

Programming in C++

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Programming in C++ - lab 13

<https://fan1x.github.io/cpp22.html>
tomas.faltin@matfyz.cuni.cz

Reminder

- Software project
 - POC: 05/03/2023 (postponed)
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Feedback: Calculator

- Add tests for all special cases from code (-1p)
 - E.g., $3 / 0$, $3 / 2.3$, $1 + 2 * 3.3$
- Test in clean environment (-1p)
 - Redownload and build
- Warnings (-1p)
- Not OOP (-1p)

Kahoot

Programming in C++ - lab 12

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Larger HW – 25 points, 29/11 → 23/12
- Software project
 - **Topic must be approved by 27/11/2022**
 - **POC: 05/03/2023 (postponed)**
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Feedback: Data Aggregation

- Memory leak when manual allocation – use smart pointers
- Problems with the large tests
 - `std::vector<vector<Base *>>` vs. `std::vector<BaseVector *>`

Exceptions

- Predefined types in <stdexcept>
 - Create your own type through inheritance
- Use RAI

```
template<typename T> class matrix {
public:
    T &get(size_t x, size_t y) {
        if (!is_valid_range(x, y)) {
            throw std::out_of_range("Invalid x or y value");
        }
    }
};

matrix<int> mi;
try {
    cout << mi.get(10, 10);
} catch (const std::out_of_range &e) {
    cerr << e.what() << endl;
}
```


Regex

- `<regex>`
- Regular expressions in C++

HW1: Problem With Large Tests

- `std::vector<vector<Base *>>`

Programming in C++ - lab 11

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Larger HW – 25 points, 29/11 → 23/12
- Software project
 - **Topic must be approved by 27/11/2022**
 - **POC: 05/03/2023 (postponed)**
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Feedback: Data Aggregation

- -5 points: missed deadline
- -2 points
 - Not having virtual destructor with inheritance
 - Large tests not working
- -1 point
 - Using const function for read only methods
 - Using const references for large objects
 - Warnings
 - Large functions
 - procedural code
 - no classes/objects

Streams

- `<iostream>`
 - I/O
- `<fstream>`
 - Work with files
- `<sstream>`
 - Work with `std::string`

Homework – A Simple Text Editor

- Open/Edit/Save a file
- Print a directory
 - <filesystem>

Programming in C++ - lab 10

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, 15/11 → 5/12
 - Larger HW – 25 points, 29/11 → 23/12
- Software project
 - **Topic must be approved by 27/11/2022**
 - **POC: 05/03/2023 (postponed)**
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

2nd Large homework: Calculator

- Deadline: 23/12/2022 23:59
- 25 points
 - Functionality: 15 points
 - Tests & code culture: 10 points
 - 2/3 of points gained for functionality
- -10 points per each week (even if partial)

Piškvorky feedback

Templates



Template Functions

```
class complex {
    int real_; int im_;
public:
    int &re() { return real_; }
    int re() const { return real_; };
    int &im() { return im_; };
    int im() const { return im_; };
};

void print(int v) { cout << v; }
void print(double v) { cout << v; }
void print(const string &str) { cout << str; }

int main() {
    complex c;
    print(c.re());
}
```

```
template<typename T>
class complex {
    T real_; T im_;
public:
    T &re() { return real_; }
    T re() const { return real_; };
    T &im() { return im_; };
    T im() const { return im_; };
};

template<class T>
void print(const T &v) { cout << v; }

int main() {
    complex<int> c;
    print(c.re());
}
```


Template Classes

```
template<class Cont>
class container_wrapper {
    Cont cont;

public:
    void push_back(const typename Cont::value_type& val) {
        cont.push_back(val);
    }

    void push_back(typename Cont::value_type &&rval) {
        cont.push_back(std::move(rval));
    }
};
```

```
template<class Cont>
auto make_wrapper() {
    return container_holder<Cont>();
}
```

```
auto vector_wrapper = make_wrapper<std::vector<int>>>();
vector_wrapper.push_back(3);
```


Homework – vector<T>

- Generic vector
- Mandatory operations
 - default ctor, ctor(size_t, value_type), copy/move ctor/assignment
 - size(), capacity(), reserve(), push_back(), operator[]()

Programming in C++ - lab 9

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Improvements And Feedback

- [Online Feedback](#)

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - **Smaller HW – 15 points, 15/11 → 5/12**
 - Larger HW – 25 points, 29/11 → 23/12
- Software project
 - **Topic must be approved by 27/11/2022**
 - **POC: 05/03/2023 (postponed)**
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Iterators

- A class used for traversing and accessing containers (vector, map, ...)
- Act like pointers
 - Holds a position and points to an object inside the container
- Different types of iterators (input, forward, bidirection, random, ...)
 - Iterators on containers supports at least: *, ++, !=
- `begin()` – returns an iterator to the first element
- `end()` - returns an iterator pointing past the last element

Lambdas

- An unnamed function object ("in-place function")
- `[capture](par1, par2, ...) { /* function body */ };`
 - capture: things passed from outside function
 - Passing by reference (&), otherwise by copy
 - Can define a new variable
- ~ Anonymous functor
 - Returning from function through templates/auto



