option = "")
       virtual void TH1::Add (const TH1* h, const TH1* h2, Double_t c1 = 1, Double_t c2 = 1)
               void TArrayF::AddAt (Float_t c, Int_t i)
       virtual void AddBinContent (Int_t bin)
```

An example: TH1F

Use of *enums*

```
public:
                      enum {  kNoStats
                              kUserContour
                              kCanRebin
                              kLogX
                              kIsZoomed
                              kNoTitle
                              kIsAverage
                            };
 enum TObject::EStatusBits {  kCanDelete
                              kMustCleanup
                              kObjInCanvas
                              kIsReferenced
                              kHasUUID
                              kCannotPick
                              kNoContextMenu
                              kInvalidObject
                            };
 enum TObject::[unnamed] {    kIsOnHeap
                              kNotDeleted
                              kZombie
```

Data members are *protected*

Short_t	fBarWidth	(1000*width) for bar charts or legos
Double_t*	fBuffer	[fBufferSize] entry buffer
Int_t	fBufferSize	fBuffer size
TArrayD	fContour	Array to display contour levels
Int_t	fDimension	!Histogram dimension (1, 2 or 3 dim)
TDirectory*	fDirectory	!Pointer to directory holding this histogram
Double_t	fEntries	Number of entries
Color_t	TAttFill::fFillColor	fill area color
Style_t	TAttFill::fFillStyle	fill area style
TList*	fFunctions	->Pointer to list of functions (fits and user)
Double_t*	fIntegral	!Integral of bins used by GetRandom
Color_t	TAttLine::fLineColor	line color
Style_t	TAttLine::fLineStyle	line style
Width_t	TAttLine::fLineWidth	line width
Color_t	TAttMarker::fMarkerColor	Marker color index
Size_t	TAttMarker::fMarkerSize	Marker size
Style_t	TAttMarker::fMarkerStyle	Marker style
Double_t	fMaximum	Maximum value for plotting
Double_t	fMinimum	Minimum value for plotting
TString	TNamed::fName	object identifier
Int_t	fNcells	number of bins(1D), cells (2D) +U/Overflows
Double_t	fNormFactor	Normalization factor
TString	fOption	histogram options
TVirtualHistPainter*	fPainter	!pointer to histogram painter
TArrayD	fSumw2	Array of sum of squares of weights
TString	TNamed::fTitle	object title
Double_t	fTsumw	Total Sum of weights
Double_t	fTsumw2	Total Sum of squares of weights
Double_t	fTsumwx	Total Sum of weight*X
Double_t	fTsumwx2	Total Sum of weight*X*X
TAxis	fXaxis	X axis descriptor
TAxis	fYaxis	Y axis descriptor
TAxis	fZaxis	Z axis descriptor
static Bool_t	fgAddDirectory	!flag to add histograms to the directory
static Int_t	fgBufferSize	!default buffer size for automatic histograms
static Bool_t	fgDefaultSumw2	!flag to call TH1::Sumw2 automatically at histogram creation time
static Bool_t	fgStatOverflows	!flag to use under/overflows in statistics

- **Variable are comments**
- Use "**rules**" for name
- Use of ***static*** variable
- ***Pointers*** are also used

Another example: TLorentzVector

TLorentzVector is a general four-vector class, which can be used either for the description of position and time (x,y,z,t) or momentum and energy (px,py,pz,E).

Inheritance

class TLorentzVector: public TObject

Class: TLorentzVector
Header: #include “TLorentzVector.h”
Library: libPhysics

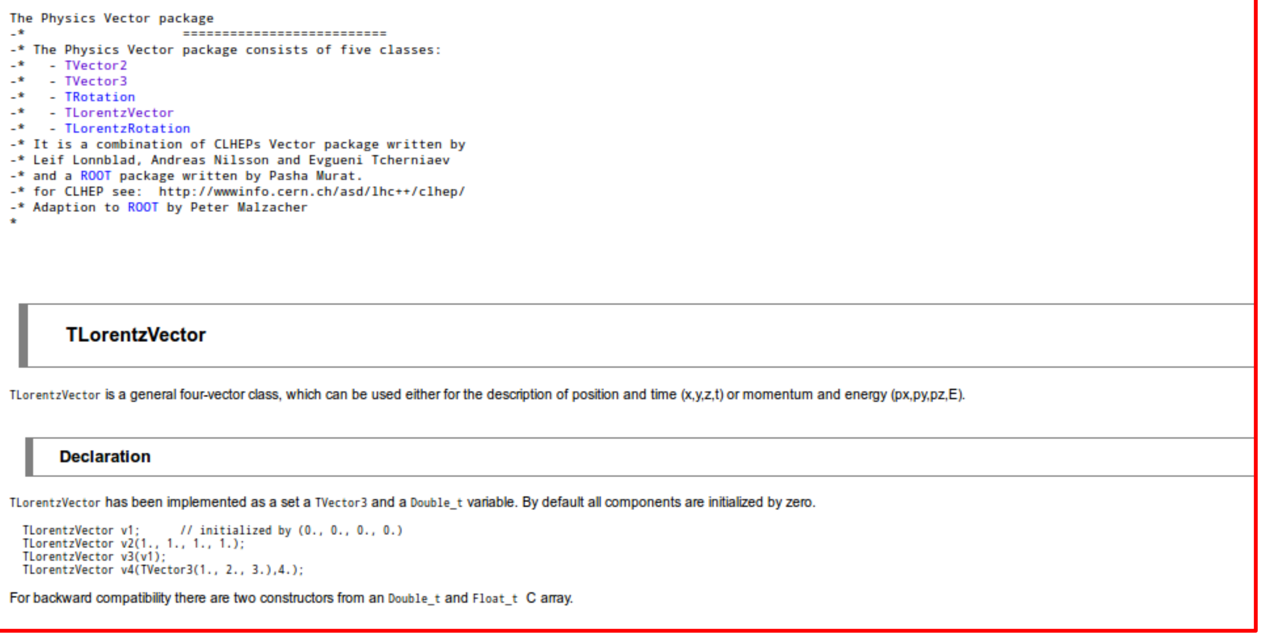
Many constructors

```
TLorentzVector (const Double_t* carray)
TLorentzVector (const Float_t* carray)
TLorentzVector (const TLorentzVector& lorentzvector)
TLorentzVector (const TVector3& vector3, Double_t t)
TLorentzVector (Double_t x = 0.0, Double_t y = 0.0, Double_t z = 0.0, Double_t t = 0.0)
```

Overloaded operators

```
         Bool_t operator!= (const TLorentzVector& q) const
       Double_t operator() (int i) const
      Double_t& operator() (int i)
 TLorentzVector operator* (Double_t a) const
       Double_t operator* (const TLorentzVector& q) const
TLorentzVector& operator*= (Double_t a)
TLorentzVector& operator*= (const TRotation& m)
TLorentzVector& operator*= (const TLorentzRotation&)
 TLorentzVector operator+ (const TLorentzVector& q) const
TLorentzVector& operator+= (const TLorentzVector& q)
 TLorentzVector operator- () const
 TLorentzVector operator- (const TLorentzVector& q) const
TLorentzVector& operator-= (const TLorentzVector& q)
TLorentzVector& operator= (const TLorentzVector& q)
         Bool_t operator== (const TLorentzVector& q) const
       Double_t operator[] (int i) const
      Double_t& operator[] (int i)
```

Importance of the documentation



