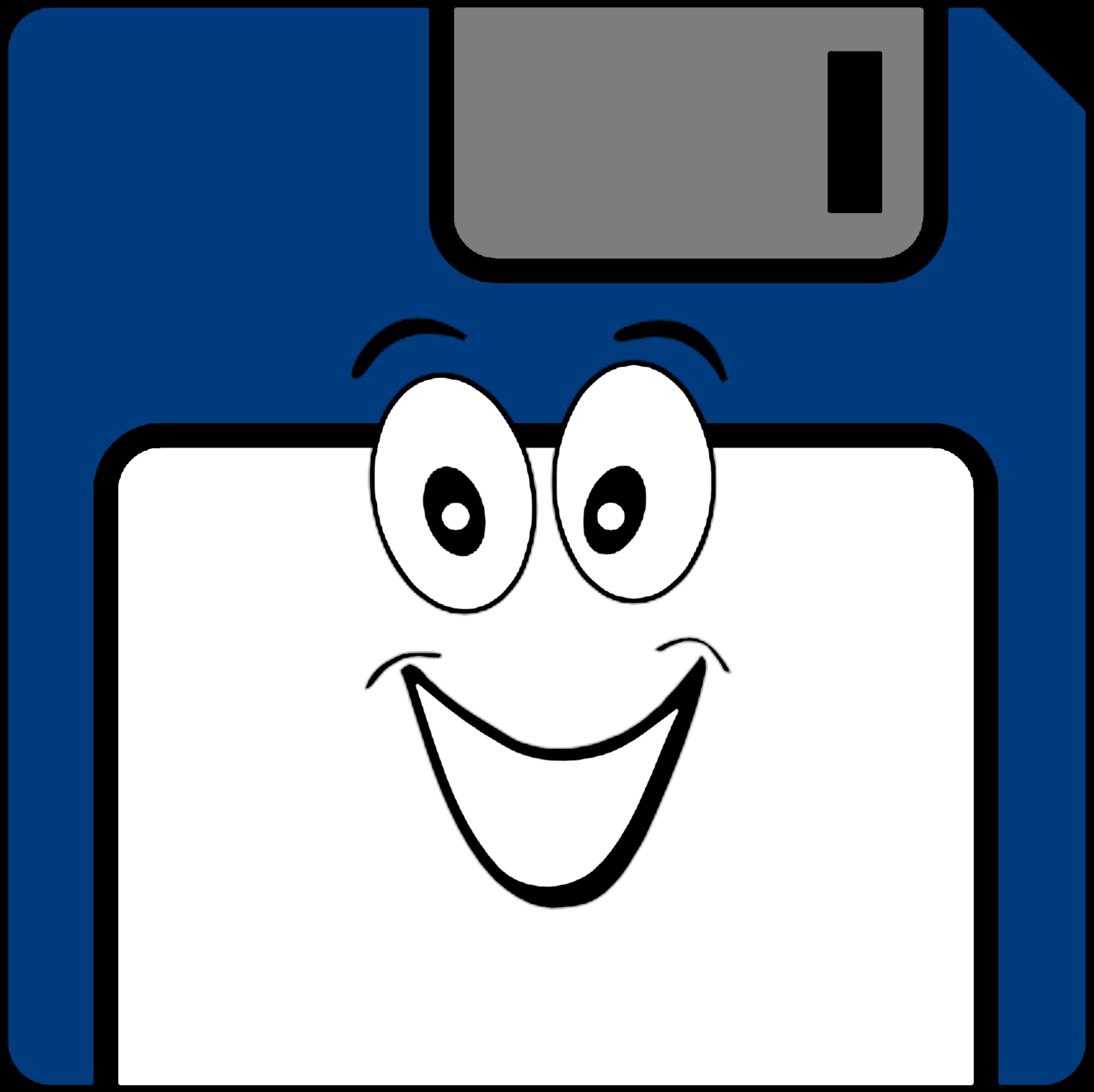
Modern C++ Course

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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- Hello World
- Core syntax and types
- Arrays and Pointers
- Scopes / namespaces
- Class and enum types
- References
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- Control structures
- Headers and interfaces
- auto keyword
- inline keyword
- Assertions

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The first classic application

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program.cpp

```
#include <iostream>

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

```cmake
cmake_minimum_required(VERSION 3.20)

project(hello_world)
add_executable(${PROJECT_NAME} program.cpp)
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}
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project(hello_world)
add_executable(${PROJECT_NAME} program.cpp)
```

Output

```
> Hello, World!
```

The first classic application

program.cpp

```cpp
#include <print>

auto main() -> int {
  std::println("Hello, World!");
}
```

CMakeLists.txt

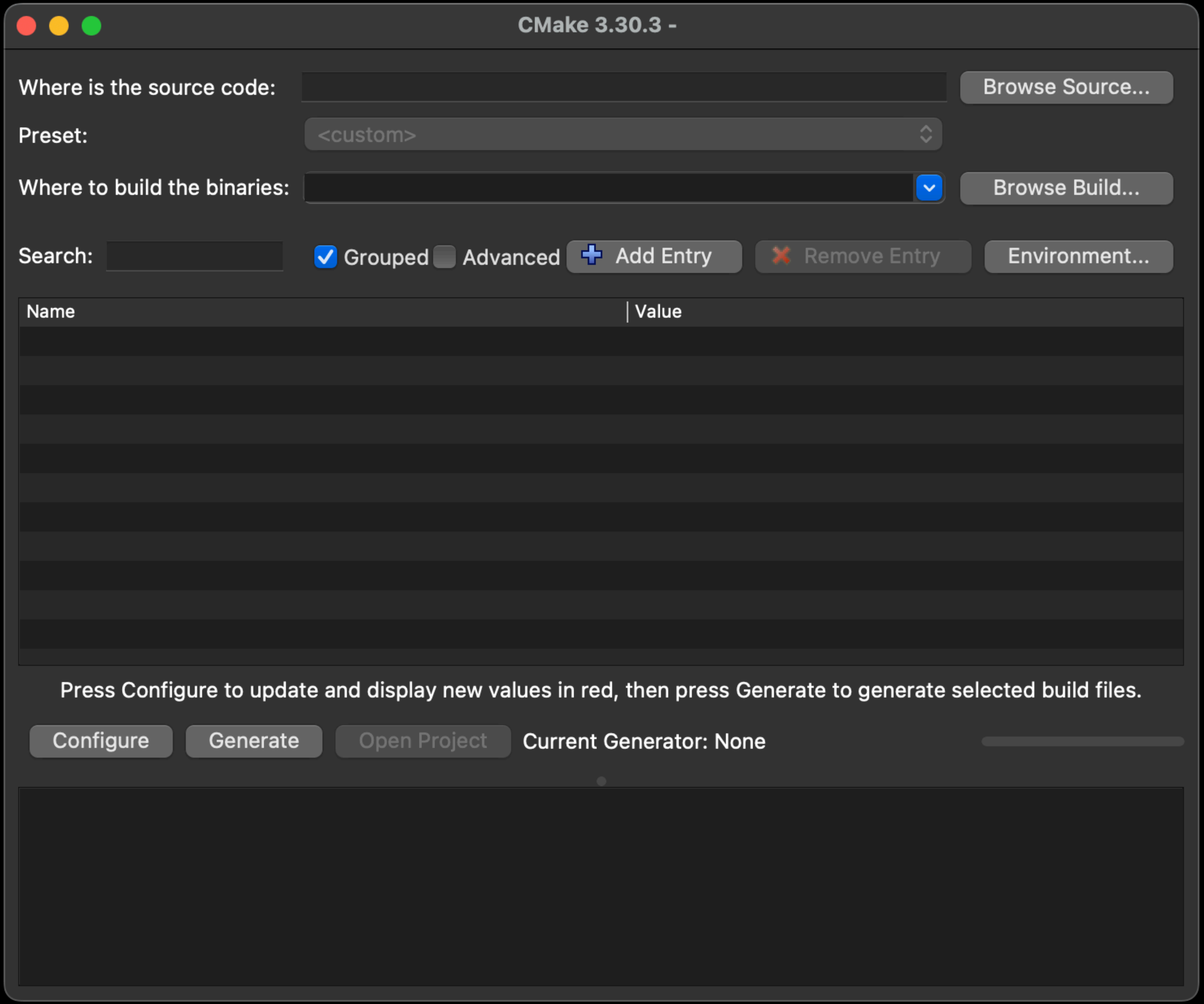
```cmake
cmake_minimum_required(VERSION 3.20)

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

```
#include <iostream>

int main() {
  std::cout << "maint without arguments" << std::endl;
}
```

