

C++ Course 3: C++ Language Basics 2

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const Modifier

Variables with **const** modifier are *read-only*

```
const int a = 17;
```

```
a = 19; // ERROR ! a is read-only!
```

```
const int b; // ERROR ! b is not initialized!
```

```
auto c = a; // c is int, auto ignores const
```

```
decltype(auto) d = a; // d is const int
```

const is part of the *data type*.

```
using CULL = const unsigned long long; // const in a type declaration
```

```
CULL a = 17; // a is const unsigned long long
```

```
array<const int, 4> cia{4, 3, 2, 1}; // const in a template argument
```

constexpr Modifier

constexpr is a *compile-time* constant

```
constexpr int SIZE = 18;
```

```
constexpr const char * NAME = "Lucifer"; // Type "const char *"
```

```
static_assert(SIZE == 18); // Compile-time check
```

```
int cArray[SIZE]; // C Array
```

```
array<int, SIZE> cppArray; // C++ Array class
```

constexpr variables must be of a *literal* type (int, char, const char * ...)

References

```
int a = 17;
```

```
int b = a; // Regular variable initialized with value 17
```

```
int &c = a; // Reference to a
```

```
const int &d = a; // const reference to a
```

Now **c** is a reference (alias) to **a**. Let us re-assign **c**:

```
c = 18; // Also changes a, d: Note: changes value of a, d, c, not "pointer"
```

```
// Now a == 18, b == 17, c == 18, d == 18
```

```
// d = 19; // Error ! Cannot modify via const reference
```

Important ! Once **c** "points" to **a**, it will "point" to **a** forever!

Cannot be re-assigned to point somewhere else (like pointer)!

```
auto x = d; // x is int, auto ignores both ref and const
```

```
decltype(auto) y = c; // y is ref to a
```

```
decltype(auto) z = d; // z is const ref to a
```

References in range for loops

```
vector<string> vs{"Zero", "One", "Two", "Three", "Four"};
```

```
// Copy: inefficient !
```

```
for (string s : vs) // or (auto s : vs)  
    cout << s << " ";
```

```
// Use string & to change elements
```

```
for (string & s : vs) // or (auto & s : vs)  
    s += s; // "Zero" -> "ZeroZero"
```

```
// Use const string & for read-only access (no copying !)
```

```
for (const string & s : vs) // or (const auto & s : vs)  
    cout << s << " ";
```

Pointers

Pointer type variable keeps a *memory address* (Low level!) 8 or 4 bytes (64/32 bit)

int * = pointer to int

&a = Address of variable **a** (*address of* operator)

***p** = Value which is found at address **p** (*dereferencing* operator)

```
int a = 13;
```

```
int *p = &a;
```

```
cout << "a = " << a << ", p = " << p << ", *p = " << *p << endl;
```

Pointers

Pointer type variable keeps a *memory address* (Low level!) 8 or 4 bytes (64/32 bit)

`int *` = pointer to `int`

`&a` = Address of variable `a` (*address of operator*)

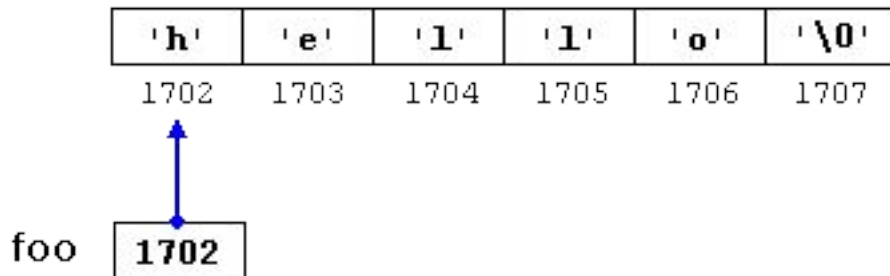
`*p` = Value which is found at address `p` (*dereferencing operator*)

```
int a = 13;
```

```
int *p = &a;
```

```
cout << "a = " << a << ", p = " << p << ", *p = " << *p << endl;
```

```
a = 13, p = 0x67fb7c, *p = 13
```



