Charles University

Programming in C++

Labs - winter 2025/26

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Lab 6

07/11/2025

Credit Project

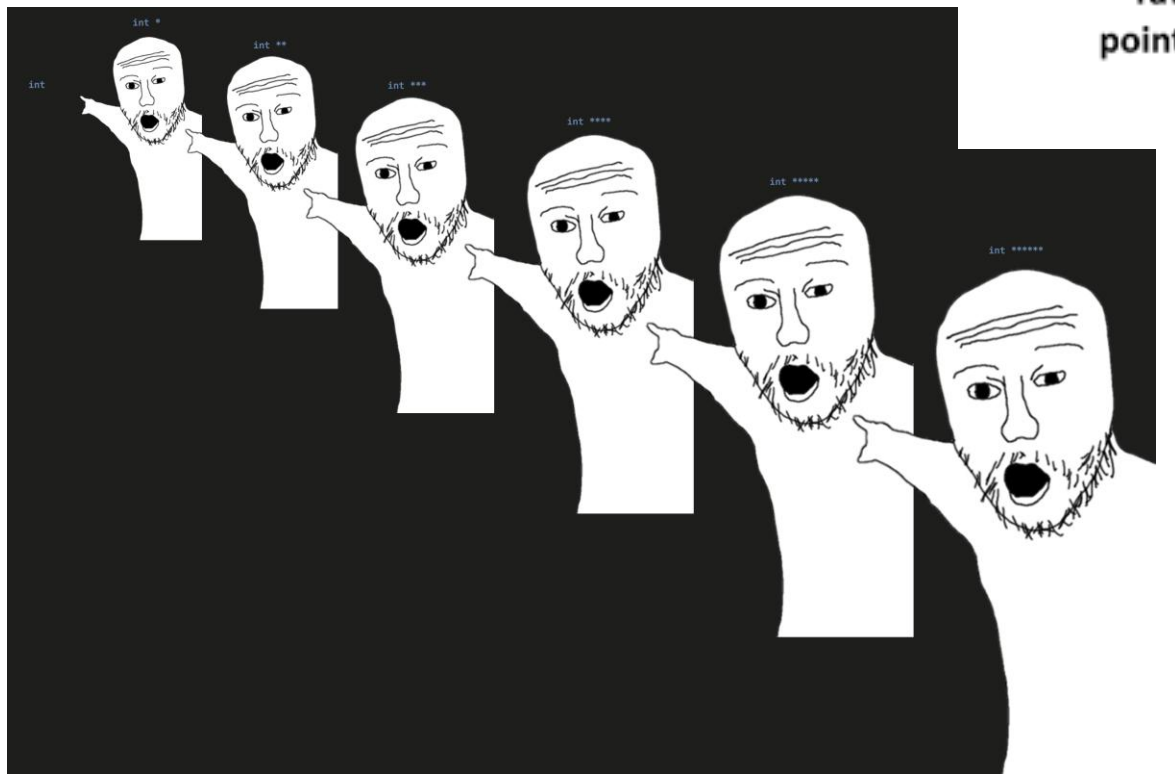
Topic must be **approved** by Friday November 14th

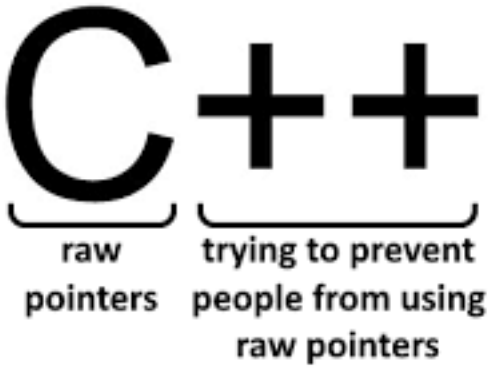
- DM me Mattermost

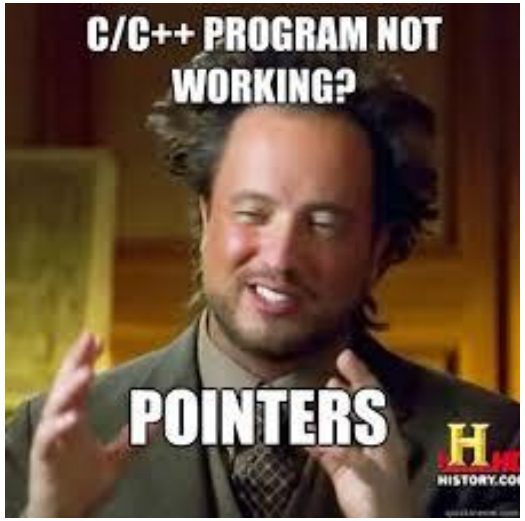
Homework Discussion

Pointers

random dev: I got stuck with this problem. Can anyone give me some pointers?

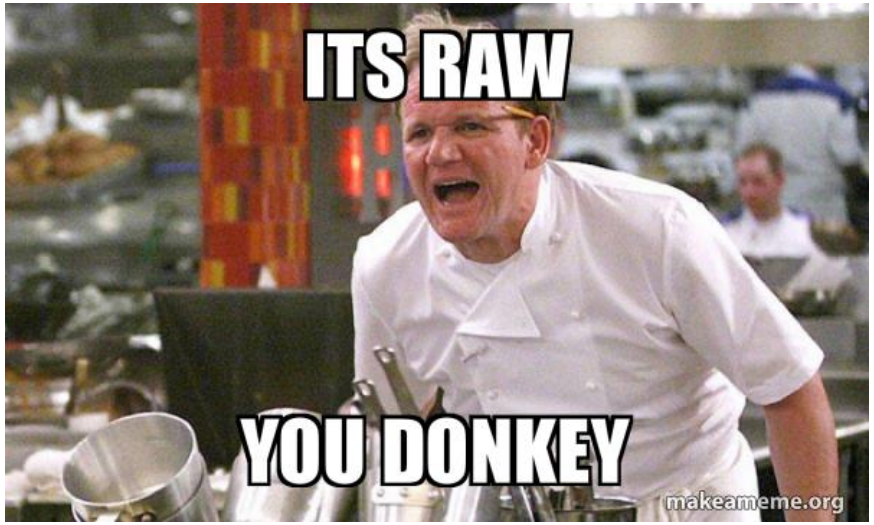






Dynamic Allocation

Use smart pointers (no raw pointers, i.e., **no new/new[]**)



Single owner

Most common case

Passing the ownership - move only, no copy

`unique_ptr<T>`

Shared ownership (multiple owners)

`shared_ptr<T>`

`weak_ptr<T>` // to break the cycle

Do you **really** need to own or just observe/work with the object?

Creation

`make_unique<T>, make_shared<T>`

```
make_unique<int[10]>() // Allocation of consecutive memory (~array)
```

Observers

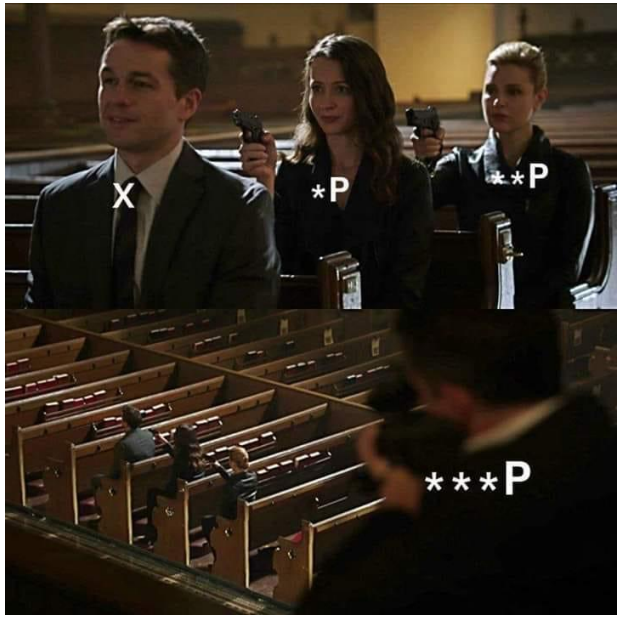
Working with the pointer with **no changes to ownership**

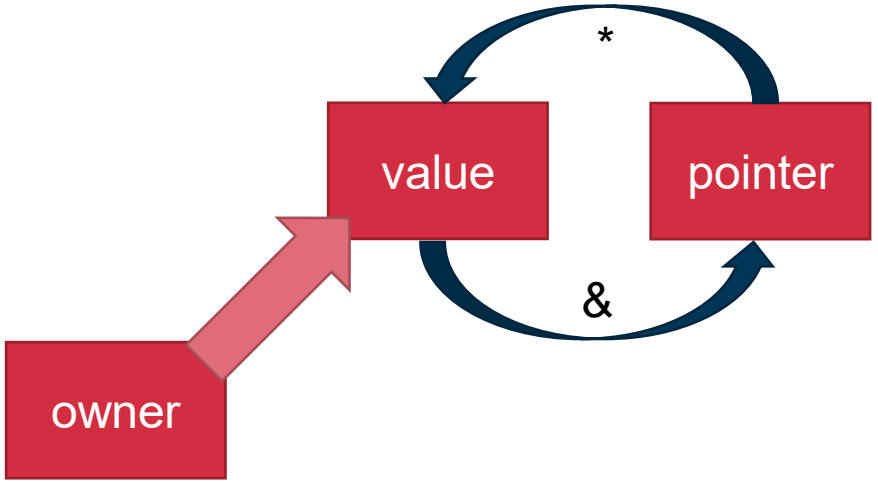
Return type (pointer)
Modifying observer → `T *` (pointer)
Read-only observer → `const T *`

Getting an observer
smart pointers → `get()`
otherwise → `&` (observer ~ address)

Accessing the value
access the value directly → `*`
access member attribute → `->` (same as doing (*var).