Functors

- A special object behaving like a function
- Defines `operator()`
- Can hold its state

Algorithms

- `#include <algorithm>`
- A library defining functions for variety of purposes
 - `sort`, `make_heap`, `set_intersection`
- Define range through iterators
 - Anything iterator-like (iterators, pointers, ...)
- Define action through function/functor/lambda
 - Anything function-like (functions, functors, ...)
- 😊 `ranges`

Homeworks: Fix Previous Homeworks Using Algorithms

- Dictionary (exo6)
- Simple People Database (exo6, Recodex)
 - Add a function that can do multiple things through a single iteration
 - Use functors (or somethings similar)
 - Gather min, max, sum, avg, ...
- Sorting in Polymorphic Vector

Programming in C++ - lab 8

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Improvements And Feedback

- [Online Feedback](#)

Homework Discussion

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, 15/11 → 5/12
 - Larger HW – 25 points, most probably 29/11 → 23/12
 - Ping me if you want to start sooner
- Software project
 - Topic must be approved by 27/11/2022
 - POC: 18/12/2022
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Data Aggregation - Hints

- Download example input+output and debug locally
 - `PRG.exe < input_file.txt > output_file.txt`
- Check logs what's wrong
- Write your own tests!
 - (get inspired by ReCodex's tests)
- Time & memory limits
 - Store necessary things once
 - Use observers (pointers, references) instead
 - Use proper types
 - Don't store numbers as string
 - Avoid copying – `const` &

Functions As Parameter – std::function

- std::function<RET(PAR1, PAR2,...)>

```
void for_each(const std::vector<int> &vi,  
             const std::function<void(int)> &fn) {  
    for (int x : vi) {  
        fn(x);  
    }  
}
```

```
void print(int x) { cout << x << endl; }
```

```
int main(int argc, char* argv[]) {  
    vector<int> vi{1, 2, 3, 4, 5, 6};  
    for_each(vi, print);  
}
```


Function As Parameter – Other Options

- Lambdas
- Templates
- Function pointers/references
 - ☹ C-style

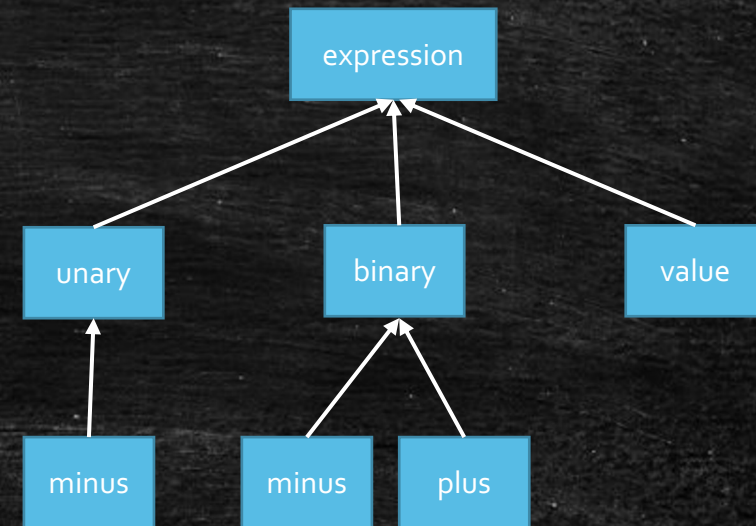
Inheritance

- To inherit (=use) attributes and methods of the ancestor class

```
class container {  
public:  
    using size_type = size_t;  
  
    size_t size() const { return size_; }  
  
protected:  
    size_t size_t;  
};  
  
class vector_int : public container { ... };  
class list_int : public container { ... };  
  
int main() {  
    vector_int vi;  
    cout << vi.size();  
}
```