Pointers

Pointers can be changed (Unlike references)

```
int a = 13;
```

```
int *p = &a; // Now p points to a and *p = 13
```

```
int b = 17;
```

```
p = &b; // Now p points to b and *p = 17
```

```
p++; // increases p by sizeof(int) = 4 bytes
```

```
p += 11; // increases p by 11*sizeof(int) = 44 bytes
```

```
p[n] == *(p + n) // Array-like indexing (C-arrays and pointers are VERY similar)
```

void * is a memory address without type

nullptr Null pointer (also you can see 0, NULL)

```
if (p) ... // True if p != nullptr
```


Pointers and const

// p1 is a pointer to int, both p1 and *p1 can be changed

int * p1 = &a;

***p1 = 22 ; // OK**

p1 = &b; // OK

// p2 is a pointer to const int, p2 can be changed, but not p2

const int * p2 = &a;

***p2 = 22 ; // ERROR !**

p2 = &b; // OK

// p3 is a constant pointer to int, *p3 can be changed, but not p3

int * const p3 = &a;

***p3 = 22 ; // OK**

p3 = &b; // ERROR

// p4 is a constant pointer to const int, neither p4 nor *p4 can be changed

const int * const p4 = &a;

***p4 = 22 ; p4 = &b; // ERROR**

Pointers as array iterators

A C-style Array (NOT class) :

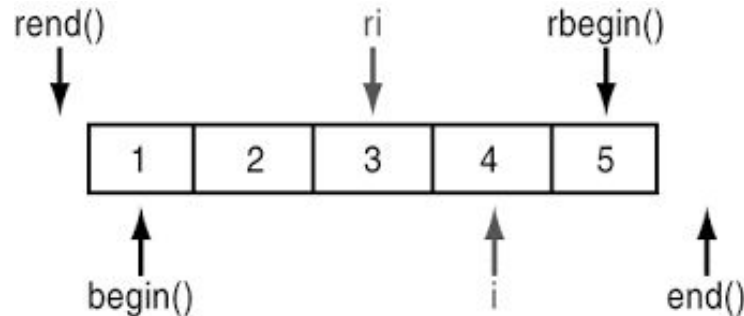
```
const string names[] = {"Karen", "Lucia", "Anastasia", "Margaret", "Alice"};
```

Print it with pointers :

```
const string * eit = names + 5;    // Position just after the last element
for (const string * it = names; it != eit; ++it)
    cout << *it << " ";
```

Or using C++ iterator style (Same loop works for C++ containers like **std::vector** !):

```
for (auto it = begin(names); it != end(names); ++it)
    cout << *it << " ";
```



Using new and delete

!!! Don't use this without a serious reason !!!

!!! A good C++ code DOES NOT use **new** + **delete** !!!

new : Creates object in the heap

```
string *pS = new string("Eowyn"); // Returns pointer to string
```

delete: Must be called to free memory, otherwise **MEMORY LEAK** !

```
delete pS; // Calls the destructor of *pS, then frees memory
```

Array version (don't use this, use **std::vector** instead)

```
int * myArray = new int[size]; // Reserves memory for size ints
```

...

```
delete [] myArray;
```

Extra slides:

C-style memory management (malloc, free)

C-style memory operations (memset, memcpy, memmove)

Functions

A function is defined as

`<return_type> myFunction(<par1>, <par2>, ..) { <body> }`

For example (**void** = no return):

```
void hello() {  
    cout << "Hello There !" << endl;  
}
```

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

Using **auto**:

```
auto add(int a, int b) -> int {return a + b;}
```

```
auto add(int a, int b) {return a + b;} // C++ 14
```

```
decltype(auto) add(int a, int b) {return a + b;} // C++ 14
```

Reference parameters

Passing argument by reference :

Function can change argument variables !

```
void change(string & s){  
    s = "Hello " + s;    // Modify s  
}
```

```
string s = "Medea";  
change(s); // Now we change s !  
cout << "s = " << s << endl;
```

const & parameters are used for class types to avoid copying large objects

Not needed the for primitives (int, double ...)

```
string addStrings(const string & s1, const string & s2){  
    return s1 + s2;  
}
```

Returns **string** , not **string &** or **const string &** !!!

Return by value or reference

Functions almost always return by value, e.g.

```
string somefun( ... ){  
    string s;  
    ...  
    return s;    // Return Value Optimization : No copy !  
}
```

Returning reference OK for *getters*, otherwise ERROR !!!