Pointing to nothing → `nullptr`





Dynamic Allocation: Final Notes

Prefer static/automatic storage

☺ complex c;

☹ auto c = make_unique<complex>();

Dynamic allocation **is slow!**

Prefer containers

☺ vector<int> vi(10);

☹ auto ia = make_unique<int[]>(10);

Prefer `unique_ptr`

use shared_ptr only for complex ownership, e.g., unknown ownership protocol (multithreading)

Use only when necessary

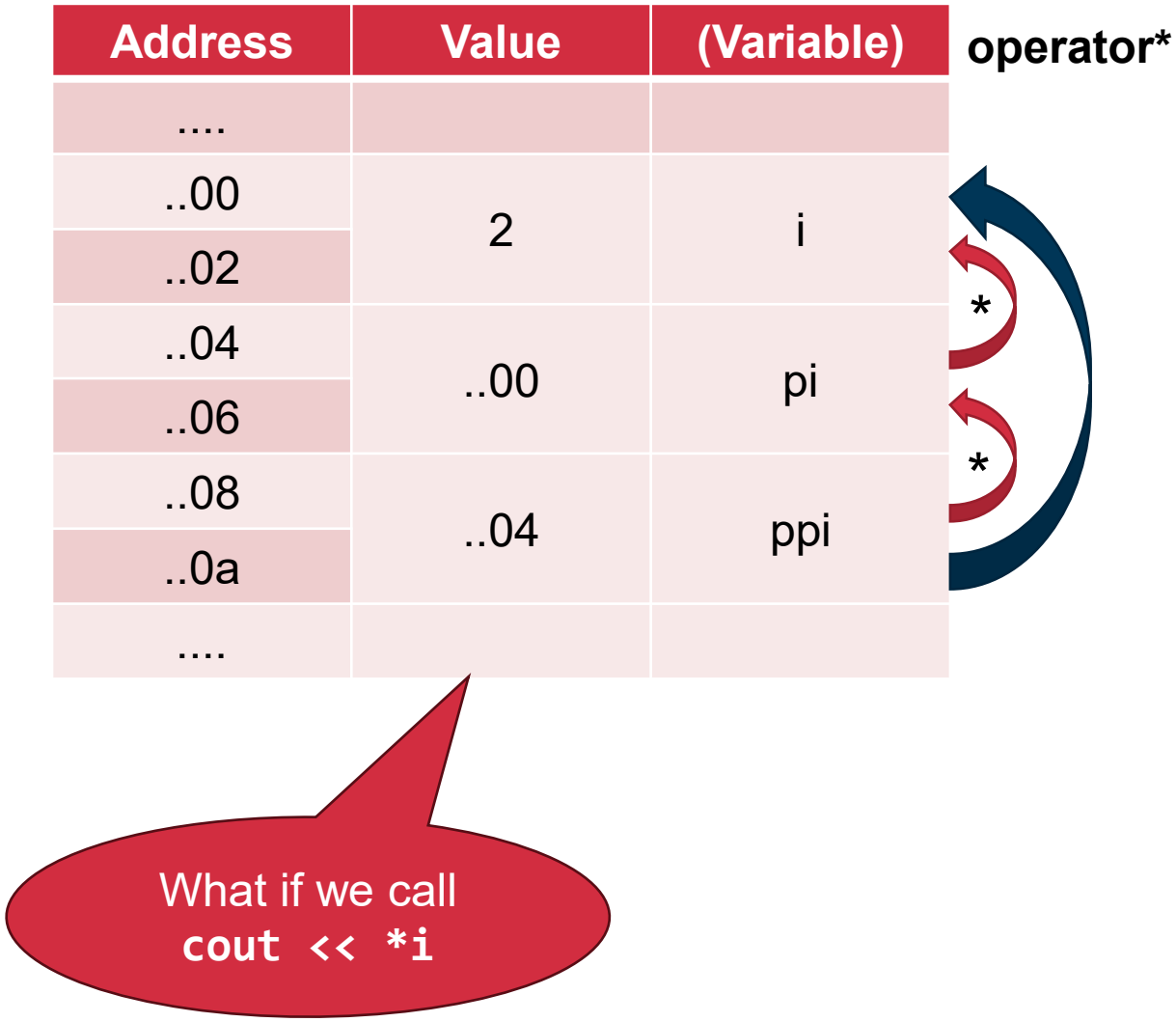
Object lifetime doesn't correspond to function invocations

Polymorphism

Is it really that **complex** or just **messy code?**

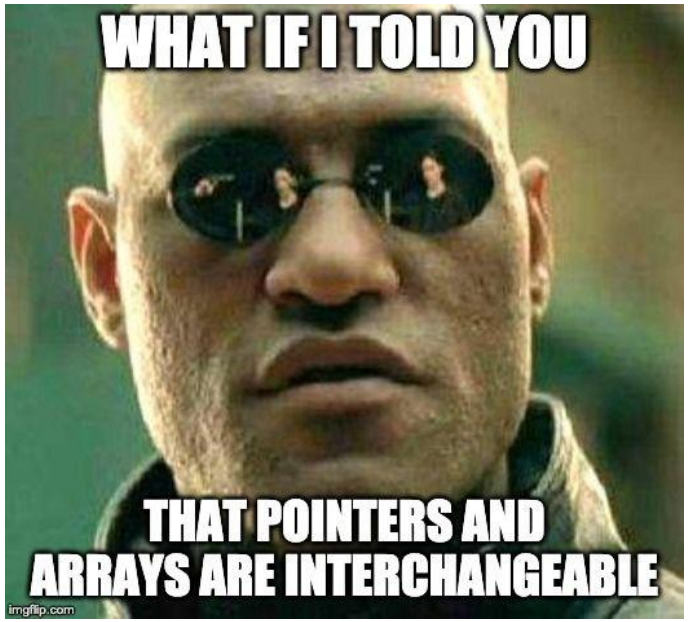
Pointers in Memory

```
int main() {
  int i = 2;
  int *pi = &i;
  int **ppi = &pi;
  cout << i;      // 2
  cout << pi;     // ..00
  cout << *pi;    // 2
  cout << ppi;    // ..04
  cout << *ppi;   // ..00
  cout << **ppi; // 2
}
```



Pointer Arithmetic

```
unique_ptr<int[]> int_arr = make_unique<int[]>(10);
for (size_t i = 0; i < 10; ++i) { int_arr[i] = 0; }
int *ptr = int_arr.get();
(*ptr) = 1;
*(ptr + 1) = 2;
cout << *ptr << ' ' << *(ptr + 1) << endl; // 1 2
ptr += 1;
cout << *ptr++ << endl; // 2
cout << *ptr << ' ' << *(ptr - 1) << endl; // 0 2
*ptr-- = 3;
cout << ptr[-1] << ' ' << ptr[0] << ' ' << ptr[1] << endl; // 1 2 3
```



Takes type into account

Linked List: Example

```
struct node {
  unique_ptr<node> next;
  int value;

  node(int value, unique_ptr<node> &&next) :
    value(value), next(std::move(next)) {}
};

class linked_list {
  unique_ptr<node> first_node;
public:
  node *front() {
    return first_node.get(); // Observer
  }

  const node *back() const {
    node *ptr = first_node.get(); // Observer
    if (ptr != nullptr) {
      while (ptr->next != nullptr) {
        ptr = (*ptr).next.get(); // Equivalent to ->
      }
    }
    return ptr;
  }
```

```
  void push_front(int value) {
    auto new_node = std::make_unique<node>(
        value,
        std::move(first_node));
    first_node = std::move(new_node);
  }

  void pop_front() {
    auto first = std::move(first_node);
    first_node = std::move(first->next);
  } // automatic deallocation of first
```

Work 1: Finish the LL

```
size(), print(), push_back(), pop_back()
ctor(), ctor(init_size, default_value), dtor
operator[]
```

Submit the final version to Gitlab → 1 point

- **Create a *merge-request***
- **Deadline: Thursday November 13th 5:00**

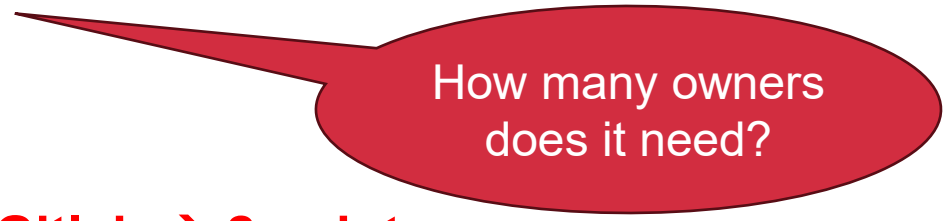
Work 2: `vector<int>`

Implement your own integer vector

Mandatory operations

default ctor, ctor(size_t, value_type), copy/move ctor/assignment
size(), capacity(), reserve(), push_back(), operator[]()

Use array allocation, no LL



Submit the final version to Gitlab → 2 point

- **Create a *merge-request***
- **Deadline: Thursday November 13th 5:00**

Lab 5

31/10/2025

Credit Project

Topic must be **approved** by Friday November 14th

- DM me Mattermost

Declaration/Definition

```
// file: my_class.hpp

#ifndef MY_CLASS_HPP
#define MY_CLASS_HPP

void fn(int x);

class my_class {
public:
  my_class();
  int exec(int x);

private:
  double d;
  static size_t i;
};

#endif // MY_CLASS_HPP
```

```
// file: my_class.cpp

#include “my_class.hpp”
#include <iostream>

void fn(int x) {
  cout << “fn()”;
}

my_class::my_class() : d(1.0) {
  cout << “ctor”;
}

int my_class::exec(int x) {
  for(int i=0; i < x; ++i) { … }
}

size_t my_class::i = 0;
```

Declaration/Definition

```
// file: my_class.hpp

#ifndef MY_CLASS_HPP
#define MY_CLASS_HPP

void fn(int x);

class my_class {
public:
  my_class();
  int exec(int x);

private:
  double d;
  static size_t i;
};

#endif // MY_CLASS_HPP
```

Declaration

```
// file: my_class.cpp

#include “my_class.hpp”
#include <iostream>

void fn(int x) {
  cout << “fn()”;
}

my_class::my_class() : d(1.0) {
  cout << “ctor”;
}

int my_class::exec(int x) {
  for(int i=0; i < x; ++i) { … }
}

size_t my_class::i = 0;
```

Include header

Definition

Declaration/Definition

```
// file: my_class.hpp

#ifndef MY_CLASS_HPP
#define MY_CLASS_HPP

void fn(int x);

class my_class {
public:
  my_class();
  int exec(int x);

private:
  double d;
  static size_t i;
};

#endif // MY_CLASS_HPP
```

Include guards

```
// file: my_class.cpp

#include “my_class.hpp”
#include <iostream>

void fn(int x) {
  cout << “fn()”;
}

my_class::my_class() : d(1.0) {
  cout << “ctor”;
}

int my_class::exec(int x) {
  for(int i=0; i < x; ++i) { … }
}

size_t my_class::i = 0;
```

Declaration/Definition

```
// file: my_class.hpp

#ifndef MY_CLASS_HPP
#define MY_CLASS_HPP

void fn(int x);

class my_class {
public:
  my_class();
  int exec(int x);

private:
  double d;
  static size_t i;
};

#endif // MY_CLASS_HPP
```

#pragma once

Include guards

```
// file: my_class.cpp

#include “my_class.hpp”
#include <iostream>

void fn(int x) {
  cout << “fn()”;
}

my_class::my_class() : d(1.0) {
  cout << “ctor”;
}

int my_class::exec(int x) {
  for(int i=0; i < x; ++i) { … }
}

size_t my_class::i = 0;
```

Sequence Containers

std::vector<Type> - dynamic array

- my_vec[idx] = value, push_back(), …

std::array<Type, Size> - fixed size array

- my_array[idx] = value, …

std::deque<Type> - double ended dynamic array

- push_back(), push_front(), back(), front(), …

std::list<Type> - linked list

Adaptors
Stack, queue, priority_queue
flat_set, flat_map, flat_multiset, flat_multimap