Main function

```
#include <iostream>

int main() {
  std::cout << "maint without arguments" << std::endl;
}
```

```
#include <iostream>

int main(int argc, char* argv[]) {
  std::cout << "maint with argc and argv arguments" << std::endl;
}
```

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

```cpp
// single-line comment
int value = 0;

/*
 * multi-line comment
 */
std::string name();

/// Doxygen comments
/// @brief Adds two specified integers.
/// @param a the first integer to add.
/// @param a the second integer to add.
/// @return The result of the addition.
/// @see https://www.doxygen.nl/manual/commands.html
int add(int a, int b);
```

Basic types

```
bool b = true; // boolean, true or false

char c = 'a';         // min 8 bit integer
char cs = -1;         // may be signed
char cu = '\2';       // or not
                      // can store an ASCII character

signed char sc = -3;  // min 8 bit signed integer
unsigned char uc = 4; // min 8 bit unsigned integer

short int si = -5;          // min 16 bit signed integer
short s = -6;               // int is optional
unsigned short int usi = 7; // min 16 bit unsigned integer
unsigned short us = 8;      // int is optional
```

Basic types

```
int i = -9;             // min 16, usually 32 bit
unsigned int ui = 10; // min 16, usually 32 bit

long l = -11l;                // min 32 bit signed integer
long int li = -12l;           // int is optional
unsigned long ul = 13Ul;      // min 32 bit unsigned integer
unsigned long int uli = 14Ul; // int is optional

long long ll = -15ll;                   // min 64 bit signed integer
long long int lli = -16ll;              // int is optional
unsigned long long ull = 17ull;         // min 64 bit unsigned integer
unsigned long long int ulli = 18ull; // int is optional
```

Basic types

```cpp
float f = 0.19f;         // 32 (1+8+23) bit float
double d = 0.20;         // 64 (1+11+52) bit float
long double ld = 0.21l; // min 64 bit float

const char* nstr = "native string"; // array of chars ended by \0
std::string str = "string";         // class provided by the STL
```

Fixed width integer types

```cpp
#include <cstdint>

std::int8_t i8 = -1;     //  8 bit signed integer
std::uint8_t ui8 = 1;    //  8 bit unsigned integer

std::int16_t i16 = -2;   // 16 bit signed integer
std::uint16_t ui16 = 3;  // 16 bit unsigned integer

std::int32_t i32 = -4;   // 32 bit signed integer
std::uint32_t ui32 = 5;  // 32 bit unsigned integer

std::int64_t i64 = -4;   // 64 bit signed integer
std::uint64_t ui64 = 5;  // 64 bit unsigned integer
```

Fixed width floating-point types

```
#include <stdfloat> // may define these:

std::float16_t value = 3.14f16;   // 16 (1+5+10) bit float
std::float32_t value = 3.14f32;   // like float (1+8+23)
                                  // but different type
std::float64_t value = 3.14f64;   // like double (1+11+52)
                                  // but different type
std::float128_t value = 3.14f128; // 128 (1+15+112) bit float
std::bfloat16_t value = 3.14bf16; // 16 (1+8+7) bit float

// also F16, F32, F64, F128 or BF16 suffix possible
```

Integer literals

```
int value = 4284;                   // decimal (base 10)
int value = 0b0001000010111100;     // binary (base 2) since C++14
int value = 010274;                 // octal (base 8)
int value = 0x10bc;                 // hexadecimal (base 16)
int value = 0x10BC;                 // hexadecimal (base 16)

int value = 123'456'789;            // digit separators, since C++14
int value = 0b0001'0000'1011'1100; // digit separators, since C++14

4284              // int
4284u,   4284U    // unsigned int
4284l,   4284L    // long
4284ul,  4284UL   // unsigned long
4284ll,  4284LL   // long long
4284ull, 4284ULL // unsigned long long
```

Floating-point literals

```
double value = 12.34;
double value = 12.;
double value = .34;
double value = 12e34;           // 12 * 10^34
double value = 12E34;           // 12 * 10^34
double value = 12e-34;          // 12 * 10^-34
double value = 12.34e34;        // 12.34 * 10^34

double value = 123'456.789'101; // digit separators, C++14
double value = 0x4d2.4p3;       // hexfloat, 0x4d2.4 * 2^3
                                // = 1234.25 * 2^3 = 9874

3.14f, 3.14F, // float
3.14, 3.14,   // double
3.14l, 3.14L, // long double
```

Sizeof

```cpp
#include <cstddef> // (and others) defines:

int value = 42;
std::size_t size = sizeof(value); // 4
std::size_t size = sizeof(int);   // 4
std::size_t size = sizeof(42);    // 4
```

Pointer to integer

```cpp
#include <cstdint> // defines:

int value1 = 42;
int value2 = 84;

// can hold any diff between two pointers
std::ptrdiff_t ptrdiff = &value2 - &value1;

// can hold any pointer value
std::intptr_t intptr = reinterpret_cast<intptr_t>(&value1);
std::uintptr_t uintptr = reinterpret_cast<uintptr_t>(&value2);
```

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Static arrays

```
int ints[4] = {1, 2, 3, 4};
int ints[] = {1, 2, 3, 4}; // identical

char chars[3] = {'a', 'b', 'c'};    // char array
char chars[4] = "abc";              // valid native string
char chars[4] = {'a', 'b', 'c', 0}; // same valid native string

int i = ints[2];   // i = 3
char c = chars[8]; // at best garbage, may segfault
int i = ints[4];   // also garbage !
```

