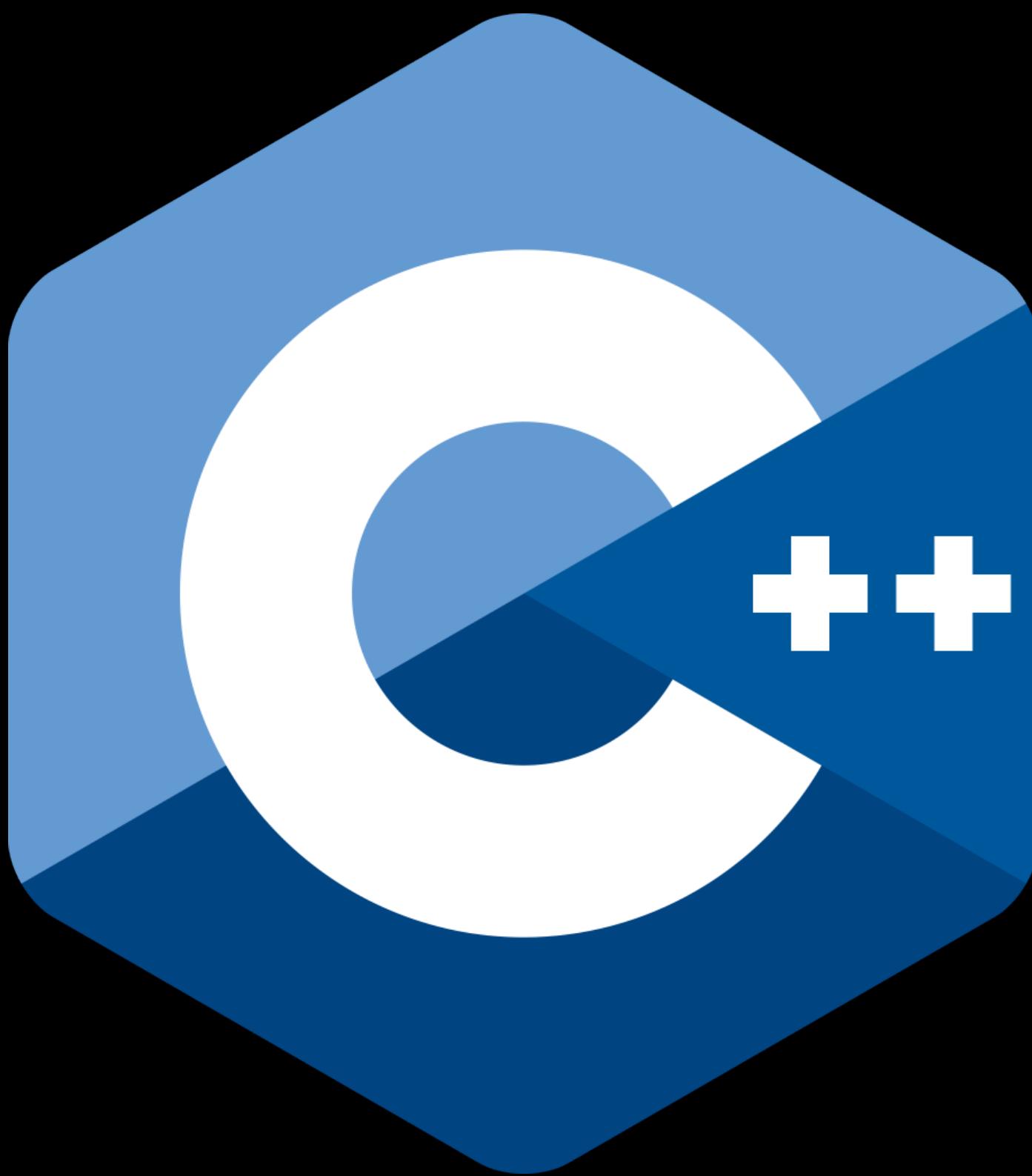


# Modern C++ Course



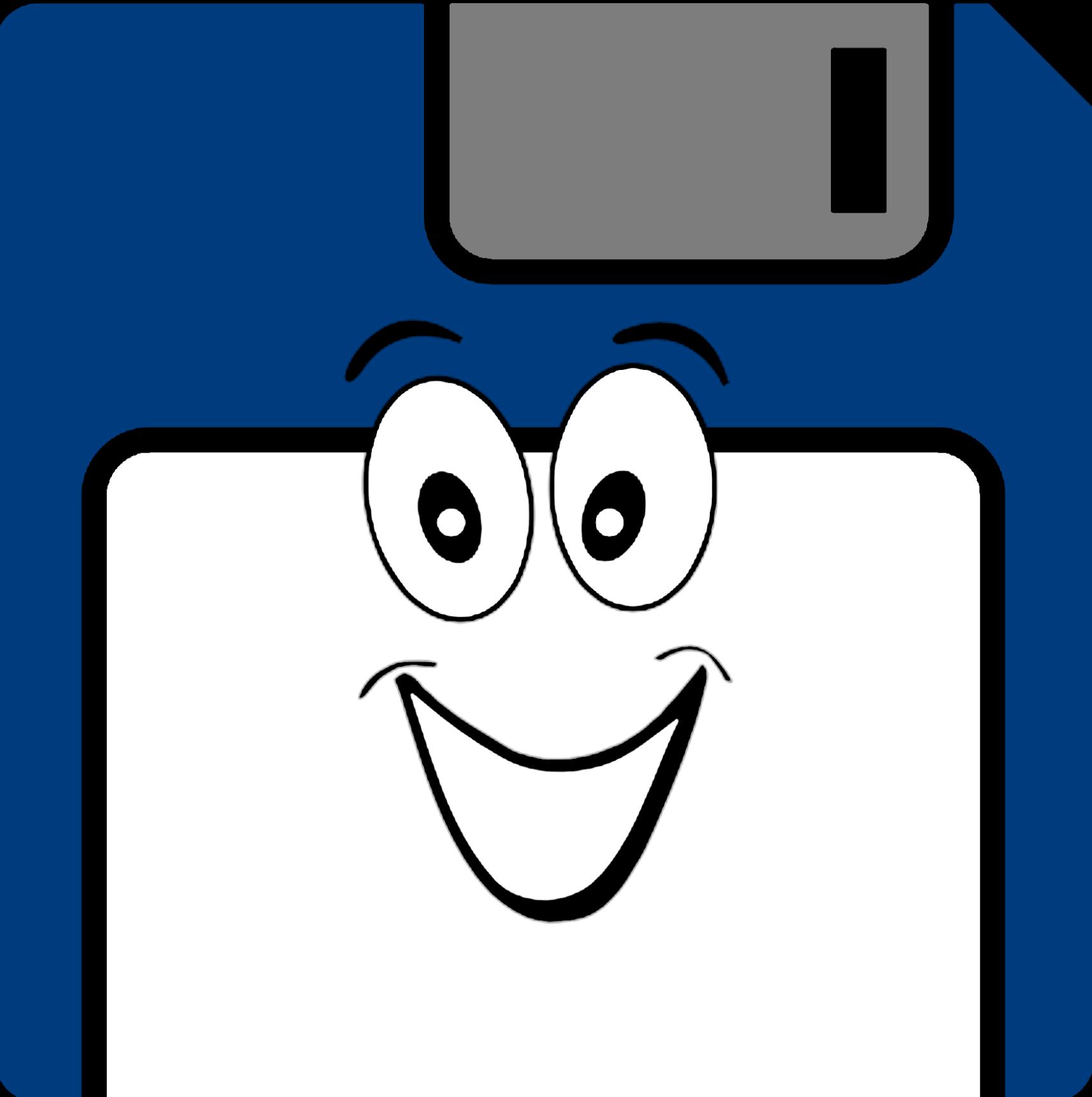
# Who am I ?

## Gammasoft

Gammasoft aims to make c++ fun again.

## About

- Gammasoft is the nickname of Yves Fiumefreddo.
- More than thirty years of passion for high technology especially in development (c++, c#, objective-c, ...).
- Object-oriented programming is more than a mindset.
- more info see my GitHub : <https://github.com/gammasoft71>



# Outline

1. Introduction
2. Language Basics
3. Object Oriented Programming (OOP)
4. Core Modern C++
5. Modern C++ Expert
6. Advanced Programming



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- What this course is?
- History
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- References
- C++ development tools



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# What this course is?

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- This course aimed at inexperienced developers as well as experienced developers with no knowledge of Modern C++.



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- This course covers concepts from C++98 to C++23, while keeping modern C++ in mind.



# What this course is?

- This course aimed at inexperienced developers as well as experienced developers with no knowledge of Modern C++.
- This course covers concepts from C++98 to C++23, while keeping modern C++ in mind.
- The corresponding C++ version is indicated for each concept and feature.

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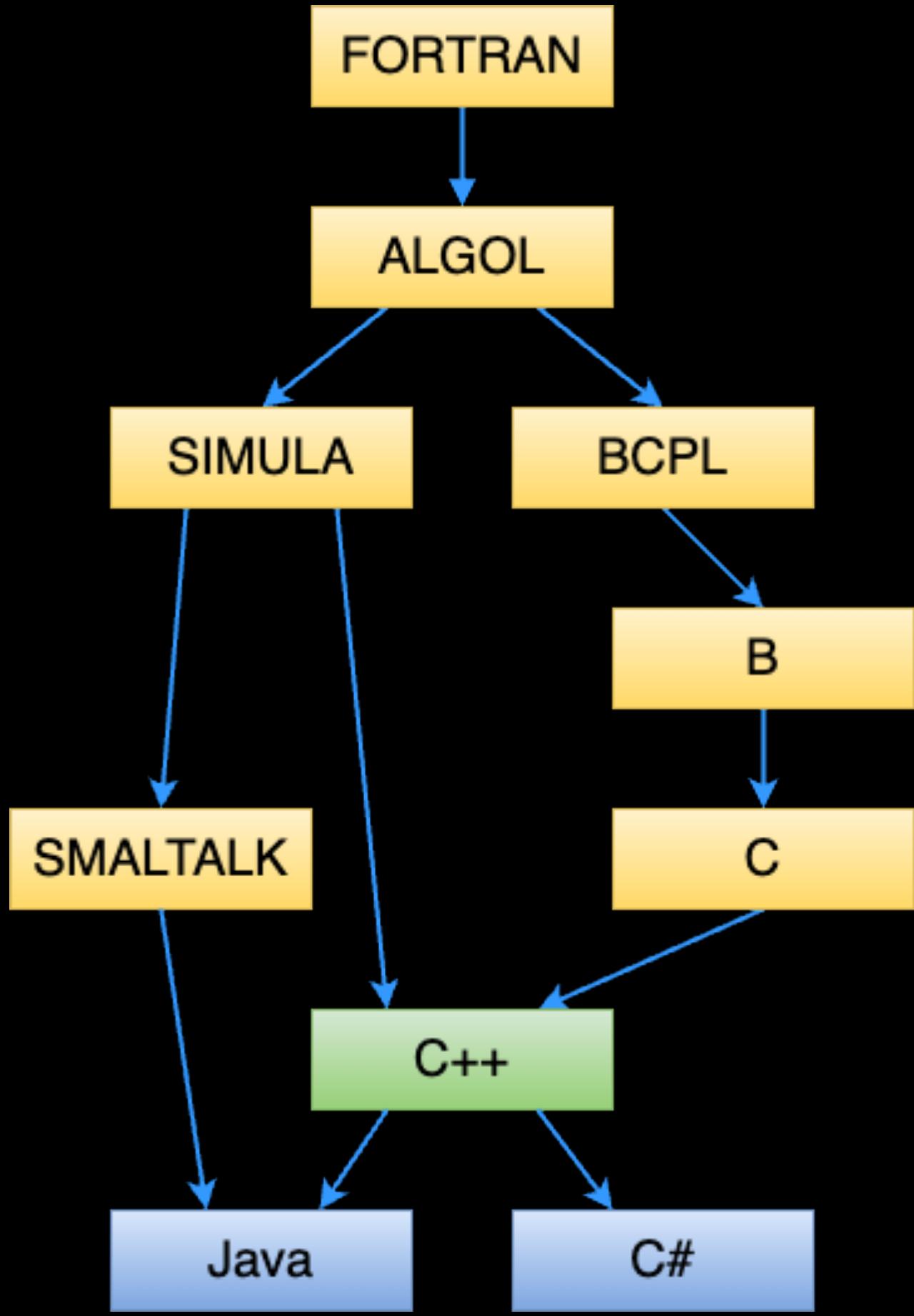
# Bjarne Stroustrup

Bjarne Stroustrup, a Danish computer scientist, is the creator of C++.



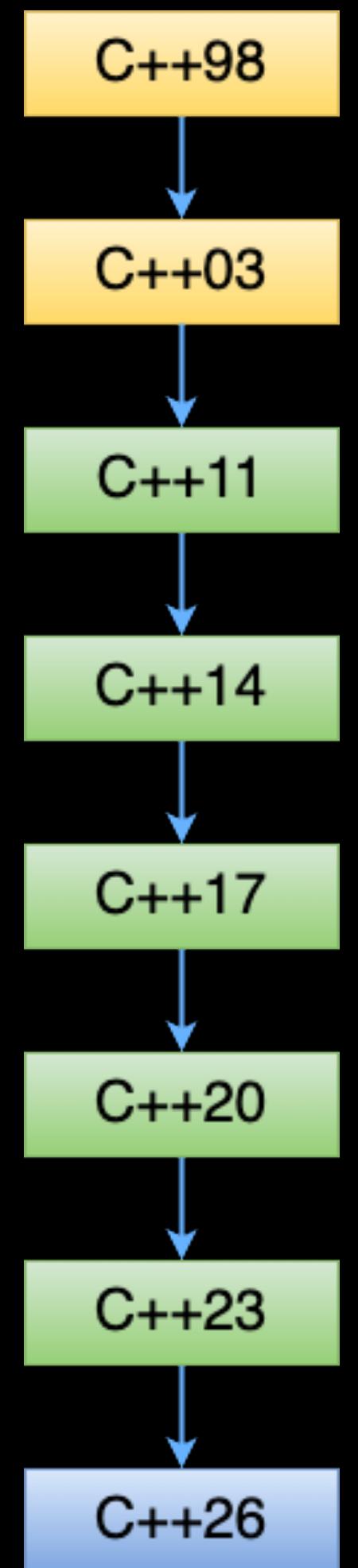
# C++ language

- In 1979, Bjarne Stroustrup began work on "**C with Classes**", the predecessor to "C++".
- In 1982, Stroustrup started to develop a successor to "C with Classes", which he named "C++".
- In 1985, the first edition of The C++ Programming Language was released
- In 1998, C++98 was released, standardizing the language



# C++ Standards

- 1998 | 14882:1998 | C++98
- 2003 | 14882:2003 | C++03
- 2011 | 14882:2011 | C++11
- 2014 | 14882:2014 | C++14
- 2017 | 14882:2017 | C++17
- 2020 | 14882:2020 | C++20
- 2024 | 14882:2024 | C++23
- TBA | | C++26



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# Adapted to large projects



# Adapted to large projects

- Statically and strongly typed



# Adapted to large projects

- Statically and strongly typed
- Object oriented



# Adapted to large projects

- Statically and strongly typed
- Object oriented
- Widely used (and taught)



# Adapted to large projects

- Statically and strongly typed
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- Many available libraries



# Adapted to large projects

- Statically and strongly typed
- Object oriented
- Widely used (and taught)
- Many available libraries
- Many available documentations and examples on the net



# Fast



# Fast

- unlike some other languages (Java, C#, Python, ...) C++ is compiled to native machine code



# Fast

- unlike some other languages (Java, C#, Python, ...) C++ is compiled to native machine code
- close to hardware when needed



# What we get?



# What we get?

- The most powerful language



# What we get?

- The most powerful language
- The most complicated one



# What we get?

- The most powerful language
- The most complicated one
- The most error prone?