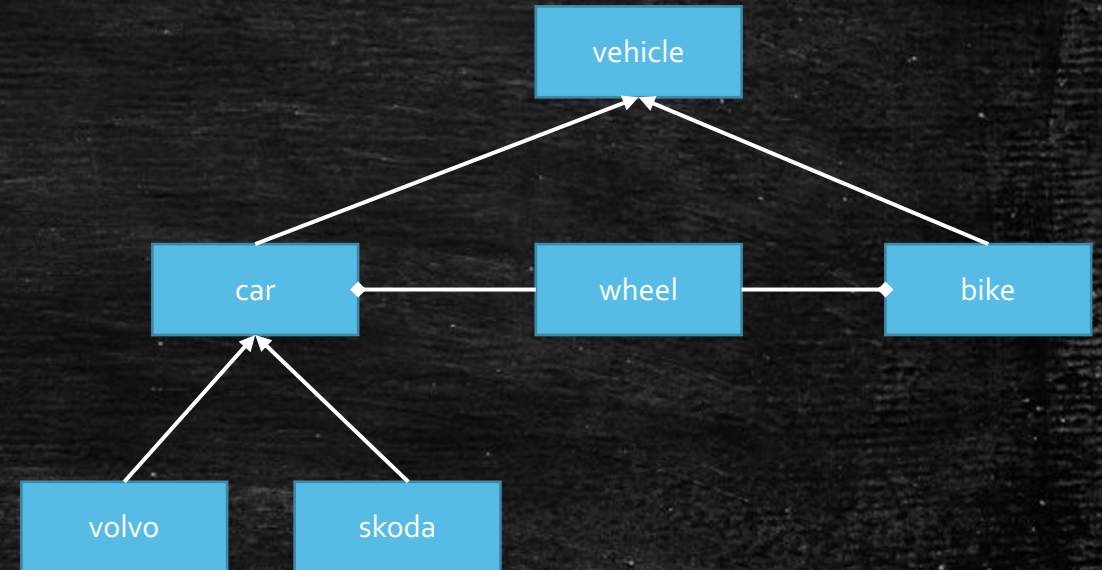

Inheritance Examples

```
class car {};  
class volvo : public car {};  
class skoda : public car {};  
  
class animal {};  
class dog : public animal {};  
class cat : public animal {};  
  
class employee {};  
class accountant : public employee {};  
  
class expression {};  
class binary : public expression {};  
class plus : public binary {};  
  
class object {} // JAVA  
class XYZ : public object {};
```



Inheritance Vs. Composition

- Inheritance – logical hierarchy
- Composition – no logical hierarchy
 - Can be implemented through inheritance



Inheritance Comments

- Think about the API
- Hide type specific things inside methods/functions
- `if-else` → bad design

Polymorphism

- Base class acts(=works) as the (internally stored) derived class
- Function must be **virtual** and gets **called via reference/pointer**

```
class base {
protected:
    int value = 0;
public:
    virtual ~base() = default;
    virtual void print() const {
        std::cout << "base: " << value;
    }
};

class derived : public base {
public:
    void print() const override {
        std::cout << "derived: " << value;
    }
};
```

```
int main() {
    derived d;
    d.print(); // derived: 0
    base &b = d;
    b.print(); // derived: 0
    base *b_ptr = &d;
    b_ptr->print(); // derived: 0
    base b2 = d;
    b2.print(); // base: 0
}
```


Homework: Polymorphic Vector

- Create a vector which can store different types
 - int, double, string
- Use inheritance (no union, variant, ...)
 - Dynamic allocation

```
// API
```

```
// insert a value  
push_back(value);  
// print the value of i-th element  
print(size_type i);  
// print all values inside the array  
print_all();
```

```
int main() {  
    my_vec v;  
    v.push_back(1);  
    v.push_back(2.3);  
    v.push_back("four");  
    v.print(0); // 1  
    v.print(2); // "four"  
    v.print_all(); // [1, 2.3, "four"]  
}
```


Programming in C++ - lab 6

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

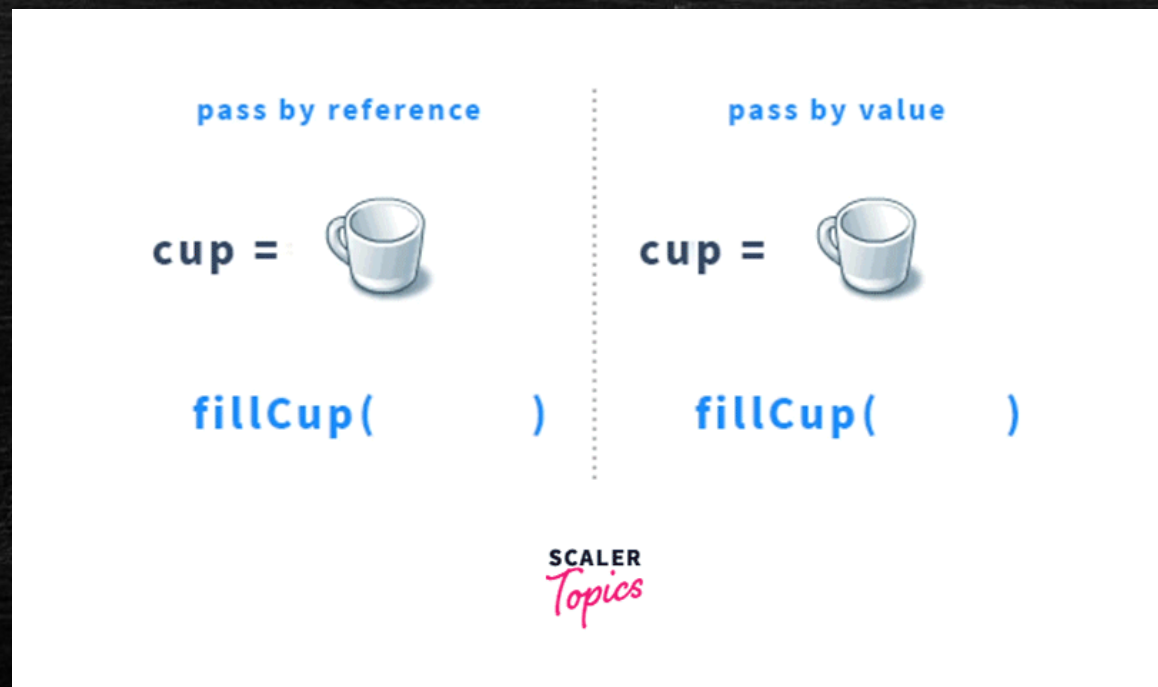
Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, assigned 15/11
 - Larger HW – 25 points, ~December
- Software project
 - Topic must be approved by 27/11/2022
 - POC: 18/12/2022
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Homework1 Solution