```
The Physics Vector package
-*                    ==========================
-* The Physics Vector package consists of five classes:
-*    - TVector2
-*    - TVector3
-*    - TRotation
-*    - TLorentzVector
-*    - TLorentzRotation
-* It is a combination of CLHEPs Vector package written by
-* Leif Lonnblad, Andreas Nilsson and Evgueni Tcherniaev
-* and a ROOT package written by Pasha Murat.
-* for CLHEP see:  http://wwwinfo.cern.ch/asd/lhc++/clhep/
-* Adaption to ROOT by Peter Malzacher
*
```

TLorentzVector

`TLorentzVector` is a general four-vector class, which can be used either for the description of position and time (x,y,z,t) or momentum and energy (px,py,pz,E).

Declaration

`TLorentzVector` has been implemented as a set a `TVector3` and a `Double_t` variable. By default all components are initialized by zero.

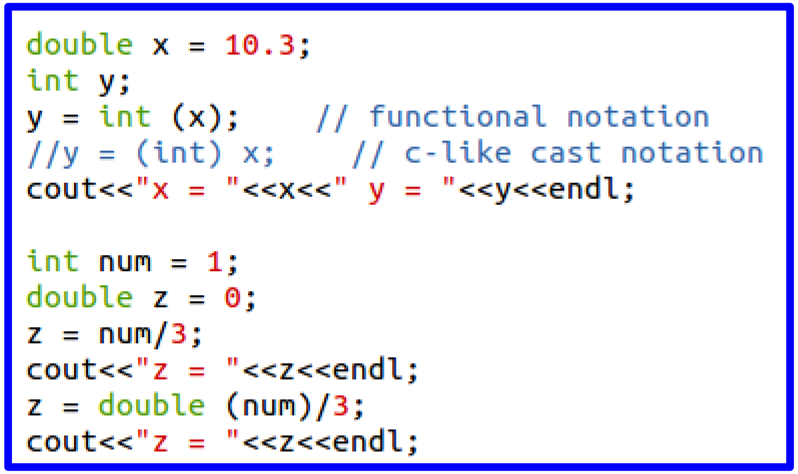
```
TLorentzVector v1;      // initialized by (0., 0., 0., 0.)
TLorentzVector v2(1., 1., 1., 1.);
TLorentzVector v3(v1);
TLorentzVector v4(TVector3(1., 2., 3.),4.);
```

For backward compatibility there are two constructors from an `Double_t` and `Float_t` C array.

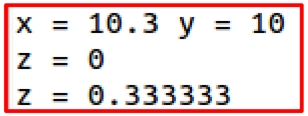
Type casting

Type casting

Can lead to code that while being syntactically correct can cause runtime errors or give undesired results



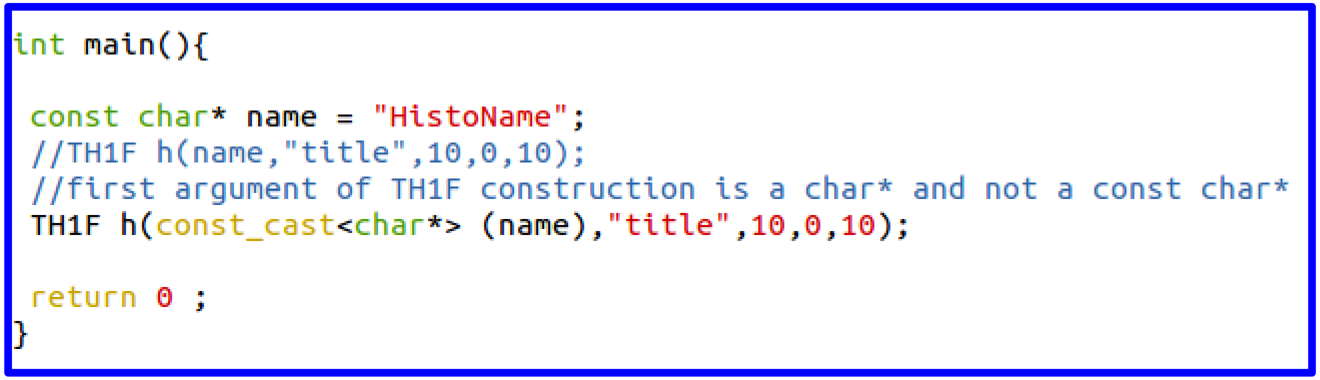
```
double x = 10.3;
int y;
y = int (x);    // functional notation
//y = (int) x;    // c-like cast notation
cout<<"x = "<<x<<" y = "<<y<<endl;

int num = 1;
double z = 0;
z = num/3;
cout<<"z = "<<z<<endl;
z = double (num)/3;
cout<<"z = "<<z<<endl;
```



```
x = 10.3 y = 10
z = 0
z = 0.333333
```

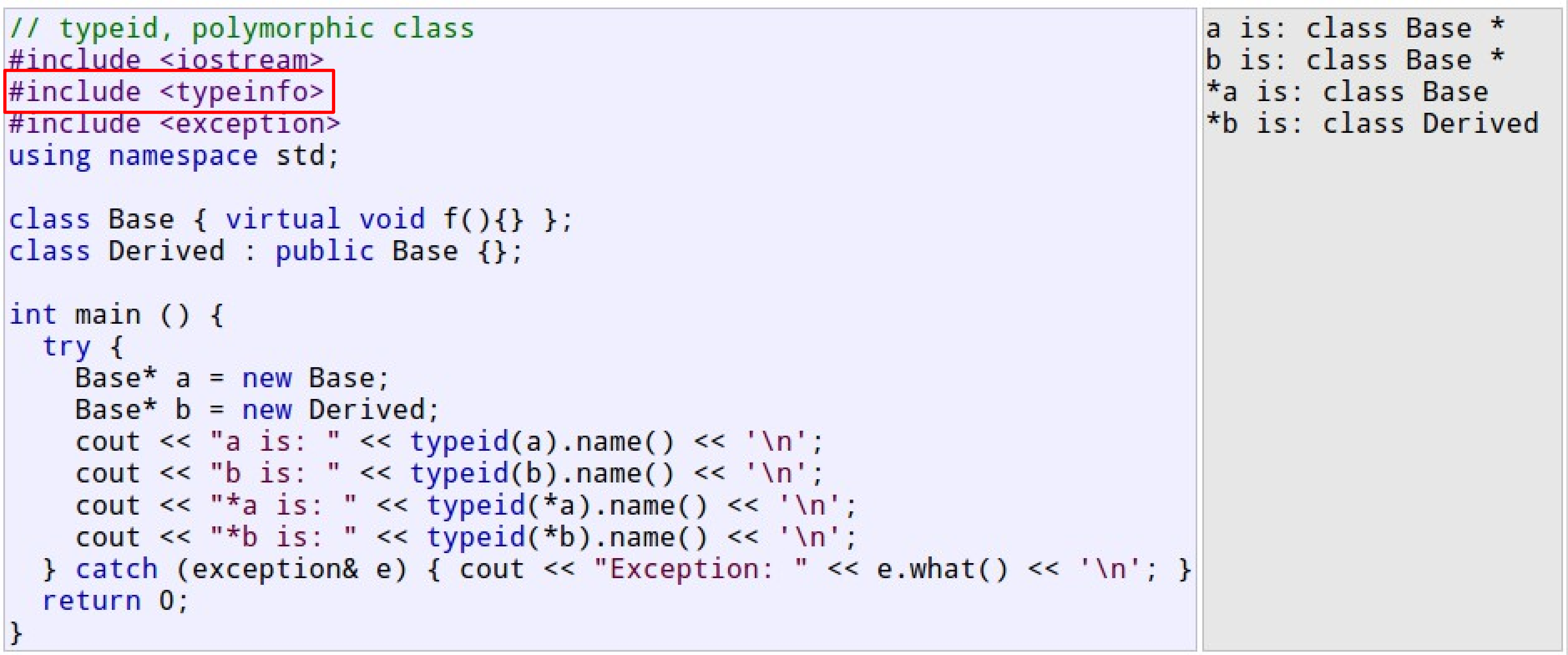
const_cast

Manipulates the constness of the object pointed by a pointed, either to be set or to be removed