Pointers

```
int i = 4;
int* pi = &i;
int j = *pi + 1;

int ai[] = {1, 2, 3};
int* pai = ai; // decay to pointer
int* paj = pai + 1;
int k = *paj + 1;

// compile error
int* pak = k;

// segmentation fault !
int* pak = (int*)k;
int l = *pak;
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int i = 4;
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Memory layout

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

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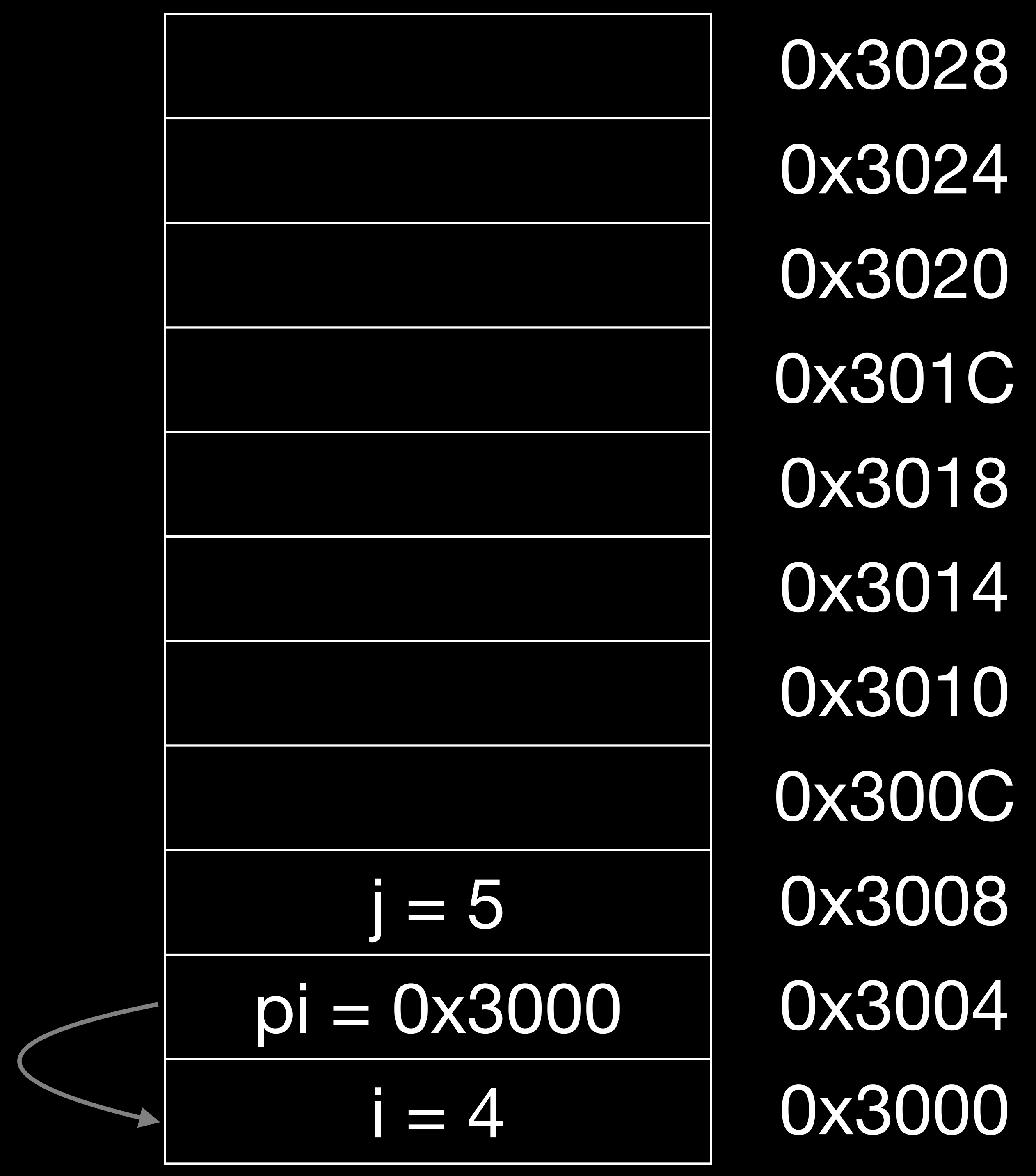

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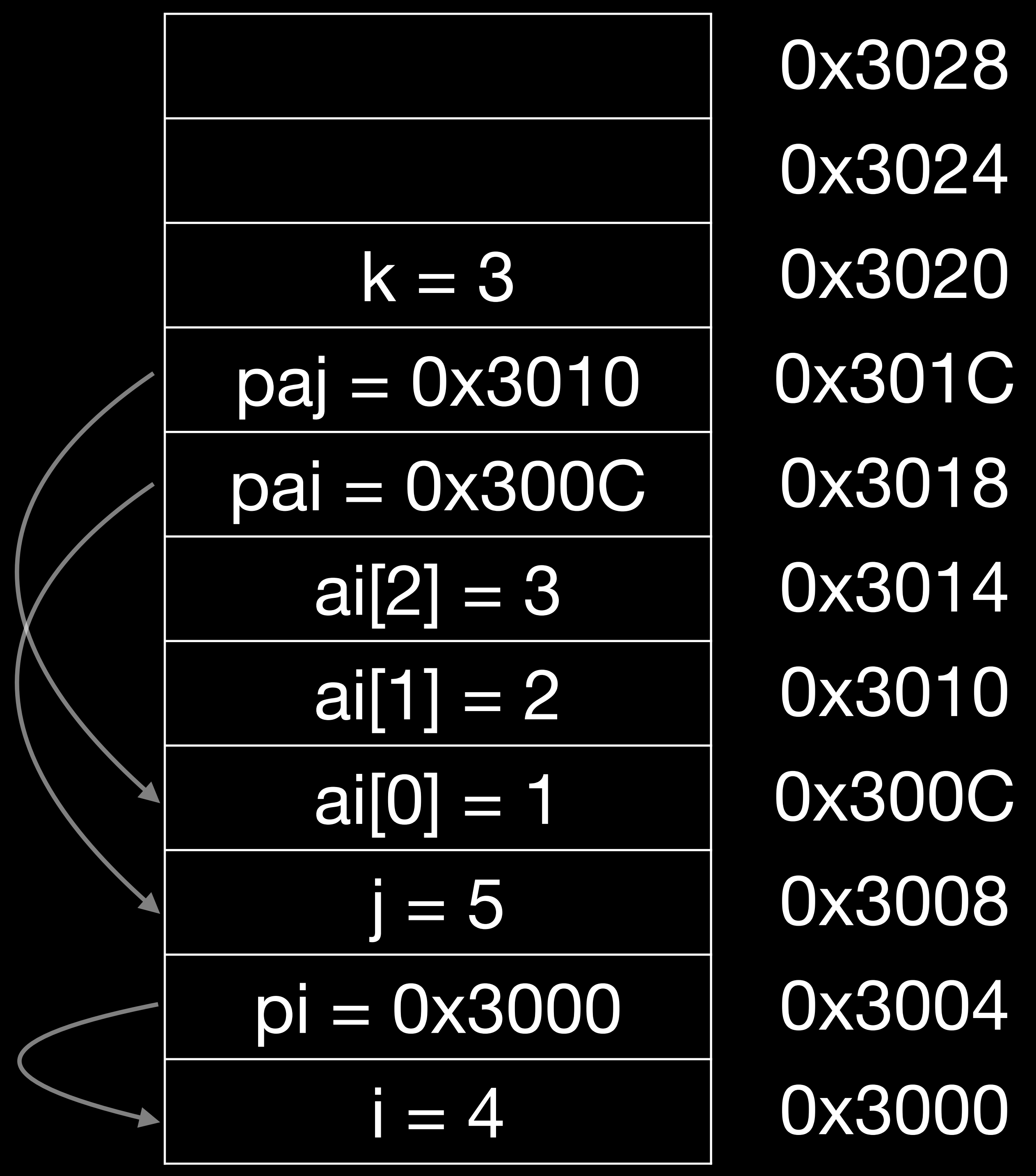

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??

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

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- triggers compilation error when assigned to integer

```
int* ip = nullptr;
int i = NULL; // compiles, bug?
int i = nullptr; // ERROR
```

Dynamic arrays using C

```
#include <cstdlib>
#include <cstring>

int* bad;           // pointer to random address
int* ai = nullptr; // better, deterministic, testable

// allocate array of 10 ints (uninitialized)
ai = (int*)malloc(10 * sizeof(int));
memset(ai, 0, 10 * sizeof(int)); // and set them to 0

ai = (int*)calloc(10, sizeof(int)); // both in one go

free(ai); // release memory
```

Dynamic arrays using C++

```
#include <cstdlib>
#include <cstring>

// allocate array of 10 ints
int* ai = new int[10];    // uninitialized
int* ai = new int[10] {}; // zero-initialized

delete[] ai; // release array memory

// allocate a single int
int* pi = new int;
int* pi = new int {};

delete pi; // release scalar memory
```

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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)

```
{
  int a = 0;
  {
    int b = 0;
  } // end of b scope
}
// end of a scope
```

Scope and lifetime of variables

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

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

Scope and lifetime of variables

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i = 4	0x3000

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Memory layout

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

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int a = 1;
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Memory layout

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

Scope and lifetime of variables

- Variables are (statically) allocated when defined
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```
int a = 1;
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  int b[4];
  b[0] = a;
}
// Doesn't compile here:
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```

Memory layout

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

Namespaces

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

```cpp
int value = 0;
namespace n {
  int value = 0;
}

namespace p {
  int value = 0;
  namespace inner {
    int value = 0;
  }
}

void f() {
  ::value = 42;
  n::value = 84;
  n::inner::value = 21;
}
```

Nested namespaces

- Easier way to declare nested namespaces

C++98

```cpp
namespace a {
  namespace b {
    namespace c {
      // ...
    }
  }
}
```

C++17

```cpp
namespace a::b::c {
  // ...
}
```

namespace alias

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

```
namespace very_long_namespace {
  int value = 0;
}

void f() {
  very_long_namespace::value = 42;
}
```

namespace alias

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

```
namespace very_long_namespace {
  int value = 0;
}

void f() {
  namespace vln = very_long_namespace;
  vln::value = 42;
}
```

namespace alias

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

```
namespace a::b::c::d {
  int value = 0;
}

void f() {
  a::b::c::d::value = 42;
}
```

namespace alias

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

```
namespace a::b::c::d {
  int value = 0;
}

void f() {
  namespace l = a::b::c::d;
  l::value = 42;
}
```

Using namespace directive

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

```
namespace a {
  int value = 0;
}

void f() {
  a::value = 42;
}
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Using namespace directive

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

```
namespace a::b::c {
  int value = 0;
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  value = 42;
}
```

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.

```cpp
namespace a::b::c {
  int value = 0;
}

void f() {
  using namespace a::b;
  c::value = 42;
}
```

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

```cpp
namespace {
  int locale_variable = 0;
}
```

equivalent

```cpp
static int locale_variable = 0;
```

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Struct

“members” grouped together under one name

```cpp
struct individual {
  unsigned char age;
  float weight;
};

individual student;
student.age = 25;
student.weight = 78.5f;

individual teacher = {45, 67.0f};

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

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

Memory layout

				0x3010
				0x300C
				0x3008
				0x3004
				0x3000

Struct

“members” grouped together under one name