??? Reference to what exactly ???

```
const string & bad1(){  
    string s = "HAHAHA !";  
    return s;    // ERROR !!! Reference to a local variable !  
}
```

```
const string & bad2(){  
    return string("HAHAHA !");    // ERROR !!! Ref to a temporary !  
}
```

Factory function should return **unique_ptr** (best), or the object by value

Function overloading

Overloading: Same name, different parameter list

```
void print(int a) { ... }  
void print(int a, double b) { ... }  
void print(const string &) { ... }
```

```
print(17); // print(int)  
print(22.8); // print(int), double is converted to int  
print(4, 5.7); // print(int, double)  
print(13, 23); // print(int, double), int is converted to double  
print(string("Nel Zelpher")); // print(string)  
print("Maria Traydor"); // print(string), const char * is converted to string
```

Automatic type conversion

Compiler error if ambiguity

```
void print(double a, int b) { ... }  
void print(int a, double b) { ... }
```

```
print(1, 2); // ERROR !! Ambiguity !!!
```

Extra Slide: Parameter Default Values

Function templates

Function template to add two objects (anything which can be added by "+"):

Template Instantiation : **T** is replaced by a concrete type (e.g. **int** or **string**)

```
template <typename T> // OR "template <class T>"  
T tmpAdd(T a, T b) {  
    return a + b;  
}
```

In many cases, type **T** can be inferred automatically (*automatic instantiation*):

tmpAdd(3, 4) // T == int

tmpAdd(3.2, 4.2) // T == double

tmpAdd(string("Hello "), string("World !")) // Note: does not work with string literals!

tmpAdd(3, 4.2) // Error ! T == int ? Or T == double ? Cannot infer!

You can always specify **T** explicitly (*explicit instantiation*):

tmpAdd<double>(3, 4.2) // T == double

tmpAdd<string>("Hello ", "World !") // T == string (Literals converted to string)

Function templates

Function template to add two objects (anything which can be added by "+"):

Template Instantiation : **T** is replaced by a concrete type (e.g. **int** or **string**)

```
template <typename T> // OR "template <class T>"
T tmpAdd(T a, T b) {
    return a + b;
}
```

- Works with both primitive types and classes (unlike Java)
- Template Instantiation is done at *compile time*: Separate machine code is created for every **T**! No single machine code for every **T** is created! (also unlike Java)
- *Duck typing*: "If it walks like a duck and it quacks like a duck, ..."
- Template defined in a **.cpp** file can be used in this **.cpp** file only!
- Define "library" templates in **.h** files! Then everybody can use them!
- *Template specialization* is different from *Template Instantiation*!

Do it yourself: Look at the second template example in e3_2

Namespaces

In a large project ...

```
a.cpp          : void fatalError(const string & s);  
b.cpp          : void fatalError(const string & s);  
OpenCV library : void fatalError(const string & s);  
ffmpeg library : void fatalError(const char * s);
```

Name conflict !!!

Solution: namespaces. Namespace is a named scope.

```
namespace A{  
    void fatalError(const string & s);  
}  
...  
A::fatalError("Camera device not found !");
```

Namespace tree

```
namespace A{  
  namespace A{  
    namespace X{  
      namespace A{  
        ...  
      }  
    }  
  }  
}
```

:: is the Root scope

A::A::X::A::myFuction(17); // Starts from the **current** scope (relative path)

::myFuction(17); // :: is the root scope

::A::A::X::A::myFuction(17); // Starts from the **root** scope (absolute path)

using statement

using std::vector; // Use only class vector from namespace std

using namespace std; // Use the entire namespace std

..

vector <int> vi; // Without std:: prefix !

using can lead to a name conflict

Resolve it with the absolute path **::A::A::myFun();** (Starting from the root !)

using rules:

1. Never in header (*.h) files ! Important! Namespace leaks into ALL *.cpp files !
2. Cannot be used inside class definition (Syntax error).
3. Best: inside function or method body, does not leak beyond the closing }.
4. OK but not best: In *.cpp file, affects this cpp file only.

Note: **main()** must NEVER be in any namespace ! Otherwise the executable will not link !