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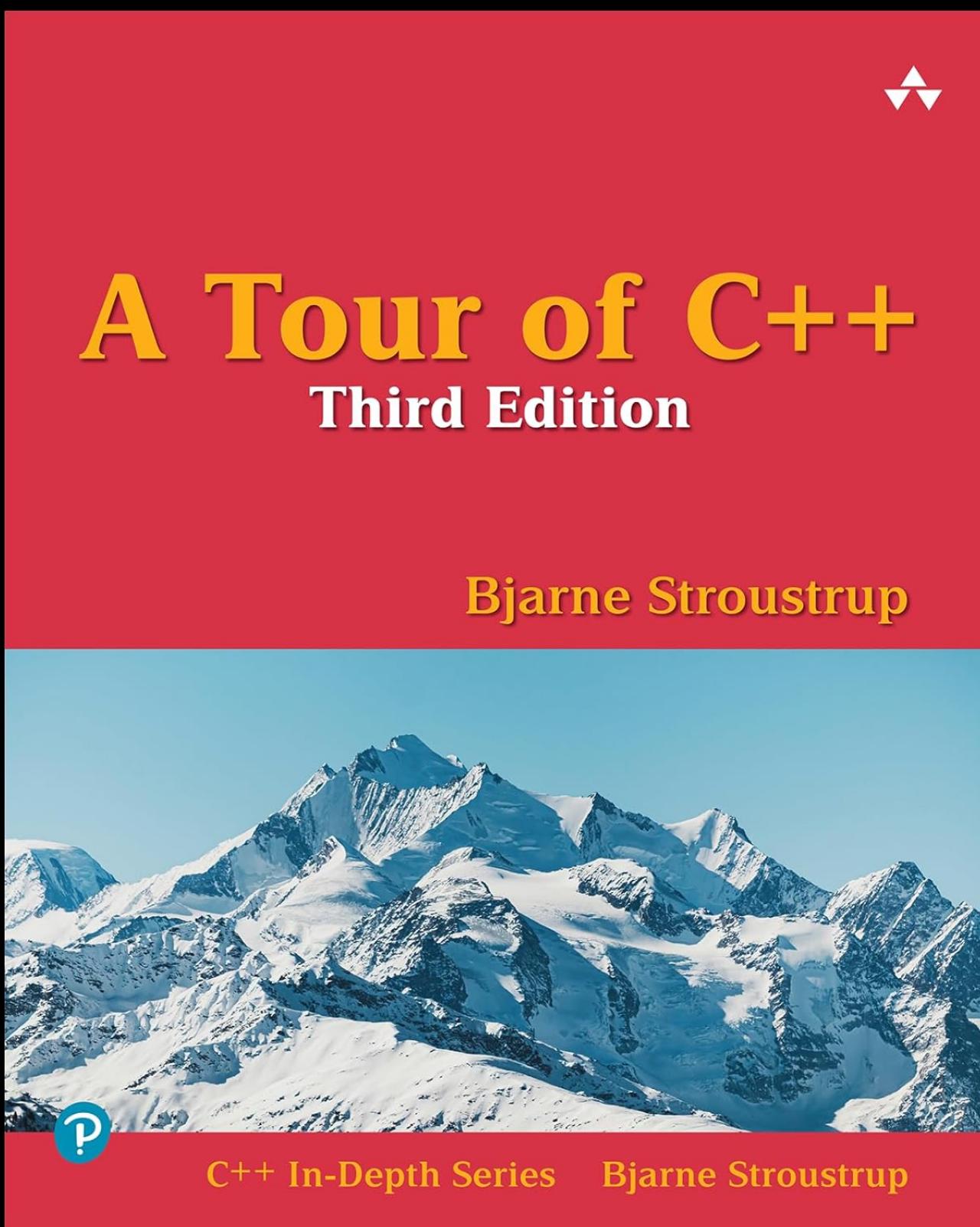
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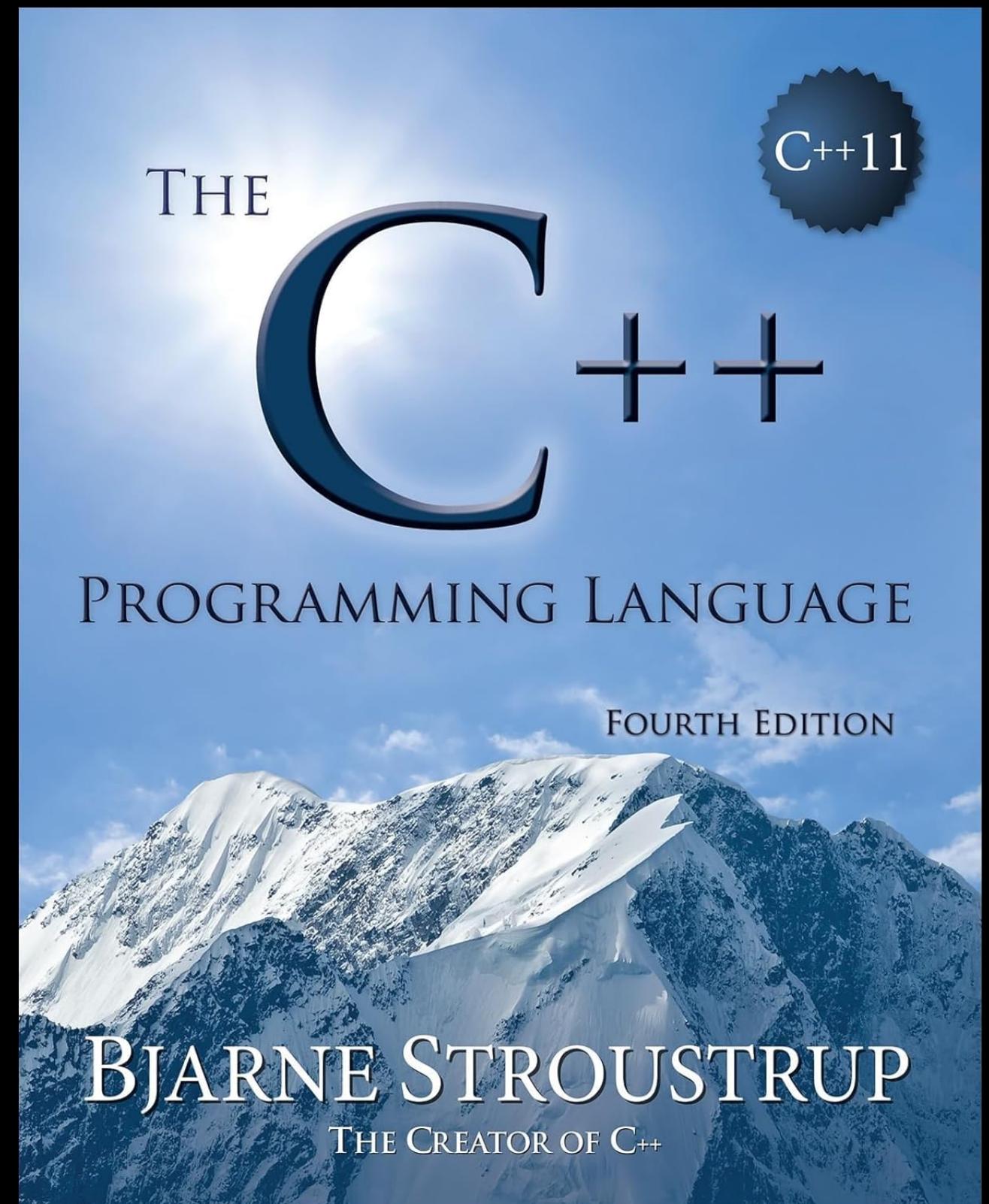
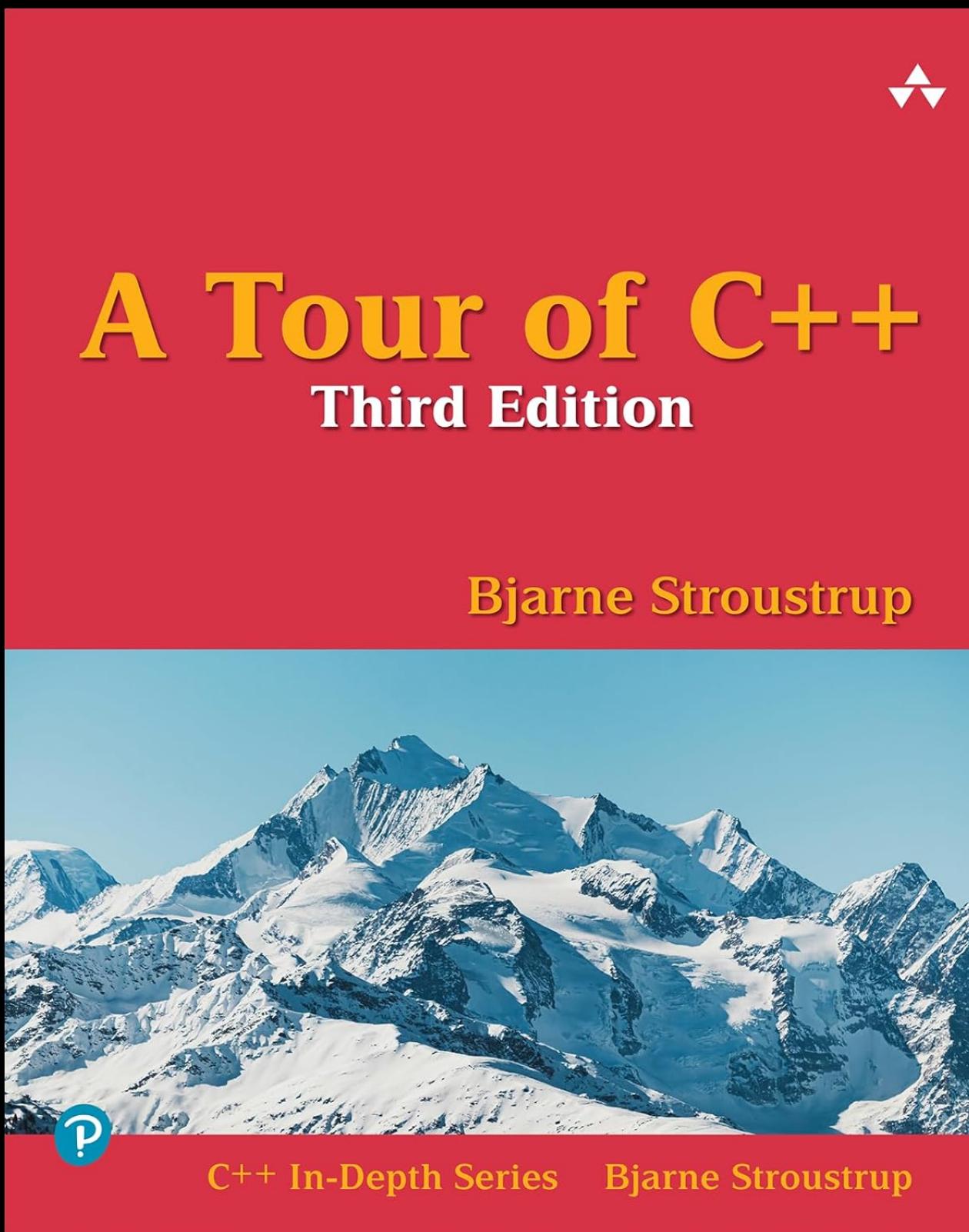
# Books



# Books



# Books



# Useful links



# Useful links

- <https://isocpp.org>



# Useful links

- <https://isocpp.org>
- <https://cppreference.com>



# Useful links

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- And more...



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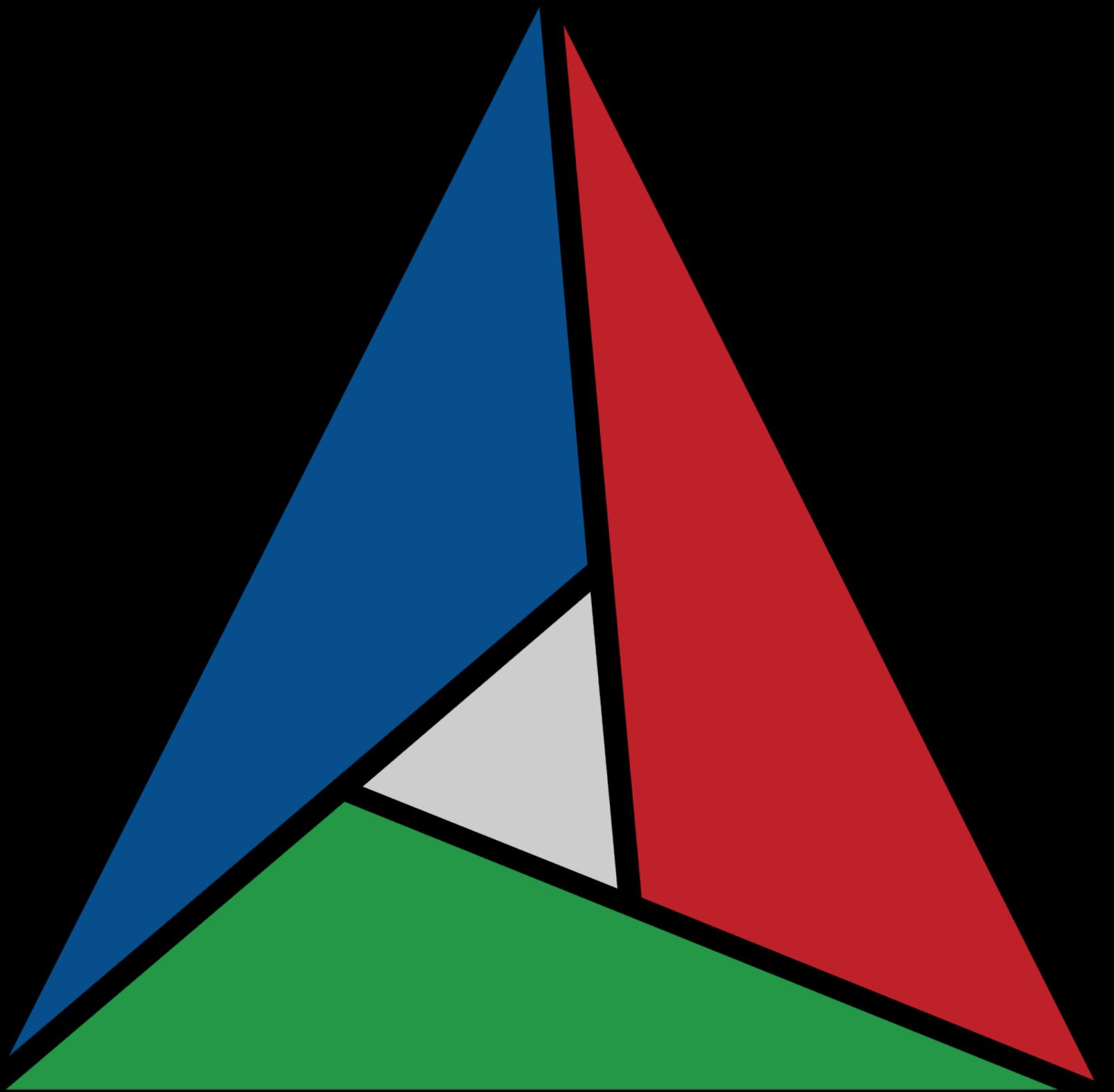


# Compilers

C++	GCC	Clang	MSVC	Apple Clang
11	$\geq 4.8$	$\geq 3.3$	$\geq 19$	$\geq 3.3$
14	$\geq 4.9$	$\geq 3.4$	$\geq 19$	$\geq 3.3$
17	$\geq 7.3$	$\geq 5$	$\geq 19.01$	$\geq 10$
20	$\geq 11$	$\geq 19$	$\geq 19.29$	$\geq 15$
23	$\geq 15$	$\geq 19$	$\geq 19.40$	$\geq 15$

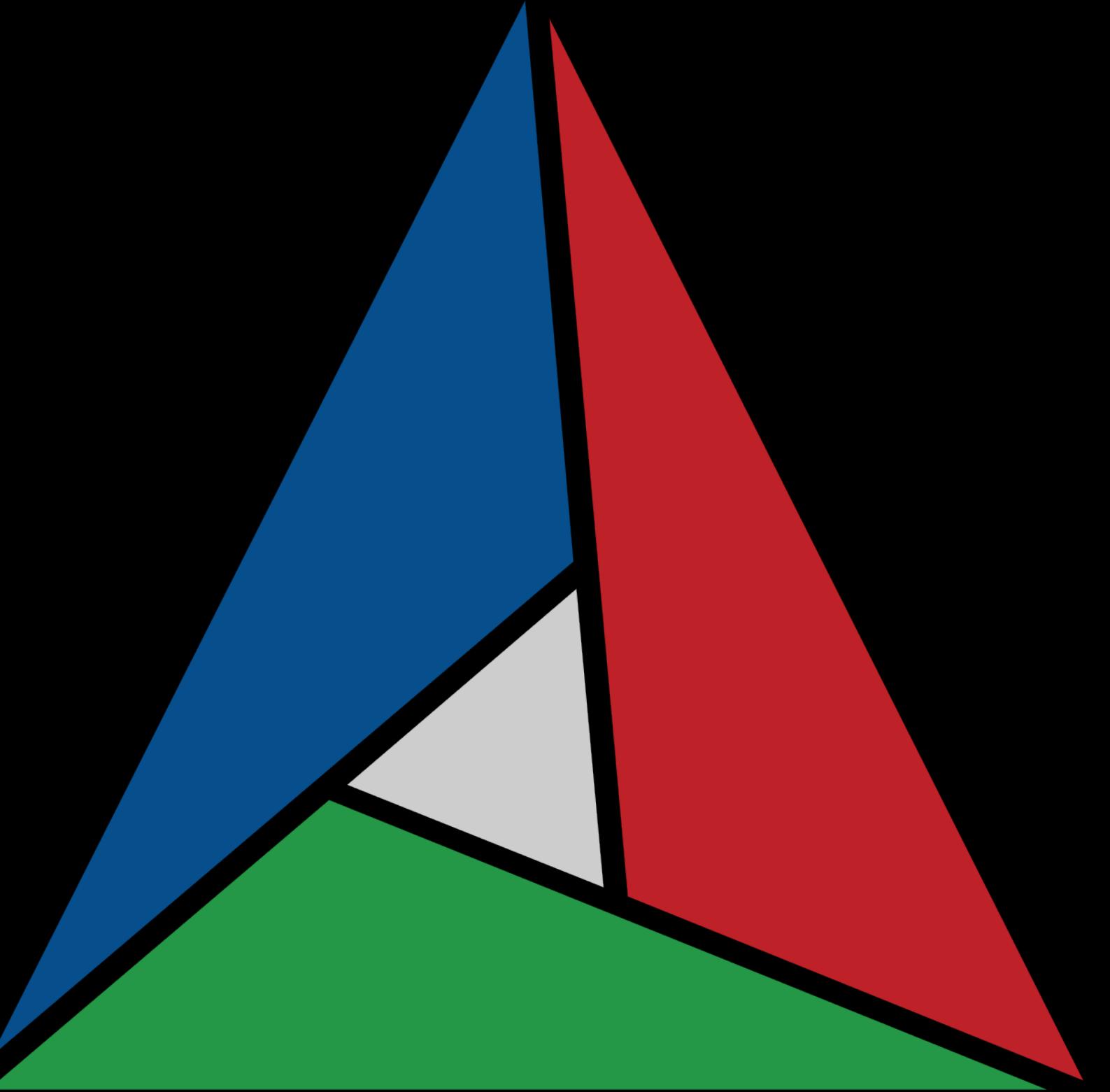


# CMake



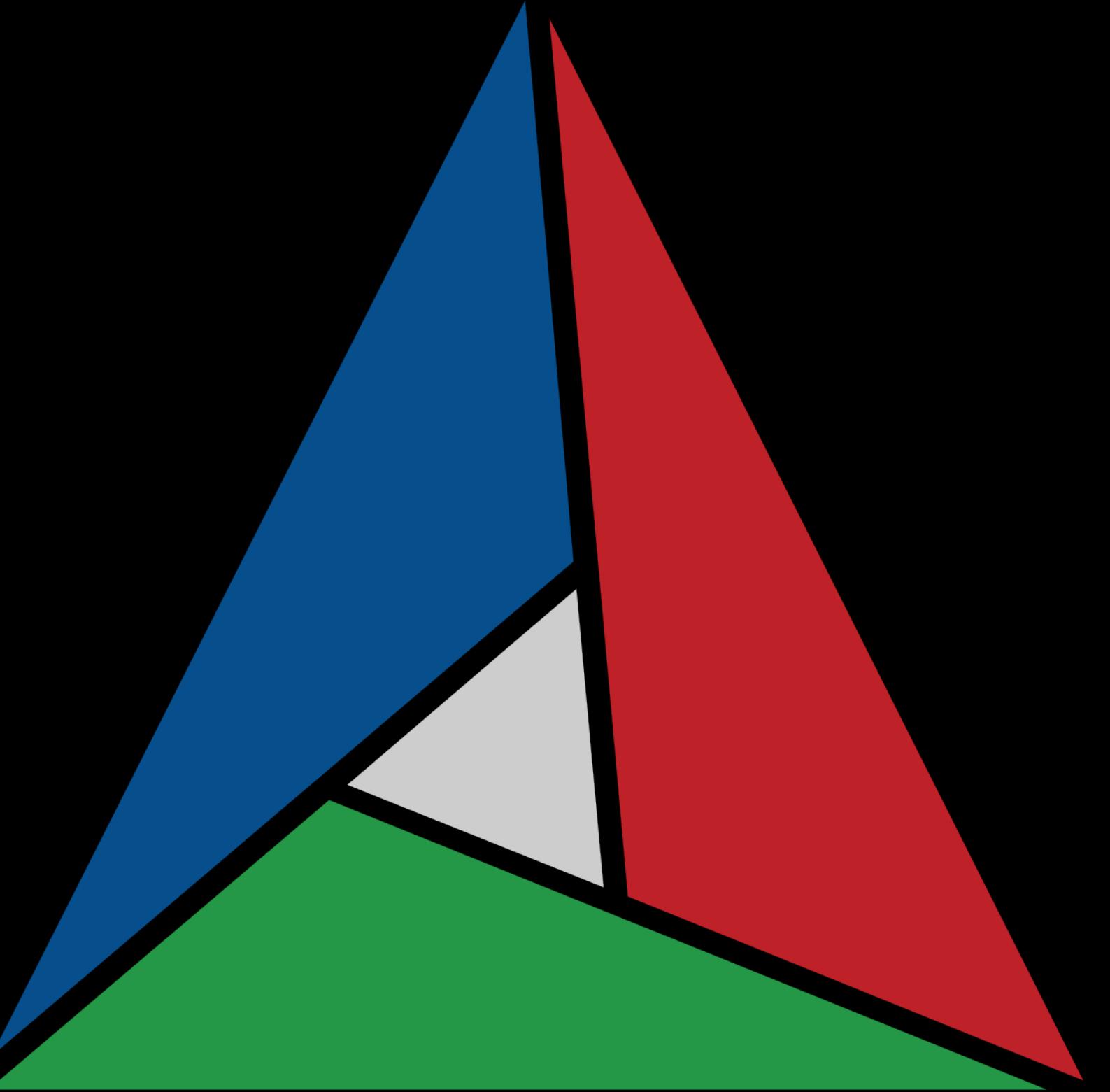
# CMake

- Single source builds on multiple platforms



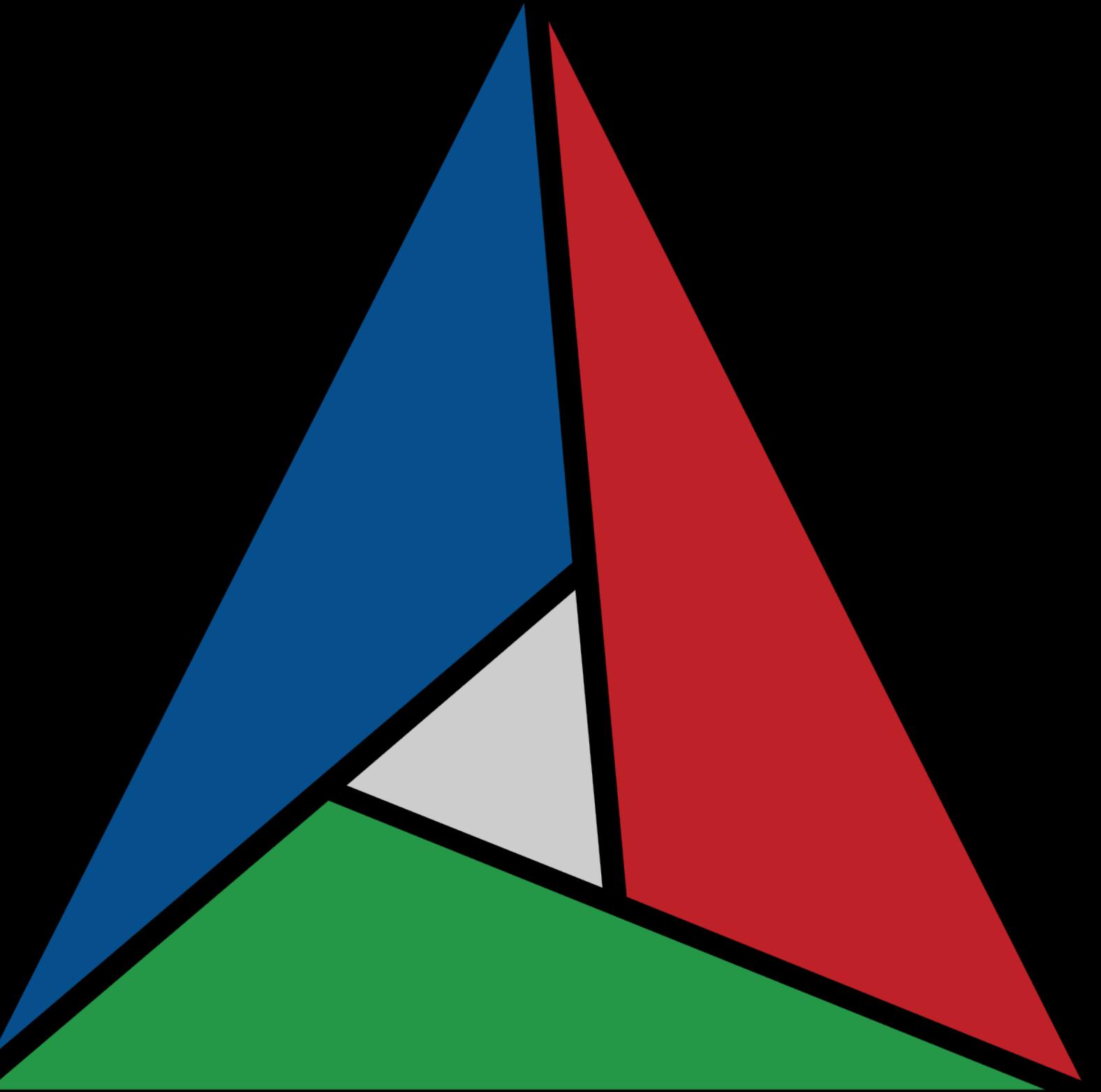
# CMake

- Single source builds on multiple platforms
- Accurate dependencies and minimal rebuilds