```
struct individual {
  unsigned char age;
  float weight;
};

individual student;
student.age = 25;
student.weight = 78.5f;

individual teacher = {45, 67.0f};

individual* ptr = &student;
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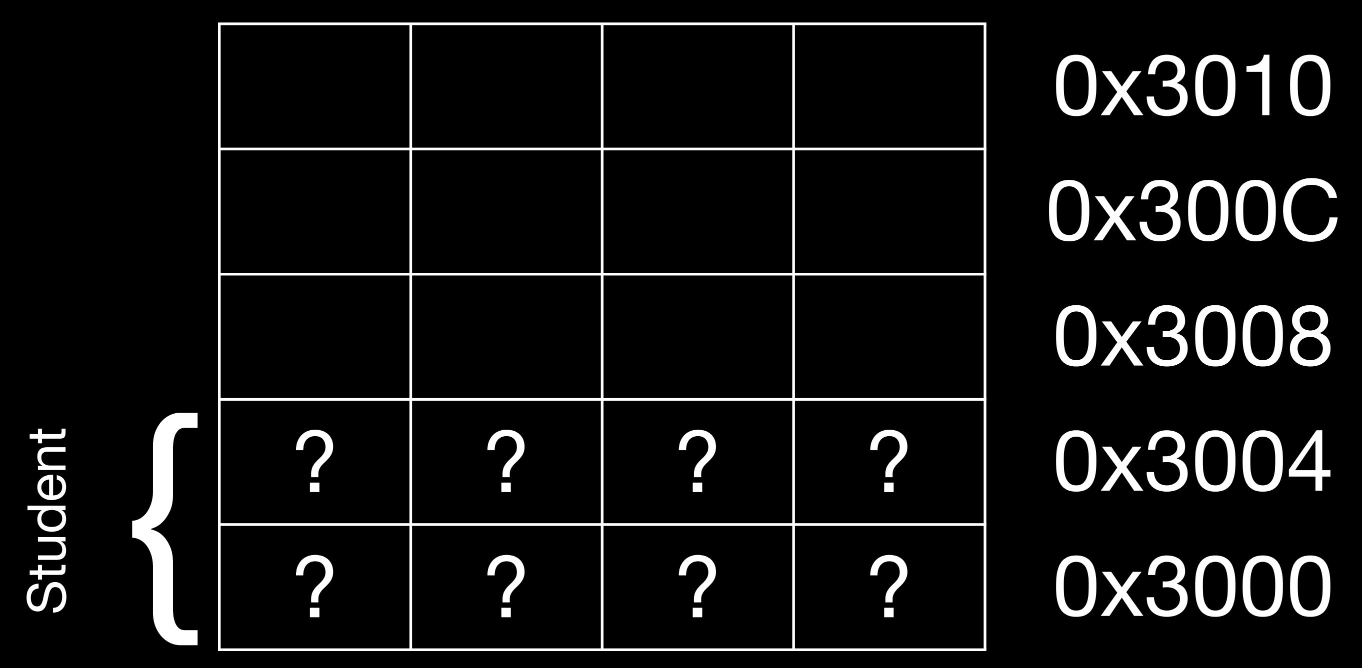
Memory layout



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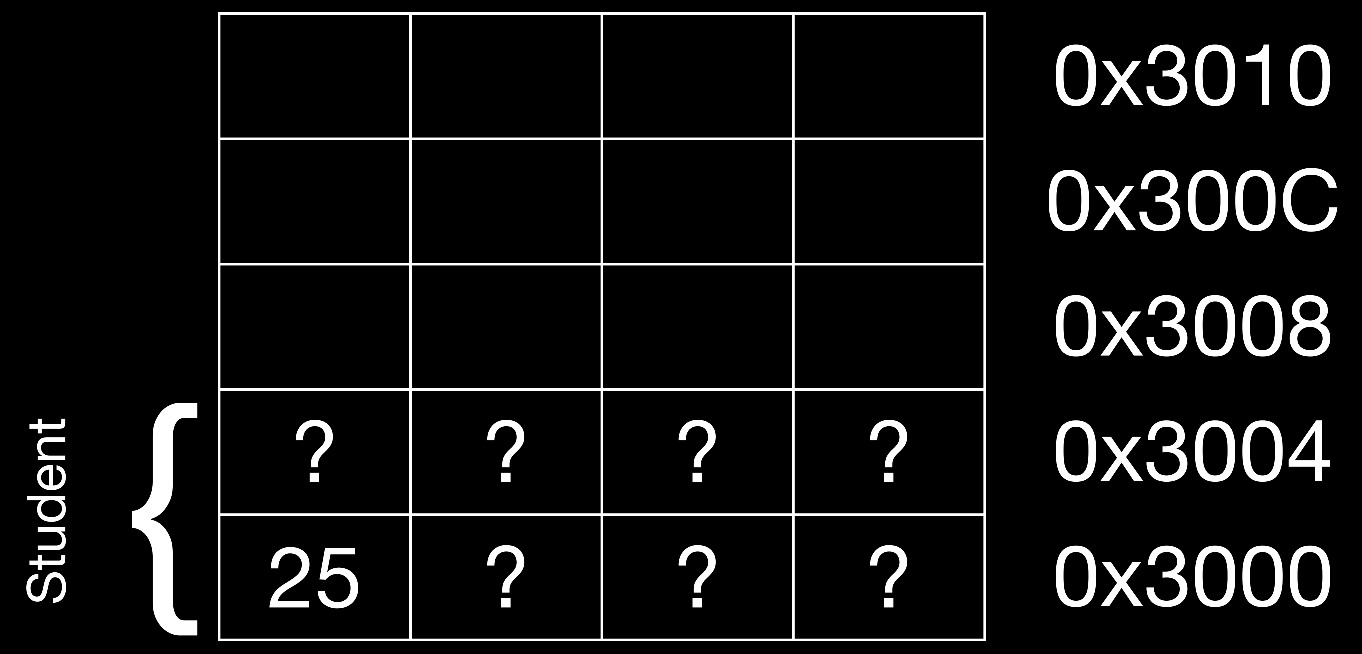

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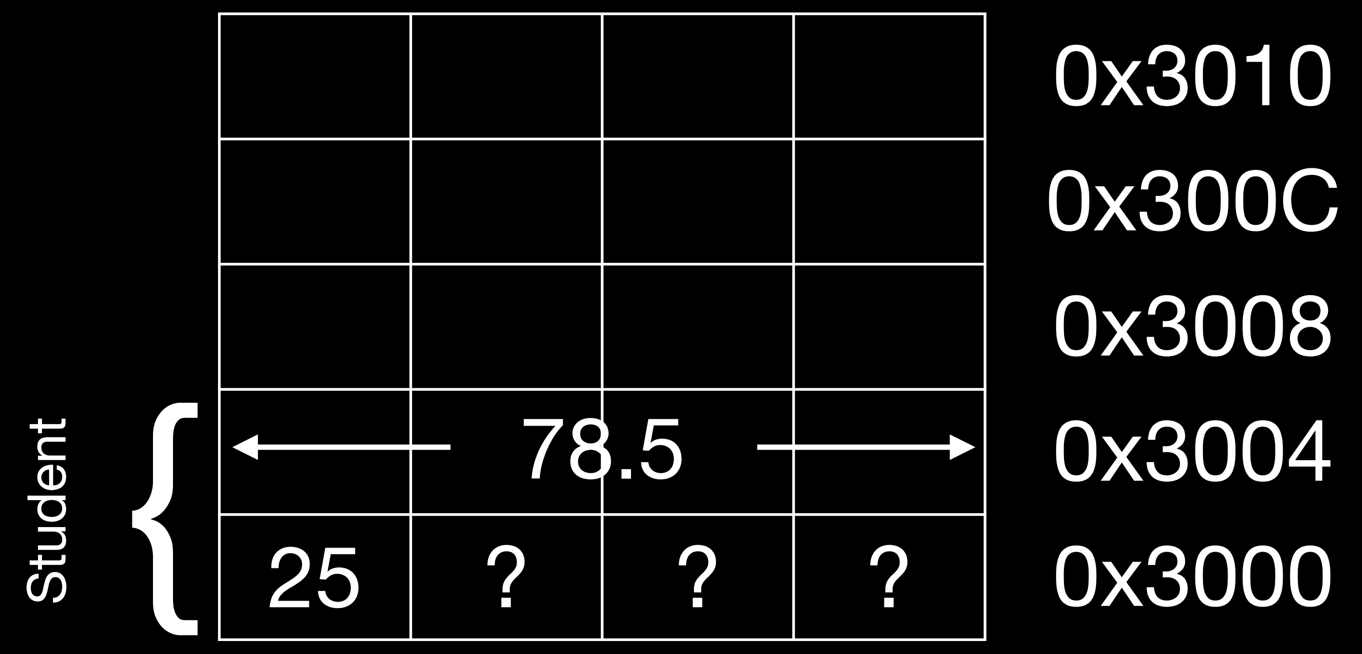