Iterators

*An object representing **references to elements** inside a container*

```
struct Complex { double re; double im; };
using ComplexVec = std::vector<ComplexVec>;
ComplexVec cvec{{1., 1.}, {2., 2.}, {3., 3.}};

for (ComplexVec::const_iterator i = cvec.cbegin(); i != cvec.cend(); i++)
  cout << “[“ << i->re << “,” << i->im << “]” << endl;

std::vector<int> vi{1, 2, 3};
cout << “begin: “ << *vi.begin() << “, end: “ << *vi.end(); << endl;
```

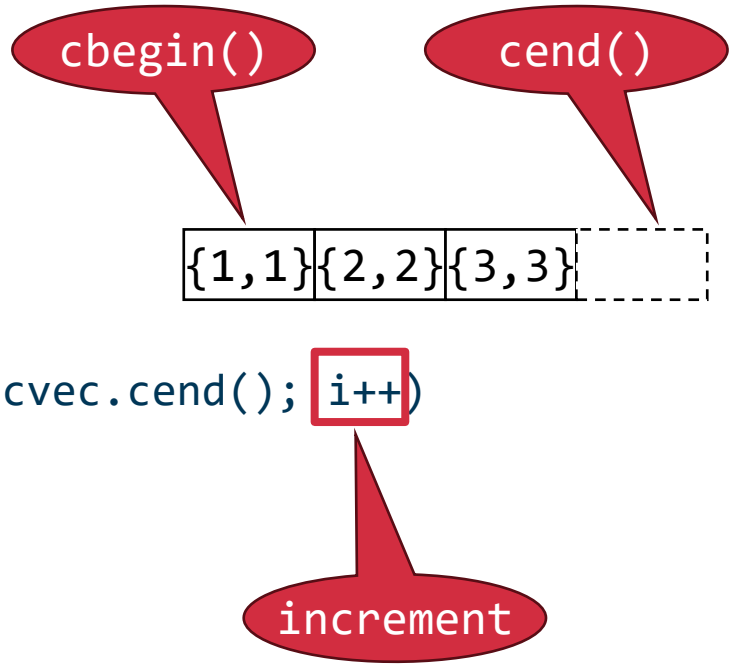
Iterators

*An object representing **references to elements** inside a container*

```
struct Complex { double re; double im; };
using ComplexVec = std::vector<ComplexVec>;
ComplexVec cvec{{1., 1.}, {2., 2.}, {3., 3.}};

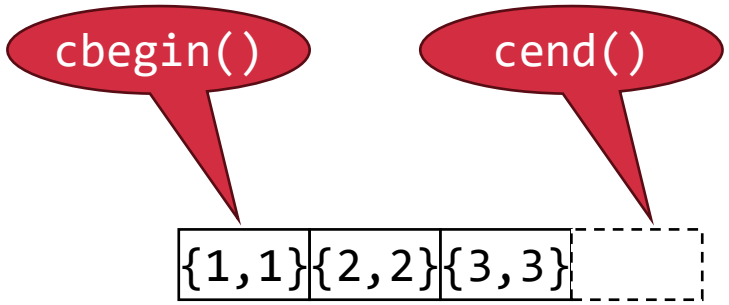
for (ComplexVec::const_iterator i = cvec.cbegin(); i != cvec.cend(); i++)
  cout << "[" << i->re << "," << i->im << "]" << endl;

std::vector<int> vi{1, 2, 3};
cout << "begin: " << *vi.begin() << endl;
```



Iterators

*An object representing **references to elements** inside a container*




```
struct Complex { double re; double im; };
using ComplexVec = std::vector<ComplexVec>;
ComplexVec cvec{{1., 1.}, {2., 2.}, {3., 3.}};

for (ComplexVec::const_iterator i = cvec.cbegin(); i != cvec.cend(); i++)
  cout << "[" << i->re << "," << i->im << "]" << endl;

std::vector<int> vi{1, 2, 3};
cout << "begin: " << *vi.begin() << ", end: " << *vi.end(); << endl;
```

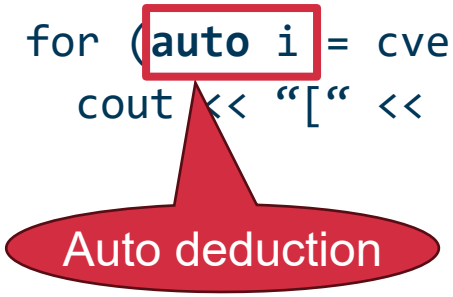
What happens?

Iterators

*An object representing **references to elements** inside a container*

```
struct Complex { double re; double im; };
using ComplexVec = std::vector<ComplexVec>;
ComplexVec cvec{{1., 1.}, {2., 2.}, {3., 3.}};

for (auto i = cvec.cbegin(); i != cvec.cend(); i++)
  cout << “[“ << i->re << “,” << i->im << “]” << endl;
```



Iterators

*An object representing **references to elements** inside a container*

```
struct Complex { double re; double im; };
using ComplexVec = std::vector<ComplexVec>;
auto cvec{{1., 1.}, {2., 2.}, {3., 3.}};

for (aut i = cvec.cbegin(); i != cvec.cend(); i++)
  cout << "[" << i->re << "," << i->im << "]" << endl;
```

What is the type here?

Work 1: Summing Program

Program that prints a sum of all numbers

Implement **special methods only in C/D**

- Ctors, dtors, operators, …

Can add O(1) **attributes into C** (e.g., no `vector`)

`C::print()` **only** used for printing

Goal: Understand **when** special methods are called

Submit the final version to Gitlab → 1 point

- **Deadline: Thursday November 6th 5:00**

```
class C {
  /* CAN ADD MORE ATTRIBUTES */
  const int value;
  /* USE THIS FUNCTION FOR PRINTING */
  void print() const {
    cout << value << "\n";
  }

public: /* IMPLEMENT SPECIAL METHODS ONLY */
};

class D {
  std::vector<C> cs; /* NO MORE ATTRIBUTES */
public: /* IMPLEMENT SPECIAL METHODS ONLY */
};

int main(int argc, char *argv[]) {
  int first, last;
  cin >> first >> last;
  cout << ”Summing numbers:\n";
  D d(first, last); // prints: first, ..., last
  cout << "Preparing...\n";
  D d2 = d;
  cout << "Sum of the numbers:\n";
  d2 = d; // prints sum of numbers first...last
}
```

Work 2: N-in-row for P players

A generic N-in-row (“Piškvorky”) for P players

Set the **number of players** and **how many symbols in row** is needed
Set the **names** and **symbols** for individual players to **visualize** the game
Players take **turns**
Game ends when the **first** player has **N-in-row**
Validate player **inputs**

Submit the final version to Gitlab → 3 point

- **Deadline: Thursday November 6th 5:00**

Lab 4

24/10/2025

Homework Feedback

Will be put today into Gitlab

The **first occurrence** of mistakes **can be corrected** during one iteration of code review.

Repeated mistakes will be **penalized**.

Defining Your Own Types

Use **`using`** (or **`typedef`** in old C/C++)
Can be templated (later)

```
using my_int = int;
using int_pair_t = std::pair<my_int, my_int>;
using my_string = std::vector<char>;
using int_vector_t = std::vector<int>;

my_int x = 3;
int_pair_t p{10, 20};
my_string str = {‘a’, ‘b’, ‘c’};
int_vector_t vi(10, 0);
```

Constant Values

Read only value that cannot be changed
Naming values in code
~ Every number in the code should be a named constant

```
constexpr double PI = 3.14;
constexpr size_t MAX_SIZE = 16 * 1024 * 1024;
```

`const`
A constant value that cannot be changed

`constexpr`
Constant value (potentially) evaluated at **compile time**
Can be used as arguments to templates

Both can be used together with `static` (later)

Argument Passing - Recap

How would you design a (global) function that sums two matrixes and return the new one?

Return

a) `Matrix sum(...)`
b) `const Matrix sum(...)`
c) `Matrix &sum(...)`
d) `const Matrix &sum(...)`
e) `Matrix &&sum(...)`
f) `Matrix *sum(...)`
g) `const Matrix *sum(...)`

Argument Passing - Recap

How would you design a (global) function that sums two matrixes and return the new one?

Arguments

a) `Matrix sum(Matrix m1, Matrix m2)`
b) `Matrix sum(const Matrix m1, const Matrix m2)`
c) `Matrix sum(const Matrix &m1, const Matrix &m2)`
d) `Matrix sum(Matrix &m1, Matrix &m2)`
e) `Matrix sum(Matrix &&m1, Matrix &&m2)`

Transferring Ownership

R-value references - &&

Moves the object somewhere (into a function)

- Use `std::move` on the caller side

The object no longer lives outside (the function)

Typical usage

A single owner, e.g., `std::unique_ptr`

Processing large objects

```
vector<unique_ptr<int>>::push_back(
    unique_ptr<int> &&new_obj);

vector<unique_ptr<int>> vector_of_ints;
vector_of_ints.push_back(move(make_unique<int>(x));
```

Transferring Ownership

R-value references - &&

Moves the object somewhere (into a function)

- Use `std::move` on the caller side

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Typical usage

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Processing large objects

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vector<unique_ptr<int>>::push_back(
    unique_ptr<int> &&new_obj);

vector<unique_ptr<int>> vector_of_ints;
vector_of_ints.push_back(move(make_unique<int>(x));
```

```
vector<int> vi1{1, 2, 3};
vector<int> vi2 = std::move(vi1);
print(vi1);
```

Special Methods

```
class Verbose {
  int x;
public:
  Verbose() {
    cout << "default ctor\n";
    this->x = 1;
  }

  Verbose(const Verbose &v) {
    cout << "copy ctor\n";
    this->x = v.x;
  }

  Verbose(Verbose &&v) {
    cout << "move ctor\n";
    this->x = v.x;
    v.x = 0;
  }

  ~Verbose() {
    cout << "dtor\n";
  }

  Verbose(int x) {
    cout << "user ctor\n";
    this->x = x;
  }

  Verbose &operator=(const Verbose &v) {
      cout << "copy assignment\n";
      this->x = v.x;
      return *this;
    }

    Verbose &operator=(Verbose &&v) {
      cout << "move assignment\n";
      this->x = v.x;
      return *this;
    }
};

int main()
{
  Verbose v1; // default ctor
  Verbose v2(2); // user ctor
  Verbose v3{3}; // user ctor
  Verbose v4(v2); // copy ctor
  Verbose v5 = v3; // copy ctor
  Verbose v6(std::move(v1)); // move ctor
  Verbose v7 = std::move(v4); // move ctor
  v1 = v2; // copy assignment
  v2 = std::move(v3); // move assignment
} // Calls destructors
```

Static Members

Attribute/method belongs to a class (not an object/instance)

Need to **share** attribute/method **among** all the objects/**instances**

Accesses through `::`

Most things belong to an object

```
class Verbose {
  static int cnt;
}; // class

int Verbose::cnt = 0;

int main()
{
  Verbose v1; // 1st object/instance
  Verbose v2(2); // 2nd object/instance
  std::cout << Verbose::cnt;
}
```

Static Members - Example

```
class CountingClass {
  static size_t num_instances;

  static void change_num_instances(int val) {
    num_instances += val;
  }

public:
  static bool has_instance() {
    return num_instances > 0;
  }
  static size_t get_num_instances() {
    return num_instances;
  }