Returning A (Const) Reference

- To give an access to data inside an object
 - E.g., getters, operator=(), ...
- The returned data lives even after end of the function



Returning A (Const) Reference - Example

```
class complex_double {
    double im;
    double re;
public:
    explicit complex_double(double re, double im = 0.0) {
        this->im = im;
        this->re = re;
    }

    double &real_part() {
        return re;
    }
    double real_part() const {
        return re;
    }

    double &imaginary_part() {
        return im;
    }
    double imaginary_part() const {
        return im;
    }
};
```

```
int main() {
    complex_double cd(1, 2);
    cout << '{' << cd.real_part()
        << ',' << cd.imaginary_part() << '}' << endl;

    cd.imaginary_part() = 0;
    cout << '{' << cd.real_part()
        << ',' << cd.imaginary_part() << '}' << endl;
}
```


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 queue/array
 - `push_back()`, `push_front()`, `back()`, `front()`, ...
- `std::list<Type>` - linked list
- `std::map<Key, Value>`, `std::unordered_map<Key, Value>` - map
 - `my_map[key] = value`, `find()`, `insert()`, ...
- `std::set<Key>`, `std::unordered_set<Key>` - set
 - `contains()`, `insert()`, `find()`, ...

Homework1: Dictionary

```
// An example of API
class Dictionary {

    // Insert a new language and returns its ID
    size_t add_language(const string &name);

    // Insert new words into a dictionary
    bool add_vocabulary(size_t words1_language_id, const string &word1,
        size_t words2_language_id, const string &word2);

    // Translate a given text with the given language into the output language
    string translate(size_t input_language_id, const string &text,
        size_t output_language_id) const;

    // Automatically translate a given text into a given language
    string translate(const string &text, size_t output_language_id) const;

    // Return all vocabularies for a given language
    const vector<string> &all_vocabulary(size_t language_id) const;
};
```


Homework2: Simple People Database

- In Recodex: <https://recodex.mff.cuni.cz/>
- Deadline: Monday 13:00
- **NOT** the official large homework
 - Just to test your knowledge and the access to the ReCodex

Programming in C++ - lab 7

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

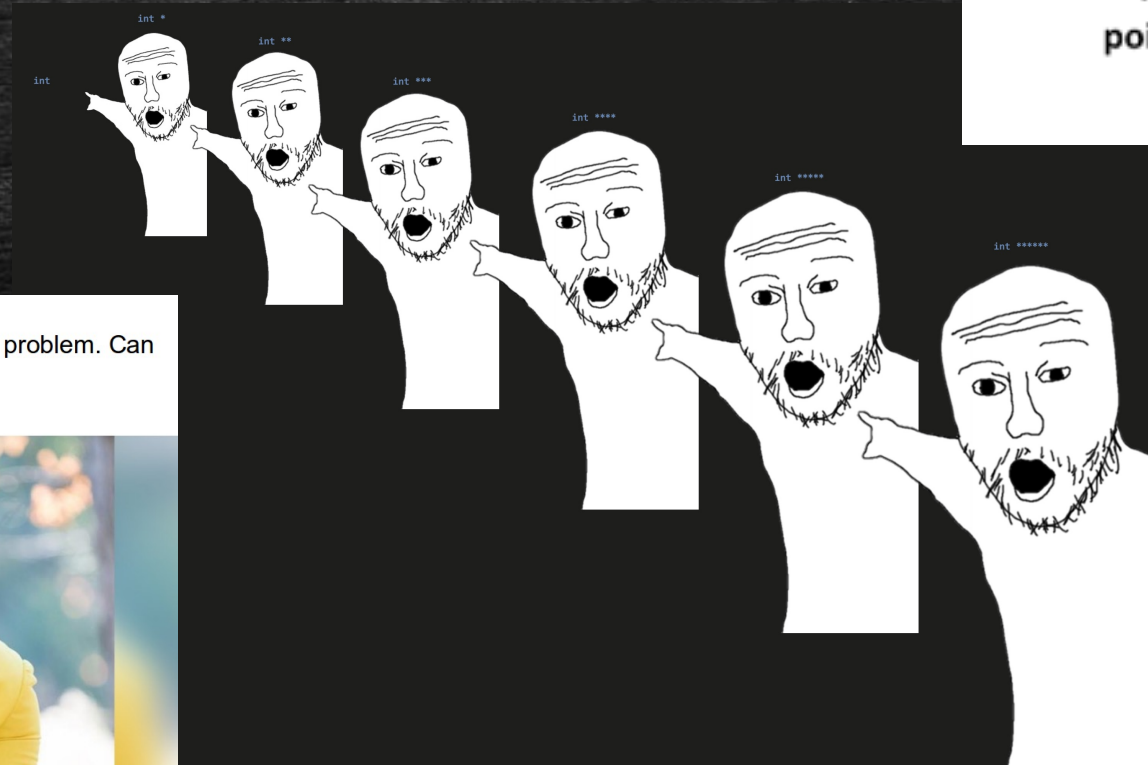
Homework Discussion

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, 15/11 → 5/12
 - Larger HW – 25 points, most probably 29/11 → 23/12
 - Ping me if you want to start sooner
- Software project
 - Topic must be approved by 27/11/2022
 - POC: 18/12/2022
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