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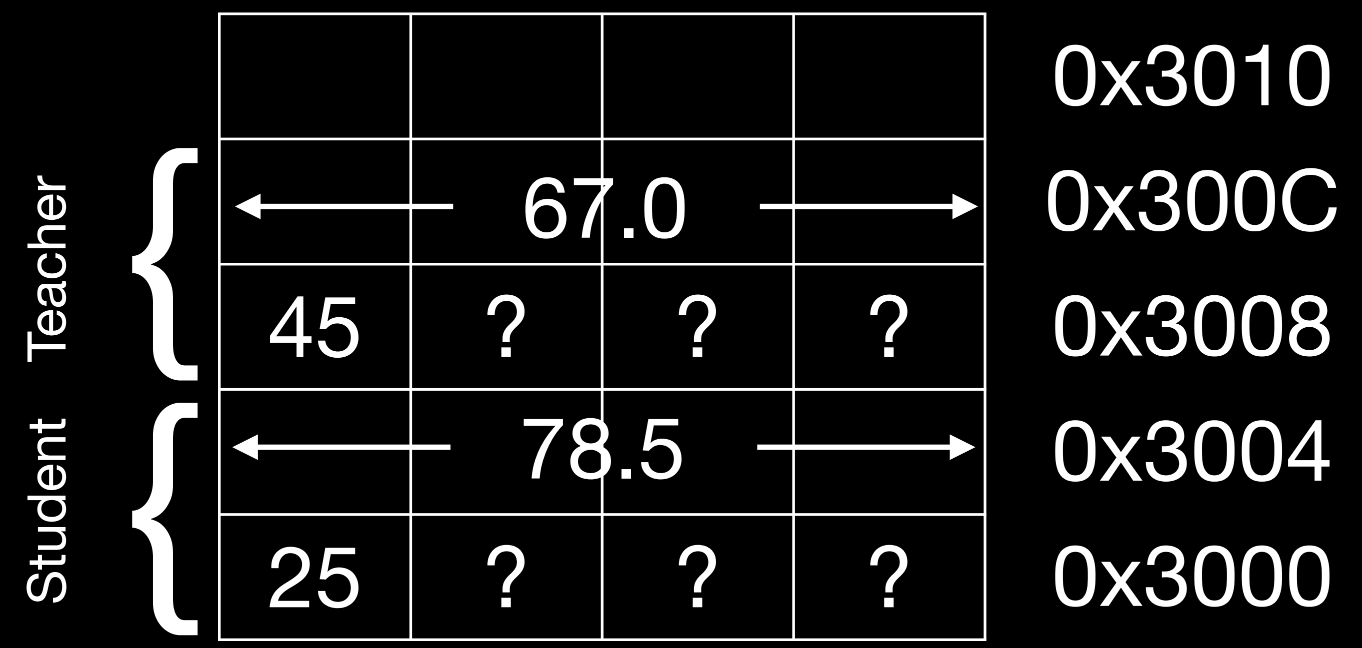

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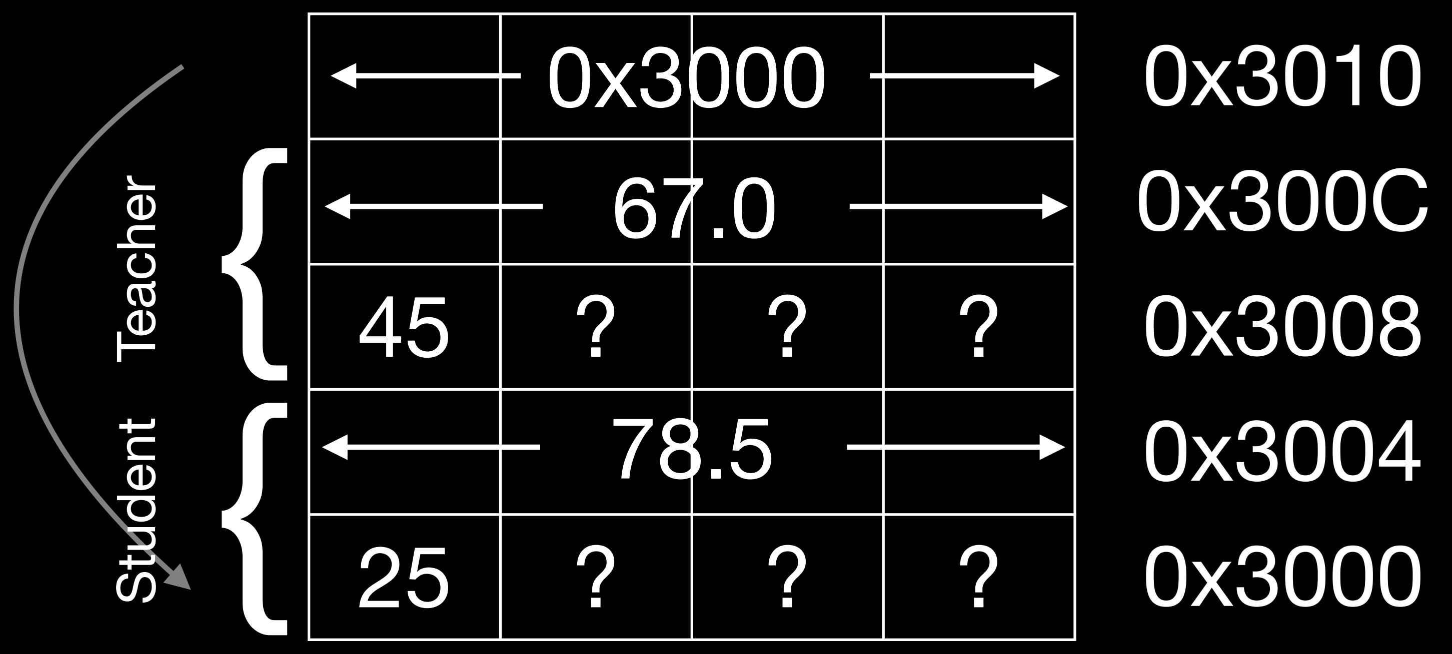

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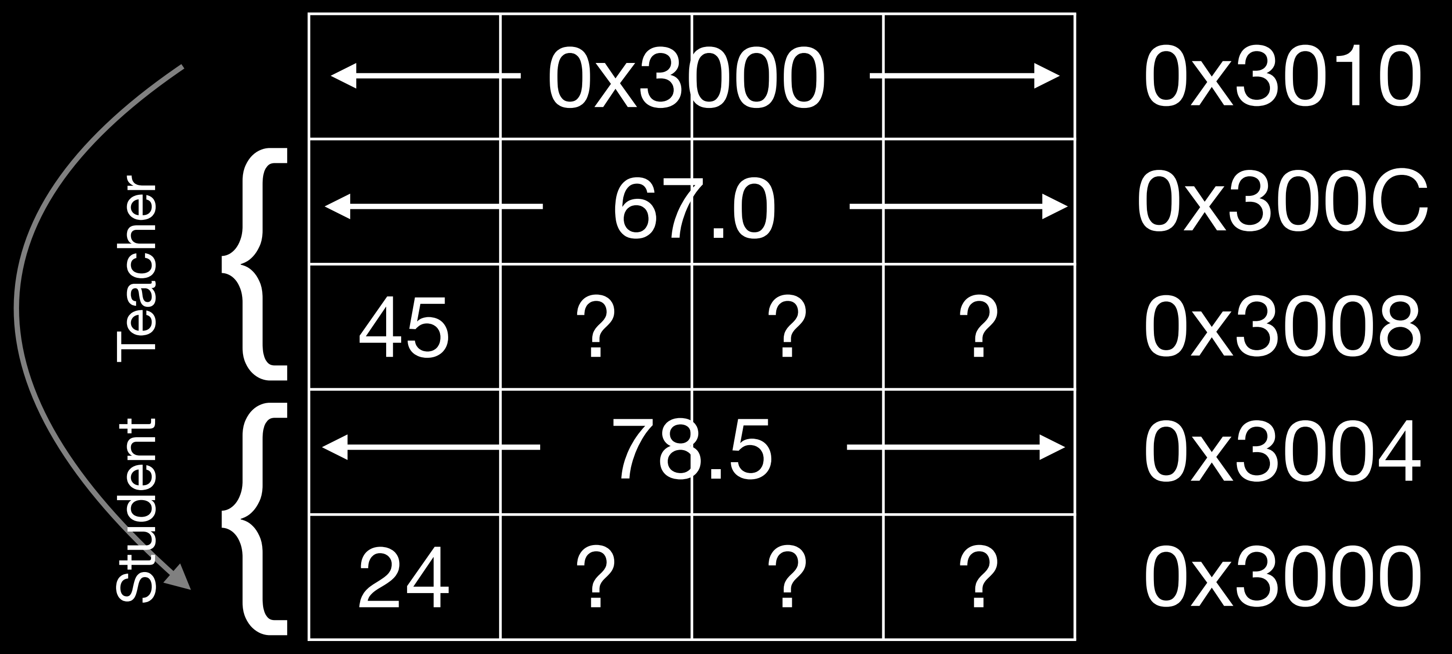