  CountingClass() { ??? }
 ~CountingClass() { ??? }

  CountingClass(const CountingClass &) {
    ???
  }
  CountingClass(CountingClass &&) { ??? }
};

size_t CountingClass::num_instances = 0;
```

```
void f() {
  cout << CountingClass::get_num_instances() << endl; // 0
  CountingClass cc1;
  cout << CountingClass::get_num_instances() << endl; // 1
  CountingClass cc2 = cc1;
  cout << CountingClass::get_num_instances() << endl; // 2
  std::vector<CountingClass> ccs(10);
  cout << CountingClass::get_num_instances() << endl; // 12
}

int main() {
  cout << CountingClass::get_num_instances() << endl; // 0
  f();
  cout << CountingClass::get_num_instances() << endl; // 0
}
```

Static Members - Example

```
class CountingClass {
  static size_t num_instances;

  static void change_num_instances(int val) {
    num_instances += val;
  }

public:
  static bool has_instance() {
    return num_instances > 0;
  }
  static size_t get_num_instances() {
    return num_instances;
  }

  CountingClass() { change_num_instances(+1); }
 ~CountingClass() { ??? }

  CountingClass(const CountingClass &) {
    ???
  }
  CountingClass(CountingClass &&) { ??? }
};

size_t CountingClass::num_instances = 0;
```

```
void f() {
  cout << CountingClass::get_num_instances() << endl; // 0
  CountingClass cc1;
  cout << CountingClass::get_num_instances() << endl; // 1
  CountingClass cc2 = cc1;
  cout << CountingClass::get_num_instances() << endl; // 2
  std::vector<CountingClass> ccs(10);
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}

int main() {
  cout << CountingClass::get_num_instances() << endl; // 0
  f();
  cout << CountingClass::get_num_instances() << endl; // 0
}
```

Static Members - Example

```
class CountingClass {
  static size_t num_instances;

  static void change_num_instances(int val) {
    num_instances += val;
  }

public:
  static bool has_instance() {
    return num_instances > 0;
  }
  static size_t get_num_instances() {
    return num_instances;
  }

  CountingClass() { change_num_instances(+1); }
 ~CountingClass() { change_num_instances(-1); }

  CountingClass(const CountingClass &) {
    ???
  }
  CountingClass(CountingClass &&) { ??? }
};

size_t CountingClass::num_instances = 0;
```

```
void f() {
  cout << CountingClass::get_num_instances() << endl; // 0
  CountingClass cc1;
  cout << CountingClass::get_num_instances() << endl; // 1
  CountingClass cc2 = cc1;
  cout << CountingClass::get_num_instances() << endl; // 2
  std::vector<CountingClass> ccs(10);
  cout << CountingClass::get_num_instances() << endl; // 12
}

int main() {
  cout << CountingClass::get_num_instances() << endl; // 0
  f();
  cout << CountingClass::get_num_instances() << endl; // 0
}
```

Static Members - Example

```
class CountingClass {
  static size_t num_instances;

  static void change_num_instances(int val) {
    num_instances += val;
  }

public:
  static bool has_instance() {
    return num_instances > 0;
  }
  static size_t get_num_instances() {
    return num_instances;
  }

  CountingClass() { change_num_instances(+1); }
 ~CountingClass() { change_num_instances(-1); }

  CountingClass(const CountingClass &) {
    change_num_instances(+1);
  }
  CountingClass(CountingClass &&) { ??? }
};

size_t CountingClass::num_instances = 0;
```

```
void f() {
  cout << CountingClass::get_num_instances() << endl; // 0
  CountingClass cc1;
  cout << CountingClass::get_num_instances() << endl; // 1
  CountingClass cc2 = cc1;
  cout << CountingClass::get_num_instances() << endl; // 2
  std::vector<CountingClass> ccs(10);
  cout << CountingClass::get_num_instances() << endl; // 12
}

int main() {
  cout << CountingClass::get_num_instances() << endl; // 0
  f();
  cout << CountingClass::get_num_instances() << endl; // 0
}
```

Static Members - Example

```
class CountingClass {
  static size_t num_instances;

  static void change_num_instances(int val) {
    num_instances += val;
  }

public:
  static bool has_instance() {
    return num_instances > 0;
  }
  static size_t get_num_instances() {
    return num_instances;
  }

  CountingClass() { change_num_instances(+1); }
 ~CountingClass() { change_num_instances(-1); }

  CountingClass(const CountingClass &) {
    change_num_instances(+1);
  }
  CountingClass(CountingClass &&) { ??? }
};

size_t CountingClass::num_instances = 0;
```

```
void f() {
  cout << CountingClass::get_num_instances() << endl; // 0
  CountingClass cc1;
  cout << CountingClass::get_num_instances() << endl; // 1
  CountingClass cc2 = cc1;
  cout << CountingClass::get_num_instances() << endl; // 2
  std::vector<CountingClass> ccs(10);
  cout << CountingClass::get_num_instances() << endl; // 12
}

int main() {
  cout << CountingClass::get_num_instances() << endl; // 0
  f();
  cout << CountingClass::get_num_instances() << endl; // 0
}
```

Work 1: Implement Class C

Implement class C so the program outputs:
`1,2,3,…,16`

Touch **only** class C, nothing else

- Nothing can be added/changed main() or fn_XXX()

Don't use `exit()`, `break`, `goto`, …

Hint: which methods are called?

Submit the final version to Gitlab → 1 point

- **Deadline: Thursday October 30th 5:00**

```
class C { /* implement me */ };
```

```
// Don't touch anything below!!!
void fn_copy(C) {}
void fn_cref(const C&) {}
void fn_rref(C&&) {}

int main(int argc, char* argv[])
{
  cout << "1\n";
  C c1;
  cout << "3\n";
  C c2(c1);
  cout << "5\n";
  C c3 = c2;
  cout << "7\n";
  fn_copy(c1);
  cout << "9\n";
  fn_cref(c1);
  fn_copy(std::move(c1));
  fn_rref(std::move(c2));
  cout << "11\n";
  c3 = c2;
  cout << "13\n";
  c2 = std::move(c1);
  cout << "15\n";
}
```

Work 2: 3D Matrix for Integers v2.0

New API

- `print()`
- `sort_vector(x, y) // check STL`

Try and benchmark performance of different containers: `std::vector, std::deque, std::list, std::array`

- Should be ~2 (un)commented lines only to change the container
- `std::chrono::system_clock::now();`
- Put your measured numbers into a comment
  - **Release** mode, **large enough tests**, …

Correct all issues from the previous HW
Implement correctly all special methods
Show usage/test

Submit the final version to Gitlab → 2 points

- **Deadline: Thursday October 30th 5:00**

Lab 2

10/10/2025

Homework

Comments in Gitlab

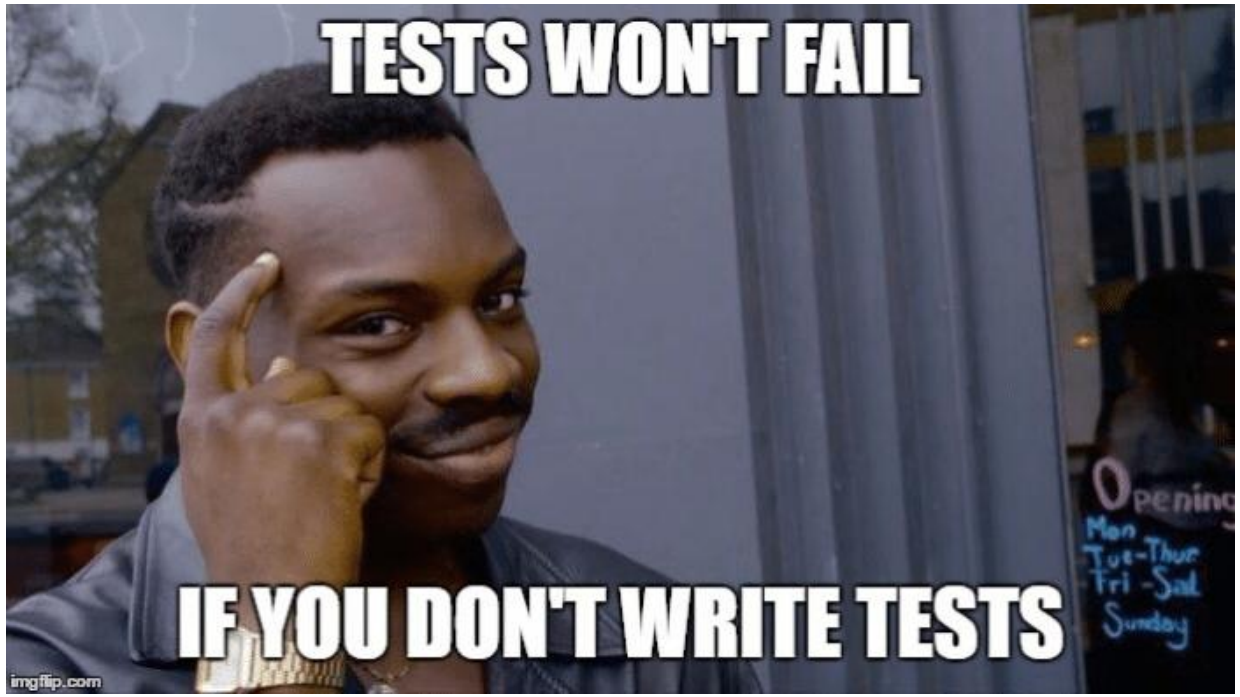
Points can be found in “Studijní mezivýsledky”

Homework Feedback

Testing is integral part of the assignment

I expected to see at least an attempt

Don’t choose the easier way out



Homework Feedback

Testing is integral part of the assignment

Use STL wherever possible

- Someone **smart** already spent lots of time **programming** and **testing** it

std::stod instead of handmade parsing:

Core Guidelines

Set of guidelines for using C++ well

https://isocpp.github.io/CppCoreGuidelines/CppCoreGuidelines

https://isocpp.github.io/CppCoreGuidelines/CppCoreGuidelines#fcall-parameter-passing

Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	`string &`

```
_GLIBCXX_NODISCARD _GLIBCXX20_CONSTEXPR
      reference
      operator[](size_type __n) _GLIBCXX_NOEXCEPT
      {
         __glibcxx_requires_subscript(__n);
         return *(this->_M_impl._M_start + __n);
      }

_GLIBCXX_NODISCARD _GLIBCXX20_CONSTEXPR
      const_reference
      operator[](size_type __n) const _GLIBCXX_NOEXCEPT
      {
         __glibcxx_requires_subscript(__n);
         return *(this->_M_impl._M_start + __n);
      }
```

Link: https://github.com/gcc-mirror/gcc/blob/master/libstdc%2B%2B-v3/include/bits/stl_vector.h

Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	**`const string &`**	`string &`