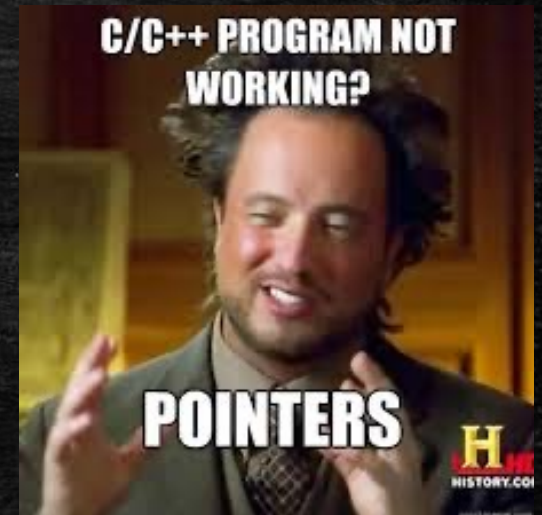
Pointers

C++
[C] raw pointers [++] trying to prevent people from using raw pointers



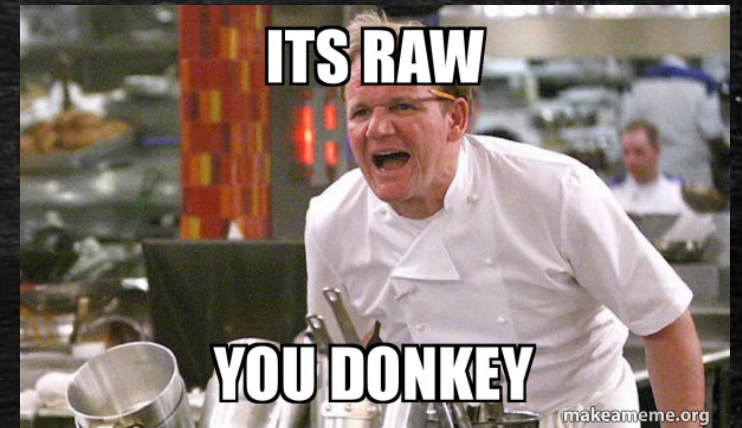
random dev: I got stuck with this problem. Can anyone give me some pointers?

C programmers



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
- Creation: `make_unique<T>`, `make_shared<T>`
- Allocation of consecutive memory (~array)
 - `make_unique<int[10]>()`



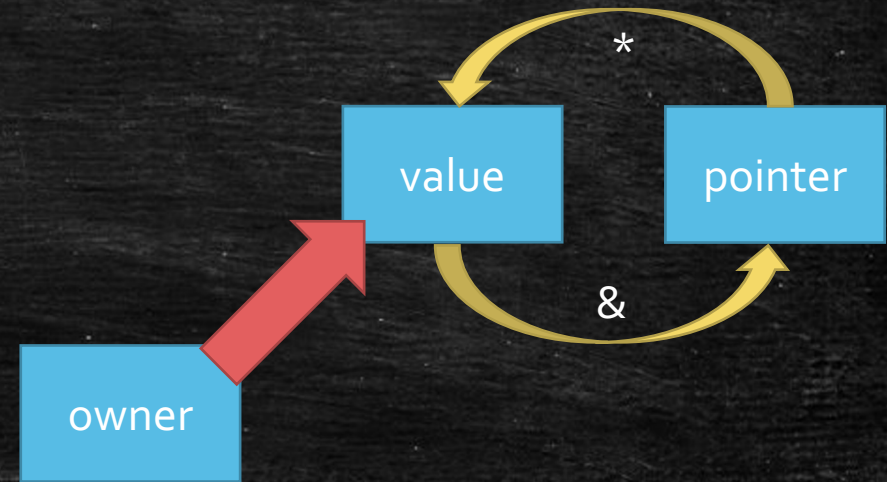
Observers

- Working with the pointer with **no changes to ownership**
- Returned type is a (const) pointer
 - Smart pointers - **get()**
 - Observer ~ Address
 - Getting an address: **&x**
- To access the values through a pointer
 - operator*****(), operator**->**()



Owners And Observers: Quick Rules

- Owner $\rightarrow$ `unique_ptr<T>`, `shared_ptr<T>`
- Modifying observer $\rightarrow$ `T * (pointer)`
- Read-only observer $\rightarrow$ `const T *`
- Getting an observer
 - smart pointers $\rightarrow$ `get()`
 - otherwise $\rightarrow$ `&(observer ~ address)`
- Accessing the value
 - access the value directly $\rightarrow$ `*`
 - access member attribute $\rightarrow$ `->` (same as doing `(*var)`).
- Pointing to nothing $\rightarrow$ `nullptr`



