Modern C++ Programming

4. Basic Concepts III

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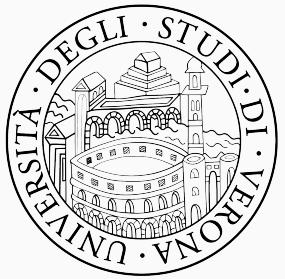

Agenda

- **Declaration and Definition**
- **Functions**
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  - Overloading
- **Preprocessing**
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  - Stringizing operator
  - Token-pasting operator
  - Variadic macro
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Declaration and Definition

Declaration/Definition

Declaration/Prototype

A **declaration** (or prototype) of an entity is an identifier describing its type

A declaration is what the compiler and the linker needs to accept references to that identifier

Definition/Implementation

An entity **definition** is the implementation of a declaration

Incomplete Type

A declaration without a concrete implementation is an incomplete type (as `void`)

C++ Entities (class, functions, etc.) can be declared multiple times (with the same signature)

```
struct A;   // declaration 1
struct A;   // declaration 2 (ok)

struct B {  // declaration and definition
    int b;
//  A   x;    // incomplete type
    A*  y;    // ok
};

struct A {  // definition
    char c;
}
```

Functions

Overview

A **function** (**procedure** or **routine**) is a piece of code that performs a *specific task*

Purpose:

- **Avoiding Code Duplication** less code for the same functionality $\rightarrow$ less bugs
- **Readability** better express what the code does
- **Organization** break the code in separate modules

Signature

Type signature defines the *inputs* and *outputs** for a function. A type signature includes the number of arguments, the types of arguments and the order of the arguments contained by a function

Function Parameter [formal]

A parameter is the variable which is part of the method's signature

Function Argument [actual]

An argument is the actual value (instance) of the variable that gets passed to the function

* (return type) if the function is generated from a function template
`https://stackoverflow.com/a/292390`

```
int f(int a, char* b);  // function declaration
                        // signature:  (int, char*)
                        // parameters: int a, char* b

int f(int a, char*) {   // function definition
}                       // b can be omitted if not used

// char f(int a, char* b); // compile error!! same signature

// int f(const int a, char* b); // invalid declaration!
                                // const int == int

int f(int a, const char* b);    // ok

int main() {
    f(3, "abc");  // function arguments: 3, "abc"
                  // "f" call f(int, const char*)
}
```

Call-by-Value

Call-by-value

The object is copied and assigned to input arguments of the method

Advantages:

- Changes made to the parameter inside the function have no effect on the argument

Disadvantages:

- Performance penalty if the copied arguments are large (e.g. a structure with a large array)

When to use:

- Built-in data type and small objects ($\leq$ 8 bytes)

When not to use:

- Fixed size arrays which decay into pointers
- Large objects

Call-by-Pointer

Call-by-pointer

The address of a variable is copied and assigned to input arguments of the method

Advantages:

- Allows a function to change the value of the argument
- Copy of the argument is not made (fast)

Disadvantages:

- The argument may be `nullptr`
- Dereferencing a pointer is slower than accessing a value directly

When to use:

- When passing *raw* arrays (use `const *` if read-only)

When not to use:

- Small objects

Call-by-Reference

Call-by-reference

The reference of a variable is copied and assigned to input arguments of the method

Advantages:

- Allows a function to change the value of the argument
- Copy of the argument is not made (fast)
- References must be initialized (no null pointer)
- Avoid implicit conversion

When to use:

- Structs or Classes (use `const &` if read-only)

Examples

```
struct MyStruct {
    int field;
};

void f1(int a);          // call by value
void f2(int& a);         // call by reference
void f3(const int& a); // call by const reference
void f4(MyStruct& a);  // call by reference
                         // note: requires a.field to access

void f5(int* a);         // call by pointer
void f6(const int* a); // call by const pointer
void f7(MyStruct* a);  // call by pointer
                         // requires a->field to access
//-----------------------------------------------
char c = 'a';
f1(c);    // ok, pass by value
// f2(c); // compile error!! pass by reference
```

`inline` Function Declaration

inline

`inline` specifier is a hint for the compiler. The code of the function can be copied where it is called (inlining)

```
inline void f(int a) { ... }
```