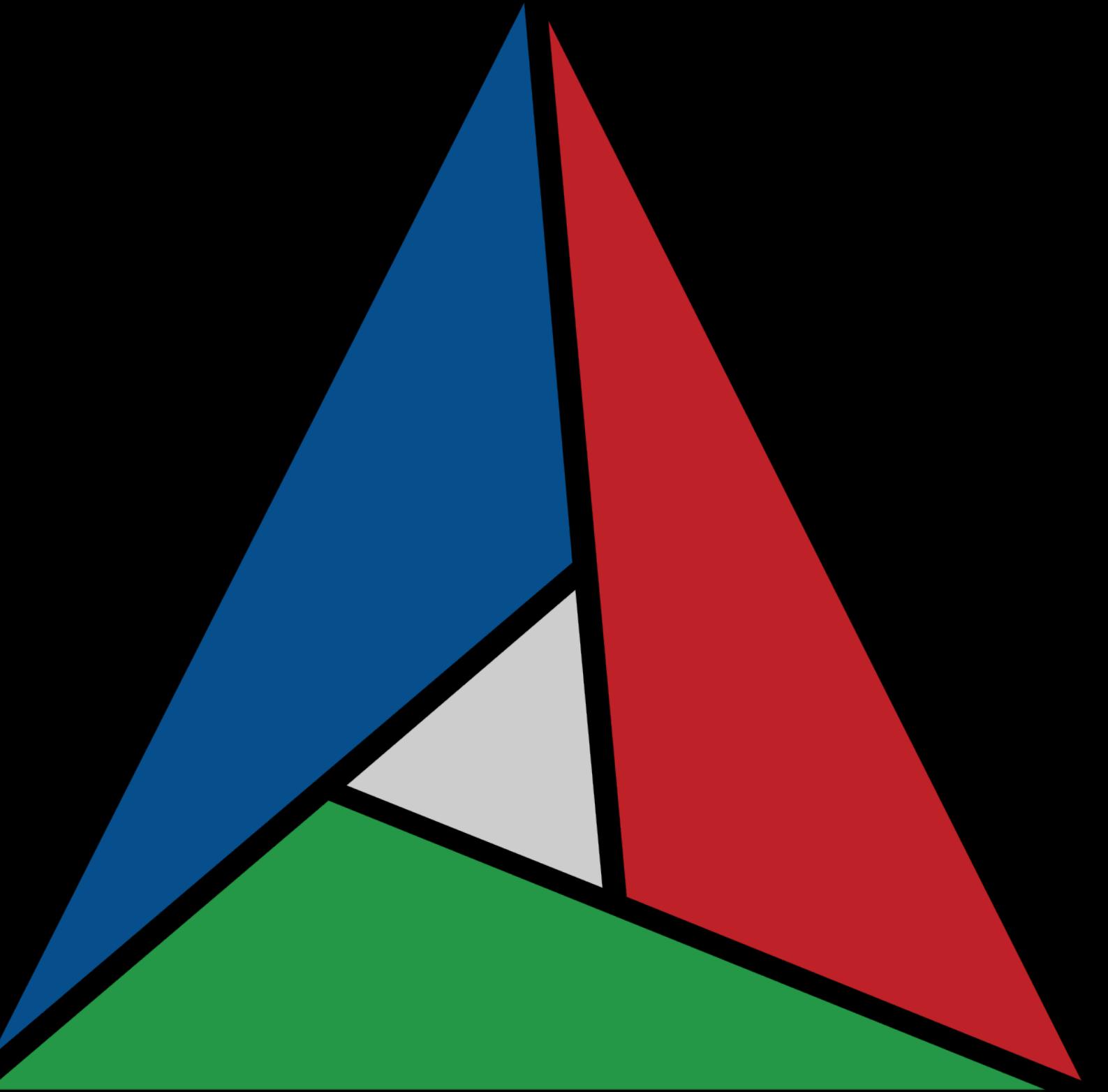
# CMake

- Single source builds on multiple platforms
- Accurate dependencies and minimal rebuilds
- Out-of-source builds



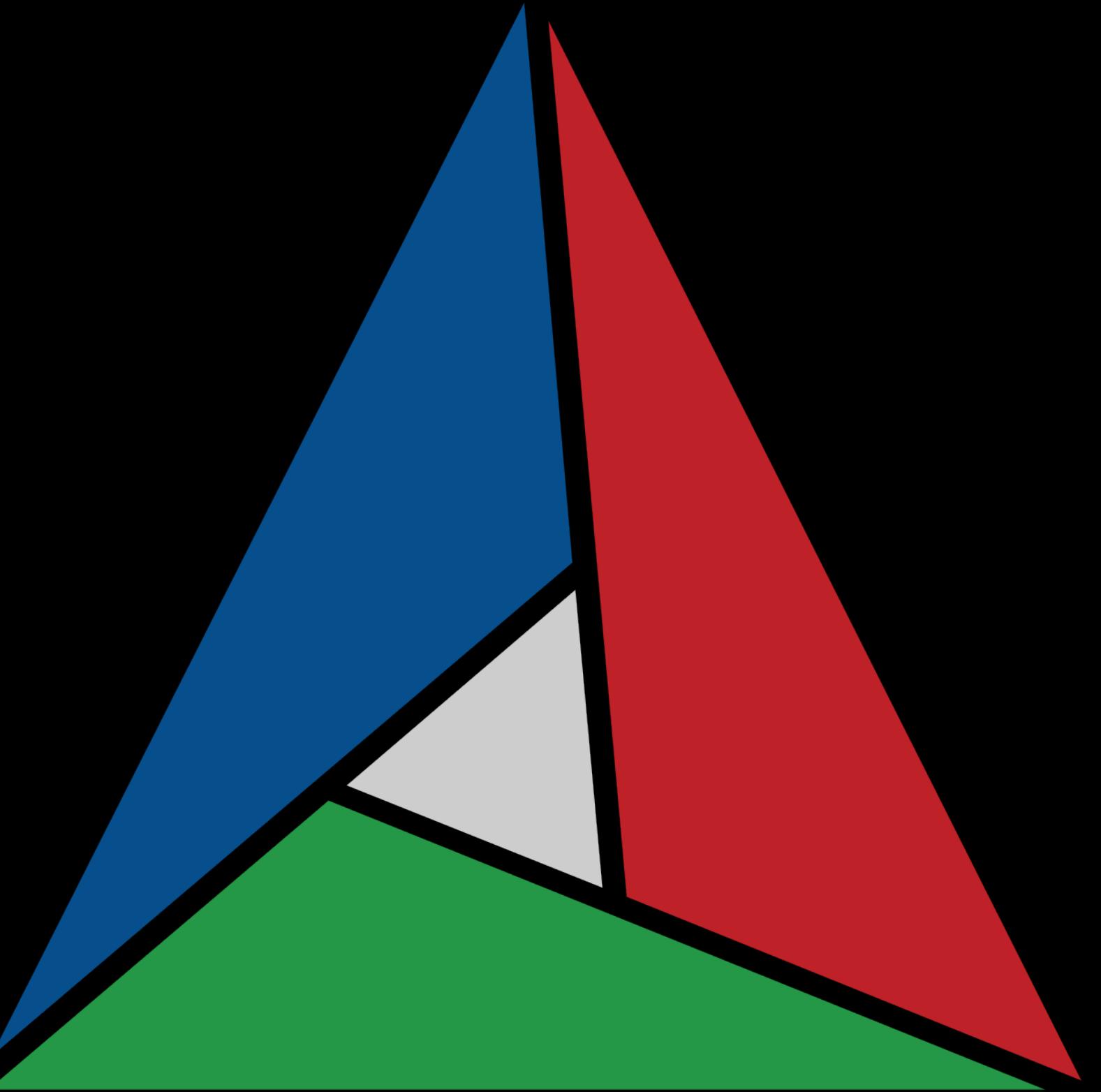
# CMake

- Single source builds on multiple platforms
- Accurate dependencies and minimal rebuilds
- Out-of-source builds
- Cross-platform packaging system



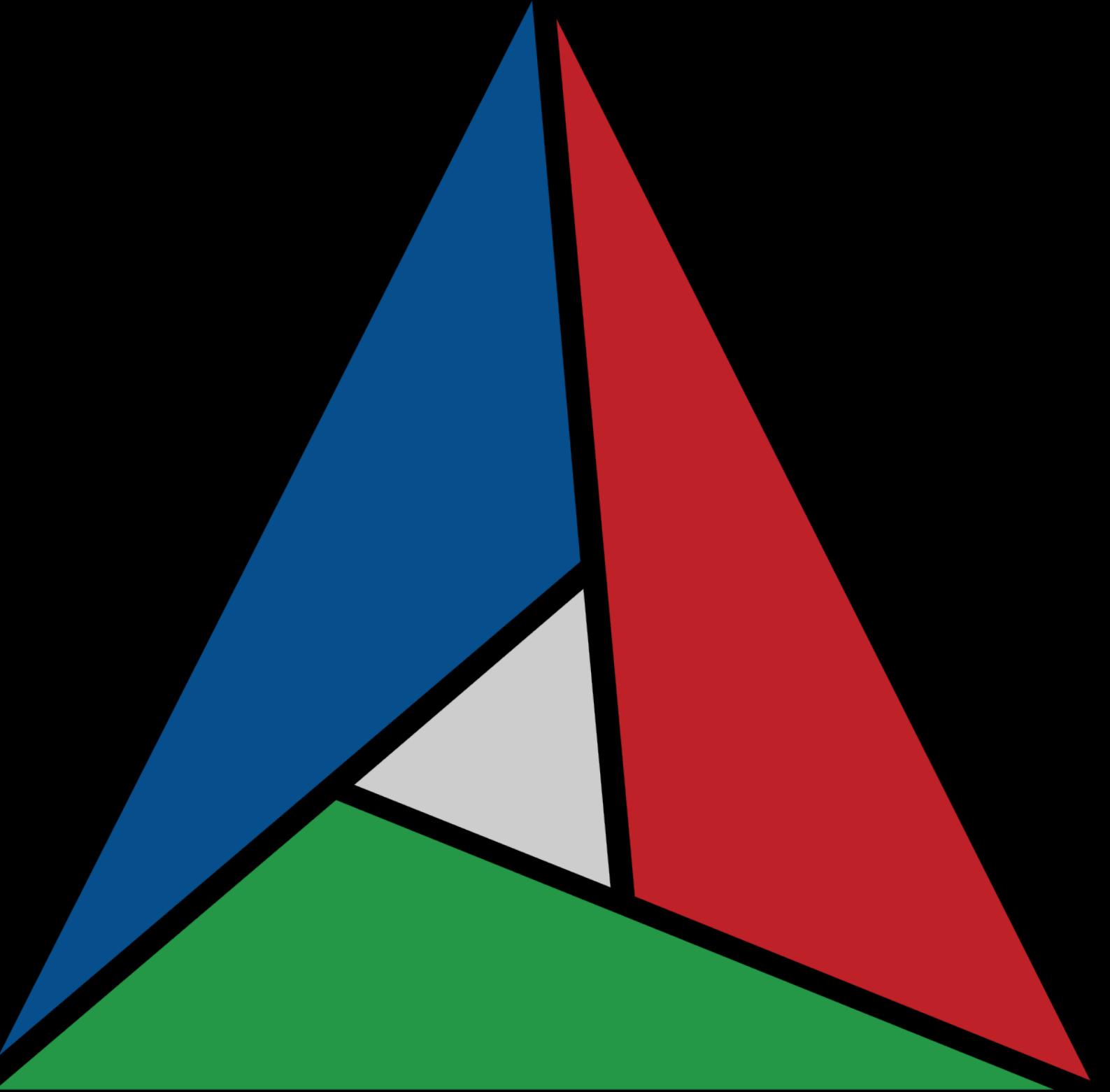
# CMake

- Single source builds on multiple platforms
- Accurate dependencies and minimal rebuilds
- Out-of-source builds
- Cross-platform packaging system
- Cross-platform testing system



# CMake

- Single source builds on multiple platforms
- Accurate dependencies and minimal rebuilds
- Out-of-source builds
- Cross-platform packaging system
- Cross-platform testing system
- And more...



# Integrated Development Environment (IDE)



# Integrated Development Environment (IDE)

-  Microsoft Visual Studio (Windows)



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-  Xcode (macOS)

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-  Microsoft Visual Studio (Windows)
-  Xcode (macOS)
-  Microsoft Visual Studio Code (Windows, macOS and Linux)

# Integrated Development Environment (IDE)

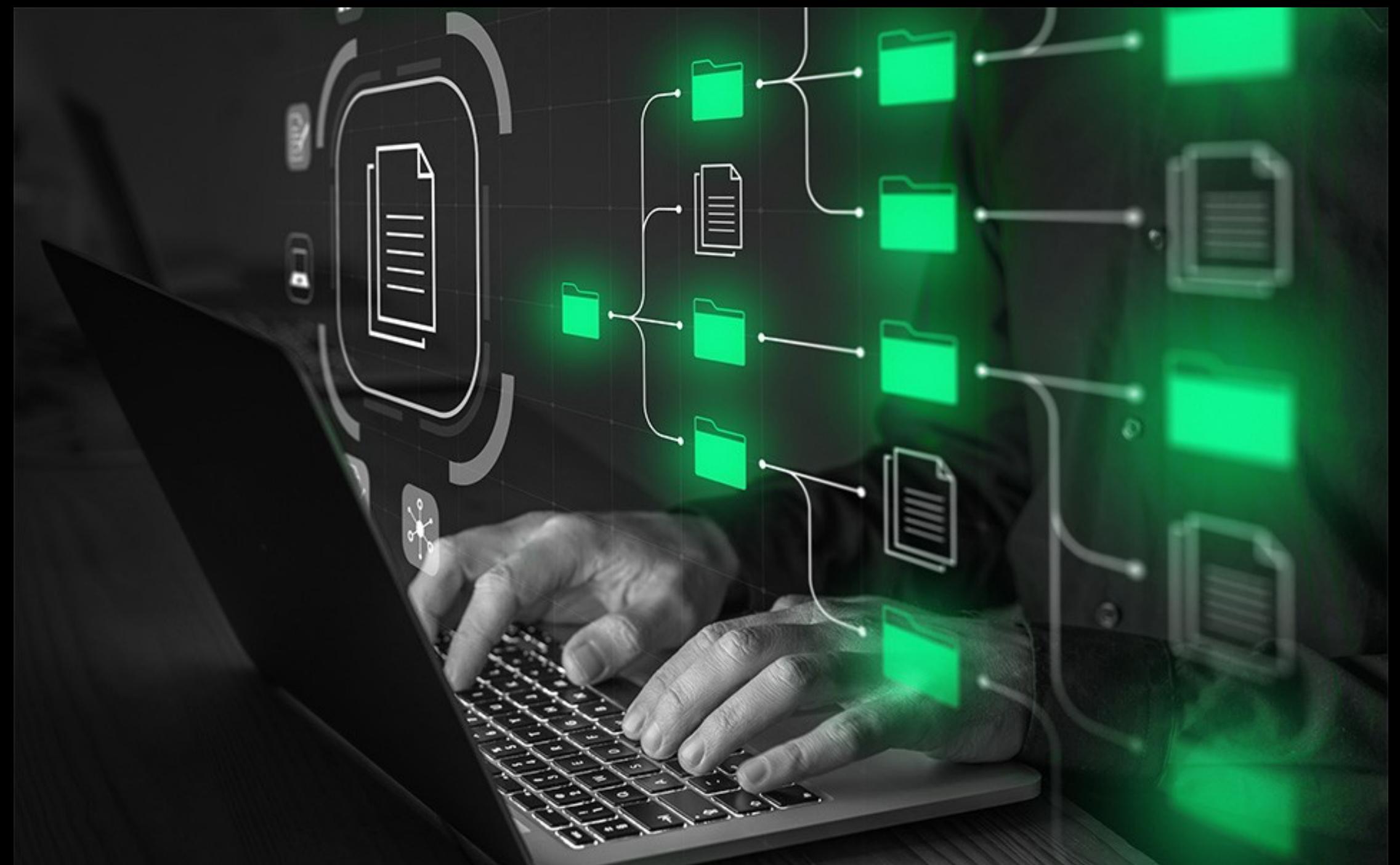
-  Microsoft Visual Studio (Windows)
-  Xcode (macOS)
-  Microsoft Visual Studio Code (Windows, macOS and Linux)
-        and others

# Configure your development environment



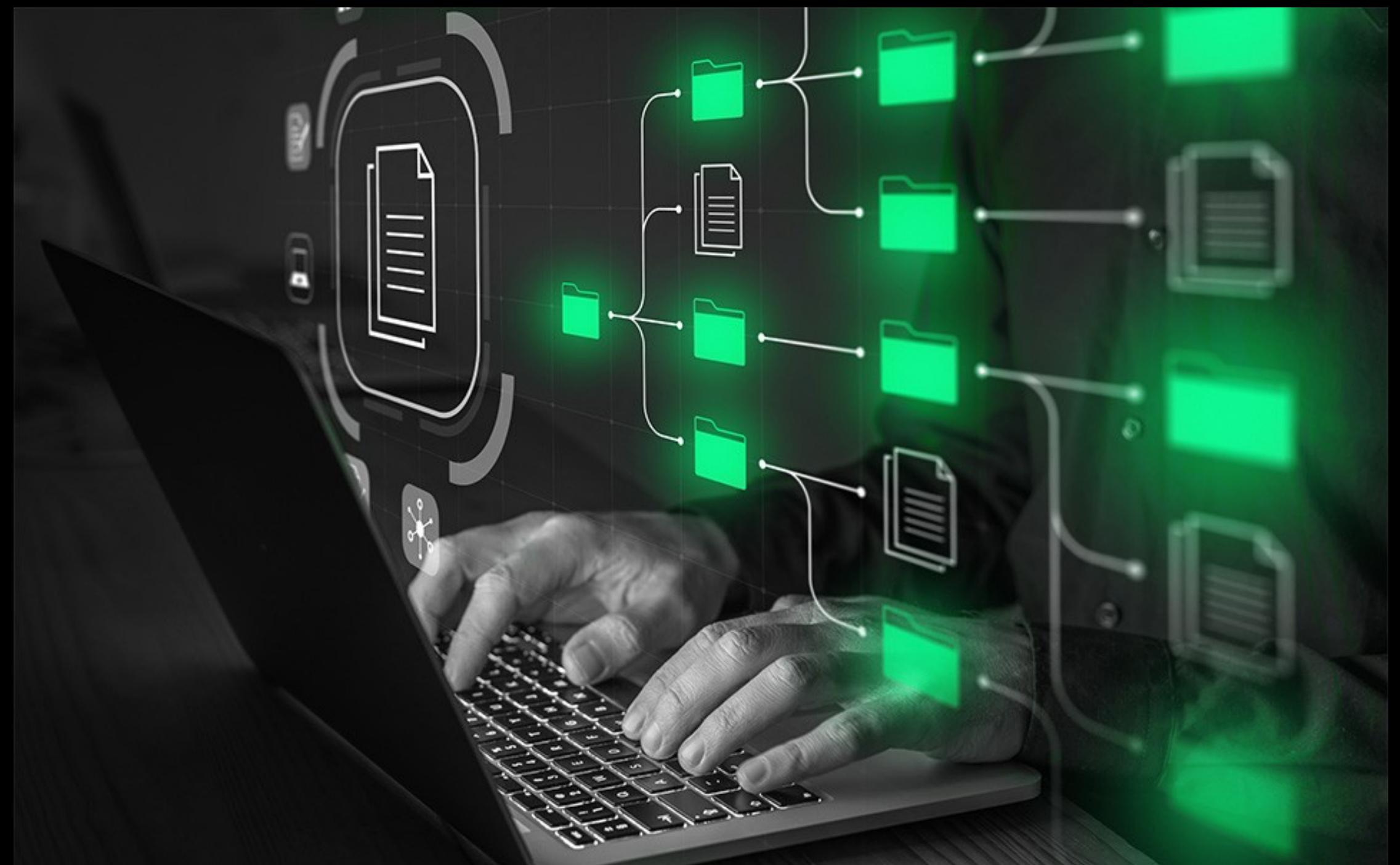
# Configure your development environment