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  
}
```

Address	Value	(Variable)	operator*
....			
..00	2	i	*
..02			
..04	..00	pi	*
..06			
..08	..04	ppi	*
..0a			
....			



The diagram illustrates the memory layout and pointer dereferencing. A large yellow curved arrow points from the 'ppi' variable (at address ..08) to the 'pi' variable (at address ..04). A blue curved arrow points from the 'pi' variable (at address ..04) to the 'i' variable (at address ..00). The asterisks (*) and double asterisks (**) indicate the dereferencing process: * for single dereferencing and ** for double dereferencing.

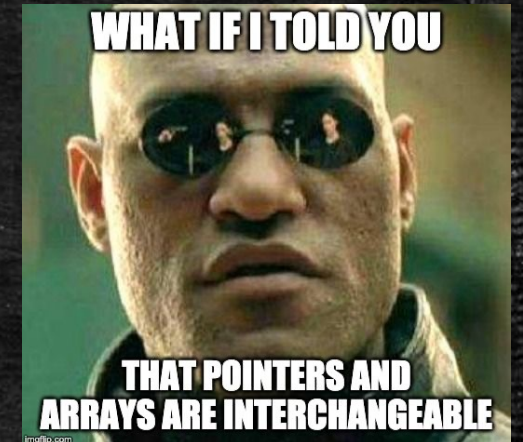
Q: What if we call `cout << *i`?

Q: Is there a difference between static and dynamic allocation?

Pointer Arithmetic

- Takes type into account

```
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
```



Notes On Dynamic Allocation

- Prefer static/automatic storage
 - ☺ `complex c;`
 - ☹ `auto c = make_unique<complex>();`
- Prefer containers
 - ☺ `vector<int> vi(10);`
 - ☹ `auto ia = make_unique<int[]>(10);`
- Dynamic allocation is slow
- Use only when necessary
 - Object lifetime doesn't correspond to function invocations
 - Polymorphism

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
```


Operator overloading

- Implement your own operators
 - +, -, ->, /, [], ...
- Keep the semantic!
- <https://en.cppreference.com/w/cpp/language/operators>

Homework1: Finish the LL

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

Homework2: int vector

- 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
- Q: How many owners does it need?

Large homework – Data Aggregation

- In ReCodex
- Deadline: 5/12 (Monday) 23:59
- 15 points (10p + 5p)
 - Functionality: max 10 points
 - Code culture: max 5 points
 - $\sim \text{points_for_functionality} / 2$
 - -5 points per each week

Programming in C++ - lab 5

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Reminder

- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, ~November
 - Larger HW – 25 points, ~December
- Software project
 - Topic must be approved by 27/11/2022
 - POC: 18/12/2022
 - First submission: 02/04/2023
 - Final submission: 28/05/2023

Homework1 Solution

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

guards

declarations

// file: my_class.cpp

#include "my_class.hpp"
#include <iostream>

void fn(int x) {
cout << "fn()";
}

#include
header

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

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

definitions

size_t my_class::i = 0;

Homework1: Summing Program

- Implement special methods only
 - ctors, dtor, operators, ...
- You can add $O(1)$ attributes into C
 - E.g., cannot add a vector
- Use `C::print()` for printing
 - Cannot use anything else for printing
- Example (
 - Input: 5 7
 - Output: Summing numbers:
5
6
7
Preparing...
Sum of the numbers:
18

```
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;
    /* CANNOT ADD 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 number first, first+1, ..., last
    cout << "Preparing...\n";
    D d2 = d;
    cout << "Sum of the numbers:\n";
    d2 = d; // prints sum of numbers first..last
}
```


Homework2: Piškvorky for 2 players

- For 2 players only
 - Set the names at the beginning
- Game ends when one of the player has 5 in a row
 - Write who is the winner
- Validate user inputs

Programming in C++ - lab 4

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Homework Feedback

- Use `const` functions for read-only functions
 - `print()` `const`, `get_matrix()` `const`, `get_vector()` `const`
- Use `class` or `using` to create new types
 - Decomposition!
 - `using` can be anywhere (inside the class as well)

Argument Passing - Recap

- By copy/value
 - `int max(int x, int y);`
- By const-reference:
 - `Matrix sum(const Matrix &m1, const Matrix &m2);`
- By reference
 - `void find_zero_matrix(const vector<Matrix> &ms,
Matrix &zero_matrix);`

Argument Passing – By R-value Reference (&&)

- To transfer an ownership
- **Moves** the object into a function
 - the object no longer lives outside the function
- Typical usage
 - a single owner (`std::unique_ptr`)
 - moving large objects
- Use `std::move()` on the caller side

```
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)));
```


Static With Classes

- Attribute/method belongs to a class (not an object/instance)
- Need to share attribute/method among the objects/instances
- Most things belong to an object

```
class Verbose {};
```

```
int main()  
{  
    Verbose v1; // object/instance  
    Verbose v2(2); // object/instance  
}
```