- It is just a hint. The compiler can ignore the hint (`inline` increases the compiler heuristic threshold)
- The compiled code is larger because the `inline` function is expanded in-place for every function call

GCC/Clang extensions allow to *force* inline/non-inline functions:

```
__attribute__((always_inline)) void f(int a) { ... }
__attribute__((noinline))      void f(int a) { ... }
```

Function Default Parameters

Default/Optional parameter

A **default parameter** is a function parameter that has a default value provided to it

If the user does not supply a value for this parameter, the default value will be used. If the user does supply a value for the default parameter, the user-supplied value is used instead of the default value

- All default parameters must be the rightmost parameters
- Default parameters can only be declared once
- Default parameters can improve compile time because they avoid defining other overloaded functions

```
void f(int a, int b = 20);
// void g(int a = 10, int b); // compile error!!

void f(int a, int b) { ... }  // default value of "b" already set

f(5);  // b is 20
```

Function Overloading (+ Ambiguous Matches)

Overloading

An **overloaded declaration** is a declaration with the same name as a previously declared identifier (in the same scope), which have different number of arguments and types

Overload resolution rules:

- An exact match
- A promotion (e.g. `char` to `int`)
- A standard type conversion (e.g. between `float` and `int`)
- A constructor or user-defined type conversion

```
void f(int a);
void f(float value);


void g(int a);

void h(int a);
void h(int a, int b = 0);
```

```
   f(0);   // ok
// f('a'); // ambiguous matches, compile error
   f(2.3f); // ok
// f(2.3); // ambiguous matches, compile error

   g(2.3);  // ok, standard type conversion


// h(3);   // ambiguous matches, compile error
```

Functor (Function as Argument)

Functor

Functors, or **function object**, are objects that can be treated as parameters*

```
int eval(int a, int b, int (*f)(int, int)) {
    return f(a, b);
}
int add(int a, int b) { // type: int (*)(int, int)
    return a + b;
}
int sub(int a, int b) {
    return a - b;
}
cout << eval(4, 3, add); // print 7
cout << eval(4, 3, sub); // print 1
```

*C++11 provides a more efficient and convenience way to pass *"procedure"* to other function called `lambda expression`

C++ allows marking functions with standard properties to better express their intent:

- C++11 `[[noreturn]]` indicates that the function does not return
- C++14 `[[deprecated]]`, `[[deprecated("reason")]]` indicates the use of a function is discouraged (for some reason). It issues a warning if used
- C++17 `[[nodiscard]]` issues a warning if the return value is discarded
- C++17 `[[maybe_unused]]` suppresses compiler warnings on unused functions, if any (it applies also to other entities)

Function Attributes 2/2

```cpp
[[noreturn]] void f() {
    std::exit(0);
}

[[deprecated]] void my_rand() {
    rand();
}

[[nodiscard]] int g() {
    return 3;
}

[[maybe_unused]] void h() {}

//-------------------------------
my_rand();    // warning "deprecated"
g();          // warning "discard return value"
int x = g(); // no warning
```

Preprocessing

Preprocessing and Macro

Preprocessor directives are lines preceded by a *hash* sign (#) which tell the compiler how to interprets the source code *before* compiling

Macro are preprocessor directives which replace any occurrence of an *identifier* in the rest of the code by replacement

Macro are evil:

Do not use macro expansion!!

...or use as little as possible

- Macro cannot be debugged
- Macro expansions can have strange side effects
- Macro have no namespace or scope

Very Common Preprocessors

- `#include "my_file.h"`
  Inject the code in the current file

- `#define MACRO <expression>`
  Define a new macro

- `#undef MACRO`
  Undefine a macro
  (a macro should be undefined as early as possible for safety reasons)

Multi-line Preprocessing: `\` at the end of the line

Indent: `#   define`

Conditional Compiling

- ```
  #if <condition>
      code
  #elif <condition>
      code
  #else
      code
  #endif
  ```

- `#if defined(MACRO)` equal to `#ifdef MACRO`

  Check if a macro is defined

- `#if !defined(MACRO)` equal to `#ifndef MACRO`

  Check if a macro is not defined
  ```

Macro (Common Error 1)

Do not define macro in header file and before includes!!

Example:

```cpp
#include <iostream>

#define value    // very dangerous!!
#include "big_lib.hpp"

int main() {
    std::cout << f(4); // should print 7, but it prints always 3
}
```

big_lib.hpp:

```cpp
int f(int value) {    // 'value' disapear
    return value + 3;
}
```

Macro (Common Error 2)

Use parenthesis in macro definition!!

Example:

```
#include <iostream>

#define SUB1(a, b)  a - b       // wrong
#define SUB2(a, b) (a - b)      // wrong
#define SUB3(a, b) ((a) - (b))  // correct

int main() {
    std::cout << (5 * SUB1(2, 1));   // print 9 not 5!!
    std::cout << SUB2(3 + 3, 2 + 2); // print 6 not 2!!
    std::cout << SUB3(3 + 3, 2 + 2); // print 2
}
```

Macro (Common Error 3)

Macros make hard to find compile errors!!

Example:

```
 1: #include <iostream>
 2:
 3: #define F(a) {          \
 4:         ...              \
 5:         ...              \
 6:         return v;
 7:
 8: int main() {
 9:     F(3);      // compile error at line 9!!
10: }
```

- **In which line is the error??!**

Macro (Common Error 4)

Use curly brackets in multi-lines macros!!

Example:

```
#include <iostream>
#include <nuclear_explosion.hpp>

#define NUCLEAR_EXPLOSION                          \  // {
    std::cout << "start nuclear explosion"; \
    nuclear_explosion();
                                                      // }
int main() {
    bool never_happen = false;
    if (never_happen)
        NUCLEAR_EXPLOSION
} // BOOM!!
```

The second line is executed!!

Macro (Common Error 5)

Macros do not have scope!!

Example:

```
#include <iostream>

void f() {
    #define value 4
    std::cout << value;
}

int main() {
    f();                    // 4
    std::cout << value;     // 4
    #define value 3
    f();                    // 4
    std::cout << value;     // 3
}
```

Macro (Common Error 6)

Macros can have side effect!!

Example:

```c
#define MIN(a, b) ((a) < (b) ? (a) : (b))

int main() {
    int array1[] = { 1, 5, 2 };
    int array2[] = { 6, 2, 4 };
    int i = 0;
    int j = 0;
    int v1 = MIN(array1[i++], array2[j++]); // v1 = 5!!
    int v2 = MIN(array1[i++], array2[j++]); // segfault
}
```

Reference: arne-mertz.de/2019/03/macro-evil

When Preprocessors are Necessary

- **Conditional compiling**: different architectures, compiler features, etc.
- **Mixing different languages**: code generation (example: `asm` `assembly`)
- **Complex name replacing**: see template programming

Otherwise, prefer `const` and `constexpr` for constant values and functions

```
#define SIZE 3       // replaced with
const int SIZE = 3; // only C++11 at global scope

#define SUB(a, b) ((a) - (b)) // replaced with
constexpr int sub(int a, int b) {
    return a - b;
}
```

Commonly used macros:

`__LINE__` Integer value representing the current line in the source code file being compiled

`__FILE__` A string literal containing the presumed name of the source file being compiled

`__DATE__` A string literal in the form "MMM DD YYYY" containing the date in which the compilation process began

`__TIME__` A string literal in the form "hh:mm:ss" containing the time at which the compilation process began

main.cpp:

```cpp
#include <iostream>
int main() {
    std::cout << __FILE__ << ":" << __LINE__;  // print main.cpp:2
}
```

Select code depending on the C/C++ version

- `#if defined(__cplusplus)` C++ code
- `#if __cplusplus == 199711L` ISO C++ 1998/2003
- `#if __cplusplus == 201103L` ISO C++ 2011
- `#if __cplusplus == 201402L` ISO C++ 2014
- `#if __cplusplus == 201703L` ISO C++ 2017

Select code depending on the compiler

- `#if defined(__GNUG__)` The compiler is `gcc/g++`
- `#if defined(__clang__)` The compiler is `clang/clang++`
- `#if defined(_MSC_VER)` The compiler is `Microsoft Visual C++`

Select code depending on the operation system or environment

- `#if defined(_WIN64)` OS is `Windows 64-bit`
- `#if defined(__linux__)` OS is `Linux`
- `#if defined(__APPLE__)` OS is `Mac OS`
- `#if defined(__MINGW32__)` OS is `MinGW 32-bit`
- ...and many others

Very Comprehensive Macro list:

`sourceforge.net/p/predef/wiki/Home/`

Stringizing Operator (#)

The **stringizing macro operator** (`#`) causes the corresponding actual argument to be enclosed in double quotation marks `"`