- Install compiler



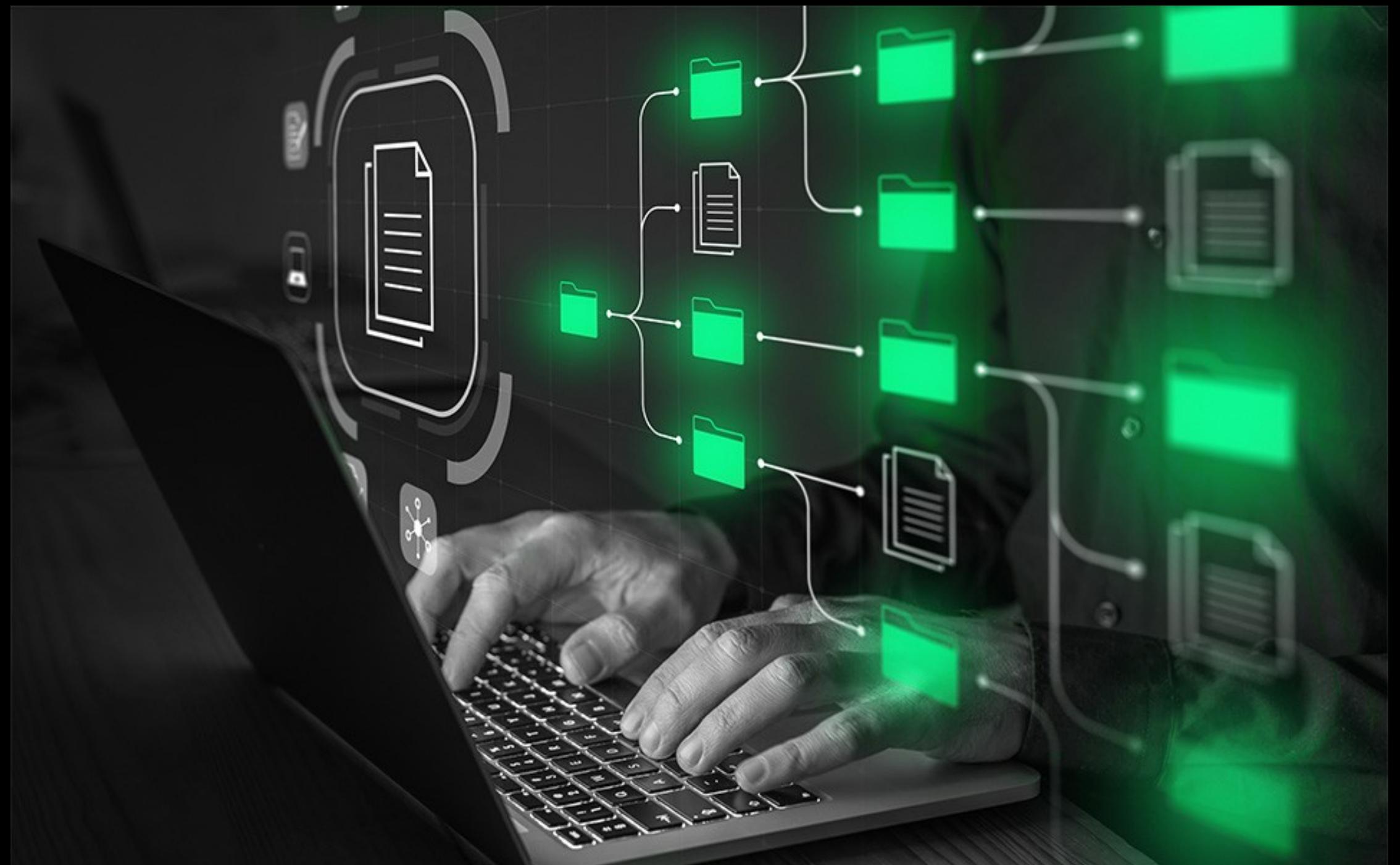
# Configure your development environment

- Install compiler
- Install IDE (according to OS)



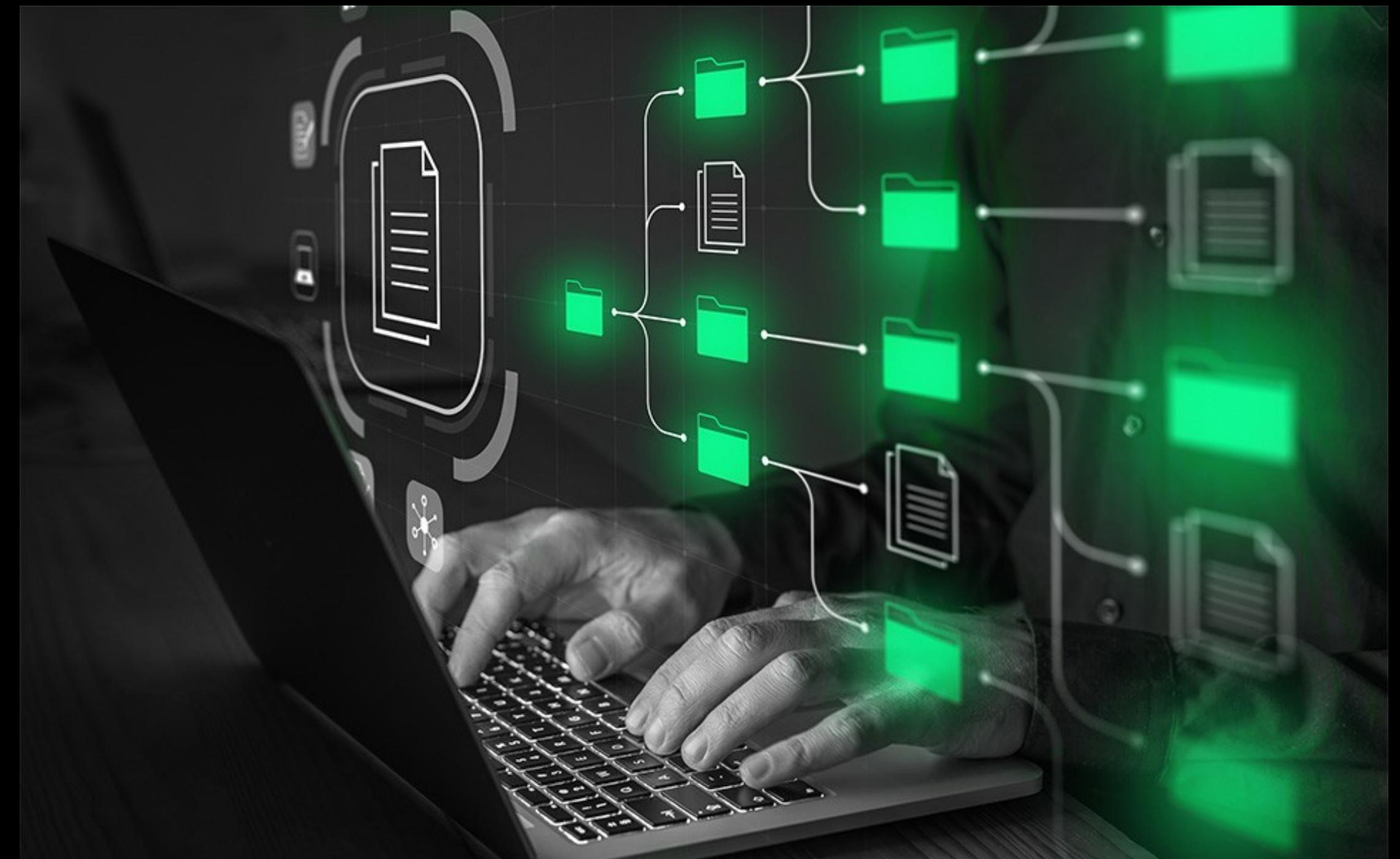
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- Install compiler
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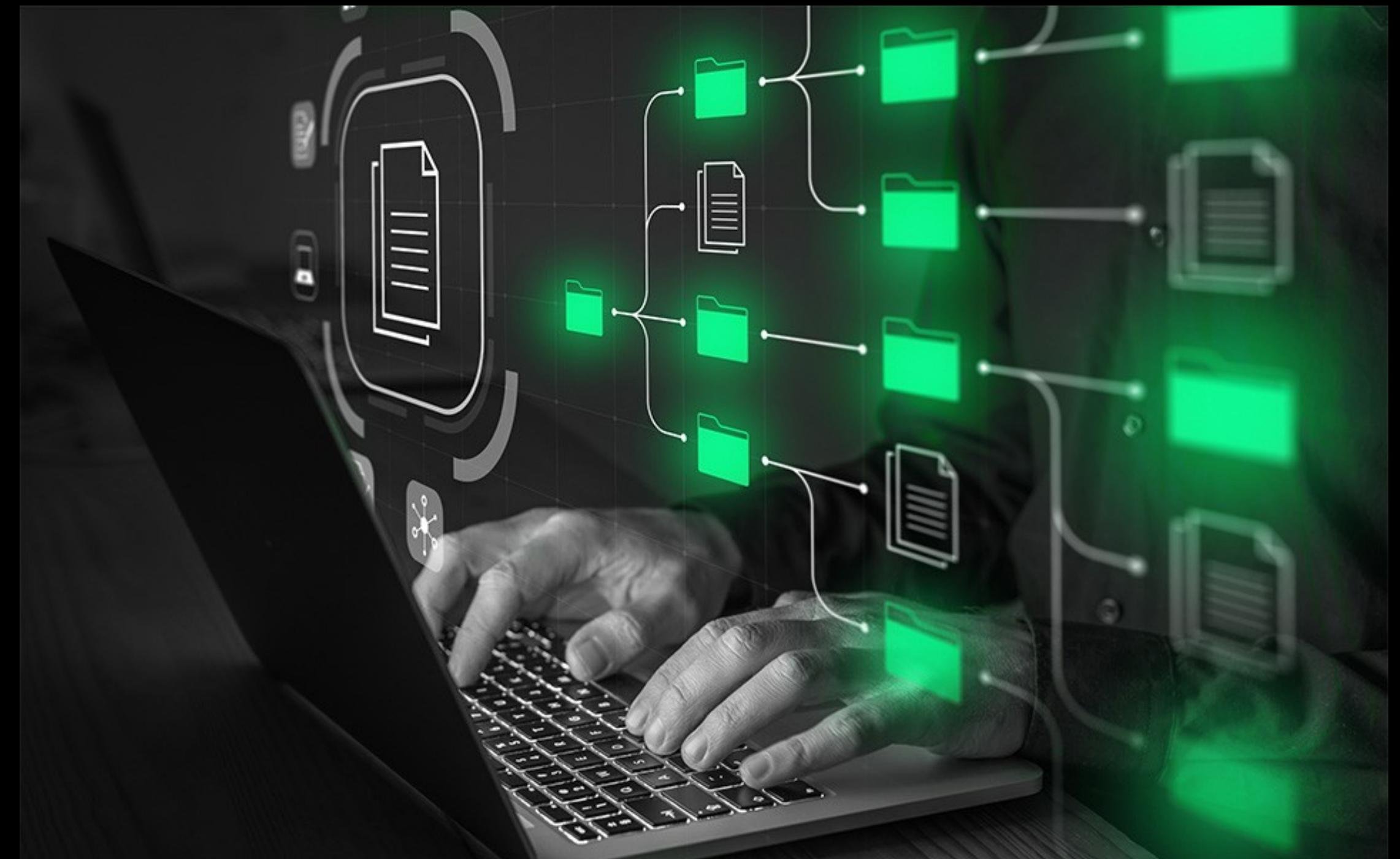
# Configure your development environment

- Install compiler
- Install IDE (according to OS)
- Install CMake
- Install SCM like git (not mandatory)



# Configure your development environment

- Install compiler
- Install IDE (according to OS)
- Install CMake
- Install SCM like git (not mandatory)
- Subscribe to GitHub (not mandatory)



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# Language Basics

- Hello World
- Core syntax and types
- Arrays and Pointers
- Scopes / namespaces
- Struct and enum types
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# The first classic application

# The first classic application

program.cpp

```
● ● ●

#include <iostream>

int main() {
    std::cout << "Hello, World!" << std::endl;
}
```



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program.cpp

```
● ● ●  
#include <iostream>  
  
int main() {  
    std::cout << "Hello, World!" << std::endl;  
}
```

CMakeLists.txt

```
● ● ●  
cmake_minimum_required(VERSION 3.20)  
  
project(hello_world)  
add_executable(${PROJECT_NAME} program.cpp)
```



# The first classic application

program.cpp

```
● ● ●  
#include <iostream>  
  
int main() {  
    std::cout << "Hello, World!" << std::endl;  
}
```

CMakeLists.txt

```
● ● ●  
cmake_minimum_required(VERSION 3.20)  
  
project(hello_world)  
add_executable(${PROJECT_NAME} program.cpp)
```

## Output

```
● ● ●  
> Hello, World!
```



# The first classic application

program.cpp

```
● ● ●  
#include <print>  
  
auto main() -> int {  
    std::println("Hello, World!");  
}
```

CMakeLists.txt

```
● ● ●  
cmake_minimum_required(VERSION 3.20)  
  
project(hello_world)  
set(CMAKE_CXX_STANDARD 23)  
set(CMAKE_CXX_STANDARD_REQUIRED ON)  
add_executable(${PROJECT_NAME} program.cpp)
```

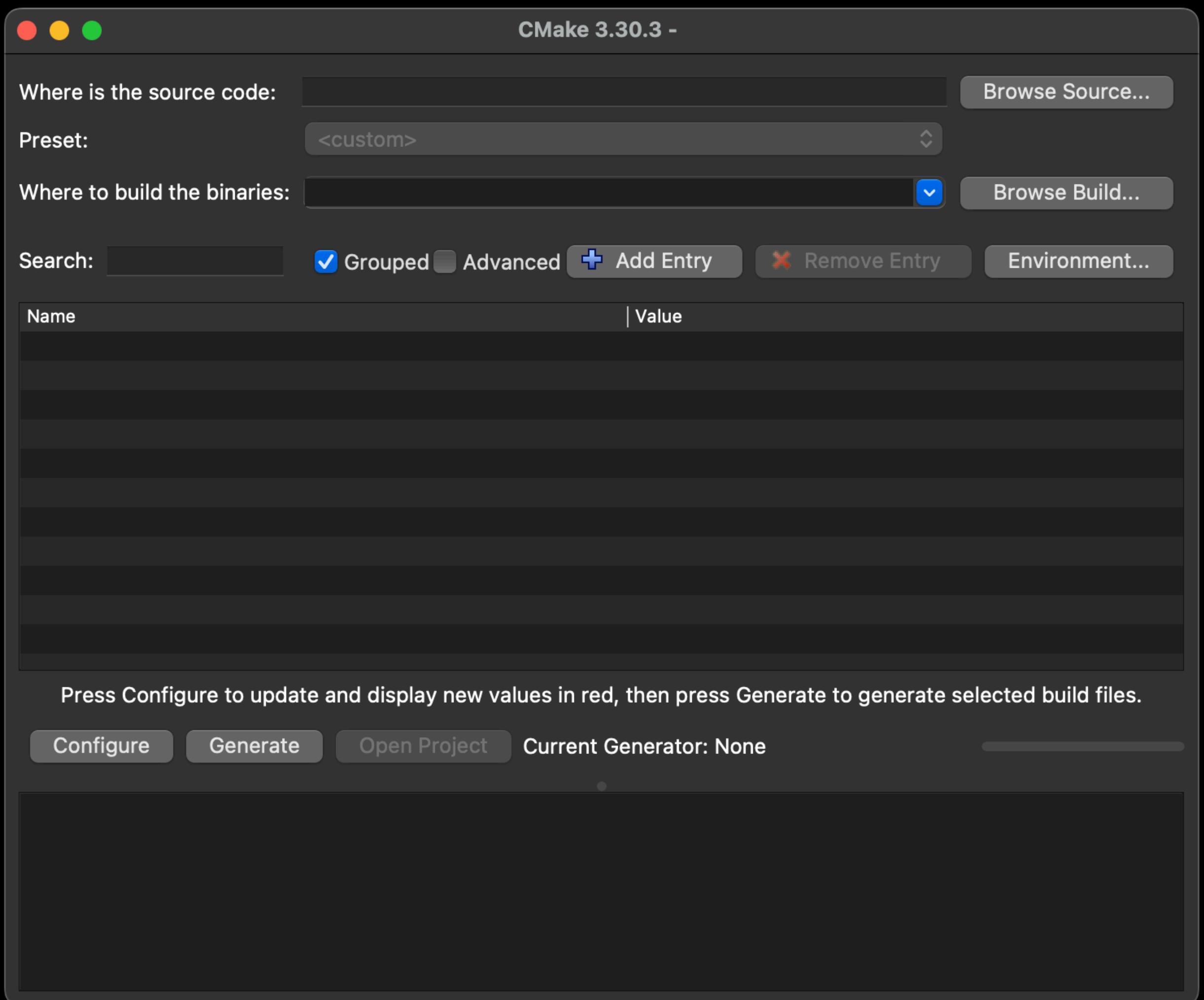
## Output

```
● ● ●  
> Hello, World!
```



# Execute with CMake GUI

- Open the CMake GUI application
- Click on "Browse Sources..." button and select the "Hello world" folder.
- Copy the path from "Where is the source code:", past it in the "Where to build the binaries:" and add "/build".
- Click on "Configure" button and select the generator.
- Click on "Generate" button to generate the project.
- Finally, click on “Open project” button.



# Main function



```
1 #include <iostream>
2
3 int main() {
4     std::cout << "main function" << std::endl;
5 }
```

# Main function



```
1 #include <iostream>
2
3 int main() {
4     std::cout << "main function" << std::endl;
5 }
```



```
1 #include <iostream>
2
3 int main(int argc, char* argv[]) {
4     for (auto index = 0; index < argc; index++)
5         std::cout << (index == 0 ? "main function with arguments [ " : ", ") << argv[index];
6     std::cout << "]" << std::endl;
7 }
```

# Exercise : environment

Learn how to use CMake to generate a project.