```
int main(){

 const char* name = "HistoName";
 //TH1F h(name,"title",10,0,10);
 //first argument of TH1F construction is a char* and not a const char*
 TH1F h(const_cast<char*> (name),"title",10,0,10);

 return 0 ;
}
```

Run-Time Type Information (RTTI)



```
// typeid, polymorphic class
#include <iostream>
#include <typeinfo>
#include <exception>
using namespace std;

class Base { virtual void f(){} };
class Derived : public Base {};

int main () {
  try {
    Base* a = new Base;
    Base* b = new Derived;
    cout << "a is: " << typeid(a).name() << '\n';
    cout << "b is: " << typeid(b).name() << '\n';
    cout << "*a is: " << typeid(*a).name() << '\n';
    cout << "*b is: " << typeid(*b).name() << '\n';
  } catch (exception& e) { cout << "Exception: " << e.what() << '\n'; }
  return 0;
}
```

```
a is: class Base *
b is: class Base *
*a is: class Base
*b is: class Derived
```

- It can be applied on any build-in type or user-defined class
- ***typeid*** uses the **RTTI** to keep track of the type of dynamic objects.
  - When ***typeid*** is applied to an expression whose type is a polymorphic class, the result is the type of the *most derived complete object*

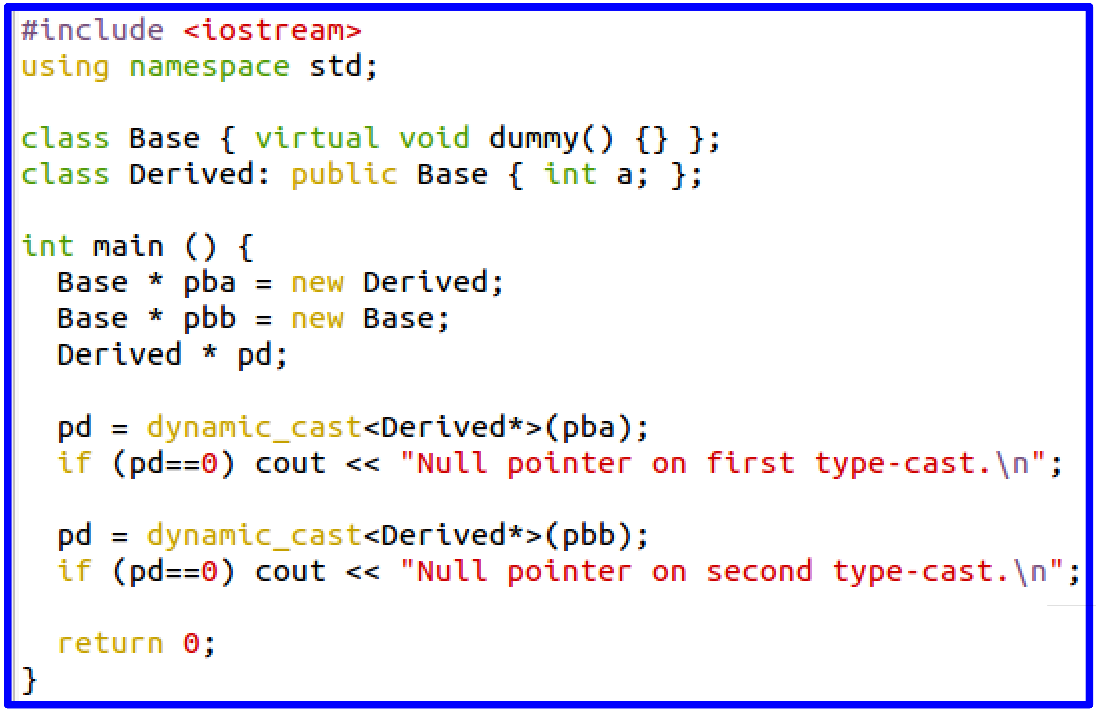
Type casting

dynamic_cast

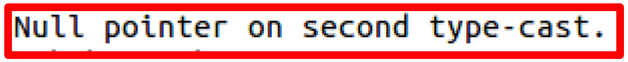
- Can be used with pointers and references to classes.
- Ensure that the result of the type conversion points to a valid complete object of the destination pointer type.
- Pointer is null (==0) if the cast failed

Upcast: converting from pointer-to-derived to pointer-to-base classes
in the same way as allowed as an implicit conversion.

Downcast: converting from pointer-to-base to pointer-to-derived polymorphic classes
if -and only if- the pointed object is a valid complete object of the target type.



```
#include <iostream>
using namespace std;

class Base { virtual void dummy() {} };
class Derived: public Base { int a; };

int main () {
  Base * pba = new Derived;
  Base * pbb = new Base;
  Derived * pd;

  pd = dynamic_cast<Derived*>(pba);
  if (pd==0) cout << "Null pointer on first type-cast.\n";

  pd = dynamic_cast<Derived*>(pbb);
  if (pd==0) cout << "Null pointer on second type-cast.\n";