Static With Class

```
class CountingClass {
    static size_t num_instances;

    static void inc_num_instances() {
        ++num_instances;
    }

    static void dec_num_instances() {
        --num_instances;
    }

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

    static size_t get_num_instances() {
        return num_instances;
    }

    CountingClass() { inc_num_instances(); }

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

    ~CountingClass() { dec_num_instances(); }
};
```

```
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
}
```


Special Methods In Classes

```
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
```


Homework1: Implement class C

- Finish program so it writes: 1, 2, 3, ..., 16
- Touch **only** class C, nothing else
 - Nothing can be into main() or fn_XXX()
- Don't use exit(), break, goto, ...
- Hint: which methods are called?

```
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";
}
```


Homework2: Finish 3DMatrix For Integers

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

Programming in C++ - lab 3

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Down to operator

```
void op_downto(int x) {  
    while (x --> 0) {  
        cout << x;  
    }  
}
```

```
op_downto(10); // prints 9,8,7,...,1,0
```


Homework Feedback

- Use `const` & for large objects
- Only source codes and project/config files to GIT
 - No binaries (they can be compiled from the source codes)
- Use STL functions
 - `isdigit()`, `stoi()`, ...
- Prefer C++ strings to C-style strings
 - `std::string`, `std::string_view`

Class/Struct - Recap

- Put all related things (data, functions) together
- 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, ...)

Defining your own types - using

- Use using (or typedef in old C/C++)
- Can be used together with templates (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 – constexpr/const

- Read only value that cannot be changed
- Naming values in code
 - ~ Every number in the code should be a named constant
- `constexpr` – constant value (potentially) evaluated in the compile time
 - Can be used as arguments to templates
- `const` – constant value
- Both can be used together with `static` (later)

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


Coding: 3D Matrix for Integers - API

- `ctor()`, `ctor(width, length, height)`
- `set(x, y, z, value)`, `get(x, y, z)`, `print()`
- `set_width()`, `set_length()`, `set_height()`, `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()`;

Coding: 3D Matrix for Integers - Hints

- Think about the desing
 - array $\rightarrow$ matrix $\rightarrow$ 3D matrix $\rightarrow$ 4D matrix $\rightarrow$... $\rightarrow$ XD matrix
 - Design simple first, then continue to the next level
- No need to focus too much on performance yet
- Focus:
 - Passing arguments: const-references, references, ...
 - const functions
 - class design
 - Decomposition into functions
 - Function reusing
 - private/public

Coding: 3D Matrix - Improvements

- `print()`
- `sort_vector(x, y)`
 - Use `std::sort()`
- change underlying matrix container - `std::deque`, `std::list`
 - the change to different container must be only few lines of change
 - Hint: use `using`
- change underlying matrix container - `std::array`
 - Use large enough array
 - ! Use constants
 - Report error in case of overflow

Programming in C++ - lab 2

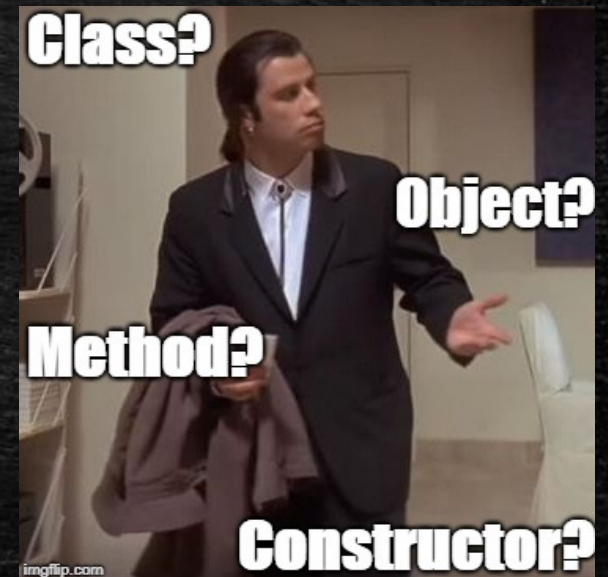
<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Recap

Homework Example

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

```
private:  
    void multiply();
```

can be used
multiple
times

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

```
private:  
};
```

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");  
c2.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
- 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_height()`, `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()`;

3D Matrix for Integers - Hints

- Think about the desing
 - array $\rightarrow$ matrix $\rightarrow$ 3D matrix $\rightarrow$ 4D matrix $\rightarrow$... $\rightarrow$ XD matrix
 - Design simple first, then continue to the next level
- No need to focus too much on performance yet
- Focus:
 - Passing arguments: const-references, references, ...
 - const functions
 - class design
 - Decomposition into functions
 - Function reusing
 - private/public

Programming in C++ - lab 1

<https://fan1x.github.io/cpp21.html>
tomas.faltin@matfyz.cuni.cz

Basic information

- Email: tomas.faltin@matfyz.cuni.cz
- Labs web: <https://fan1x.github.io/cpp22.html>
- Lecture web: <https://www.ksi.mff.cuni.cz/teaching/nprgo41-web/>
- Mattermost
 - Invite link in [SIS/Notice-board](#)
 - Channel: `nprgo41-cpp-faltin`
- Gitlab
 - <https://gitlab.mff.cuni.cz/>
 - <https://gitlab.mff.cuni.cz/teaching/nprgo41/2022-23/faltin>