- Go to exercises/environment
- Look at environment.cpp and CMakeLists.txt
- Compile it (make) and run the program (./environment)
- Work on the tasks that you find in environment.cpp



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# Comments



```
1 // single-line comment
2 int value = 0;
3
4 /*
5  * multi-line comment
6  */
7 std::string name();
8
9 /// Doxygen comments
10 /// @brief Adds two specified integers.
11 /// @param value_a The first integer to add.
12 /// @param value_b The second integer to add.
13 /// @return The result of the addition.
14 /// @see https://www.doxygen.nl/manual/commands.html
15 int add(int value_a, int value_b);
```

# Basic types



```
1 bool b = true; // boolean, true or false
2
3 char c = 'a'; // min 8 bit integer
4 char cs = -1; // may be signed
5 char cu = '\2'; // or not
6 // can store an ASCII character
7
8 signed char sc = -3; // min 8 bit signed integer
9 unsigned char uc = 4; // min 8 bit unsigned integer
10
11 short int si = -5; // min 16 bit signed integer
12 short s=-6; // int is optional
13 unsigned short int usi = 7; // min 16 bit unsigned integer
14 unsigned short us = 8; // int is optional
```

# Basic types



```
1 int i = -9;           // min 16, usually 32 bit
2 unsigned int ui = 10; // min 16, usually 32 bit
3
4 long l = -111;        // min 32 bit signed integer
5 long int li = -121;   // int is optional
6 unsigned long ul = 13Ul; // min 32 bit unsigned integer
7 unsigned long int ulli = 14Ul; // int is optional
8
9 long long ll = -1511; // min 64 bit signed integer
10 long long int lli = -161l; // int is optional
11 unsigned long long ull = 17ull; // min 64 bit unsigned integer
12 unsigned long long int ulli = 18ull; // int is optional
```

# Basic types



```
1 float f = 0.19f;          // 32 (1+8+23) bit float
2 double d = 0.20;           // 64 (1+11+52) bit float
3 long double ld = 0.211;   // min 64 bit float
4
5 const char* nstr = "native string"; // array of chars ended by \0
6 std::string str = "string";        // class provided by the std
```

# Fixed width integer types

```
1 #include <cstdint>
2
3 std::int8_t i8 = -1; // 8 bit signed integer
4 std::uint8_t ui8 = 1; // 8 bit unsigned integer
5
6 std::int16_t i16 = -2; // 16 bit signed integer
7 std::uint16_t ui16 = 3; // 16 bit unsigned integer
8
9 std::int32_t i32 = -4; // 32 bit signed integer
10 std::uint32_t u132 = 5; // 32 bit unsigned integer
11
12 std::int64_t i64 = -4; // 64 bit signed integer
13 std::uint64_t ui64 = 5; // 64 bit unsigned integer
```



# Fixed width floating-point types



```
1 #include <stdfloat>
2
3 std:: float16_t value = 3.14f16;    // 16 (1+5+10) bit float
4 std:: float32_t value = 3.14732;   // like float (1+8+23)
5                                         // but different type
6 std:: float64_t value = 3.14f64;    // like double (1+11+52)
7                                         // but different type
8 std:: float128_t value = 3.14f128; // 128 (1+15+112) bit float
9 std:: bfloat16_t value = 3.14bf16; // 16 (1+8+7) bit float
10
11 // also F16, F32, F64, F128 or BF16 suffix possible
```

# Integer literals



```
1 int value = 4284;                      // decimal (base 10)
2 int value = 0b0001000010111100;        // binary (base 2) since C++14
3 int value = 010274;                     // octal (base 8)
4 int value = 0x10bc;                     // hexadecimal (base 16)
5 int value = 0x10BC;                     // hexadecimal (base 16)
6
7 int value = 123'456'789;                // digit separators, since C++14
8 int value = 0b0001'0000'1011'1100; // digit separators, since C++14
9
10 4284           // int
11 4284u,   4284U // unsigned int
12 4284l,   4284L // long
13 4284ul,  4284UL // unsigned long
14 4284ll,  4284LL // long long
15 4284ull, 4284ULL // unsigned long long
```

# Floating-point literals



```
1 double value = 12.34;
2 double value = 12.;
3 double value = .34;
4 double value = 12e34;           // 12 * 10^34
5 double value = 12E34;          // 12 * 10^34
6 double value = 12e-34;         // 12 * 10^-34
7 double value = 12.34e34;        // 12.34 * 10^34
8
9 double value = 123'456.789'101; // digit separators, C++14
10 double value = 0x4d2.4p3;       // hexfloat, 0x4d2.4 * 2^3
11                           // = 1234.25 * 2^3 = 9874
12
13 3.14f, 3.14F, // float
14 3.14, 3.14, // double
15 3.14l, 3.14L, // long double
```

# Sizeof



```
1 #include <cstddef>
2
3 int value = 42;
4
5 std::size_t size_1 = sizeof(value); // 4
6 std::size_t size_2 = sizeof(int);   // 4
7 std::size_t size_3 = sizeof(42);    // 4
```

# Pointer to integer



```
1 #include <cstdint>
2
3 int value1 = 42;
4 int value2 = 84;
5
6 // can hold any diff between two pointers
7 std::ptrdiff_t ptrdiff = &value2 - &value1;
8
9 // can hold any pointer value
10 std::intptr_t intptr = reinterpret_cast<intptr_t>(&value1);
11 std::uintptr_t uintptr = reinterpret_cast<uintptr_t>(&value2);
```

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# Static arrays



```
1 int ints1[4] = {1, 2, 3, 4};  
2 int ints2[] = {1, 2, 3, 4}; // identical  
3  
4 char chars1[3] = {'a', 'b', 'c'};    // char array  
5 char chars2[4] = "abc";           // valid native string  
6 char chars3[4] = {'a', 'b', 'c', 0}; // same valid native string  
7  
8 int i1 = ints1[2]; // i1 = 3  
9 char c = chars1[8]; // at best garbage, may segfault  
10 int i2 = ints1[4]; // also garbage !
```

# Pointers



```
1 int i = 4;
2 int* pi = &i;
3 int j= *pi + 1;
4
5 int ai[] = {1, 2, 3};
6 int* pai = ai; // decay to pointer
7 int* paj = paj + 1;
8 int k = *paj + 1;
9
10 // compile error
11 int* pak = k;
12
13 // segmentation fault !
14 int* pak = (int*)k;
15 int l = *pak;
```



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## Memory layout

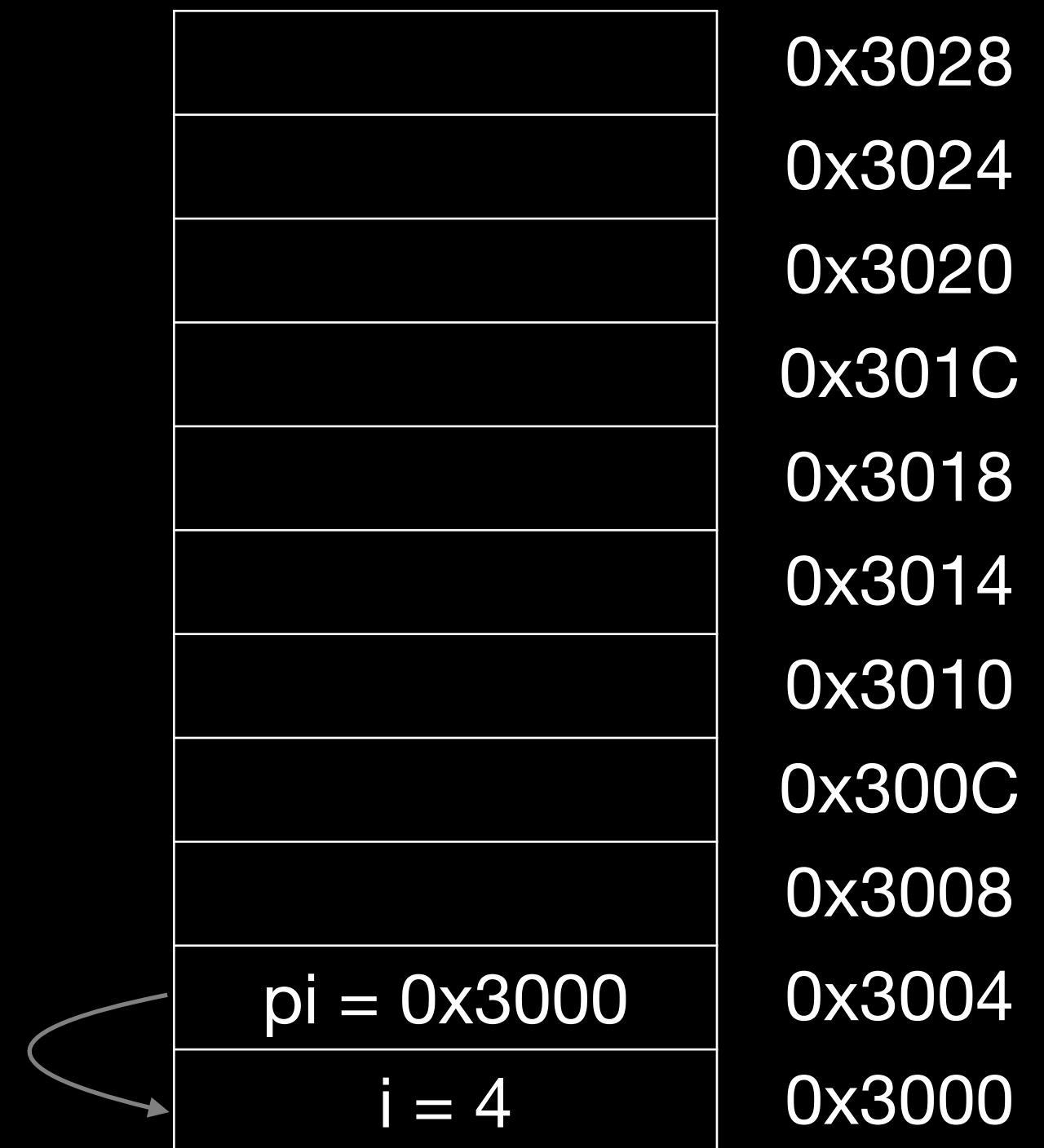
	0x3028
	0x3024
	0x3020
	0x301C
	0x3018
	0x3014
	0x3010
	0x300C
	0x3008
	0x3004
i = 4	0x3000

# Pointers



```
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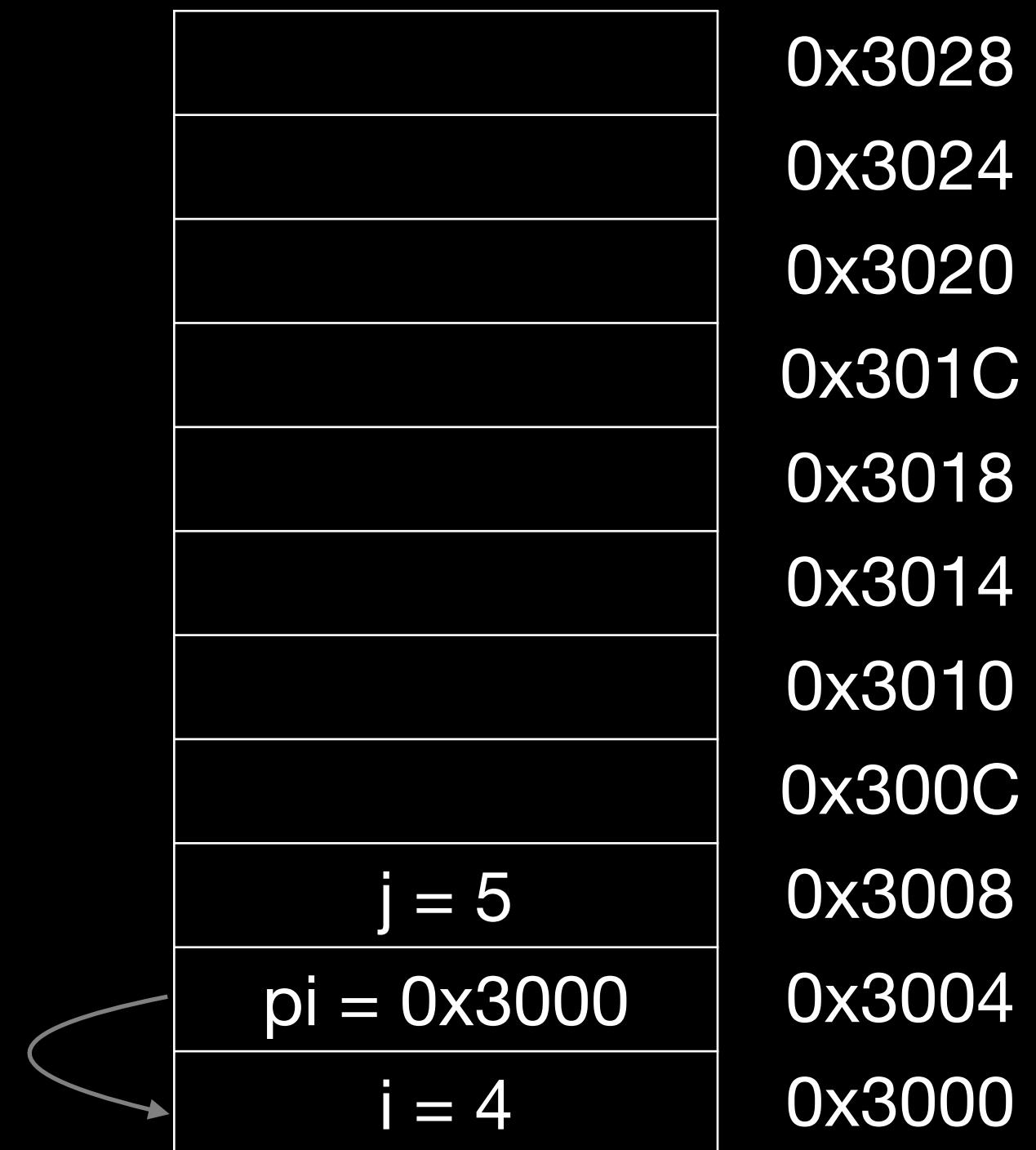


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```
1 int i = 4;
2 int* pi = &i;
3 int j= *pi + 1;
4
5 int ai[] = {1, 2, 3};
6 int* pai = ai; // decay to pointer
7 int* paj = paj + 1;
8 int k = *paj + 1;
9
10 // compile error
11 int* pak = k;
12
13 // segmentation fault !
14 int* pak = (int*)k;
15 int l = *pak;
```

## Memory layout



# Pointers



```
1 int i = 4;
2 int* pi = &i;
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5 int ai[] = {1, 2, 3};
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```

## Memory layout

	0x3028
	0x3024
	0x3020
	0x301C
	0x3018
ai[2] = 3	0x3014
ai[1] = 2	0x3010
ai[0] = 1	0x300C
j = 5	0x3008
pi = 0x3000	0x3004
i = 4	0x3000

# Pointers



```
1 int i = 4;
2 int* pi = &i;
3 int j= *pi + 1;
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5 int ai[] = {1, 2, 3};
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## Memory layout

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ai[2] = 3	0x3014
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## Memory layout

	0x3028
	0x3024
	0x3020
paj = 0x3010	0x301C
pai = 0x300C	0x3018
ai[2] = 3	0x3014
ai[1] = 2	0x3010
ai[0] = 1	0x300C
j = 5	0x3008
pi = 0x3000	0x3004
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# Pointers



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13 // segmentation fault !
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15 int l = *pak;
```

## Memory layout

	0x3028
	0x3024
k = 3	0x3020
paj = 0x3010	0x301C
pai = 0x300C	0x3018
ai[2] = 3	0x3014
ai[1] = 2	0x3010
ai[0] = 1	0x300C
j = 5	0x3008
pi = 0x3000	0x3004
i = 4	0x3000

# Pointers



```
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12
13 // segmentation fault !
14 int* pak = (int*)k;
15 int l = *pak;
```

## Memory layout

??	0x3028
pak = 3	0x3024
k = 3	0x3020
paj = 0x3010	0x301C
pai = 0x300C	0x3018
ai[2] = 3	0x3014
ai[1] = 2	0x3010
ai[0] = 1	0x300C
j = 5	0x3008
pi = 0x3000	0x3004
i = 4	0x3000

# nullptr

- if a pointer doesn't point to anything, set it to `nullptr`
  - useful to e.g. mark the end of a linked data structure
  - or absence of an optional function argument (pointer)
- same as setting it to 0 or `NULL` (before C++ 11)
- triggers compilation error when assigned to integer



# nullptr

- if a pointer doesn't point to anything, set it to `nullptr`
  - useful to e.g. mark the end of a linked data structure
  - or absence of an optional function argument (pointer)
- same as setting it to 0 or `NULL` (before C++ 11)
- triggers compilation error when assigned to integer

```
1 int* ip = nullptr;
2 int i1 = NULL;    // compiles but bug
3 int i2 = nullptr; // ERROR
```



# Dynamic arrays using C



```
1 #include <cstdlib>
2 #include <cstring>
3
4 int* bad; // pointer to random address
5 int* ai = nullptr; // better, deterministic, testable
6
7 // allocate array of 10 ints (uninitialized)
8 ai = (int*)std::malloc(10 * sizeof(int));
9 std::memset(ai, 0, 10 * sizeof(int)); // and set them to 0
10
11 ai = (int*) std::calloc(10, sizeof(int)); // both in one go
12
13 std::free(ai); // release memory
```

# Dynamic arrays using C++



```
1 // allocate array of ints
2 int* ai1 = new int[10];           // 10 ints, uninitialized
3 int* ai2 = new int[10] {};        // 10 ints, zero-initialized, since C++11
4 int* ai3 = new int[] {42, 21, 84}; // 3 ints, initialized, since C++11
5
6 // release arrays memory
7 delete[] ai1;
8 delete[] ai2;
9 delete[] ai3;
10
11 // allocate a single int
12 int* pi1 = new int;
13 int* pi2 = new int();           // zero-initialized
14 int* pi3 = new int {};         // zero-initialized, since C++11
15 int* pi4 = new int(42);        // initialized
16 int* pi5 = new int {42};       // initialized, since C++11
17
18 // release scalar memory
19 delete pi1;
20 delete pi2;
21 delete pi3;
22 delete pi4;
23 delete pi5;
```



# Language Basics

- Hello World
- Core syntax and types
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- Scopes / namespaces
- Struct and enum types
- References
- Functions
- Operators
- Control structures
- Headers and interfaces
- auto keyword
- inline keyword
- Assertions



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# Scope

Portion of the source code where a given name is valid

Typically :

- simple block of code, within {}
- function, class, namespace
- the global scope, i.e. translation unit (.cpp file + all includes)

```
1 {  
2     int a = 0;  
3     {  
4         int b = 0;  
5     } // end of b scope  
6 } // end of a scope  
7
```

# Scope and lifetime of variables

- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope

# Scope and lifetime of variables

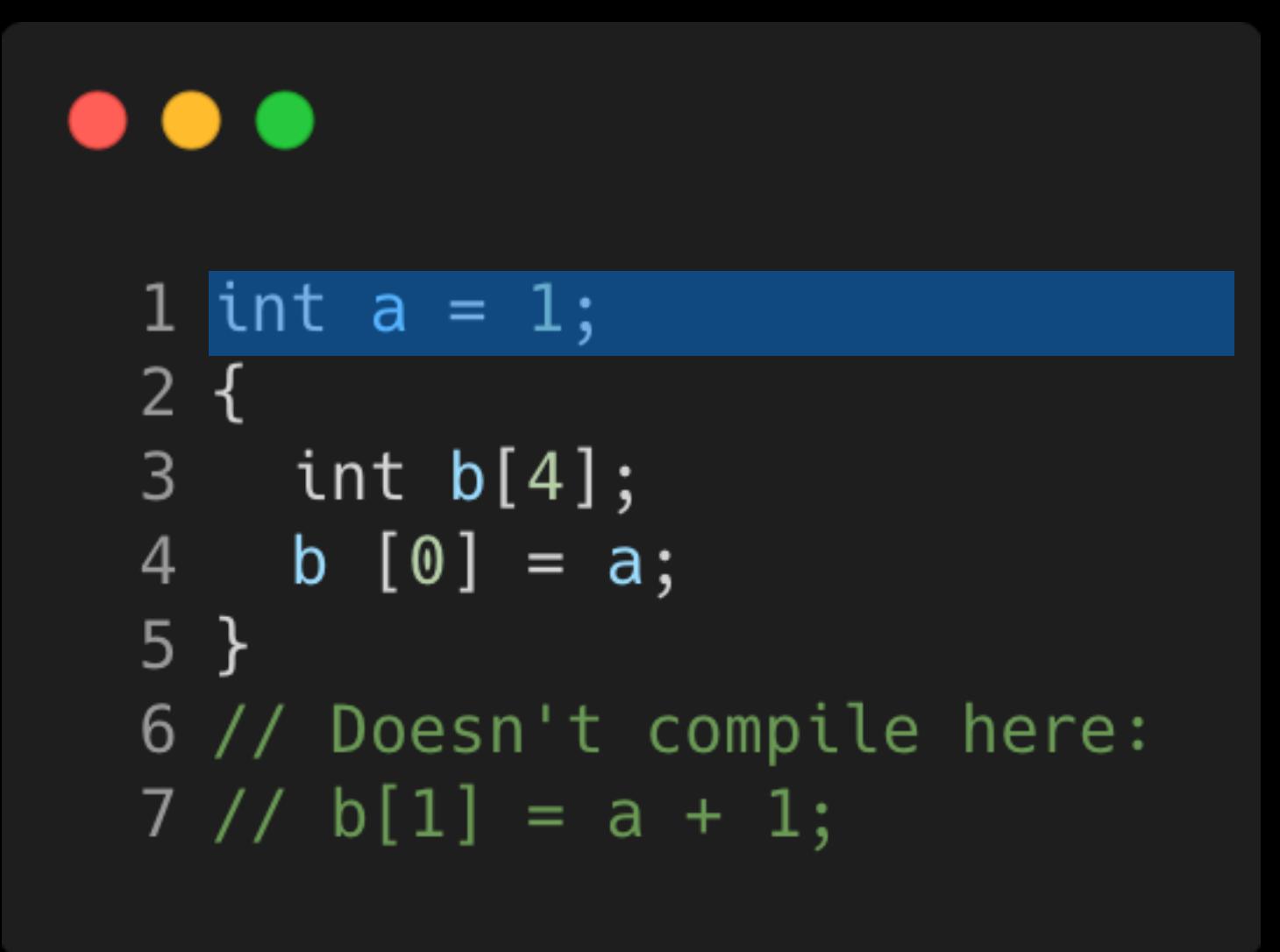
- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope



```
1 int a = 1;
2 {
3     int b[4];
4     b [0] = a;
5 }
6 // Doesn't compile here:
7 // b[1] = a + 1;
```

# Scope and lifetime of variables

- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope



The screenshot shows a debugger interface with three colored dots (red, yellow, green) at the top left. Below them is a code editor window containing the following C++ code:

```
1 int a = 1;
2 {
3     int b[4];
4     b [0] = a;
5 }
6 // Doesn't compile here:
7 // b[1] = a + 1;
```

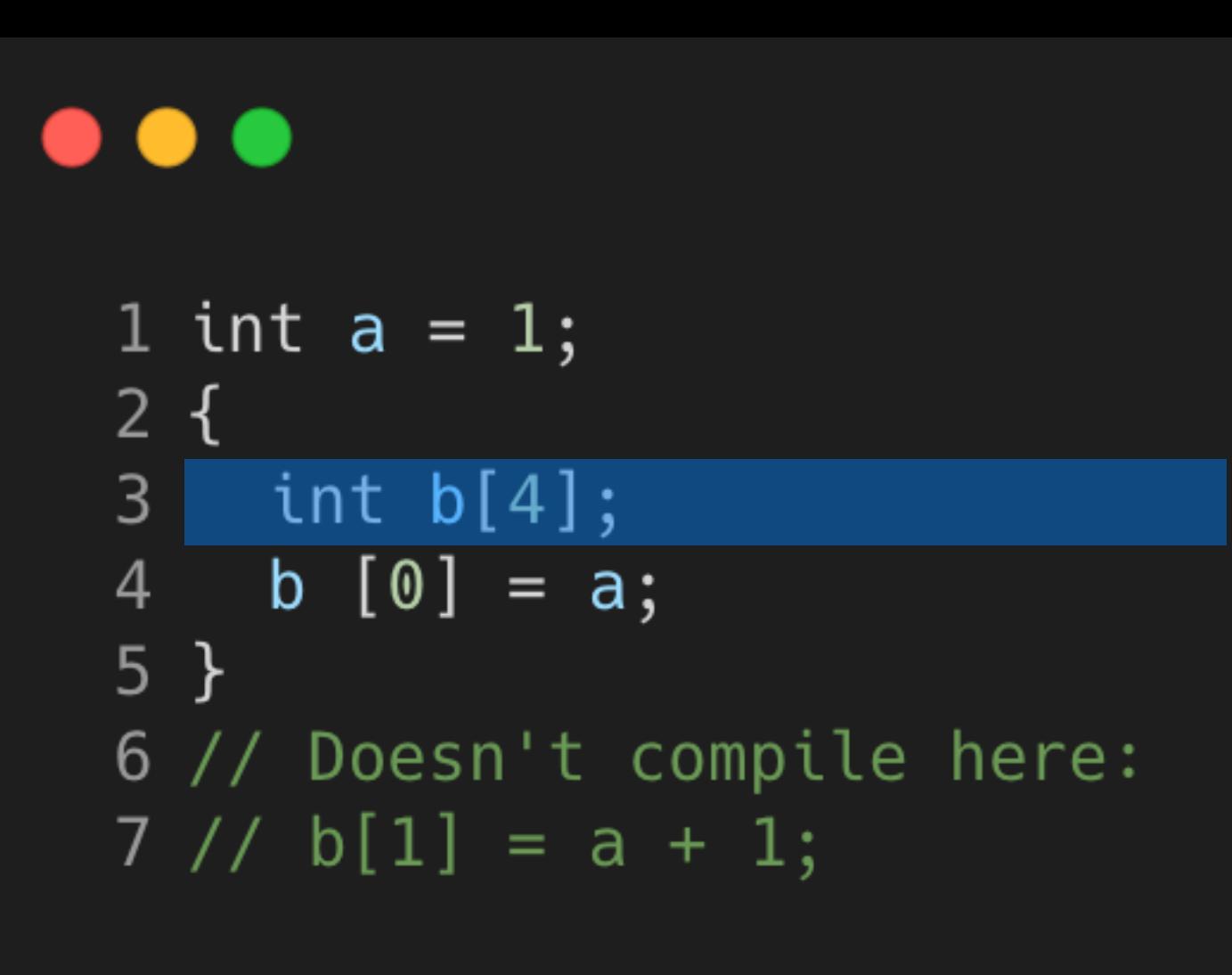
The first line, `int a = 1;`, is highlighted with a blue background.

Memory layout

	0x3010
	0x300C
	0x3008
	0x3004
i = 4	0x3000

# Scope and lifetime of variables

- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope



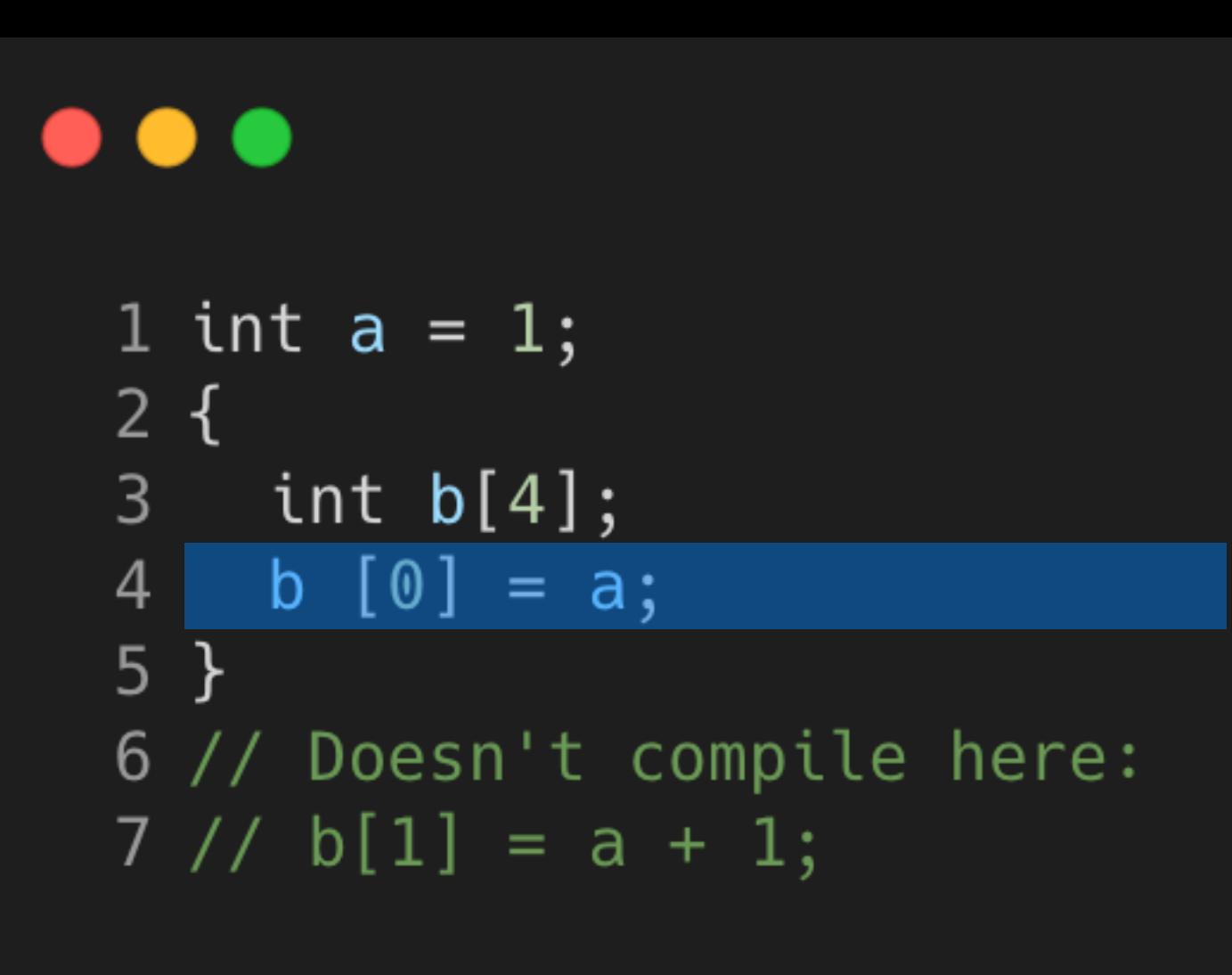
```
1 int a = 1;
2 {
3     int b[4];
4     b[0] = a;
5 }
6 // Doesn't compile here:
7 // b[1] = a + 1;
```

Memory layout

b[3] = ?	0x3010
b[2] = ?	0x300C
b[1] = ?	0x3008
b[0] = ?	0x3004
i = 4	0x3000

# Scope and lifetime of variables

- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope



```
● ● ●  
1 int a = 1;  
2 {  
3     int b[4];  
4     b [0] = a; ██████████  
5 }  
6 // Doesn't compile here:  
7 // b[1] = a + 1;
```

Memory layout

b[3] = ?	0x3010
b[2] = ?	0x300C
b[1] = ?	0x3008
b[0] = 1	0x3004
i = 4	0x3000

# Scope and lifetime of variables

- Variables are (statically) allocated when defined
- Variables are freed at the end of a scope



```
1 int a = 1;
2 {
3     int b[4];
4     b [0] = a;
5 }
6 // Doesn't compile here:
7 // b[1] = a + 1;
```

Memory layout

?	0x3010
?	0x300C
?	0x3008
1	0x3004
i = 4	0x3000

# Namepaces

- Namespaces allow to segment your code to avoid name clashes
- They can be embedded to create hierarchies (separator is `::`)

```
1 int value = 0;
2 namespace n {
3     int value = 0;
4     namespace p {
5         int value = 0;
6         namespace inner {
7             int value = 0;
8         }
9     }
10 }
11
12 void f() {
13     ::value = 42;
14     n::value = 84;
15     n::p::inner:: value = 21;
16 }
```

# Nested namespaces

- Easier way to declare nested namespaces

C++98

```
1 namespace a {  
2     namespace b {  
3         namespace c {  
4             // ...  
5         }  
6     }  
7 }
```

C++17

```
1 namespace a::b::c {  
2     // ...  
3 }
```

# namespace alias

- The **namespace** keyword can be used to create an alias on an other namespace.



```
1 namespace very_long_namespace {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     very_long_namespace::value = 42;  
7 }
```

# namespace alias

- The `namespace` keyword can be used to create an alias on an other namespace.



```
1 namespace very_long_namespace {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     namespace vln = very_long_namespace;  
7     vln::value = 42;  
8 }
```

# namespace alias

- The **namespace** keyword can be used to create an alias on an other namespace.
- Or on nested namespaces.



```
1 namespace a::b::c::d {  
2     int value = 0;  
3 }  
4  
5 void f( ) {  
6     a::b::c::d::value = 42;  
7 }
```

# namespace alias

- The `namespace` keyword can be used to create an alias on an other namespace.
- Or on nested namespaces.



```
1 namespace a::b::c::d {  
2     int value = 0;  
3 }  
4  
5 void f( ) {  
6     namespace l = a::b::c::d;  
7     l::value = 42;  
8 }
```

# Using namespace directive

- The **using namespace** directive make all members of the specified namespace visible in current scope.



```
1 namespace a {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     a::value = 42;  
7 }
```

# Using namespace directive

- The `using namespace` directive make all members of the specified namespace visible in current scope.



```
1 namespace a {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     using namespace a;  
7     value = 42;  
8 }
```

# Using namespace directive

- The **using namespace** directive make all members of the specified namespace visible in current scope.
- The same for nested namespaces.



```
1 namespace a::b::c {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     using namespace a::b::c;  
7     value = 42;  
8 }
```

# Using namespace directive

- The **using namespace** directive make all members of the specified namespace visible in current scope.
- The same for nested namespaces.
- As well as for any part of the nested namespaces.



```
1 namespace a::b::c {  
2     int value = 0;  
3 }  
4  
5 void f() {  
6     using namespace a::b;  
7     c::value = 42;  
8 }
```

# Anonymous namespace

- groups a number of declarations
- visible only in the current translation unit
- but not reusable outside
- allows much better compiler optimizations and checking
  - e.g. unused function warning
  - context dependent optimizations



```
1 namespace {  
2     int local_variable = 0;  
3 }
```

equivalent



```
1 static int local_variable = 0;
```

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# Struct

“members” grouped together under one name

```
● ● ●  
1 struct individual {  
2     unsigned char age;  
3     float weight;  
4 };  
5  
6 individual student;  
7 student.age = 25;  
8 student.weight = 78.5f;  
9  
10 individual teacher = {45, 67.0f};  
11  
12 individual director = {.weight = 80.8f, .age = 60};  
13  
14 individual* ptr = &student;  
15 ptr->age = 24; // same as: (*ptr).age = 24;
```



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## Memory layout


0x3018  
0x3014  
0x3010  
0x300C  
0x3008  
0x3004  
0x3000

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## Memory layout

				0x3018
				0x3014
				0x3010
				0x300C
				0x3008
				0x3004
				0x3000
?	?	?	?	
?	?	?	?	

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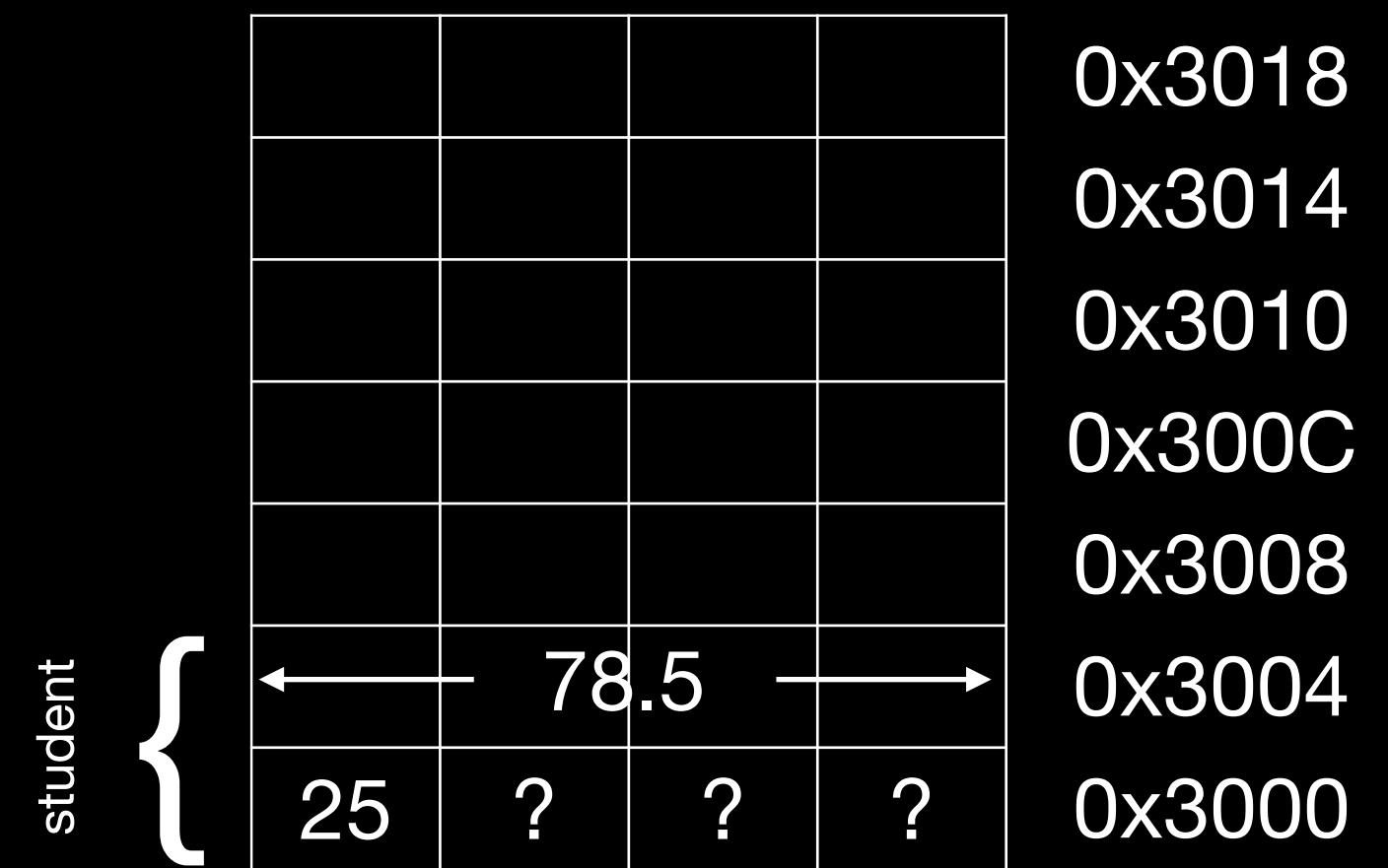
				0x3018
				0x3014
				0x3010
				0x300C
				0x3008
				0x3004
				0x3000
student	{	?	?	?
		25	?	?
			?	?

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“members” grouped together under one name

```
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4 };  
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## Memory layout



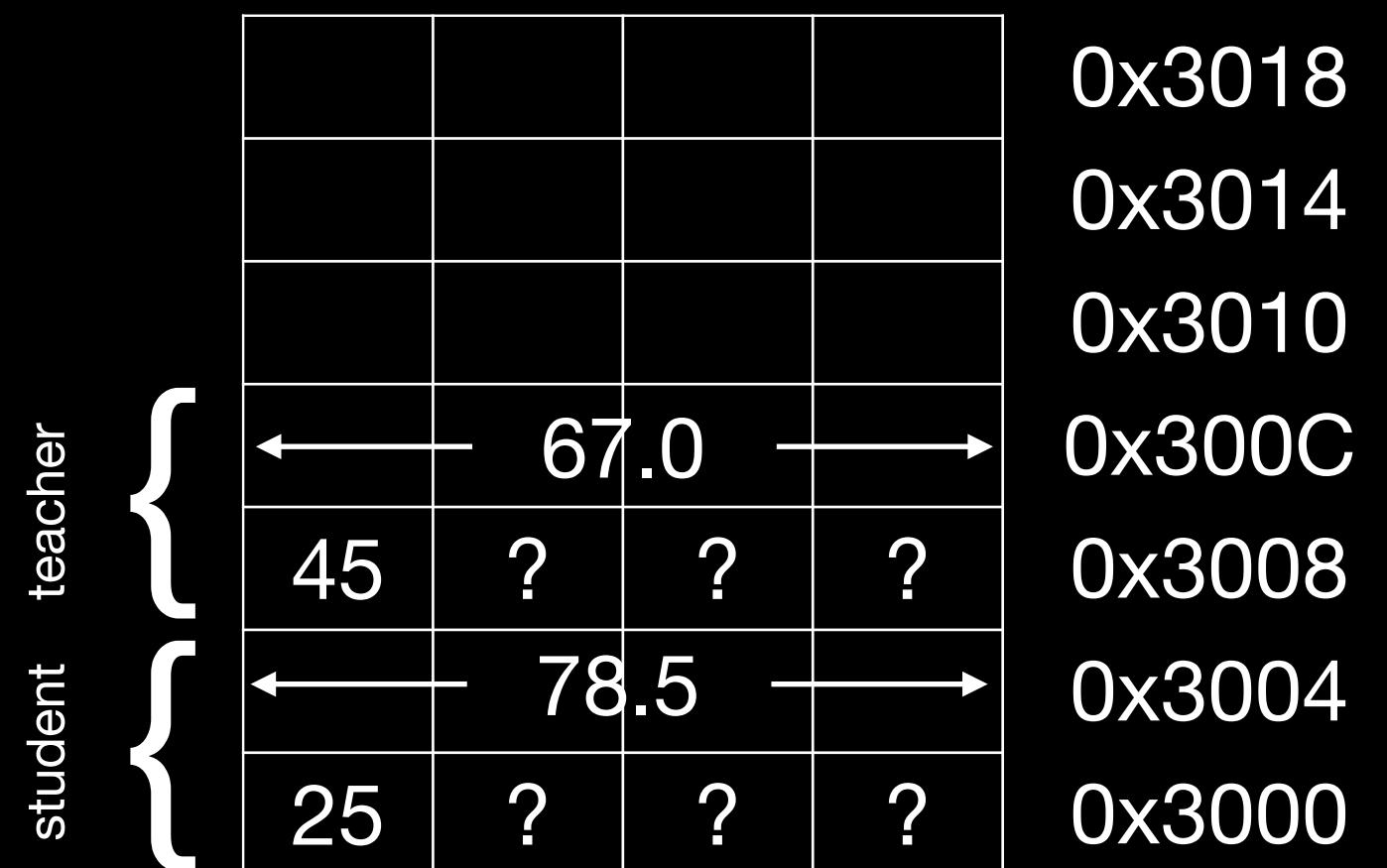
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## Memory layout



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```

## Memory layout

director	{	80.8	→	0x3018
	60	?	?	0x3014
teacher	{	67.0	→	0x3010
	45	?	?	0x300C
student	{	78.5	→	0x3008
	25	?	?	0x3004
				0x3000

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```
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13  
14 individual* ptr = &student;  
15 ptr->age = 24; // same as: (*ptr).age = 24;
```

## Memory layout

director	{	0x3000	0x3018
teacher	{	80.8	0x3014
student	{	60	0x3010
		?	?
		?	?
		67.0	0x300C
		45	0x3008
		?	?
		?	?
		78.5	0x3004
		25	0x3000
		?	?
		?	?

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“members” grouped together under one name



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1 struct individual {  
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4 };  
5  
6 individual student;  
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13  
14 individual* ptr = &student;  
15 ptr->age = 24; // same as: (*ptr).age = 24;
```

## Memory layout

student	{	0x3000	24	?	?	?	?
teacher	{	0x3008	45	?	?	?	?
director	{	0x300C	67.0	?	?	?	?
		0x3010	60	?	?	?	?
		0x3014	80.8	?	?	?	?
		0x3018	0x3000	?	?	?	?