```
template<typename _CharT, typename _Traits, typename _Alloc>
   _GLIBCXX20_CONSTEXPR
   void
   basic_string<_CharT, _Traits, _Alloc>::
   _M_assign(const basic_string& __str)
   {
     if (this != std::__addressof(__str))
         {
           const size_type __rsize = __str.length();
           const size_type __capacity = capacity();

           if (__rsize > __capacity)
             {
               size_type __new_capacity = __rsize;
               pointer __tmp = _M_create(__new_capacity, __capacity);
               _M_dispose();
               _M_data(__tmp);
               ...
```

Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	**`int &`**
Large	`const string &`	`string &`

```
template<typename _CharT, typename _Traits, typename _Alloc>
    _GLIBCXX20_CONSTEXPR
    typename basic_string<_CharT, _Traits, _Alloc>::pointer
    basic_string<_CharT, _Traits, _Alloc>::
    _M_create(size_type& __capacity, size_type __old_capacity)
    {
      // _GLIBCXX_RESOLVE_LIB_DEFECTS
      // 83.  String::npos vs. string::max_size()
      if (__capacity > max_size())
          std::__throw_length_error(__N("basic_string::_M_create"));

      // The below implements an exponential growth policy, necessary to
      // meet amortized linear time requirements of the library: see
      // http://gcc.gnu.org/ml/libstdc++/2001-07/msg00085.html.
      if (__capacity > __old_capacity && __capacity < 2 * __old_capacity)
          {
            __capacity = 2 * __old_capacity;
            // Never allocate a string bigger than max_size.
            if (__capacity > max_size())
              __capacity = max_size();
          ...
```

Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	**`string &`**

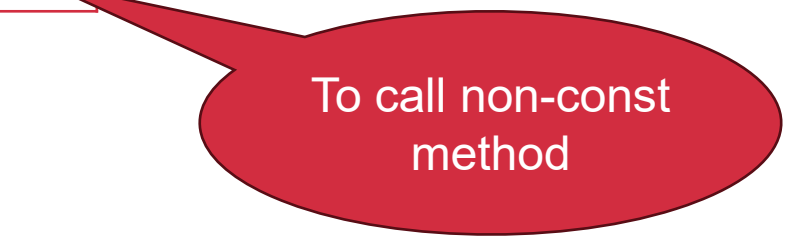
```
template<typename _Ch_type, class _Alloc, class _Rx_traits>
    inline bool
    regex_search(const _Ch_type* __s,
                 match_results<const _Ch_type*, _Alloc>& __m,
                 const basic_regex<_Ch_type, _Rx_traits>& __e
                 regex_constants::match_flag_type __f,
                 = regex_constants::match_default)
    { return regex_search(__s, __s + _Rx_traits::length(__s), __m,
__e, __f); }
```

Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	**`string &`**

```
template<typename _Ch_type, class _Alloc, class _Rx_traits>
    inline bool
    regex_search(const _Ch_type* __s,
                 match_results<const _Ch_type*, _Alloc>& __m,
                 const basic_regex<_Ch_type, _Rx_traits>& __e
                 regex_constants::match_flag_type __f,
                 = regex_constants::match_default)
    { return regex_search(__s, __s + _Rx_traits::length(__s), __m,
__e, __f); }
```

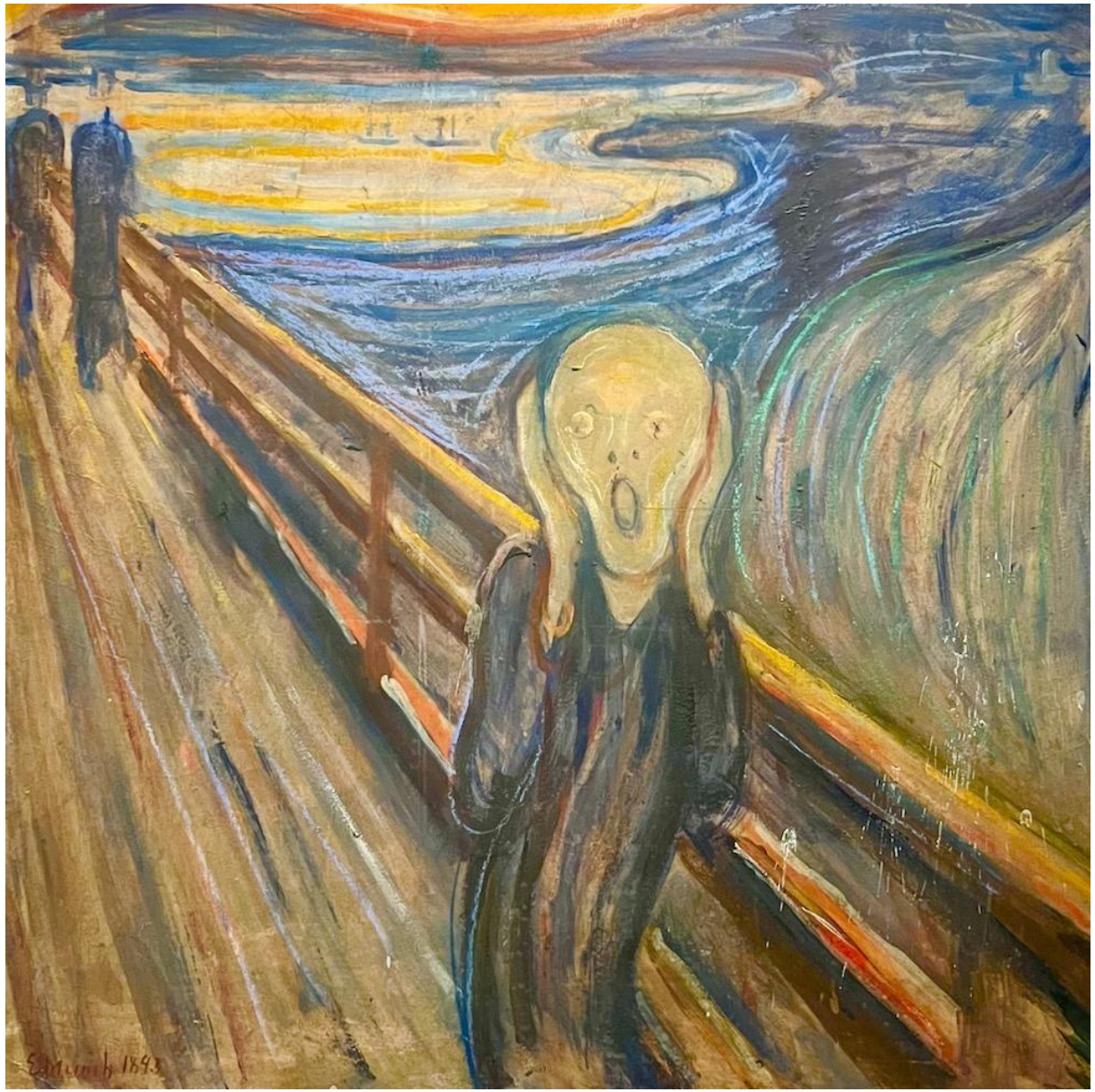


Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	**`string &`**

Why is there no Out?

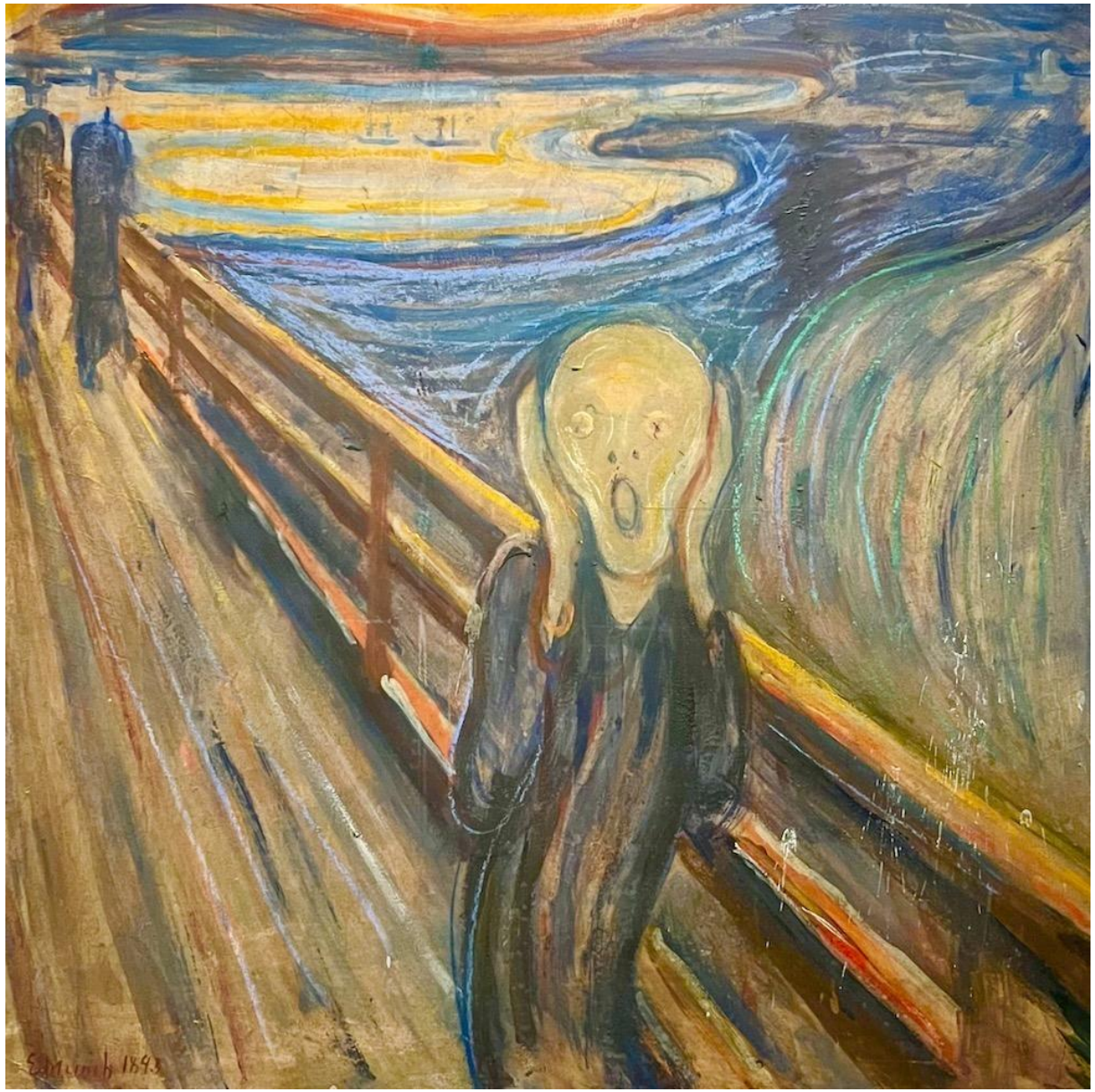


Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	**`string &`**

Use return

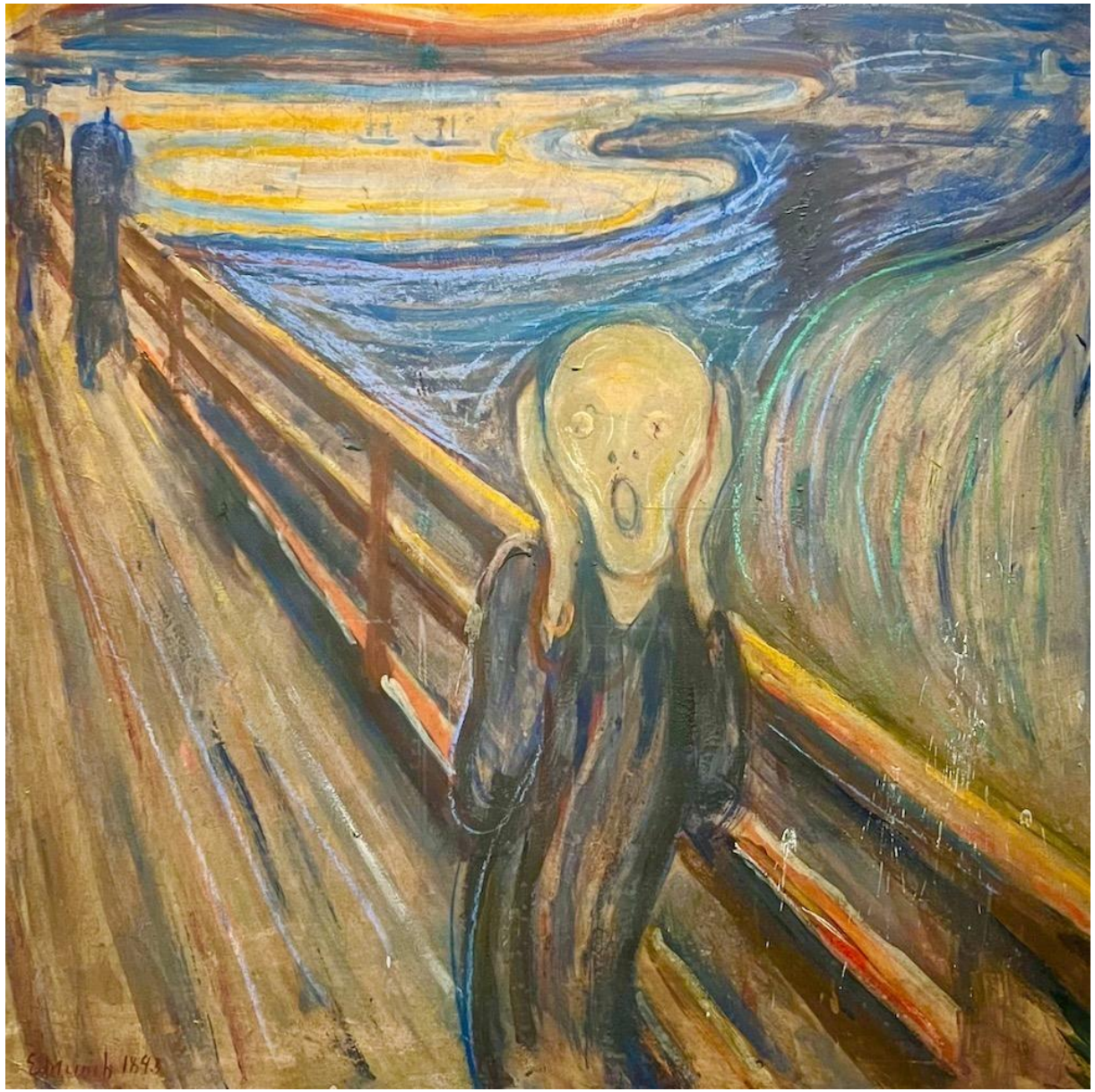


Parameter Passing

Rule of thumb

Size	In	In-Out
Small	`int`	`int &`
Large	`const string &`	**`string &`**

What if there are multiple values?



Returning from Functions

Rule of thumb

Returning multiple values