  return 0;
}
```

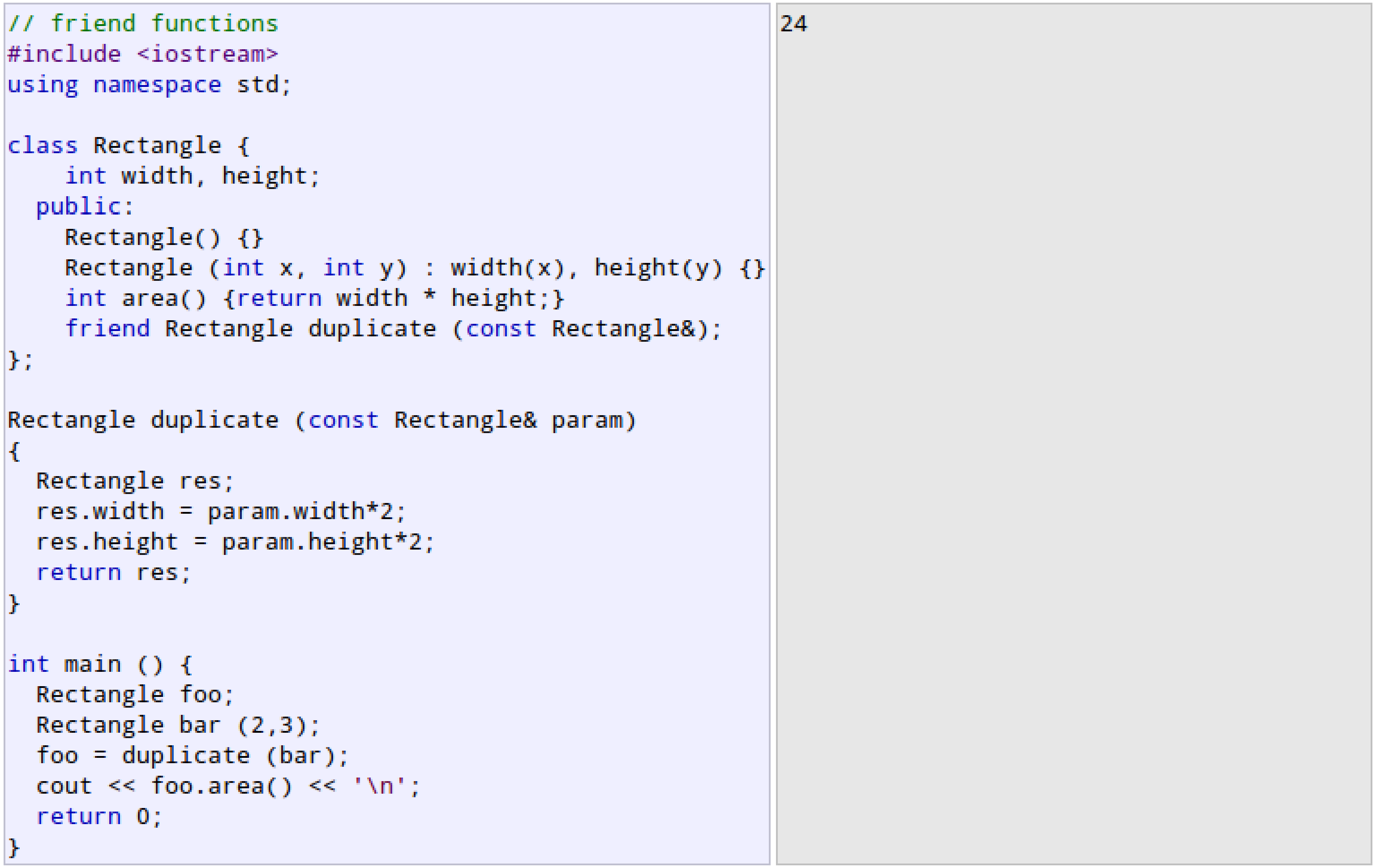


```
Null pointer on second type-cast.
```

Friendship

Friend methods

A non-member method can access the private and protected members of a class if it is declared a friend of that class



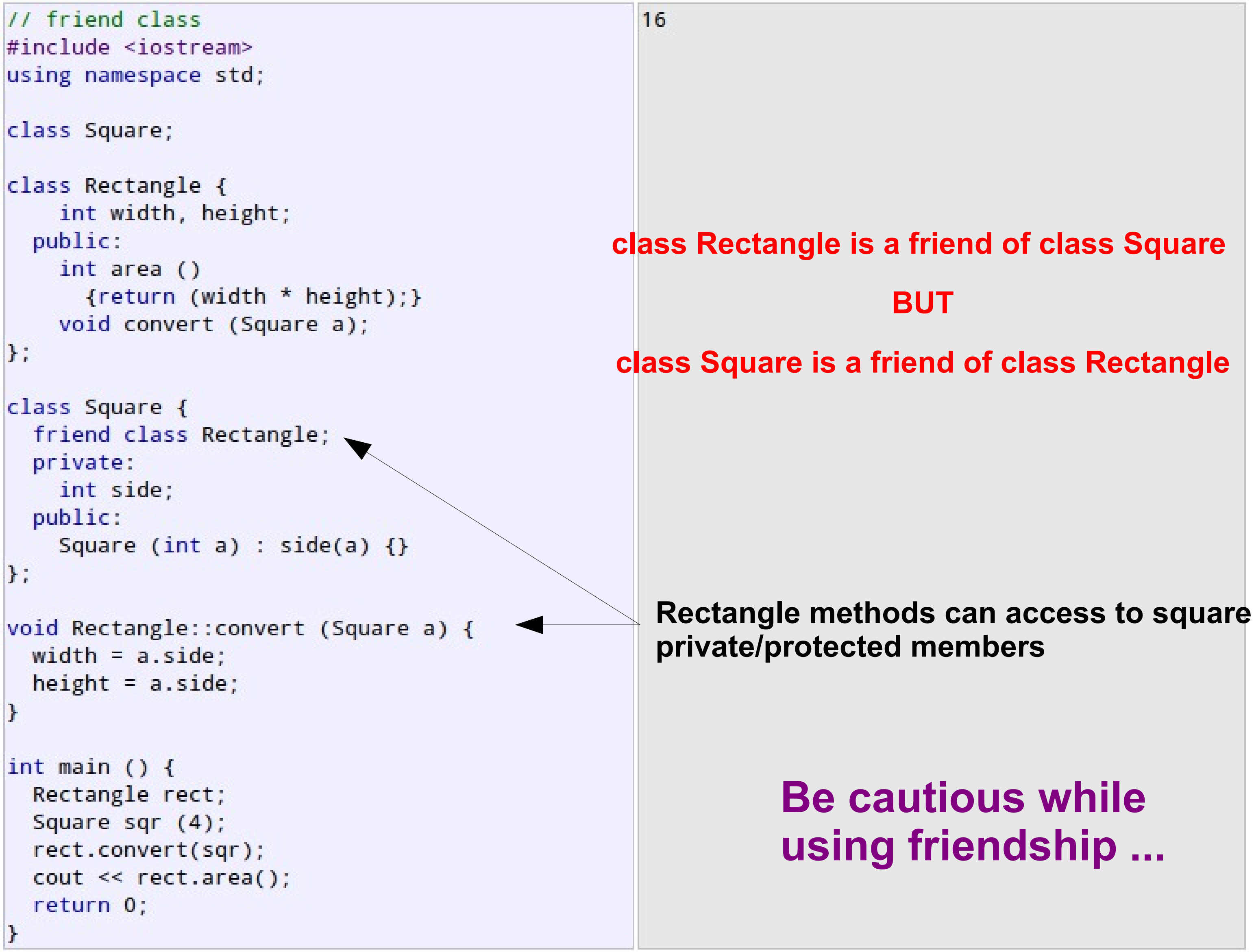
```
// friend functions
#include <iostream>
using namespace std;

class Rectangle {
    int width, height;
  public:
    Rectangle() {}
    Rectangle (int x, int y) : width(x), height(y) {}
    int area() {return width * height;}
    friend Rectangle duplicate (const Rectangle&);
};

Rectangle duplicate (const Rectangle& param)
{
  Rectangle res;
  res.width = param.width*2;
  res.height = param.height*2;
  return res;
}

int main () {
  Rectangle foo;
  Rectangle bar (2,3);
  foo = duplicate (bar);
  cout << foo.area() << '\n';
  return 0;
}
```