Union

“members” packed together at same memory location

```cpp
union duration {
  int seconds;
  short hours;
  char days;
};

duration d1, d2, d3;
d1.seconds = 259200;
d2.hours = 72;
d3.days = 3;
d1.days = 3; // d1.seconds overwritten
int a = d1.seconds; // d1.seconds is garbage
```

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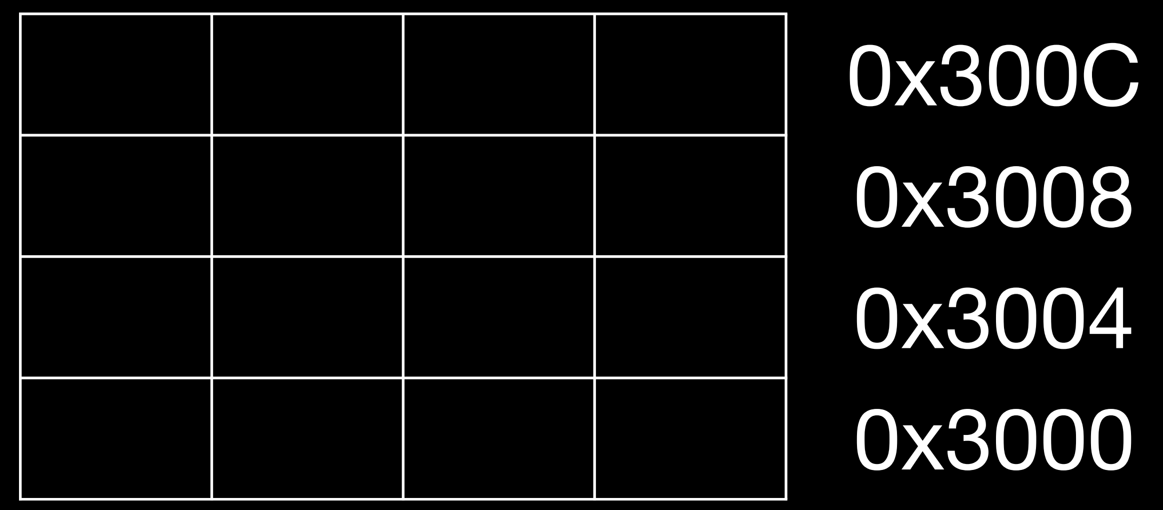
Memory layout



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Memory layout

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

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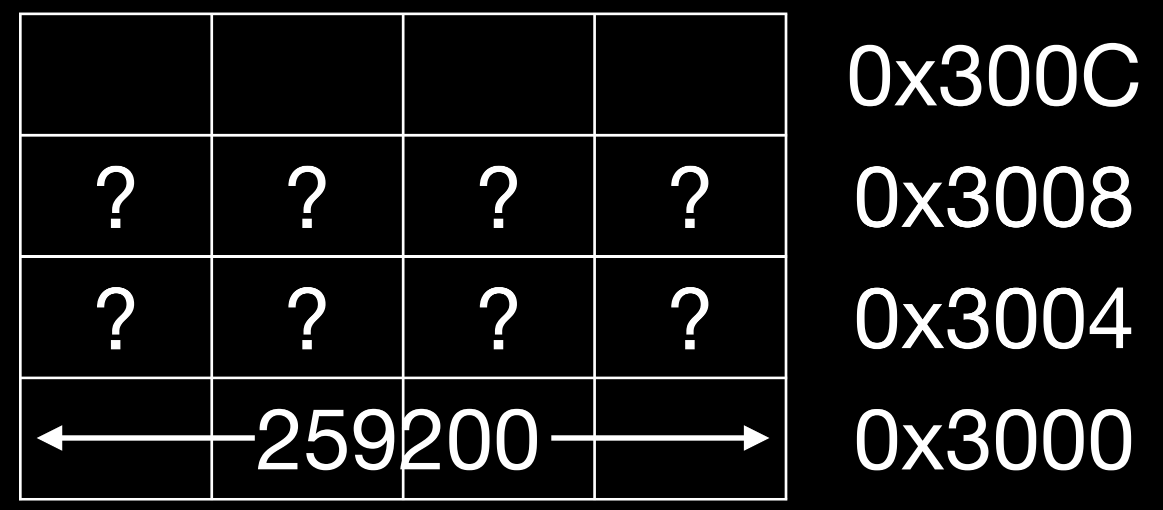

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```

Memory layout

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

Union

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  int seconds;
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Memory layout

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

Union

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Memory layout

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3	?	?	?	0x3008
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```

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

```
enum vehicle_type {
  BIKE, // 0
  CAR,  // 1
  BUS,  // 2
};

vehicle_type t = CAR;
```

```
enum vehicle_type : int { // since C++11
  BIKE = 3,
  CAR = 5,
  BUS = 7,
};

vehicle_type t = BUS;
```

Enum class

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

```
enum class vehicle_type {
  bike, // 0
  car,  // 1
  bus,  // 2
};

vehicle_type t = vehicle_type::car;
```

```
enum class vehicle_type : int {
  bike, // 0
  car,  // 1
  bus,  // 2
};

vehicle_type t = vehicle_type::car;
```

More concrete example

```cpp
enum class shape_type {circle, rectangle};

struct rectangle {
  float width;
  float height;
};

struct shape {
  shape_type type;
  union {
    float radius;
    rectangle rect;
  };
};

shape circle1 {.type = shape_type::circle, .radius =  3.4};
shape rectangle1 {.type = shape_type::rectangle, .rect = {3, 4}};
```

typedef and using

C++98

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

C++11

```
using myint = std::uint64_t;
myint count = 17;
using position = float[3];

template<typename type_t>
using myvec = std::vector<type_t>;
myvec<int> myintvec;
```

Language Basics

- Hello World
- Core syntax and types
- Arrays and Pointers
- Scopes / namespaces
- Class and enum types
- References
- Functions
- Operators
- Control structures
- Headers and interfaces
- 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

```
int i = 2;
int &iref = i; // access to i
iref = 3; // i is now 3

// const reference to a member:
struct a { int x; int y; } a;
const int &x = a.x; // direct read access to A's x
x = 4; // doesn't compile
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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Functions

Functions

```cpp
// without param and no return
void hello() {
  std::cout << "Hello, World";
}

// hello();
```

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void hello() {
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```cpp
// without param and return
float pi() {
  return 3.14159;
}

// int result = pi();
```

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float pi() {
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}

// int result = pi();
```

```cpp
// with param and no return
void print(char* msg) {
  std::cout << msg;
}

// print("Hello, World");
```

Functions

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// without param and no return
void hello() {
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// hello();
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void print(char* msg) {
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```cpp
// with param and return
int square(int a) {
  return a * a;
}

// int result = square(3);
```

Functions

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void hello() {
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// hello();
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// without param and return
float pi() {
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```cpp
// with param and no return
void print(char* msg) {
  std::cout << msg;
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// print("Hello, World");
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```cpp
// with param and return
int square(int a) {
  return a * a;
}

// int result = square(3);
```

```cpp
// with params and return
int multiply(int a, int b) {
  return a * b;
}

// int result = multiply(3, 4);
```

Functions

```cpp
// without param and no return
void hello() {
  std::cout << "Hello, World";
}

// hello();
```

```cpp
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float pi() {
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void print(char* msg) {
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```cpp
// with params and return
int multiply(int a, int b) {
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// int result = multiply(3, 4);
```

```cpp
// default argument
int add(int a, int b = 2) {
  return a + b;
}

// int result = add(3);
// int result = add(3, 1);
```

Functions

```cpp
// without param and no return
void hello() {
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int multiply(int a, int b) {
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```

```cpp
// default arguments
int add(int a = 4, int b = 2) {
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}

// int result = add();
// int result = add(3);
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```cpp
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```