```
template< class T >
void minmax(std::initializer_list<T> ilist,
        T& min, T& max);
```

Violates SOLID?

- single responsibility principle

Returning from Functions

Rule of thumb

Returning multiple values

Violates SOLID?

- single responsibility principle

Refactoring

```
template< class T >
void minmax(std::initializer_list<T> ilist,
        T& min, T& max);
```

→

```
template< class T >
T min(std::initializer_list<T> ilist);

template< class T >
T max(std::initializer_list<T> ilist);
```

Returning from Functions

Rule of thumb

Returning multiple values

Does not violate SOLID

Use `std::pair/std::tuple`

```
template< class T >
void minmax(std::initializer_list<T> ilist,
        T& min, T& max);
```

→

```
template< class T >
std::pair<T, T> minmax(
        std::initializer_list<T> ilist );
```

Class/Struct

Put all related things (data, functions) together

- Represents objects in OOP
- almost everything should belong to a class

No real difference except for default visibility, inheritance, …

- class – by default everything private
- struct – by default everything public

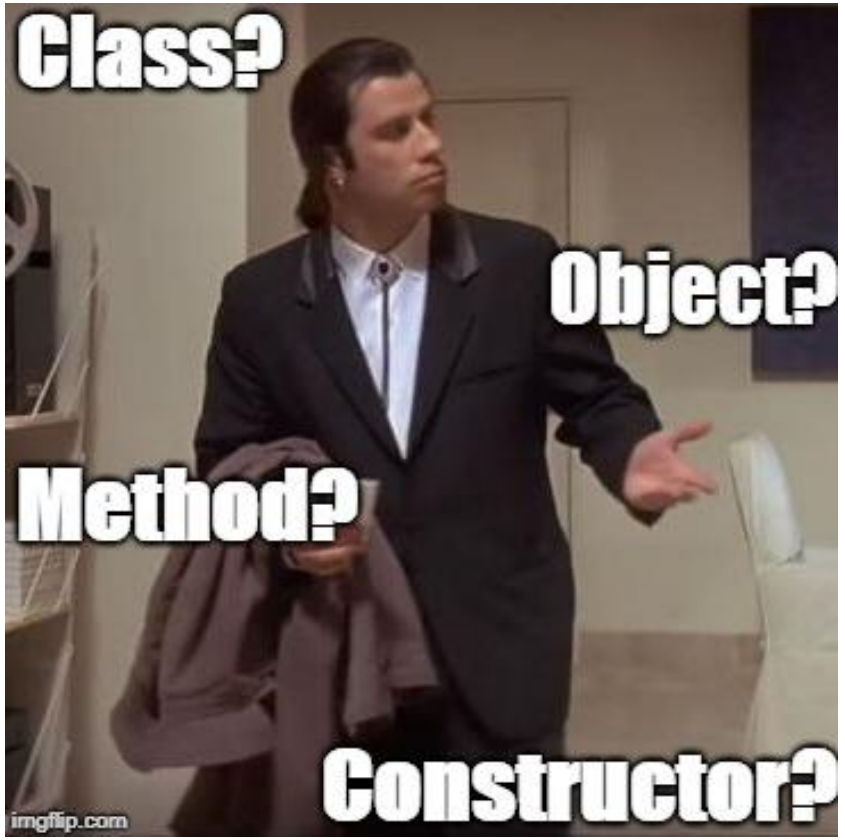
Internal things → private

- protected if need access from a child

Read-only functions → const

- const-correctness

Special methods (**constructor**, destructor, …)



Class Example

```
class calculator {
  // by default everything is private
  void sum();
  void substract();

public:
  calculator() { /* default ctor */ }
  calculator(const std::string &str) () {
    /* ctor */
  }
  void calc(const std::string &str);
  void print_result() const;

private:
  void multiply();

protected:
  void init();
};
```

can be used multiple times

semicolon at the end!

```
calculator c; // no need for new
c.calc("1+2-3");
c.print_result();

// calling non-default ctor
calculator c2("1+2-3");
c.print_result();

// creating a vector
std::vector<calculator> calcs;
```

Class vs. Struct

Use `class` if the class has an invariant;

Use `struct` if the data members can vary independently

```
struct coordinate {
  int x;
  int y;
  int z;

  coordinate();
  coordinate(int x);
  coordinate(int x, int y);
  coordinate(int x, int y, int z);

  void set(int x, int y, int z);
};
```

Dynamic Array - std::vector<T>

Beware of time complexity of individual methods

`vector<bool>` optimization

```
#include <vector>
int main() {
  std::vector<int> vi{1, 2, 3, 4, 5, 6};              // [1, 2, 3, 4, 5, 6]
  std::vector<float> vf(5, 0.0f);                     // [0.0, 0.0, 0.0, 0.0, 0.0]
  std::cout << vi[3] << " " << vf.at(3) << std::endl; // access the 4th! element
  std::cout << vi.size();
  vi[3] = 100; vi.at(6) = 600;          // access the 4th and 7th element
  vf.push_back(100.0f); vf.emplace_back(200.0f);          // insert at the end
  vf.emplace_back(200.0f);                            // create element at the end
  vf.insert(3, 300.0f); vf.emplace(3, 300.0f); // insert at the specific place
  vf.emplace(3, 300.0f);                // create element at the specific place
  vi.pop_back();                        // erase the last element
  vf.erase(2);                          // erase the 3rd element
  vi.clear();                           // clear whole container
  vi.reserve(10);          // reserve space(=memory) for 10 elements
  vi.resize(10);           // actually create 10 elements using default ctor
}
```

3D Matrix for Integers – minimal API