```
24
```

Friendship

Friend class

An object from a class A can access the private and protected members of a class B if it is declared a friend of that class



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

class Square;

class Rectangle {
    int width, height;
  public:
    int area ()
      {return (width * height);}
    void convert (Square a);
};

class Square {
  friend class Rectangle;
  private:
    int side;
  public:
    Square (int a) : side(a) {}
};

void Rectangle::convert (Square a) {
  width = a.side;
  height = a.side;
}

int main () {
  Rectangle rect;
  Square sqr (4);
  rect.convert(sqr);
  cout << rect.area();
  return 0;
}
```

```
16
```

class Rectangle is a friend of class Square

BUT

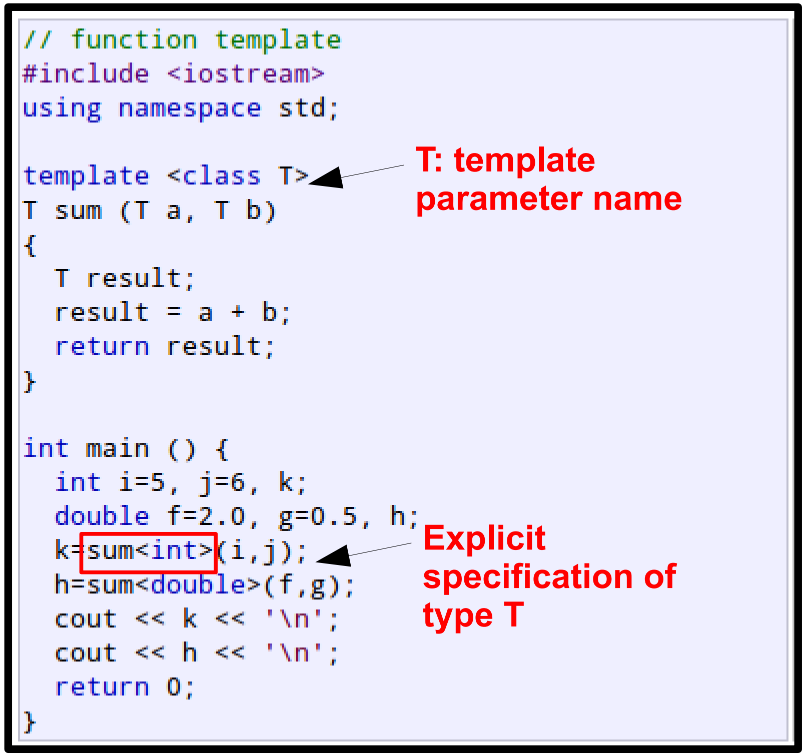
class Square is a friend of class Rectangle

Rectangle methods can access to square private/protected members

Be cautious while using friendship ...

Function template

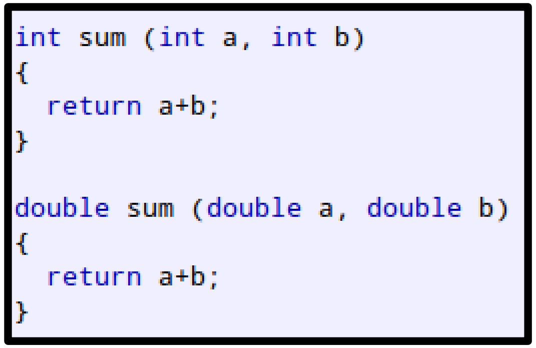
- Allow a **generalization** of a given “idea” to many different input **types**
  - Ex: you want to generalize the computation of a sum. Instead of having implementation for int, float, double … you implement it once
- **Compilation error** if you apply it to an **incorrect type**
  - Ex: *operator* + is not defined for all user-defined type
  - Ex: % is define for int but not for double



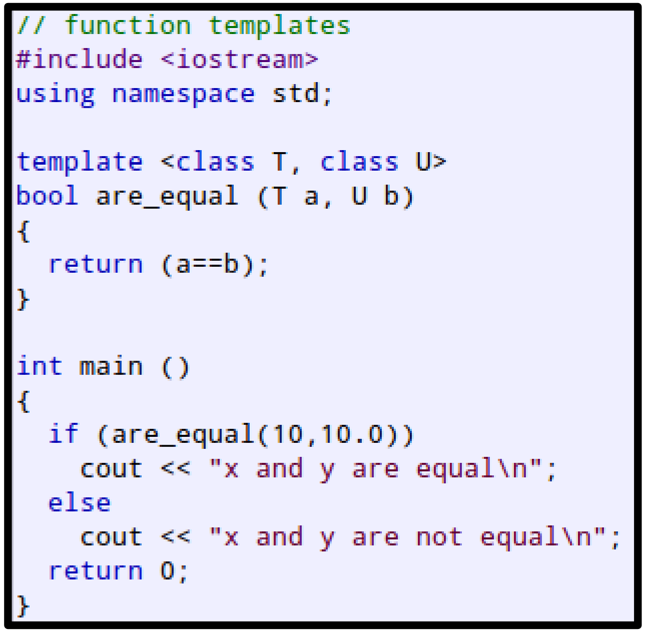
```
// function template
#include <iostream>
using namespace std;

template <class T>
T sum (T a, T b)
{
  T result;
  result = a + b;
  return result;
}

int main () {
  int i=5, j=6, k;
  double f=2.0, g=0.5, h;
  k=sum<int>(i,j);
  h=sum<double>(f,g);
  cout << k << '\n';
  cout << h << '\n';
  return 0;
}
```

T: template parameter name

Explicit specification of type T



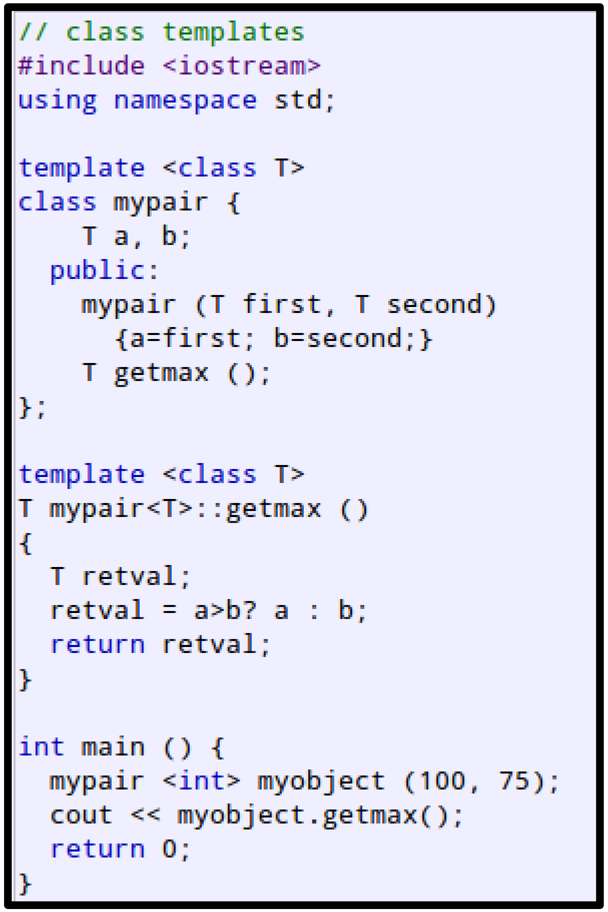
```
int sum (int a, int b)
{
  return a+b;
}

double sum (double a, double b)
{
  return a+b;
}
```



```
// function templates
#include <iostream>
using namespace std;

template <class T, class U>
bool are_equal (T a, U b)
{
  return (a==b);
}

int main ()
{
  if (are_equal(10,10.0))
    cout << "x and y are equal\n";
  else
    cout << "x and y are not equal\n";
  return 0;
}
```