Anonymous namespaces and the static keyword

`fun()` is only visible in this `.cpp` file, not in other `.cpp` files:

```
namespace{  
    void fun();  
}
```

Keyword **static** :

1. In `.cpp`: like anonymous namespace
static void fun(); // Visible in this cpp file only (also **inline** is similar)
2. Inside function/method: hidden global (!!! SUPER - EVIL !!! **!!! NEVER !!!**)
static int myVar; // Global var, not in stack !
3. Inside class: static method/field (belongs to class, not instance)
static MyClass & getInstance();

Headers

The C++ *preprocessor* processes each ***.cpp** file *before* it is compiled

header.h is a piece of code included (copy+paste !) with **#include "header.h"**

Header is *included* : treated as a part of ***.cpp**, it is not '*module/library*', not '*imported*' !

#include is a preprocessor directive, no semicolon (;) !

#include <...> Search in system/project include directories

#include "..." Search in current directory, then system/project include directories

Note: Header is never compiled, never produces any binary code by itself !

C++ system headers:

#include <iostream>

// C++ standard library headers

#include <cstdio>

// C standard library headers in namespace std (for C++)

#include <stdio.h>

// C standard library headers (don't use in C++)

Other headers:

#include <boost/asio.hpp>

// Library headers

#include "myfile.h"

// My header

Include guard

In myfile2.h :

```
#include "myfile.h"
```

In main.cpp :

```
#include "myfile2.h"
```

```
#include "myfile.h" // Included twice !!! BAD !!!
```

We want to include **myfile.h** only once

```
#ifndef _MYFILE_H_
```

```
#define _MYFILE_H_
```

```
<All code goes here>
```

```
#endif
```

Or, not in the official C++ standard, but works for all modern compilers

```
#pragma once
```

Learn it yourself: C++ preprocessor (#if, #ifdef, #define ...)

Function/class declarations and definitions

Function **declaration** (in **myfile.h**) , needed at *compile time* :

```
int add(int a, int b);    // We need this to call add, needed to compile *.cpp
```

Linking : Associate symbol "**add(int, int)**" with the function body (machine code)

Function **definition** (in **myfile.cpp**), "unresolved symbol" at link time if missing :

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

Class **definition** (in **MyClass.h**), needed at *compile time* to work with the class :

```
struct MyClass{    // Class definition  
    void method();    // Method declaration  
};
```

Class method **definition** (in **MyClass.cpp**), needed at *link time*:

```
MyClass::method() { ... }
```


Can we define a function in a header?

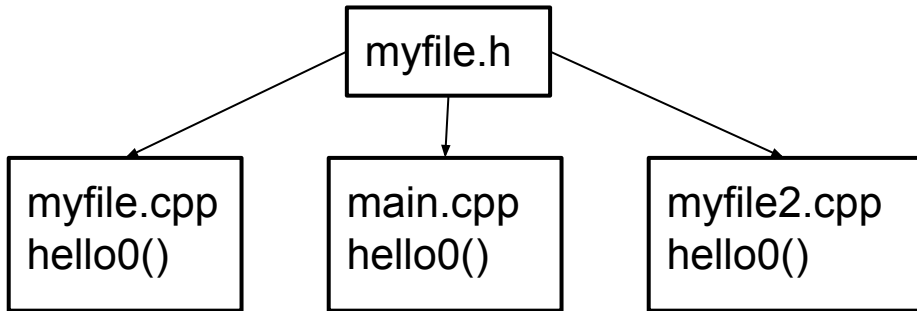
in myfile.h:

```
void hello0() { std::cout << "hello0()" << std::endl;}    // Error !
```

Can we define a function in a header?

in myfile.h:

```
void hello0() { std::cout << "hello0()" << std::endl;} // Error !
```



But if we REALLY REALLY want to define a function in myfile.h ???

```
inline void hello1() { std::cout << "hello1()" << std::endl;}  
static void hello2() { std::cout << "hello2()" << std::endl;}  
namespace {  
    void hello3() { std::cout << "hello3()" << std::endl;}  
}
```

Note: templates are always in .h, no troubles with them!

Header-only libraries

Some C++ libraries are *header-only*. They consist of **.h** files only (no **.cpp**).

Pros:

- Simpler to write and deploy the library
- No need to build library, no **.a/.so** files, platform independent
- Simpler to include the library in your CMake project
- Templates *must* be in headers anyway, so if you use templates ...

Cons:

- Longer build times
- Machine code is generated for each **.cpp** file (possibly larger executable size)
- Large headers drive IDEs crazy

Examples: Eigen, RapidJson, CTPL, CImg, most Boost modules, ...