# Union

“members” packed together at same memory location

```
1 union duration {  
2     int seconds;  
3     short hours;  
4     char days;  
5 };  
6  
7 duration d1, d2, d3;  
8 d1.seconds = 259200;  
9 d2.hours = 72;  
10 d3.days = 3;  
11 d1. days = 3; // d1.seconds overwritten  
12 int a = d1.seconds; // d1.seconds is garbage
```

# Union

“members” packed together at same memory location



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1 union duration {  
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```

## Memory layout

				0x300C
				0x3008
				0x3004
				0x3000

# Union

“members” packed together at same memory location



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11 d1. days = 3; // d1.seconds overwritten  
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```

## Memory layout

				0x300C
?	?	?	?	0x3008
?	?	?	?	0x3004
?	?	?	?	0x3000

# Union

“members” packed together at same memory location



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12 int a = d1.seconds; // d1.seconds is garbage
```

## Memory layout

?	?	?	?	0x300C
?	?	?	?	0x3008
?	?	?	?	0x3004
←	259200	→		0x3000

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“members” packed together at same memory location



```
1 union duration {  
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```

## Memory layout

				0x300C
?	?	?	?	0x3008
← 72 →		?	?	0x3004
← 259200 →				0x3000

# Union

“members” packed together at same memory location



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12 int a = d1.seconds; // d1.seconds is garbage
```

## Memory layout

				0x300C
3	?	?	?	0x3008
← 72 →	?	?	?	0x3004
← 259200 →				0x3000

# Union

“members” packed together at same memory location



```
1 union duration {  
2     int seconds;  
3     short hours;  
4     char days;  
5 };  
6  
7 duration d1, d2, d3;  
8 d1.seconds = 259200;  
9 d2.hours = 72;  
10 d3.days = 3;  
11 d1. days = 3; // d1.seconds overwritten  
12 int a = d1.seconds; // d1.seconds is garbage
```

## Memory layout

				0x300C
3	?	?	?	0x3008
← 72 →	?	?	?	0x3004
3	?	?	?	0x3000

# Union

“members” packed together at same memory location



```
1 union duration {  
2     int seconds;  
3     short hours;  
4     char days;  
5 };  
6  
7 duration d1, d2, d3;  
8 d1.seconds = 259200;  
9 d2.hours = 72;  
10 d3.days = 3;  
11 d1. days = 3; // d1.seconds overwritten  
12 int a = d1.seconds; // d1.seconds is garbage
```

## Memory layout

?	?	?	?	0x300C
3	?	?	?	0x3008
← 72 →		?	?	0x3004
3	?	?	?	0x3000

# Enum

- use to declare a list of related constants (enumerators)
- has an underlying integral type
- enumerator names leak into enclosing scope



```
1 enum vehicle_type {  
2     BIKE, // 0  
3     CAR, // 1  
4     BUS, // 2  
5 };  
6  
7 vehicle_type t = CAR;
```



```
1 enum vehicle_type : int { // Since C++11  
2     BIKE = 3,  
3     CAR = 5,  
4     BUS = 7,  
5 };  
6  
7 vehicle_type t = BUS;
```

# Enum class

- scopes enumerator names, avoids name clashes
- strong typing, no automatic conversion to int



```
1 enum class vehicle_type {  
2     bike, // 0  
3     car, // 1  
4     bus, // 2  
5 };  
6  
7 vehicle_type t = vehicle_type::car;
```



```
1 enum class vehicle_type : int {  
2     bike = 3,  
3     car = 5,  
4     bus = 7,  
5 };  
6  
7 vehicle_type t = vehicle_type::bus;
```

# More concrete example



```
1 enum class shape_type {circle, rectangle};
2 struct rectangle {
3     float width;
4     float height;
5 };
6
7 struct shape {
8     shape_type type;
9     union {
10         float radius;
11         rectangle rect;
12     } ;
13 };
14
15 shape circle1 {.type = shape_type::circle, .radius = 3.45};
16 shape rectangle1 {.type = shape_type::rectangle, .rect = 13, 4};
```

# typedef and using

C++98



```
1 typedef std::uint64_t myint;  
2 myint count = 17;  
3 typedef float position[3];
```

C++11



```
1 using myint = std::uint64_t;  
2 myint count = 17;  
3 using position = float[3];  
4  
5 template<typename type_t>  
6 using myvec = std::vector<type_t>;  
7 myvec<int> myintvec;
```

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- Control structures
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- auto keyword
- inline keyword
- Assertions



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# References

- References allow for direct access to another object
- They can be used as shortcuts / better readability
- They can be declared `const` to allow only read access



```
1 int i = 2;
2 int& iref = i; // access to i
3 iref = 3;      // i is now 3
4
5 // const reference to a member:
6 struct a_struct {int x; int y;} a;
7 const int& x = a.x; // direct read access to a_struct's x
8 x = 4;           // doesn't compile
9 a. x = 4;        // fine
```

# References vs pointers

- Natural syntax
- Cannot be null
- Must be assigned when defined, cannot be reassigned
- Prefer using references instead of pointers
- Mark references **const** to prevent modification

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# Function without param and no return



```
1 #include <iostream>
2
3 // function without param and no return
4 void hello() {
5     std::cout << "Hello, World!" << std::endl;
6 }
7
8 int main() {
9     hello();
10 }
```

# Function without param and return



```
1 #include <iostream>
2
3 // function without param and return
4 float get_pi() {
5     return 3.14159;
6 }
7
8 int main() {
9     float pi = get_pi();
10    std::cout << "pi = " << pi << std::endl;
11 }
```

# Function with param and no return



```
1 #include <iostream>
2 #include <string>
3
4 // function with param and no return
5 void println(const std::string& msg) {
6     std::cout << msg << std::endl;
7 }
8
9 int main() {
10    println("Hello, World!");
11 }
```

# Function with param and return



```
1 #include <iostream>
2
3 // function with param and return
4 int square(int value) {
5     return value * value;
6 }
7
8 int main() {
9     int result = square(3);
10    std::cout << "3^2 = " << result << std::endl;
11 }
```

# Function with params and return



```
1 #include <iostream>
2
3 // function with params and return
4 int multiply(int a, int b) {
5     return a * b;
6 }
7
8 int main() {
9     int result = multiply(3, 4);
10    std::cout << "3 * 4 = " << result << std::endl;
11 }
```

# Function with default argument



```
1 #include <iostream>
2
3 // function with default argument
4 int add(int a, int b = 1) {
5     return a + b;
6 }
7
8 int main() {
9     int result = add(3);
10    std::cout << "result = " << result << std::endl;
11
12    result = add(3, 4);
13    std::cout << "result = " << result << std::endl;
14 }
```

# Function with default arguments



```
1 #include <iostream>
2
3 // function with default arguments
4 int add(int a = 4, int b = 1) {
5     return a + b;
6 }
7
8 int main() {
9     int result = add();
10    std::cout << "result = " << result << std::endl;
11
12    result = add(3);
13    std::cout << "result = " << result << std::endl;
14
15    result = add(3, 4);
16    std::cout << "result = " << result << std::endl;
17 }
```



# Functions and references to returned values

```
1 #include <iostream>
2
3 int square(int value) {
4     return value * value;
5 }
6
7 int main() {
8     int result = square(3);
9     std::cout << "3^2 = " << result << std::endl;
10
11 // Not allowed
12 int& result_ref = square(3); // build error
13 std::cout << "3^2 = " << result_ref << std::endl;
14
15 // Ok
16 const int& result_const_ref = square(3); // Ok
17 std::cout << "3^2 = " << result_const_ref << std::endl;
18 }
```



# Parameters are passed by value



```
struct big_struct {  
    ...  
};  
  
big_struct s;  
  
// parameter by value  
void print_val(big_struct p) {  
    ...  
}  
print_val(s); // copy  
  
// parameter by reference  
void print_ref(big_struct &q) {  
    ...  
}  
print_ref(s); // no copy
```



# Parameters are passed by value



```
1 struct big_struct {  
2     // ...  
3 };  
4 big_struct s;  
5  
6 // parameter by value  
7 void print_val(big_struct p) {  
8     // ...  
9 }  
10 print_val(s); // copy  
11  
12 // parameter by reference  
13 void print_ref(big_struct& q) {  
14     // ...  
15 }  
16 print_ref(s); // no copy
```

Memory layout

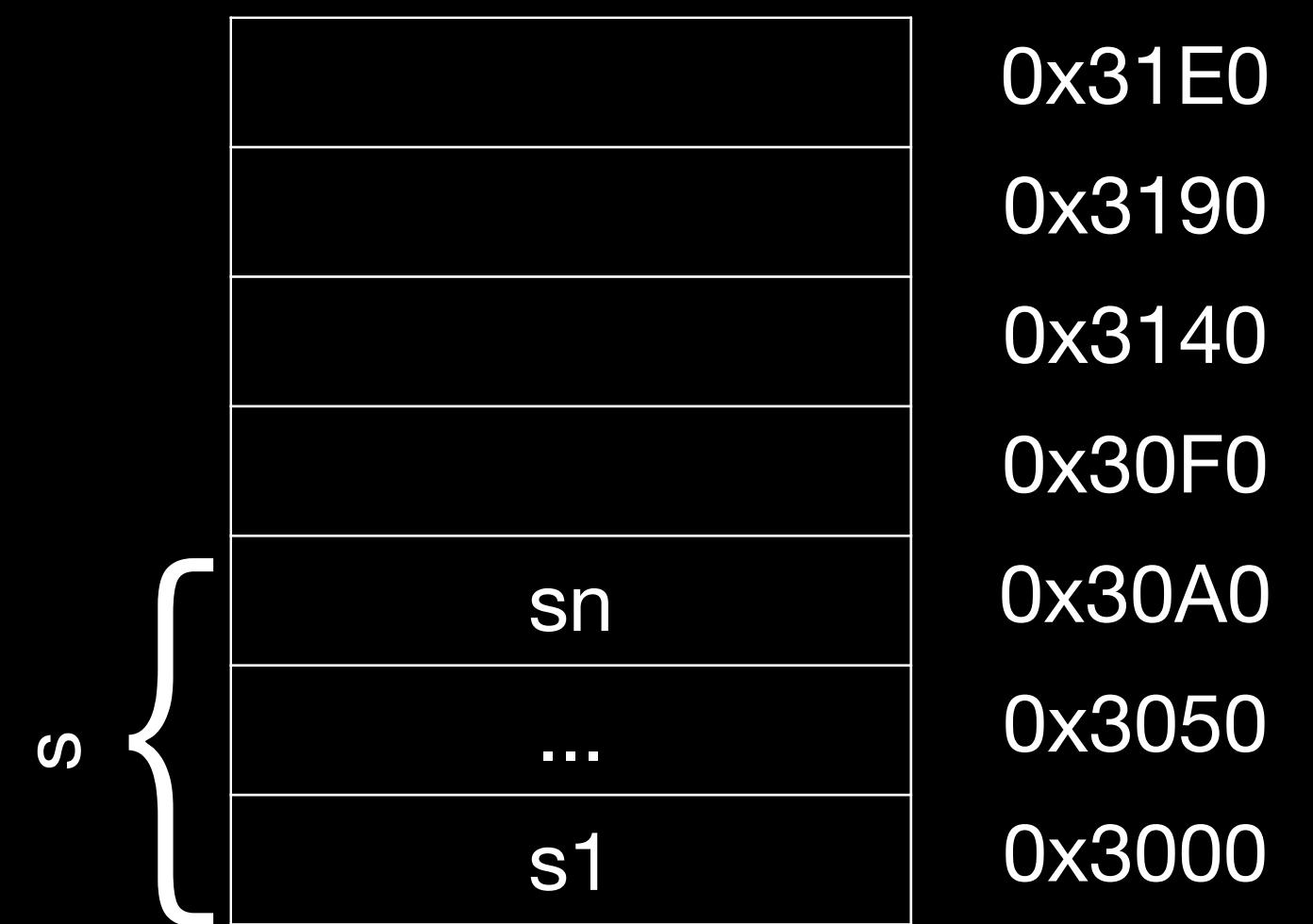
0x31E0
0x3190
0x3140
0x30F0
0x30A0
0x3050
0x3000

# Parameters are passed by value



```
1 struct big_struct {  
2     // ...  
3 };  
4  
5 big_struct s;  
6  
7 // parameter by value  
8 void print_val(big_struct p) {  
9     // ...  
10 }  
11 print_val(s); // copy  
12  
13 // parameter by reference  
14 void print_ref(big_struct& q) {  
15     // ...  
16 }  
17 print_ref(s); // no copy
```

Memory layout



# Parameters are passed by value



```
1 struct big_struct {  
2     // ...  
3 };  
4  
5 big_struct s;  
6  
7 // parameter by value  
8 void print_val(big_struct p) {  
9     // ...  
10 }  
11 print_val(s); // copy  
12  
13 // parameter by reference  
14 void print_ref(big_struct& q) {  
15     // ...  
16 }  
17 print_ref(s); // no copy
```

## Memory layout

$p$	pn	0x31E0
	...	0x3190
	p1	0x3140
	sn	0x30F0
	...	0x30A0
	s1	0x3050
$s$		0x3000

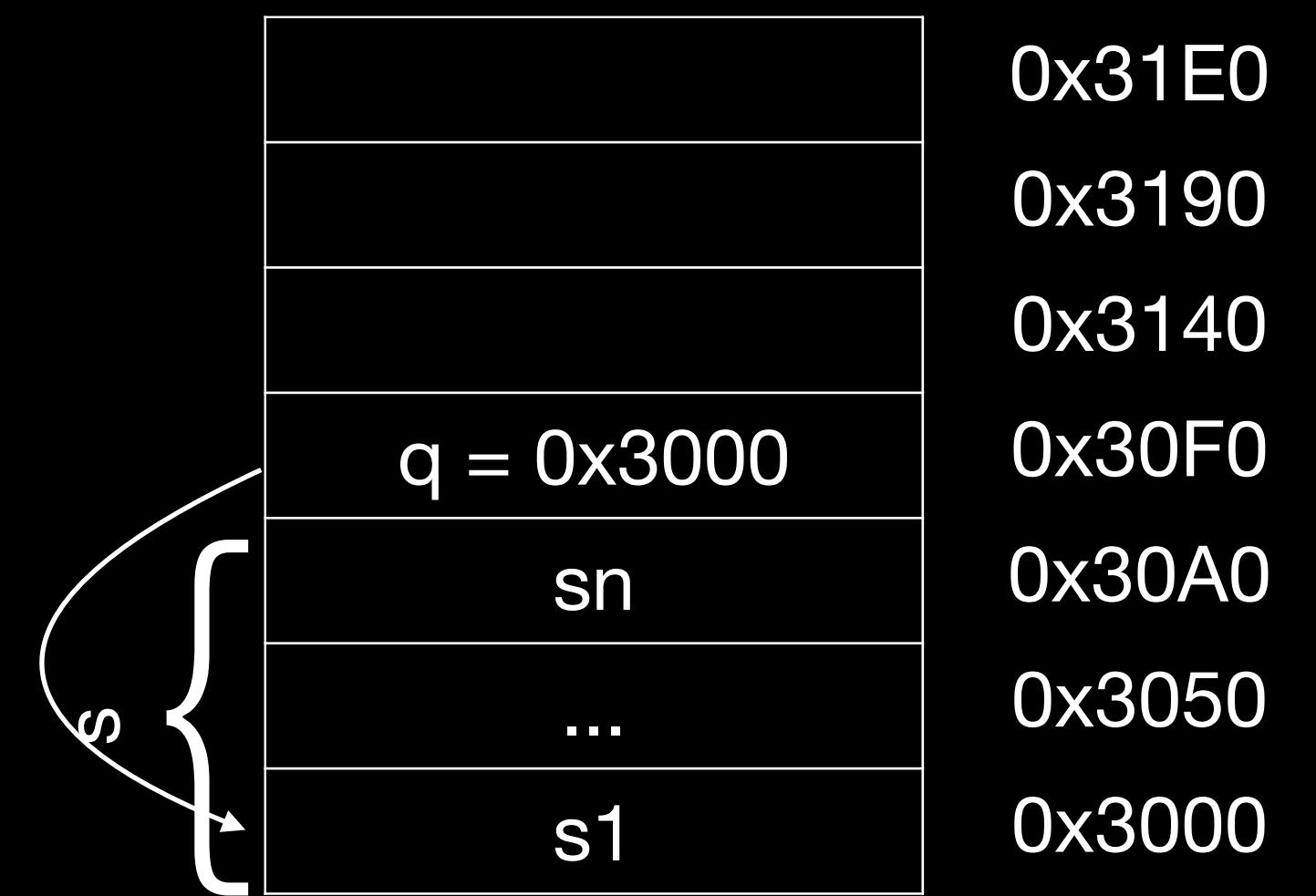


# Parameters are passed by value



```
1 struct big_struct {  
2     // ...  
3 };  
4  
5 big_struct s;  
6  
7 // parameter by value  
8 void print_val(big_struct p) {  
9     // ...  
10 }  
11 print_val(s); // copy  
12  
13 // parameter by reference  
14 void print_ref(big_struct& q) {  
15     // ...  
16 }  
17 print_ref(s); // no copy
```

Memory layout



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5     p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11     g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

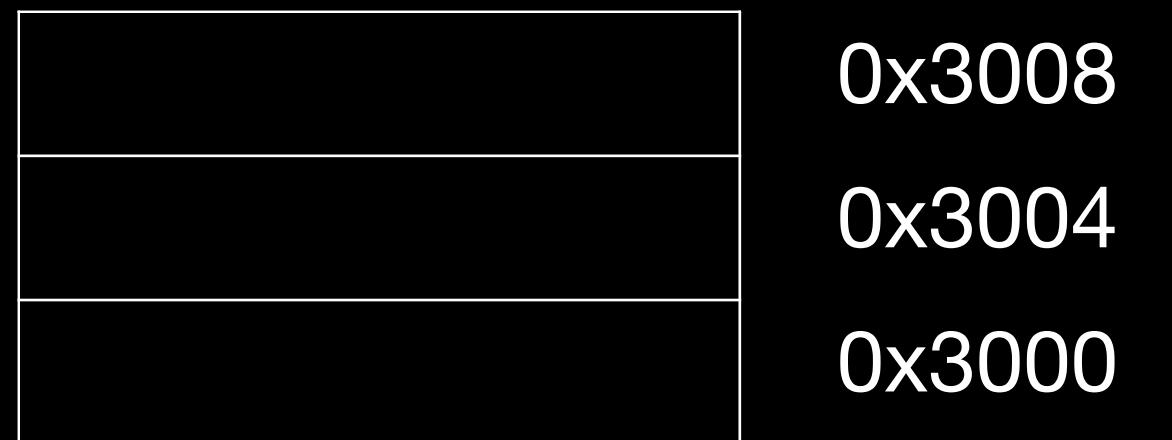


# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
	0x3004
s.a = 1	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5     p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11     g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
p.a = 1	0x3004
s.a = 1	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5     p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11     g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
p.a = 2	0x3004
s.a = 1	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
	0x3004
s.a = 1	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
q = 0x3000	0x3004
s.a = 1	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   q.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
q = 0x3000	0x3004
s.a = 2	0x3000



# Pass by value or reference ?