```
#define STRING_MACRO(string) #string

std::cout << STRING_MACRO(hello);  // equivalent to "hello"
```

```
#define INFO_MACRO(my_func)                          \
    my_func                                          \
    std::cout << "call " << #my_func << " at " \
              << __FILE__ << ":" __LINE__;

void g(int) {}

INFO_MACRO( g(3) ) // print: call g(3) at my_file.cpp:7
```

Token-Pasting Operator (##)

The **token-concatenation (or pasting) macro operator** (`##`) allows combining two tokens (without leaving no blank spaces)

```
#define FUNC_GEN_A(tokenA, tokenB)  \
    void tokenA##tokenB() {}

#define FUNC_GEN_B(tokenA, tokenB)  \
    void tokenA##_##tokenB() {}

FUNC_GEN_A(my, function)
FUNC_GEN_B(my, function)

int main() {
    myfunction();  // ok, from FUNC_GEN_A
    my_function(); // ok, from FUNC_GEN_B
}
```

Variadic Macro

In C++11, a **variadic macro** is a special macro accepting a varying number of arguments (separated by comma)

Each occurrence of the special identifier `__VA_ARGS__` in the macro replacement list is replaced by the passed arguments

Example:

```
void f(int a)                { printf("%d", a);             }
void f(int a, int b)         { printf("%d %d", a, b);       }
void f(int a, int b, int c) { printf("%d %d %d", a, b, c); }

#define PRINT(...) \
    f(__VA_ARGS__);

int main() {
    PRINT(1, 2)
    PRINT(1, 2, 3)
}
```

- `#pragma once` It indicates that a (header) file is only to be parsed once, even if it is (directly or indirectly) included multiple times in the same source file
  It is an alternative (less portable) of the standard include guard (e.g. `myfile.h`):

```
#ifndef MYFILE_H       // (first line of the file)
#define MYFILE_H
...code...
#endif // MYFILE_H     // (last line of the file)
```

- `#pragma unroll` Applied immediately before a for loop, it replicates his body to eliminates branches. Unrolling enables aggressive instruction scheduling (supported by `Intel/Ibm/Clang` compilers)

- `#pragma message "text"` Display informational messages at compile time (every time this instruction is parsed)

- `_Pragma(<command>)` (C++11)
  It is an operator (like `sizeof`), and can be embedded in a macro (ex. `#define`)

```
#define MY_LOOP                 \
    _Pragma(unroll)             \
    for(i = 0; i < 10; i++) \
        cout << "c";
```

- `#error "text"` The directive emits a user-specified error message at compile time when the compiler parse the related instruction.

Macro Tricks 1

Convert a number literal to a string literal

```
#define TO_LITERAL_AUX(x) #x
#define TO_LITERAL(x)     TO_LITERAL_AUX(x)
```

Motivation: avoid integer to string conversion (performance)

```
int main() {
   int  x1   = 3 * 10;
   int  y1   = __LINE__ + 4;
   char x2[] = TO_LITERAL(3);
   char y2[] = TO_LITERAL(__LINE__);
}
```

Macro Tricks 2

- Find the size offset of a field inside a structure:

```
#define FIELD_OFFSET(structure, field)                    \
    reinterpret_cast<size_t>(                             \
        &((reinterpret_cast<structure*>(0))->field) )
```

- Get the size of an arbitrary type without using `sizeof`

```
#define MY_SIZE(type, ret)                                \
 { type x; ret = reinterpret_cast<char*>(&x + 1) -        \
                 reinterpret_cast<char*>(&x); }
```

```
struct A {
    int   a;
    float b;
};
std::cout << FIELD_OFFSET(A, b); // print 4
int size;
MY_SIZE(A, size); // size = 8
```