Even most of C++ standard library (**vector**, **array**, **map**, ...)

Global variables : EVIL !

In **myfile.h** :

```
extern int x; // Declaration
```

In **myfile.cpp** :

```
int x = 17; // Definition. Initialize here if needed
```

Global Constant (not evil), in **myfile.h** (Don't use **#define** for constants !) :

```
constexpr int GLOBAL_CONST = 666;
```

Global variables : EVIL !

In **myfile.h** :

```
extern int x; // Declaration
```

In **myfile.cpp** :

```
int x = 17; // Definition. Initialize here if needed
```

Global Constant (not evil), in **myfile.h** (Don't use **#define** for constants !) :

```
constexpr int GLOBAL_CONST = 666;
```

Global variable means:

- Cannot run 2 or more copies of the code
- This includes multithread
- This includes unit tests

Real cases: Global variables, memory leak, seg faults ...

Case 1:

- CV engineer: My C++ algorithm code "Works"!
- Request: "Make it work in different threads ..." WTF ??? It's absurd!
- It actually had global variables
- It also had bad memory leak
- Took a lot of effort to make the code really work

Case 2:

- CV engineer: My C++ algorithm code "Works"!
- Warning: `int(..) {}` function does not return a value
- Undefined! Forbidden operation in C++
- In Debug : The code "works" ...
- In Release: Segmentation fault!

How to write good algorithm code in C++?

"The code works, here is the demo" is not good enough!

The real (deployable) algorithm code in C++ must fulfill the following requirements:

- No memory leaks
- No crashes/SEG faults, No undefined behavior
- No global variables
- All code is in namespaces
- No pointers and **new/delete/malloc/free** unless absolutely necessary
- No platform-dependent stuff (e.g. **<windows.h>**, **"pch.h"** or **_tmain()**)
- The algorithm and **main()** (especially GUI/demos) are cleanly separated
- Document the code : **README.md**, Doxygen comments, comments
- Ideally: Handle all error cases: All black/all white/empty images, negative/zero parameters:
Exceptions or error codes: Not random OpenCV exceptions!

Otherwise it is not a deployable C++ code, as it cannot be used in other people's projects without rewriting!

Tool (not library !) of the day: Doxygen

Document your code with docstrings: special comments:

```
/** @brief Multiply a and b
 *
 * This function is super-fun !
 * @param[in] a   Input parameter a
 * @param[in] b   Input parameter b
 * @return       The product of a and b */
double mul(double a, double b);
```

Or, short comment:

```
/// Divide a by b
double div(double a, double b);
```

Then run **doxygen** to generate HTML documentation (See e.g. OpenCV docs).

Real C++ programmers always do this.

Thank you for your attention !

C-style memory management

Allocate memory in the heap, C-style

void * malloc(size_t n); // Allocate n bytes

```
int * iBuffer = (int *) malloc(25 * sizeof(int)); // 25 elements
```

Allocate memory in the heap and set it to 0, C-style

void * calloc(size_t n1, size_t n2); // Allocate n1*n2 bytes

```
char * cBuffer = (char *) calloc(45, sizeof(char)); // 45 elements
```

Set count bytes to ch

void* memset(void* dest, int ch, std::size_t count); // Writes to dest

```
memset(cBuffer, (int)'Z', 45); // Fill the buffer with 'Z' (45 bytes)
```

Free memory block in the heap

```
free(iBuffer); free(cBuffer);
```

Using memcpy and memmove

Fast memory copy (num bytes)

void * memcpy (void * destination, const void * source, size_t num);

```
char s[100];    // A buffer
memcpy(s, "Jessica", 8); // Copy 8 bytes
```

Memory copy with overlap

void * memmove (void * destination, const void * source, size_t num);

```
memmove(s + 4, s, 8); // Copy 8 bytes from s to s+4
cout << s << endl;
```

```
JessJessica
```

Parameter default values

```
int add(int a = 10, int b = 5){  
    return a + b;  
}
```

```
cout << add(1, 2); // 3  
cout << add(1);    // 6  
cout << add();     // 15
```

Such parameters must be **to the right** in the parameters list !

```
int add(int a, int b = 5){return a + b;} // OK  
int add(int a = 10, int b){return a + b;} // ERROR !!!
```