```cpp
// with param and return
int square(int a) {
  return a * a;
}

// int result = square(3);
// int& r = square(2); // error
// int const& r = square(2);
```

```cpp
// with params and return
int multiply(int a, int b) {
  return a * b;
}

// int result = multiply(3, 4);
```

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// default arguments
int add(int a = 4, int b = 2) {
  return a + b;
}

// int result = add();
// int result = add(3);
// int result = add(3, 1);
```

Parameter are passed by value

```cpp
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
```

Parameter are passed by value

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struct big_struct {
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big_struct s;

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print_val(s); // copy

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}
print_ref(s); // no copy
```

Memory layout

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

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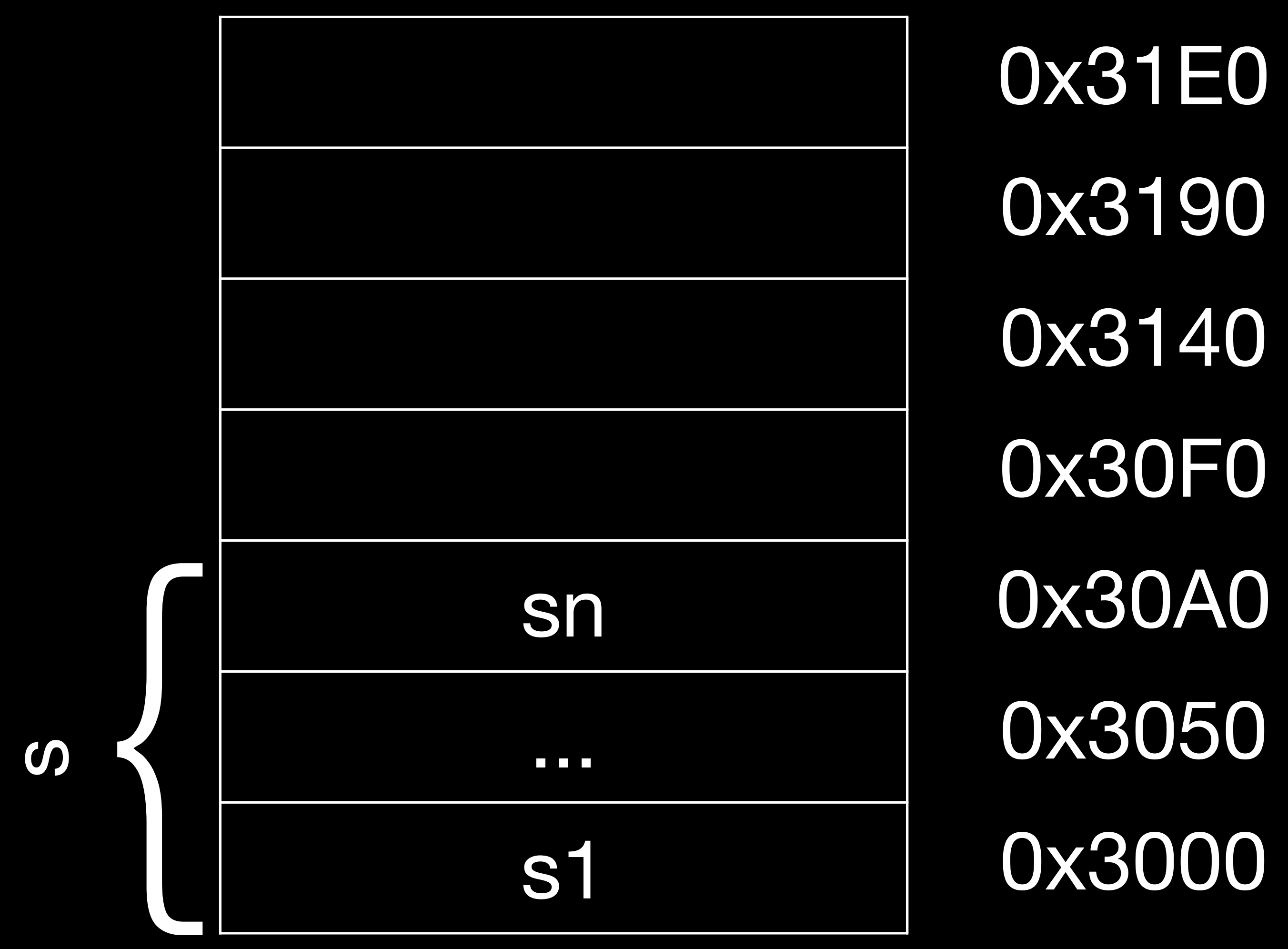
Memory layout



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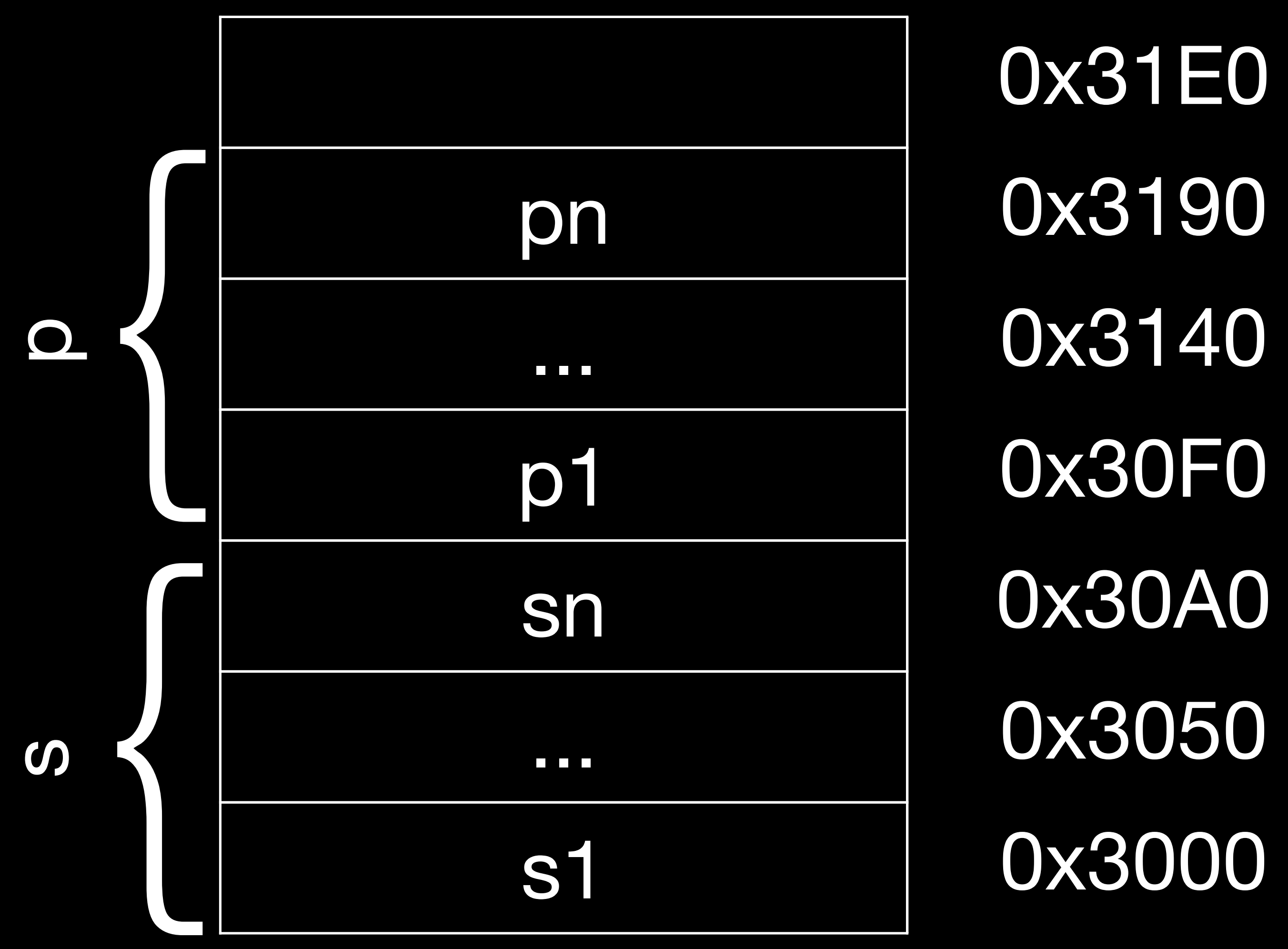

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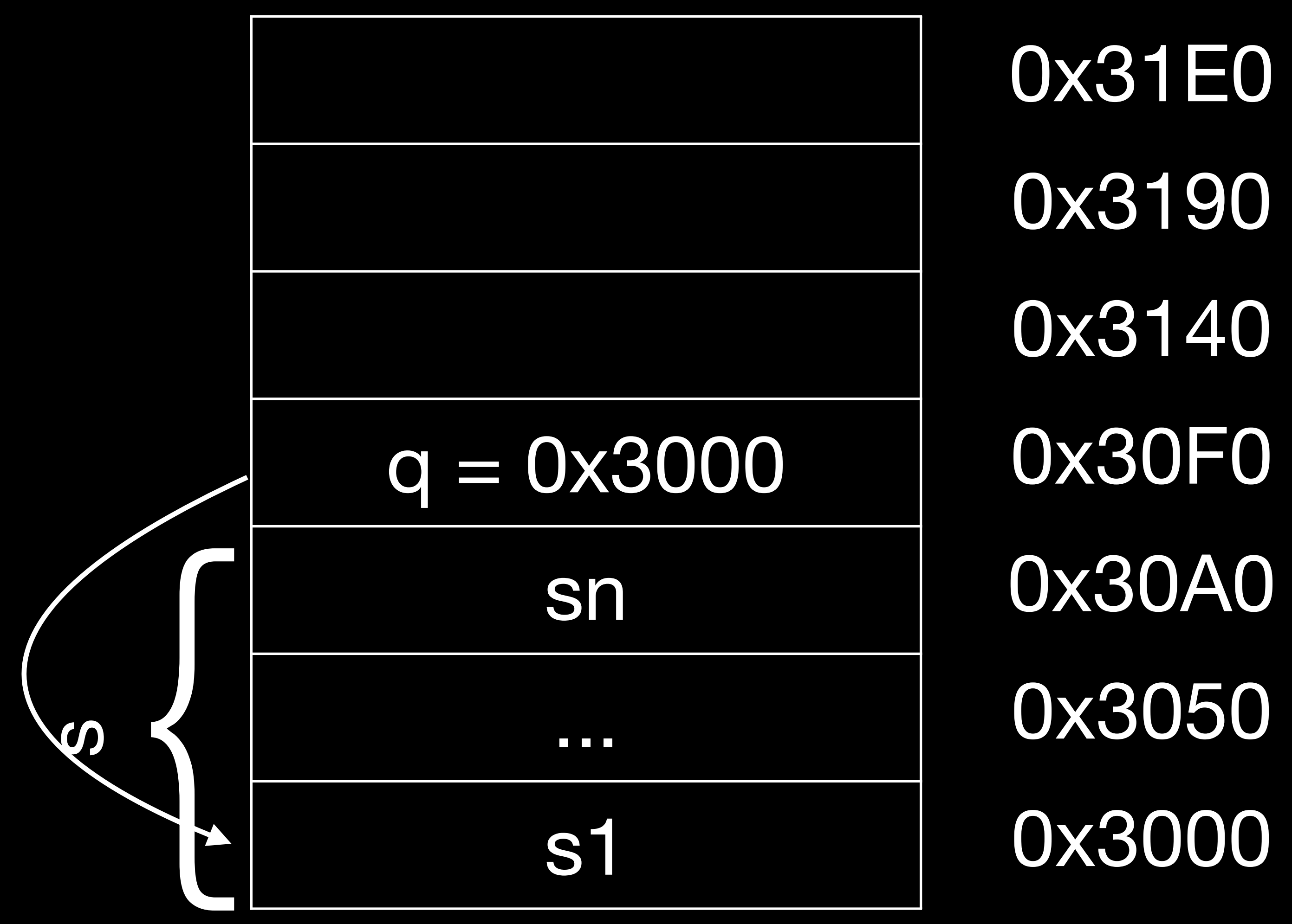
Memory layout



Pass by value or reference ?