```
ctor(), ctor(x, y, z)
set(x, y, z, value), get(x, y, z), print()
set_width(), set_length(), set_heigth(), get_width(), get_length(),
get_height()
get_matrix(x), get_matrix(y), get_matrix(z)
get_vector(x, y), get_vector(y, z), get_vector(x, z)
clear()                                  // set all values to 0 (zero)
fill_with_value(value)                   // set all values to a given value
num_zeros(), num_negatives(), num_positives(); // number of zeros/negatives/...
```

rename/adjust functions if needed – but keep the sematic

Submit the final version to Gitlab → 2 points

- **Deadline: Thursday October 16th 5:00**

3D Matrix for Integers - Hints

Think about the design

- Compose: array → matrix → 3-D matrix → 4D matrix → … → XD matrix
- Design simple first, then continue to the next level

No need to focus too much on performance yet

Focus on:

- Passing arguments: const-references, references, …
- const functions
- class design: decomposition into functions, function reusing, private/public, ...

Lab 1

3/10/2025

Basic information

Email: tomas.faltin@matfyz.cuni.cz
Labs web: https://fan1x.github.io/teaching/2025-cpp
Lecture web: https://www.ksi.mff.cuni.cz/teaching/nprg041-web/
Mattermost

- Invite link in SIS/Notice-board
- Channel: `2526/nprg041-cpp-faltin`
- DM: @faltin.tomas

Gitlab

- https://gitlab.mff.cuni.cz/
- https://gitlab.mff.cuni.cz/teaching/nprg041/2025-26/klepl

Labs Credit

Small (home) works assignments

- Submitted either to ReCodex or Gitlab
- At least 20 out of 30 points required
- Points contributed to the final exam grade

Credit project

Communication is the key

Don’t be afraid to ask
Be proactive

- via email
- on Mattermost (instant)
  - DM if related to you only
  - Into a channel if others can benefit from it

If you struggle with something
If you feel like you might miss a deadline

Try things

Research project at our University

- Contact professor directly

Internships in companies

Erasmus

Conferences

…

Or not…

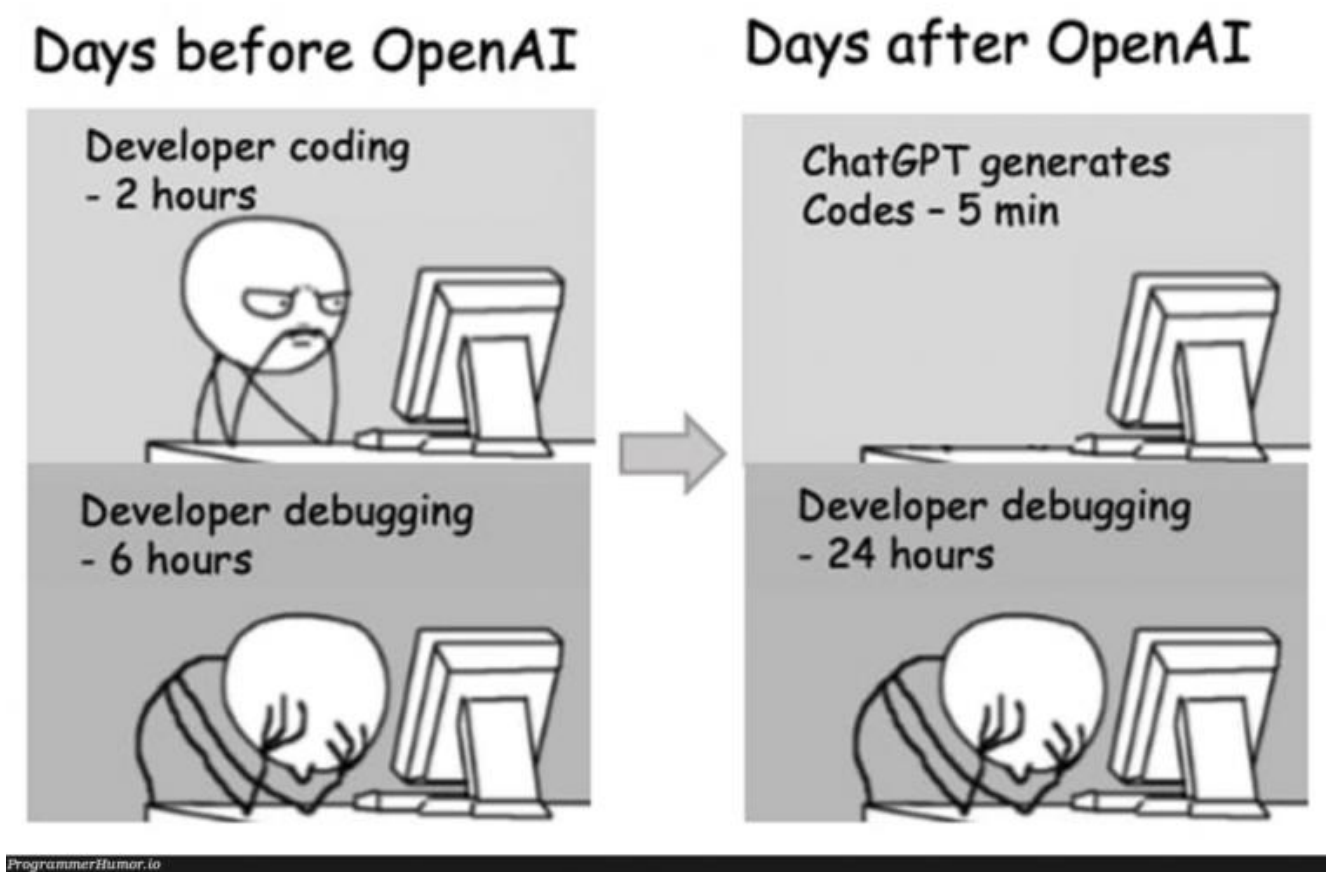
"There's a tiger in you"

Tiger in me :

Charles University

Let’s get it started

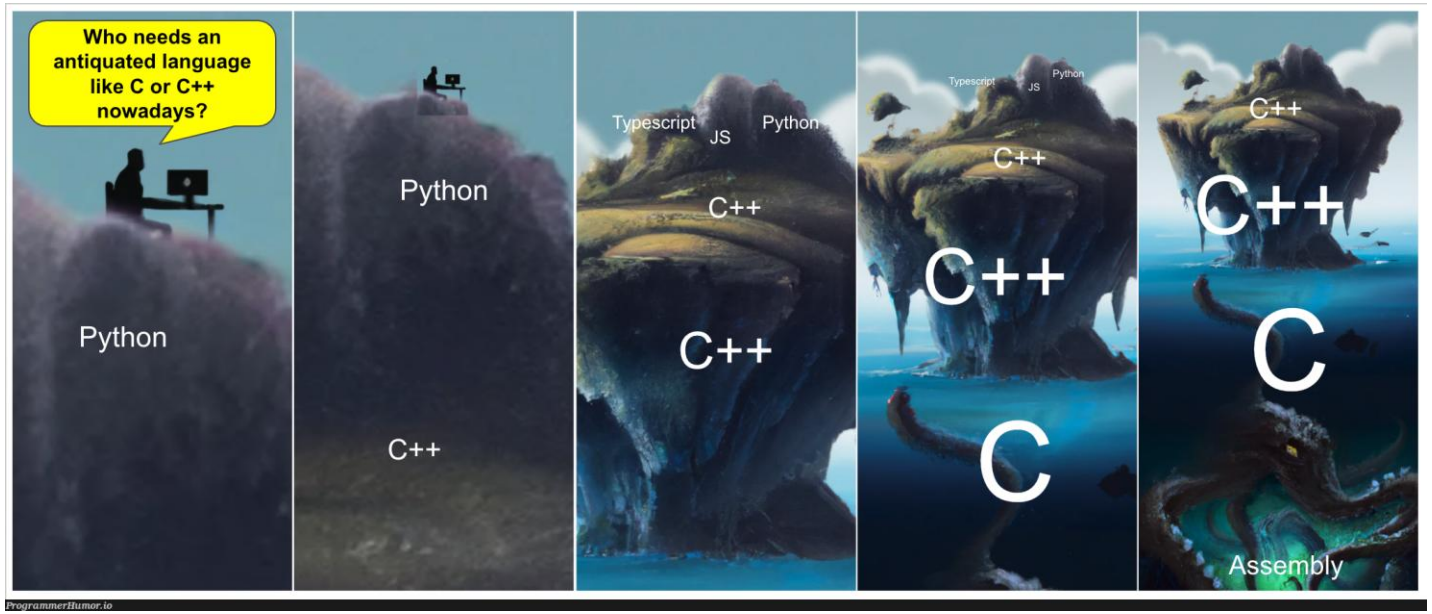
Motivation


Days before OpenAI
Developer coding
- 2 hours
Developer debugging
- 6 hours
Days after OpenAI
ChatGPT generates
Codes - 5 min
Developer debugging
- 24 hours
ProgrammerHumor.io


WAITING FOR A RESPONSE FROM
MY SUPPOSEDLY SMART AI AGENT
imgflip.com

Why C++

“C makes it easy to shoot yourself in the foot. C++ makes it harder, but when you do, it blows away your whole leg.”
-- Bjarne Stroustrup



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C++ (interesting) links

Reddit, Slack, …

https://en.cppreference.com/w/

http://www.cplusplus.com/

http://isocpp.github.io/CppCoreGuidelines/CppCoreGuidelines

https://www.youtube.com/user/CppCon

https://isocpp.org/

http://www.open-std.org/jtc1/sc22/wg21/docs/papers/

https://godbolt.org/

…

Working Environment

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Use anything you like
IDEs

- Visual Studio
  - License for students at https://portal.azure.com/...
- VS Code
- Clion
- Code::Blocks
- Eclipse
- …

Compilers

- MSVC, GCC, Clang+LLVM, ICC, …

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Quick Recap

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Code Requirements

Absence of Unforgivable Curses

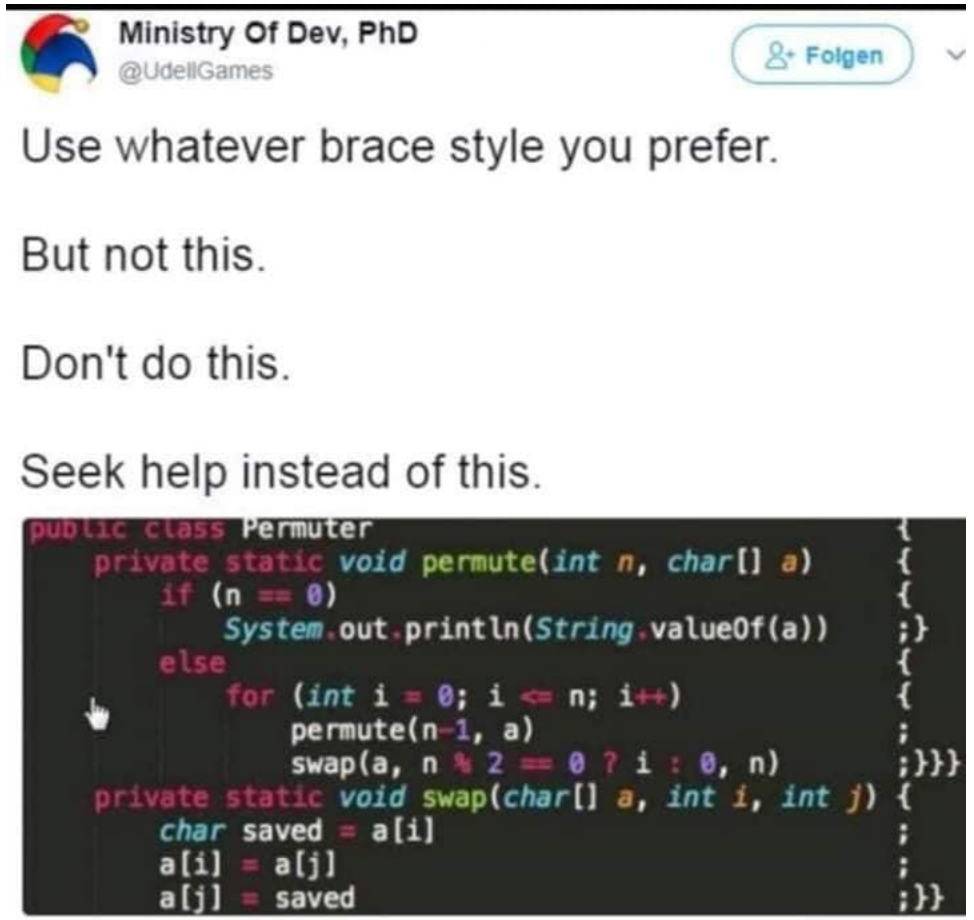
- https://teaching.ms.mff.cuni.cz/nswi170-web/pages/labs/coding/

1. Code decomposition
2. Using constants
3. DRY
4. No global variables
5. Encapsulation

Code Requirements - Consistency

Consistency

- Be consistent within the code
- keep a single code style

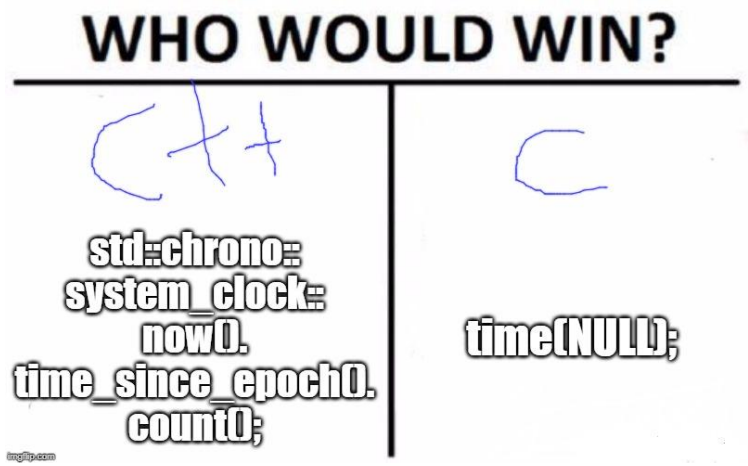


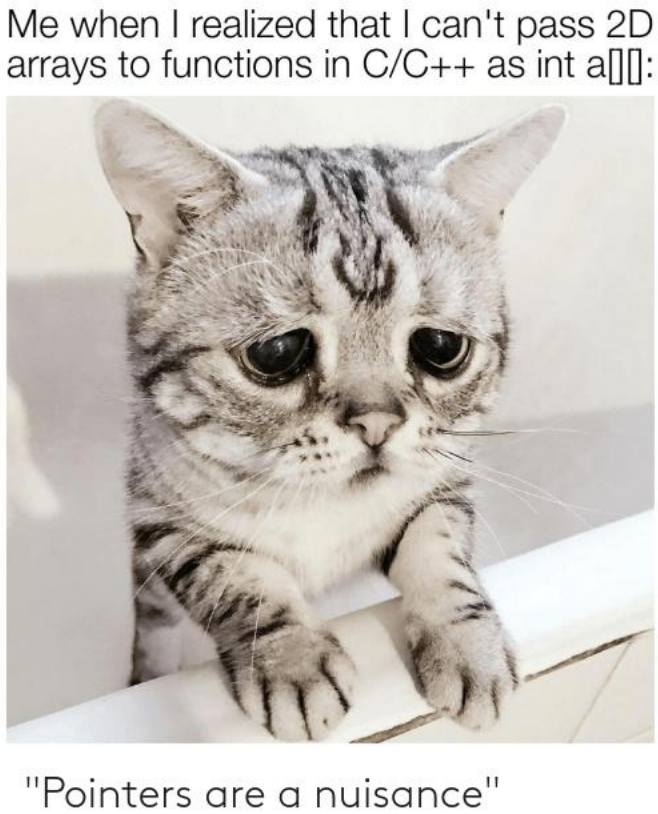
Code Requirements – Readability

Code doesn’t contain commented/dead parts
Code should be readable on its own
Comment complicated code

Code Requirements – Safe, Modern

Prefer using modern constructs
Additional safety
Maybe performance
E.g., prefer `std::vector<int>` to `new int[]`

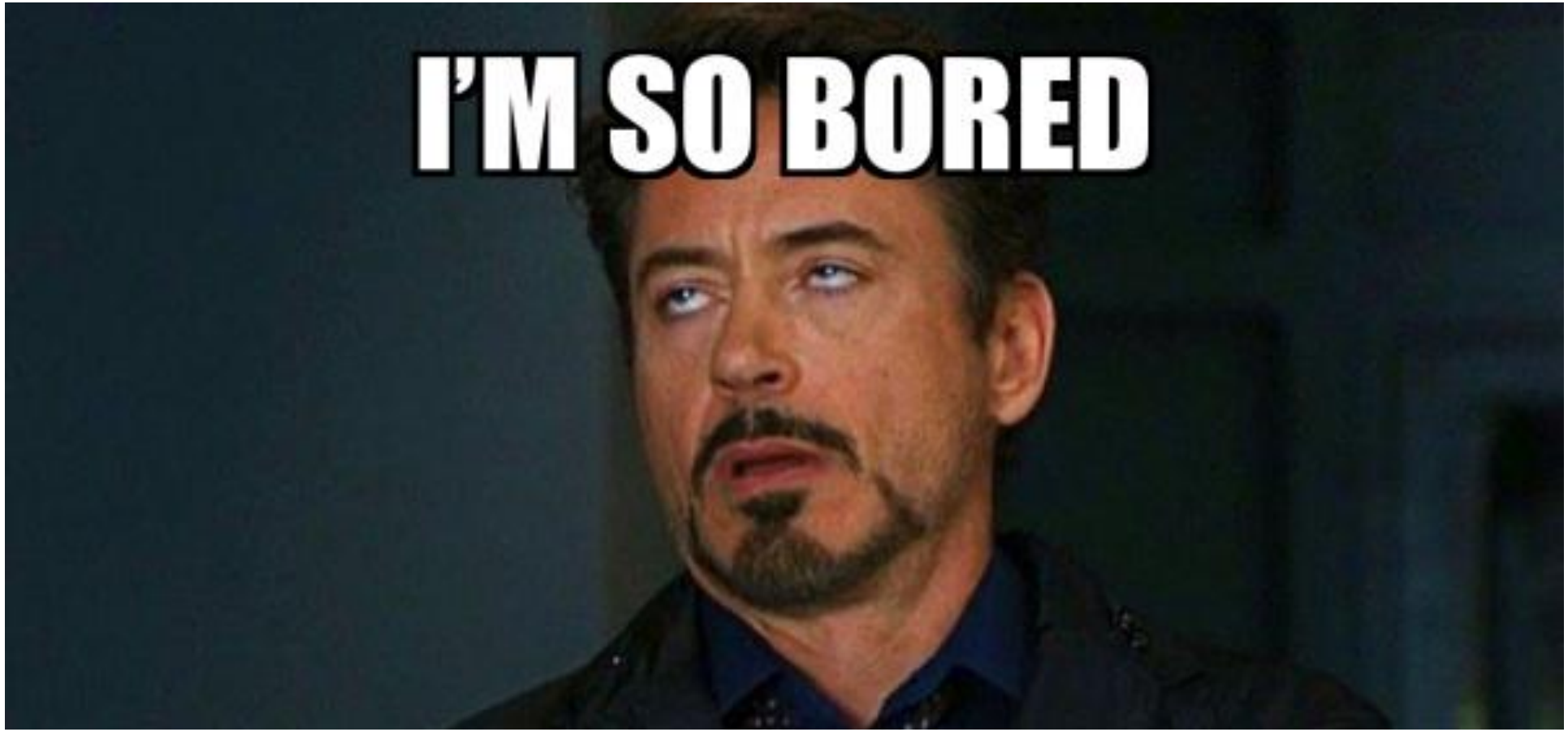




Code Requirements – Working

OFC, if the code is not working, all the above points are not that important they will help you with debugging at least ☺

Enough talking



Hello World