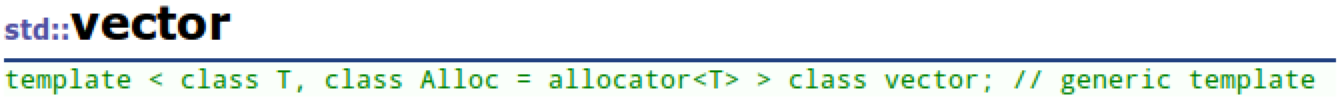
- Implicit specification is possible if unambiguous
  - Ex: Sum(2,3)
- Template with many several template types is possible

Class templates



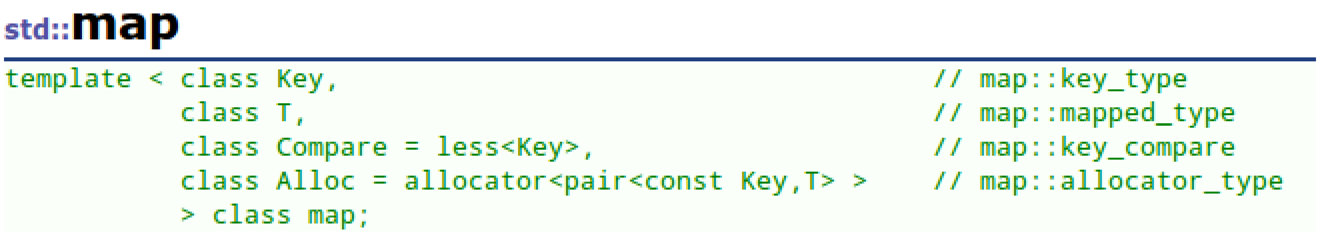
```
// class templates
#include <iostream>
using namespace std;

template <class T>
class mypair {
    T a, b;
  public:
    mypair (T first, T second)
      {a=first; b=second;}
    T getmax ();
};

template <class T>
T mypair<T>::getmax ()
{
  T retval;
  retval = a>b? a : b;
  return retval;
}

int main () {
  mypair <int> myobject (100, 75);
  cout << myobject.getmax();
  return 0;
}
```

“Famous” examples from the STL



std::**vector**

```
template < class T, class Alloc = allocator<T> > class vector; // generic template
```



std::**map**

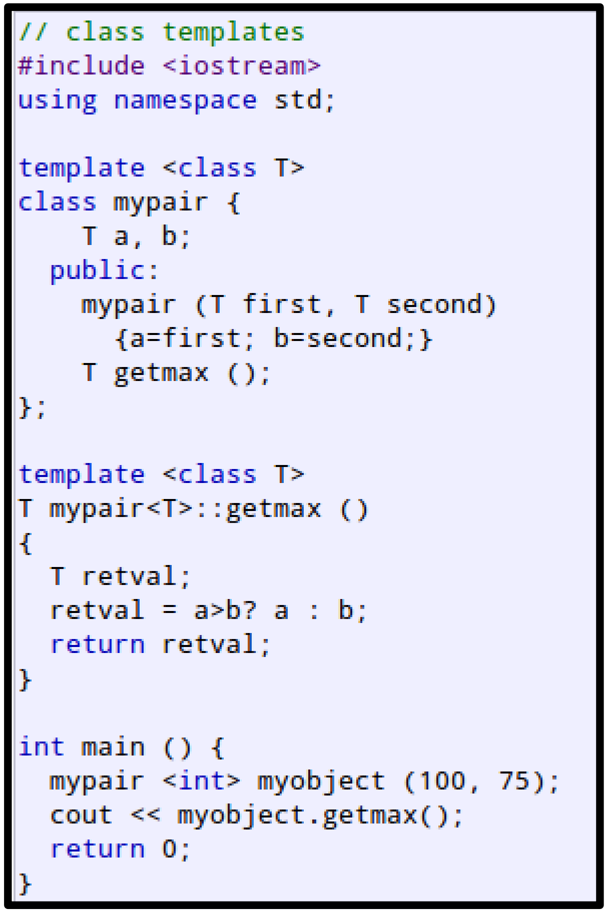
```
template < class Key,                                     // map::key_type
           class T,                                       // map::mapped_type
           class Compare = less<Key>,                     // map::key_compare
           class Alloc = allocator<pair<const Key,T> >    // map::allocator_type
           > class map;
```

Template specialization possible

Ex: vector<bool>

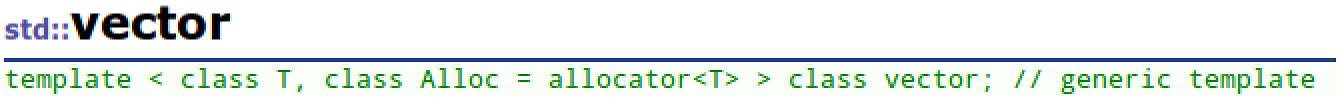
Everything should be “rewritten”

Class templates



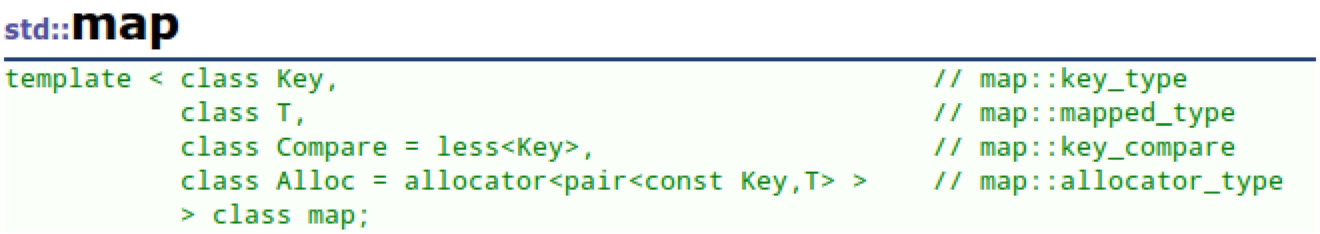
```
// class templates
#include <iostream>
using namespace std;

template <class T>
class mypair {
    T a, b;
  public:
    mypair (T first, T second)
      {a=first; b=second;}
    T getmax ();
};

template <class T>
T mypair<T>::getmax ()
{
  T retval;
  retval = a>b? a : b;
  return retval;
}

int main () {
  mypair <int> myobject (100, 75);
  cout << myobject.getmax();
  return 0;
}
```

"Famous" examples from the STL



std::**vector**

```
template < class T, class Alloc = allocator<T> > class vector; // generic template
```



std::**map**

```
template < class Key,                                     // map::key_type
           class T,                                       // map::mapped_type
           class Compare = less<Key>,                     // map::key_compare
           class Alloc = allocator<pair<const Key,T> >    // map::allocator_type
           > class map;
```