```
1 struct small_struct {int a;};
2 small_struct s = {1};
3
4 void change_val(small_struct p) {
5   p.a = 2;
6 }
7 change_val(s);
8 // s.a == 1
9
10 void change_ref(small_struct& g) {
11   g.a = 2;
12 }
13 change_ref(s);
14 // s.a == 2
```

## Memory layout

	0x3008
	0x3004
s.a = 2	0x3000



# Different ways to pass arguments to a function

- By default, arguments are passed by value (= copy) => good for small types, e.g. numbers
- Use references for parameters to avoid copies => good for large types, e.g. objects
- Use const for safety and readability whenever possible

```
1 struct foo {  
2     // ...  
3 };  
4 foo bar;  
5  
6 void fct_val(foo value);  
7 fct_val(bar);    // by value  
8  
9 void fct_ref(const foo& value);  
10 fct_ref(bar);   // by reference  
11  
12 void fct_ptr(const foo* value);  
13 fct_ptr(&bar); // by pointer  
14  
15 void fct_write(foo& value);  
16 fct_write(bar); // non-const ref
```

# Overloading

- We can have multiple functions with the same name
  - Must have different parameter lists
  - A different return type alone is not allowed
  - Form a so-called “overload set”
- Default arguments can cause ambiguities



```
1 int sum(int b);           // 1
2 int sum(int b, int c);    // 2, ok, overload
3 // float sum(int b, int c); // disallowed
4
5 sum(42);     // calls 1
6 sum(42, 43); // calls 2
7
8 int sum(int b, int c, int d = 4); // 3, overload
9
10 sum(42, 43, 44); // calls 3
11 sum(42, 43);   // error: ambiguous, 2 or 3
```

# Exercise : functions

Familiarise yourself with pass by value / pass by reference.

- Go to exercises/functions
- Look at functions.cpp
- Compile it (make) and run the program (./functions)
- Work on the tasks that you find in functions.cpp



# Good practices

- Write readable functions
- Keep functions short
- Do one logical thing (single-responsibility principle)
- Use expressive names
- Document non-trivial functions



```
1 /// @brief Counts number of dilepton events in data.  
2 /// @param a Dataset to search.  
3 /// @return The number of dilepton events.  
4 unsigned int count_dileptons(data& d) {  
5     select_events_with_muons(d);  
6     select_events_with_electrons(d);  
7     return d.size();  
8 }
```

# Good practices

Don't! Everything in one long function



```
1 unsigned int run_job() {
2     // Step 1: data
3     data d;
4     d.resize(123456);
5     d.fill(...);
6
7     // Step 2: muons
8     for (...) {
9         if (...) {
10             d.erase(...);
11         }
12     }
13
14     // Step 3: electrons
15     for (...) {
16         if (...) {
17             d.erase(...);
18         }
19     }
20
21     // Step 4: dileptons
22     int counter = 0;
23     for (...) {
24         if (...) {
25             counter++;
26         }
27     }
28
29     return counter;
30 }
```

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# Binary and Assignment Operators



```
1 int i = 1 + 4 - 2; // 3
2 i *= 3;           // short for: i = i * 3;
3 i /= 2;           // 4
4 i = 23 % i;       // modulo => 3
```

# Increment / Decrement Operators



```
1 int i = 0; i++; // i = 1
2 int j = ++i;    // i = 2, j = 2
3 int k = i++;    // i = 3, K = 2
4 int l = --i;    // i = 2, l = 2
5 int m = i--;    // i = 1, m = 2
```

# Bitwise and Assignment Operators



```
1 unsigned i = 0xee & 0x55; // 0x44
2 i |= 0xee;                // 0xee
3 i ^= 0x55;                // 0xbb
4 unsigned j = ~0xee;        // 0xffffffff11
5 unsigned k = 0x1f << 3;    // 0xf8
6 unsigned l = 0x1f >> 2;    // 0x7
```

# Logical Operators



```
1 bool a = true;
2 bool b = false;
3 bool c = a && b; // false
4 bool d = a || b; // true
5 bool e = !d;     // false
```

# Comparison Operators



```
1 bool a = (3 == 3); // true
2 bool b = (3 != 3); // false
3 bool c = (4 < 4); // false
4 bool d = (4 <= 4); // true
5 bool e = (4 > 4); // false
6 bool f = (4 >= 4); // true
7 auto g = (5 <=> 5); // std::strong_ordering::equivalent, Since C++20
```

# Operator Precedences

Avoid writing a line of operators as in  
the example on the right

- It's better to decompose the expression
- and to use parentheses



```
1 c &= 1+(++b)|(a--)*4%5^7; // ???
```

Details can be found on [cppreference](#)

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# if - syntax

- The else and else if clauses are optional
- The else if clause can be repeated
- Braces are optional if there is a single statement



```
1 if (condition1) {  
2     statement1; statement2;  
3 } else if (condition2)  
4     only_one_statement;  
5 else {  
6     statement3;  
7     statement4;  
8 }
```

# if - example



```
1 int collatz(int a) {
2     if (a <= 0) {
3         std::cout << "not supported\n";
4         return 0;
5     } else if (a == 1) {
6         return 1;
7     } else if (a % 2 == 0) {
8         return collatz(a / 2);
9     } else {
10        return collatz (3 * a + 1);
11    }
12 }
```

# Conditional operator - syntax

- If **test** is true **expression1** is returned
- Else, **expression2** is returned



```
1 test ? expression1 : expression2;
```

# Conditional operator - example



```
1 const int charge = is_lepton ? -1 : 0;
```

# Conditional operator - best practice

Avoid writing a line of conditional operators as in the example on the right

- Explicit `ifs` are generally easier to read
- Use the ternary operator with short conditions and expressions
- Avoid nesting

```
 1 int collatz(int a) {  
 2     return a == 1 ? 1 : collatz(a % 2 == 0 ? a / 2 : 3 * a + 1);  
 3 }
```

# switch - syntax

- The **break** statement is not mandatory but...
- Cases are entry points, not independent pieces
- Execution “falls through” to the next case without a **break**!
- The **default** case may be omitted
- Avoid **switch** statements with fall-through cases



```
1 switch (identifier) {  
2     case c1: statements1; break;  
3     case c2: statements2; break;  
4     case c3: statements3; break;  
5     ...  
6     default: statements3; break;  
7 }
```

# switch - example



```
1 enum class lang {french, german, english, other};  
2 lang language = ...;  
3 switch (language) {  
4     case lang::french:  
5         std::cout << "Bonjour";  
6         break;  
7     case lang::german:  
8         std::cout << "Guten Tag";  
9         break;  
10    case lang::english:  
11        std::cout << "Good morning";  
12        break;  
13    default:  
14        std::cout << "I do not speak your language";  
15 }
```

# [[fallthrough]] attribute

- New compiler warning
- Since C++ 17, compilers are encouraged to warn on fall-through

```
1 switch (c) {  
2     case 'a':  
3         f();    // Warning emitted  
4     case 'b': // Warning probably suppressed  
5     case 'c':  
6         g();  
7         [[fallthrough]]; // Warning suppressed  
8     case 'd':  
9         h();  
10 }
```

# Init-statements for if and switch

## Purpose

- Allows to limit variable scope in if and switch statements



```
1 if (value val = get_value(); condition(val)) {  
2   f(val); // ok  
3 } else  
4   g(val); // ok  
5 h(val); // error, no 'val' in scope here
```

# Init-statements for if and switch

Don't confuse with a variable declaration as condition!



```
1 if (value* val = get_value_ptr( ))  
2   f(*val);
```

# for loop - syntax

- Multiple initializations / increments are comma separated
- Initializations can contain declarations
- Braces are optional if loop body is a single statement



```
1 for (initializations; condition; increments) {  
2     statements;  
3 }
```

# for loop - example



```
1 for (int i = 0, j = 0; i < 10; i++, j = i * i)
2     std::cout << i << "^2 is " << j << std::endl;
```

# Range-based loop - syntax

- Simplifies loops over “ranges” tremendously
- Especially with std containers and ranges



```
1 for (type iteration_vairiable : range) {  
2     // body using iteration_riable  
3 }
```

# Range-based loop - example



```
1 int v[ ] = {1, 2, 3, 4};  
2 int sum = 0;  
3 for (int a : v)  
4     sum += a;
```

# Init-statements for range-based loop

## Purpose

- Allows to limit variable scope in range-based loops



```
1 std::array data = {"hello", "", "world"};
2 for (std::size_t i = 0; auto& d : data)
3     std::cout << i++ << ' ' << d << '\n';
```

# while loop - syntax

- Braces are optional if loop body is a single statement



```
1 while (condition) {  
2     statements;  
3 }  
4  
5 do {  
6     statements;  
7 } while (condition);
```

# while loop - example



```
1 int j = 2;
2 while (j < 9) {
3     std::cout << j << ' ';
4     j += 2;
5 }
6 std::cout << '\n';
```



```
1 int j = 2;
2 do {
3     std::cout << j << ' ';
4     j += 2;
5 } while (j < 9);
6 std::cout << '\n';
```

# Jump statements



# Jump statements

- **break** Exits the loop and continues after it



```
1 data_stream ds = get_data_stream();
2 while (!ds.eof()) {
3     data d;
4     ds.read(&d, 1);
5     if (d == data_breaker)
6         break;
7     consume_data(d);
8 }
```

# Jump statements

- **break** Exits the loop and continues after it
- **continue** Goes immediately to next loop iteration



```
1 data_stream ds = get_data_stream();
2 while (!ds.eof()) {
3     data d;
4     ds.read(&d, 1);
5     if (!is_data_valid(d))
6         continue;
7     consume_data(d);
8 }
```

# Jump statements

- **break** Exits the loop and continues after it
- **continue** Goes immediately to next loop iteration
- **return** Exits the current function



```
1 void println (const char* value) {  
2     if (value == nullptr) return;  
3     std::cout << value << std::endl;  
4 }
```

# Jump statements

- **break** Exits the loop and continues after it
- **continue** Goes immediately to next loop iteration
- **return** Exits the current function



```
1 bool is_odd(int value) {  
2     if (value % 2) return true;  
3     return false;  
4 }
```

# Jump statements

- **break** Exits the loop and continues after it
- **continue** Goes immediately to next loop iteration
- **return** Exits the current function
- **goto** Can jump anywhere inside a function, **avoid!**



```
1 void println (const char* value) {  
2     if (value == nullptr) goto end;  
3     std::cout << value;  
4  
5     end:  
6     std::cout << std::endl;  
7 }
```

# Exercise : control

Familiarise yourself with different kinds of control structures.

Re-implement them in different ways.

- Go to exercises/control
- Look at control.cpp
- Compile it (make) and run the program (./control)
- Work on the tasks that you find in README.md



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# Interface

Set of declarations defining some functionality



# Interface

Set of declarations defining some functionality

- Put in a so-called “header file”

hello.hpp



```
1 void print_hello();
```

# Interface

Set of declarations defining some functionality

- Put in a so-called “header file”
- The implementation can be found in the "source file"

hello.cpp



```
1 #include <iostream>
2
3 using namespace std;
4
5 void print_hello() {
6     cout << "Hello, World!" << endl;
7 }
```

# Interface

print\_hello.hpp



```
1 void print_hello();
```

print\_hello.cpp



```
1 #include <iostream>
2
3 using namespace std;
4
5 void print_hello() {
6     cout << "Hello, World!" << endl;
7 }
```

main.cpp



```
1 #include "print_hello.hpp"
2
3 int main() {
4     print_hello();
5 }
```

# Preprocessor



# Preprocessor

- Constant macros



```
1 // constant macro
2 #define THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE 42
```

# Preprocessor

- Constant macros
- Function-style macros



```
1 // function-style macro
2 #define CHECK_THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE(x) \
3     if ((x) != THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE)      \
4         std::cerr << #x " was not the response\n";
```

# Preprocessor

- Constant macros
- Function-style macros
- Checks



```
1 // compile time or platform specific configuration check
2 #if defined(USE64BITS) || defined (__GNUG__)
3     using my_int = std::uint64_t;
4 #elif
5     using my_int = std::uint32_t;
6 #endif
```

# Preprocessor

- Constant macros
- Function-style macros
- Checks

Use preprocessor only in very restricted cases

- Conditional inclusion of headers
- Customization for specific compilers/platforms



# Preprocessor

- Constant macros
- Function-style macros
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Use preprocessor only in very restricted cases

- Conditional inclusion of headers
- Customization for specific compilers/platforms



```
1 #define THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE 42
2
3 constexpr int THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE = 42;
```

# Preprocessor

- Constant macros
- Function-style macros
- Checks

Use preprocessor only in very restricted cases

- Conditional inclusion of headers
- Customization for specific compilers/platforms



```
1 #define IS_THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE(x) \
2   ((x) == THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE)
3
4 template < typename type_t>
5 bool IS_THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE (type_t x) {
6   return x == static_cast<type_t>(THE_ANSWER_TO_THE_ULTIMATE_QUESTION_OF_LIFE);
7 }
```

# Header include guards

Problem: redefinition by accident

- Headers may define new names (e.g. types)
- Multiple (transitive) inclusions of a header would define those
- names multiple times, which is a compile error



# Header include guards

Problem: redefinition by accident

- Headers may define new names (e.g. types)
- Multiple (transitive) inclusions of a header would define those names multiple times, which is a compile error
- Solution: guard the content of your headers!

Include guards



```
1 #ifndef MY_HEADER_NAME  
2 #define MY_HEADER_NAME  
3  
4 ... // header file content  
5  
6 #endif
```

# Header include guards

Problem: redefinition by accident

- Headers may define new names (e.g. types)
- Multiple (transitive) inclusions of a header would define those
- names multiple times, which is a compile error
- Solution: guard the content of your headers!

## Include guards



```
1 #ifndef MY_HEADER_NAME  
2 #define MY_HEADER_NAME  
3  
4 ... // header file content  
5  
6 #endif
```

## pragma once



```
1 #pragma once  
2  
3 ... // header file content
```

# Header / source separation

- Headers should contain declarations of functions / classes
  - Only create them if interface is used somewhere else
- Might be included/compiled many times
- Good to keep them short
- Minimise `#include` statements
- Put long code in implementation files.  
Exceptions:
  - Templates and `constexpr` functions
  - Short functions

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# Benefits

- Robustness: If the expression's type is changed—including when a function return type is changed—it just works.
- Performance: You're guaranteed that there's no conversion.
- Usability: You don't have to worry about type name spelling difficulties and typos.
- Efficiency: Your coding can be more efficient.

# Benefits

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- Performance: You're guaranteed that there's no conversion.
- Usability: You don't have to worry about type name spelling difficulties and typos.
- Efficiency: Your coding can be more efficient.



```
1 std::vector<int> v = std::vector<int> {42, 84, 21, 65};  
2 float a = v[3]; // conversion intended?  
3 int b = v.size(); // bug? unsigned to signed
```

# Benefits

- Robustness: If the expression's type is changed—including when a function return type is changed—it just works.
- Performance: You're guaranteed that there's no conversion.
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1 std::vector<int> v = std::vector<int> {42, 84, 21, 65};  
2 float a = v[3]; // conversion intended?  
3 int b = v.size(); // bug? unsigned to signed
```



```
1 auto v = std::vector<int> {42, 84, 21, 65};  
2 auto a = v[3];  
3 auto b = v.size();
```

# Declarations



```
1 auto value = ...
2 auto& value_reference = ...
3 auto* value_pointer = ...
4 const auto constant_value = ...
5 const auto& constant_value_reference = ...
6 const auto* constant_ value_pointer = ...
7 auto [value1, value2, valueN] = ...
```

# for range loop



```
1 using namespace std;
2
3 vector<tuple<int, double>> id_usages = vector<tuple<int, double>> {
4     make_tuple(8634, 0.07),
5     make_tuple(1482, 0.2),
6     make_tuple(4821, 0.15),
7     make_tuple(2563, 0.4),
8     make_tuple(3920, 0.18)
9 };
10
11 for (const tuple<int, double>& item : id_usages)
12     cout << "id: " << get<0>(item) << " => " << get<1>(item) * 100 << "%" << endl;
```

# for range loop



```
1 using namespace std;
2
3 auto id_usages = vector {
4     make_tuple(8634, 0.07),
5     make_tuple(1482, 0.2),
6     make_tuple(4821, 0.15),
7     make_tuple(2563, 0.4),
8     make_tuple(3920, 0.18)
9 };
10
11 for (auto [id, percent] : id_usages)
12     cout << "id: " << id << " => " << percent * 100 << "%" << endl;
```

# Always initialized



```
1 using namespace std;
2
3 struct my_struct {
4     int value;
5     float percent;
6 };
7
8 my_struct v1;
9 cout << "v1.value = " << v1.value << ", v1.percent = " << v1.percent << endl;
10 // v1.value = 86589520, v1.percent = 2.8026e-45
11
12 my_struct v2 {};
13 cout << "v2.value = " << v2.value << ", v2.percent = " << v2.percent << endl;
14 // v2.value = 0, v2.percent = 0
15
16 auto v3 = my_struct {};
17 cout << "v3.value = " << v3.value << ", v3.percent = " << v3.percent << endl;
18 // v3.value = 0, v3.percent = 0
```



# Exercise : loops, references, auto

Familiarise yourself with range-based for loops and references.

- Go to `exercises/loops_refs_auto`
- Look at `loops_refs_auto.cpp`
- Compile it (`make`) and run the program (`./loops_refs_auto`)
- Work on the tasks that you find in `loops_refs_auto.cpp`



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# Inline functions originally

- Applies to a function to tell the compiler to inline it
  - That is, replace function calls by the function's content (similar to how a macro works)
- Only a hint, compiler can still choose to not inline
- Avoids call overhead at the cost of increasing binary size



```
inline int mult(int a, int b) {  
    return a * b;  
}
```

# Major side effect

- The linker reduces the duplicated functions into one
- An inline function definition can thus live in header files



```
1 inline int mult(int a, int b) {  
2     return a * b;  
3 }
```

# Inline functions nowadays

- Compilers can judge far better when to inline or not
- thus primary purpose is gone
- Putting functions into headers became main purpose
- Many types of functions are marked inline by default:
  - function templates
  - constexpr functions
  - class member functions



```
1 inline int mult(int a, int b) {  
2     return a * b;  
3 }
```

# Inline variables

- Global or **static** member variable specified as **inline**
- Same side effect, linker merges all occurrences into one
- Allows to define global variables/ constants in headers
- **Avoid global variables and global constants!** **static** member are fine.

my\_struct.hpp

```
● ● ●  
#pragma once  
#include <string>  
  
inline int count_item = 0;  
inline constexpr std::string file_name = "output.txt";  
  
struct my_struct {  
    inline static int count_item = 0;  
    inline static constexpr std::string file_name = "input.txt";  
  
    int value_a;  
    int value_b;  
};
```

# Inline variables

my\_struct.hpp



```
1 #pragma once
2 #include <string>
3
4 inline int count_item = 0;
5 inline const std::string file_name = "output.txt";
6
7 struct my_struct {
8     inline static int count_item = 0;
9     inline static const std::string file_name = "input.txt";
10
11     int value_a;
12     int value_b;
13 };
```

program.cpp



```
1 #include "my_struct.hpp"
2 #include <iostream>
3
4 int main() {
5     using namespace std;
6
7     count_item += 42;
8     cout << "count_item = " << count_item << endl;
9     cout << "file_name = " << file_name << endl << endl;
10
11     my_struct::count_item += 21;
12     cout << "my_struct::count_item = " << my_struct::count_item << endl;
13     cout << "my_struct::file_name = " << my_struct::file_name << endl;
14 }
```



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# Checking invariants in a program

- An invariant is a property that is guaranteed to be true during certain phases of a program, and the program might crash or yield wrong results if it is violated
  - “Here, ‘a’ should always be positive”
- This can be checked using `assert`
- The program will be aborted if the assertion fails



```
1 #include <cassert>
2
3 double f(double a) {
4     // [...] do stuff with a
5     // [...] that should leave it positive
6     assert(a > .0);
7     return std::sqrt(a);
8 }
```

# Good practice

- Assertions are mostly for developers and debugging
- Use them to check important invariants of your program
- Prefer handling user-facing errors with helpful error messages/exceptions
- Assertions can impact the speed of a program
  - Assertions are disabled when the macro `NDEBUG` is defined
  - Decide if you want to disable them when you release code



```
1 #define NDEBUG
2 #include <cassert>
3
4 double f(double a) {
5     assert(a > .0); // no effect
6     return std::sqrt(a);
7 }
```

# Static assert

- Checking invariants at compile time
  - To check invariants at compile time, use `static_assert`
  - The assertion can be any constant expression (see later)
  - The message argument is optional in C++ 17 and later

```
● ● ●  
1 double f(user_type_t a) {  
2     static_assert(std::is_floating_point<user_type_t>::value,  
3                     "This function expects floating-point types.");  
4     return std::sqrt(a);  
5 }  
6
```

```
● ● ●  
$> static_assert.cpp:8:17 Static assertion failed due to requirement  
'std::is_floating_point<int>::value': This function expects floating-point  
types.
```

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3. Object Oriented Programming (OOP)
4. Core Modern C++
5. Modern C++ Expert
6. Advanced Programming



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