```
struct small_struct {int a;};
small_struct s = {1};

void change_val(small_struct p) {
  p.a = 2;
}
change_val(s);
// s.a == 1

void change_ref(small_struct &q) {
  q.a = 2;
}
change_ref(s);
// s.a == 2
```

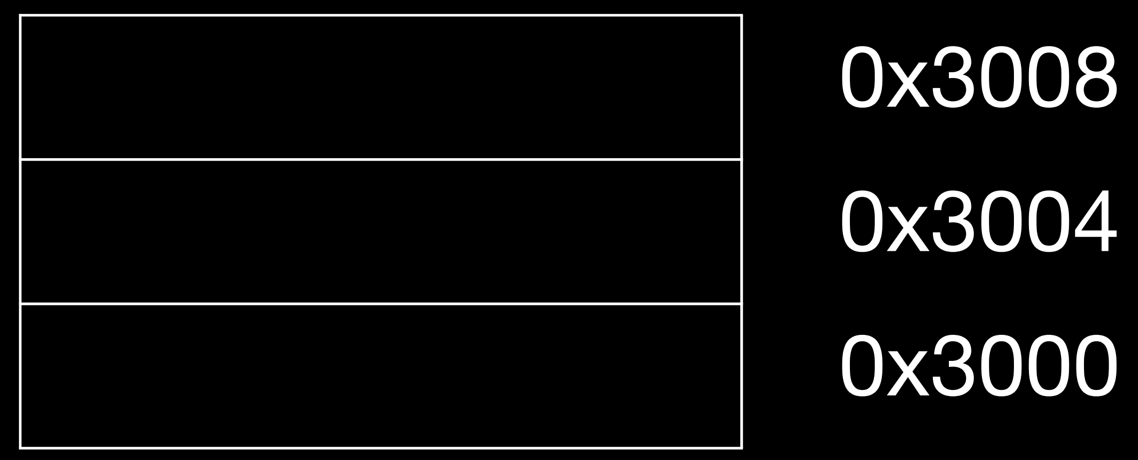
Pass by value or reference ?

```cpp
struct small_struct {int a;};
small_struct s = {1};

void change_val(small_struct p) {
  p.a = 2;
}
change_val(s);
// s.a == 1

void change_ref(small_struct &q) {
  q.a = 2;
}
change_ref(s);
// s.a == 2
```

Memory layout



Pass by value or reference ?

```
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void change_val(small_struct p) {
  p.a = 2;
}
change_val(s);
// s.a == 1

void change_ref(small_struct &q) {
  q.a = 2;
}
change_ref(s);
// s.a == 2
```

Memory layout

	0x3008
	0x3004
s.a = 1	0x3000

Pass by value or reference ?

```cpp
struct small_struct {int a;};
small_struct s = {1};

void change_val(small_struct p) {
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}
change_val(s);
// s.a == 1

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}
change_ref(s);
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```

Memory layout

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

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```

Memory layout

	0x3008
p.a = 2	0x3004
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```

Memory layout

	0x3008
	0x3004
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  q.a = 2;
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change_ref(s);
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```

Memory layout

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

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// s.a == 1

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  q.a = 2;
}
change_ref(s);
// s.a == 2
```

Memory layout

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

Pass by value or reference ?

```cpp
struct small_struct {int a;};
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// s.a == 1

void change_ref(small_struct &q) {
  q.a = 2;
}
change_ref(s);
// 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

```
struct foo {
   ...
};
foo bar;

void fct_val(foo value);
fct_val(bar); // by value

void fct_ref(const foo& value);
fct_ref(bar); // by reference

void fct_ptr(const foo* value);
fct_ptr(&bar); // by pointer

void fct_write(T &value);
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

```cpp
int sum(int b); // 1
int sum(int b, int c); // 2, ok, overload
// float sum(int b, int c); // disallowed

sum(42); // calls 1
sum(42, 43); // calls 2

int sum(int b, int c, int d = 4); // 3, overload

sum(42, 43, 44); // calls 3
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

```
/// @brief Count number of dilepton events in data.
/// @param d Dataset to search.
/// @return The number of dilepton events.
unsigned int count_dileptons(data &d) {
  select_events_with_muons(d);
  select_events_with_electrons(d);
  return d.size();
}
```

Good practices

- Don’t! Everything in one long function

```
unsigned int run_job() {
  // Step 1: data
  data d;
  d.resize(123456);
  d.fill(...);

  // Step 2: muons
  for (....) {
    if (...) {
      d.erase(...);
    }
  }

  // Step 3: electrons
  for (....) {
    if (...) {
      d.erase(...);
    }
  }

  // Step 4: dileptons
  int counter = 0;
  for (....) {
    if (...) {
      counter++;
    }
  }

  return counter;
}
```

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- Functions
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- Control structures
- Headers and interfaces
- auto keyword
- inline keyword
- Assertions

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Outline

End