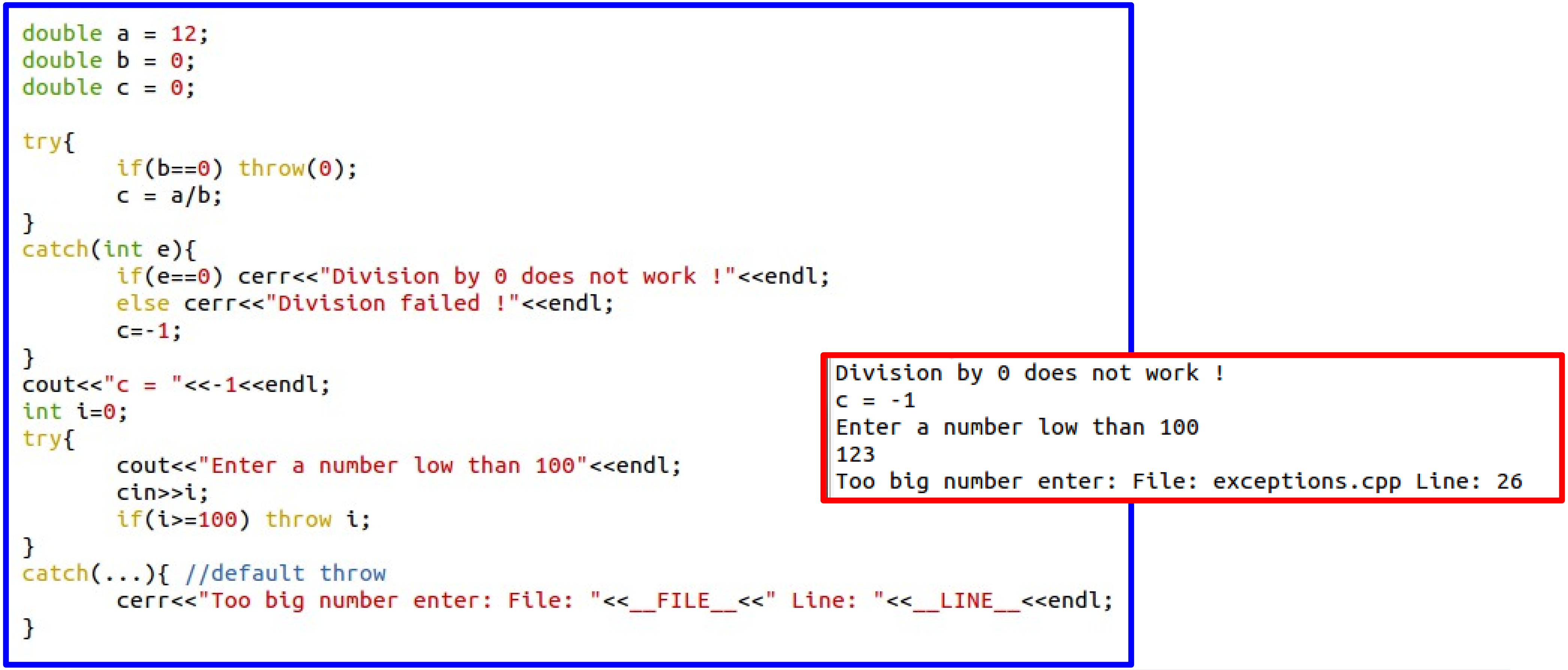
Template specialization possible

Ex: vector<bool>

Everything should be "rewritten"

Exceptions

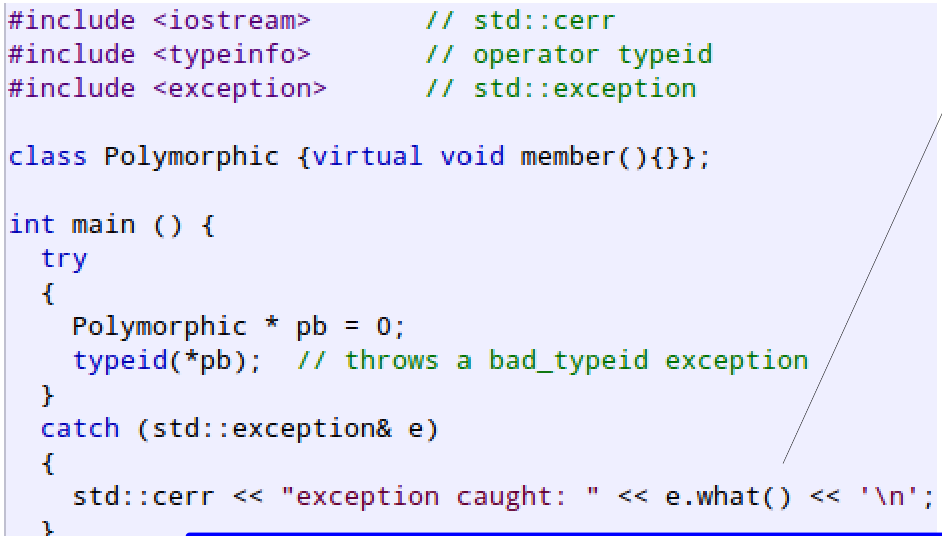
- Exceptions provide a way to react to exceptional circumstances (like runtime errors)
- Protect parts of the code
- Return an error message & decide what to do (abort the program ?)



```
double a = 12;
double b = 0;
double c = 0;

try{
        if(b==0) throw(0);
        c = a/b;
}
catch(int e){
        if(e==0) cerr<<"Division by 0 does not work !"<<endl;
        else cerr<<"Division failed !"<<endl;
        c=-1;
}
cout<<"c = "<<-1<<endl;
int i=0;
try{
        cout<<"Enter a number low than 100"<<endl;
        cin>>i;
        if(i>=100) throw i;
}
catch(...){ //default throw
        cerr<<"Too big number enter: File: "<<__FILE__<<" Line: "<<__LINE__<<endl;
}
```

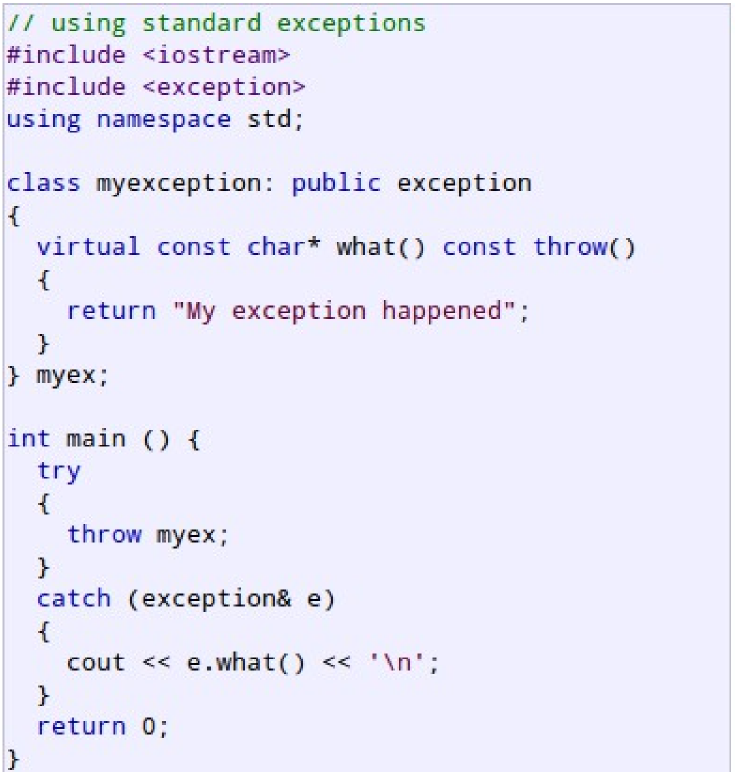
```
Division by 0 does not work !
c = -1
Enter a number low than 100
123
Too big number enter: File: exceptions.cpp Line: 26
```