```
#include <iostream>
#include <string>

int main() {
  std::string name;
  std::cin >> name;
  std::cout << "Greetings from " << name << std::endl;
  return 0;
}
```

Charles University

Hello World

```
#include <iostream>
#include <string>

int main() {
  std::string name;
  std::cin >> name;
  std::cout << “Greetings from ” << name << std::endl;
  return 0;
}
```

Include the libraries which implements the used STL constructs (string, cin, cout)

The main entry point/function for all programs. The execution starts here

Declare a variable of type string

Read from standard input (keyboard)

Write to standard output (screen)

All the STL constructs live inside `std` namespace

Compilation

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c++ --version

- c++ is a compiler, here GCC

c++ hello_world.cpp -o hello_world

- Compile program into `hello_world` executable (using default settings)

c++ -Wall -Wextra -Werror -O3 -std=c++2b hello_world.cpp -o hello_world

- Wall: Show all warnings
- Wextra: Show additional extra warnings
- Werror: Thread all warnings as errors
- O3: level of optimizations
- std=c++2b: Used C++ standard

Or use IDE ☺

More Complex Program

Charles University

```
#include <iostream>
#include <string>
#include <vector>

using namespace std;

void pretty_print(const vector<string>& args) {
  // ... args[i]
}

int main(int argc, char** argv) {
  vector<string> args(argv, argv+argc);
  pretty_print(args);
  return 0;
}
```

More Complex Program

```
#include <iostream>
#include <string>
#include <vector>

using namespace std;

void pretty_print(const vector<string>& args) {
  // ... args[i]
}

int main(int argc, char** argv) {
  vector<string> args(argv, argv+argc); // Wrap arguments
  pretty_print(args);
  return 0;
}
```

Include the whole std namespace

Passing the argument by (const) reference

Number of argument

Arguments of the program on the command line

Transform "magically" the arguments into C++ array of strings

Functions And Parameters

```
int get_max(int v1, int v2) {
  return v1 > v2 ? v1 : v2;
}

int get_max1(const vector<int> &ints) {
  int max = std::numeric_limits<int>::min();
  for (int x : ints) {
    max = get_max(x, max);
  }
  return max;
}
```

```
bool get_max2(const vector<int> &ints, int &max) {
  max = std::numeric_limits<int>::min();
  for (int x : ints) {
    max = get_max(x, max);
  }
  return !ints.empty();
}

std::tuple<bool, int> get_max3(const vector<int> &ints) {
  int max = std::numeric_limits<int>::min();
  for (int x : ints) {
    max = get_max(x, max);
  }
  return { !ints.empty(), max };
}
```

Functions And Parameters

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read-only input parameter

- Most of the types (string, vector, …) → use const-reference - const &
  - `int get_max(const vector<int> &ints)`
- For small numeric types (int, float, double, …) → use direct parameter
  - `int get_max(int v1, int v2)`

output parameters

- Single output parameter → use return value
  - `int get_max(const vector<int> &ints)`
- Few output parameters → use tuple/pair/structure
  - `std::tuple<bool, int> get_max(const vector<int> &ints)`
- Many output parameters → use reference - &
  - `bool get_max(const vector<int> &ints, int &max)`

Work

1. Hello World
2. A greeting program (use names from arguments)
   - `hello.exe Adam Eve` → `Hello to Adam and Eve`
   - What is inside args[0]?
3. Summation of numbers from arguments
   - `sum.exe 1 2 3 4 5` → `15`
   - `stoi(), stod(), stoX()`
     - Functions for transformation from **s**tring **to** <something>
4. **A simple calculator (only for operations +-)**
   - `calc.exe 1+2+3-4` → `2`
   - The previous programs are not needed, but they should give you a lead
   - **Submit the final version to Gitlab → 3 points**
     - **Deadline: Thursday October 9th 5:00**