Exceptions

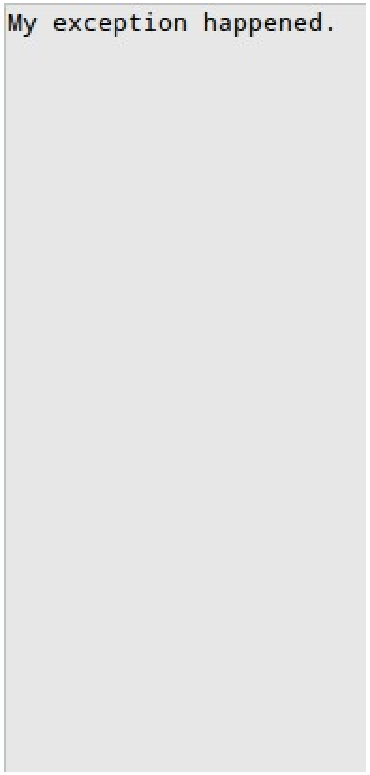


```
#include <iostream>       // std::cerr
#include <typeinfo>       // operator typeid
#include <exception>      // std::exception

class Polymorphic {virtual void member(){}};

int main () {
  try
  {
    Polymorphic * pb = 0;
    typeid(*pb);  // throws a bad_typeid exception
  }
  catch (std::exception& e)
  {
    std::cerr << "exception caught: " << e.what() << '\n';
  }
  return 0;
}
```

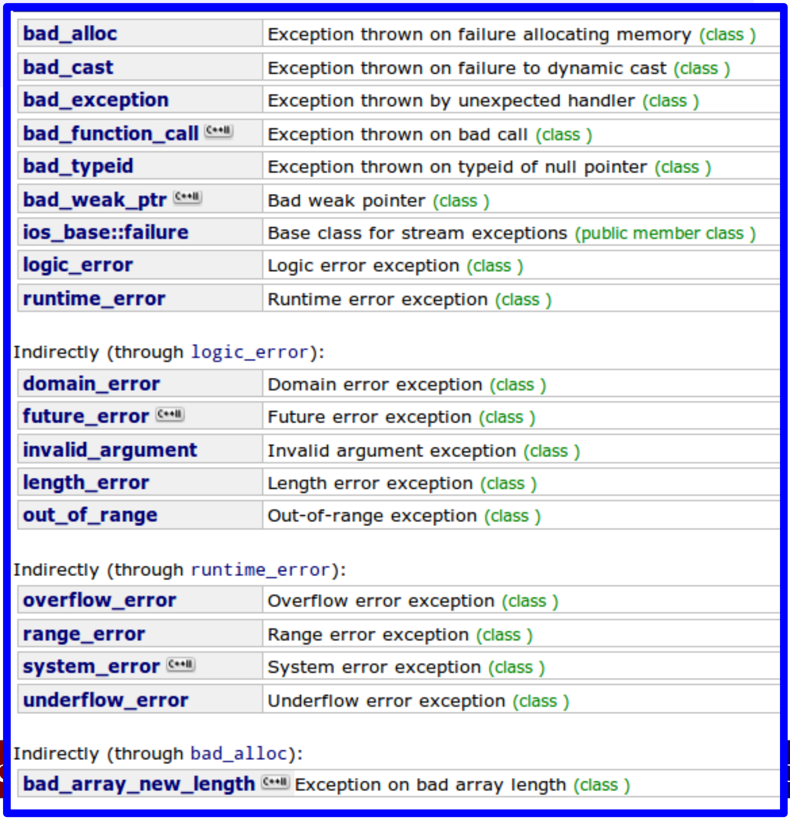
```
exception caught: St10bad_typeid
```



```
// using standard exceptions
#include <iostream>
#include <exception>
using namespace std;

class myexception: public exception
{
  virtual const char* what() const throw()
  {
    return "My exception happened";
  }
} myex;

int main () {
  try
  {
    throw myex;
  }
  catch (exception& e)
  {
    cout << e.what() << '\n';
  }
  return 0;
}
```



```
My exception happened.
```



bad_alloc	Exception thrown on failure allocating memory (class)
bad_cast	Exception thrown on failure to dynamic cast (class)
bad_exception	Exception thrown by unexpected handler (class)
bad_function_call C++11	Exception thrown on bad call (class)
bad_typeid	Exception thrown on typeid of null pointer (class)
bad_weak_ptr C++11	Bad weak pointer (class)
ios_base::failure	Base class for stream exceptions (public member class)
logic_error	Logic error exception (class)
runtime_error	Runtime error exception (class)

Indirectly (through logic_error):

domain_error	Domain error exception (class)
future_error C++11	Future error exception (class)
invalid_argument	Invalid argument exception (class)
length_error	Length error exception (class)
out_of_range	Out-of-range exception (class)

Indirectly (through runtime_error):

overflow_error	Overflow error exception (class)
range_error	Range error exception (class)
system_error C++11	System error exception (class)
underflow_error	Underflow error exception (class)

Indirectly (through bad_alloc):

bad_array_new_length C++11	Exception on bad array length (class)

- “standard” exceptions already managed
- Possibility to create your own class inheriting from std::exception (see example above)

Basic programming rules

- Indentation of the code (*more readable ..*)
- Respect conventions for the variable name (*and even more generally*)
- Always initialize variables
- Be cautious with
  - Integer division
  - Type Casting
  - Usage of array
  - Dynamical allocation & delete
- Comments
- Documentation (*possibility to use tools such as "Doxygen"*)
- Code protection and exceptions
  - Test on variables, pointers ...

Computation

Developer goal is to express computation

- Correctly // *means code protection ...*
- Simply // *means use the appropriate variable name, syntax, functions, lib, ..*
- Efficiently // *different options (cpu, memory, fiability, …)*

Organization of the code (cf UML)

- Divide big computations into many little ones (functions, classes)
- Avoid duplication
- Abstraction: provide a higher level concept that hides details

Usability:

- User-friendly: documentation, comments, abstraction

Organization of the data:

- Input/output format
- Protocols: how it communicates
- Data structure

And in all cases, don't reinvent the wheel

- User build-in types, if not sufficient use library types and if it doesn't fit your goals, define your own class
- For your computation, check if existing libraries does not fit your needs

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Programming

- First step is the conception
- Start with a simple & robust implementation
- Than perform intensive tests:
    - Should produce the desired results for all legal inputs
    - Should give a reasonable error messages for illegal inputs
- Review your code
    - Code cleaning: remove useless variables, ...
    - Style: Comments / naming & coding rules / documentation
    - Maintenance: use of functions / parameters instead of “magic numbers” ...
- Let a colleague review your code
- Only then, add features. Go to a “full scale” solution based on 1st impl.
    - It will avoid problems, delay, bugs, ...
- Code can be used by users in a largest community ...

UML: Unified Modeling Language

- General to all oriented object language
- It is a modelization language
- Allow to deal with complexity
- It can be a first step (conception) before implementation of the code
- Guidance: OMG UML: http://www.omg.org
- Will be more discussed during the computing sessions

Optimization

- Having a code properly functioning is clearly the first and most important feature !
- But in many application, memory or <u>CPU-cunsumption</u> might be a bottleneck. In that cases, optimization would be required.
- Control of execution time (*<ctime>,<chrono>, or even a simple time ./a.out*)
- Even if it is a whole topic by itself, this is few basic direction to follow
  - Prefer reference to pointer
  - Parameters might be reference (no copy)
  - Take advantage of stl containers
  - Avoid <u>extensive</u> usage of RTTI & Exception handling
  - Initialization is faster than assignment
  - Use inline functions in the most simple case
  - Compiler options can also help for optimization
  - ...