Communication is the key

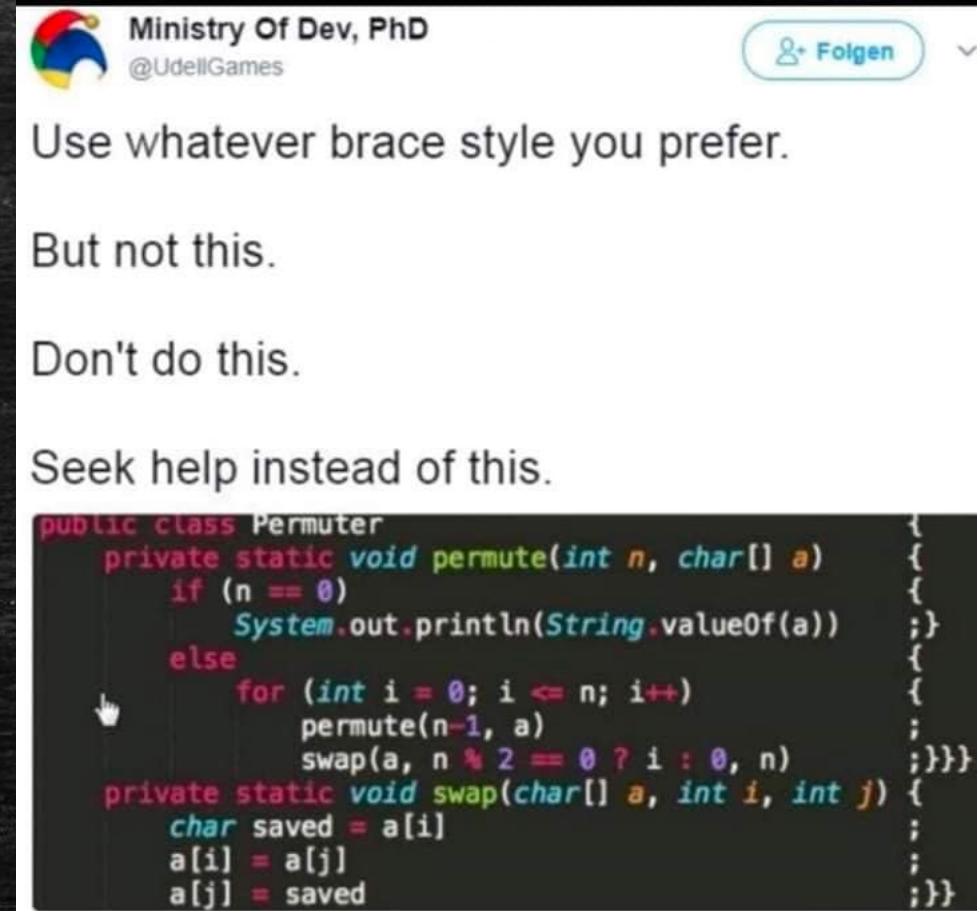
- Don't be afraid to ask
- Be proactive
 - via email
 - on Mattermost (instant)
 - DM if related to you only
 - Into a channel if others can benefit from it
- If you struggle with something
- If you feel like you might miss a deadline

Labs credit

- Submitted homeworks before Sunday midnight (Sunday 23:59)
 - to Gitlab
 - Even if not attending!
 - Won't be graded, for feedback only
- Two large homeworks in ReCodex (total 40 points)
 - Points are included in the final score from the course
 - Smaller HW – 15 points, ~November
 - Larger HW – 25 points, ~December
- Software project
 - Topic must be approved by 27/11/2022
 - POC: 18/12/2022
 - First submission: 02/04/2023
 - Final submission: 28/05/2023
 - **All the steps typically mean multiple iterations within multiple days. If you wait for the last minute, there is a chance you won't make it**

Code Requirements - Consistency

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



The image is a screenshot of a tweet from the user 'Ministry Of Dev, PhD' (@UdellGames). The tweet text reads: 'Use whatever brace style you prefer. But not this. Don't do this. Seek help instead of this.' Below the text is a code snippet in Java. The code is for a class named 'Permuter' and contains two methods: 'permute' and 'swap'. The 'permute' method has a nested 'if' statement and a 'for' loop. The 'swap' method is a private static method. The code is formatted with a mix of brace styles, including 'K&R' style (opening brace on the same line as the statement) and 'Allman' style (opening brace on a new line). The code is as follows:

```
public class Permuter
{
    private static void permute(int n, char[] a)
    {
        if (n == 0)
        {
            System.out.println(String.valueOf(a));
        }
        else
        {
            for (int i = 0; i <= n; i++)
            {
                permute(n-1, a);
                swap(a, n % 2 == 0 ? i : 0, n);
            }
        }
    }
    private static void swap(char[] a, int i, int j)
    {
        char saved = a[i];
        a[i] = a[j];
        a[j] = saved;
    }
}
```

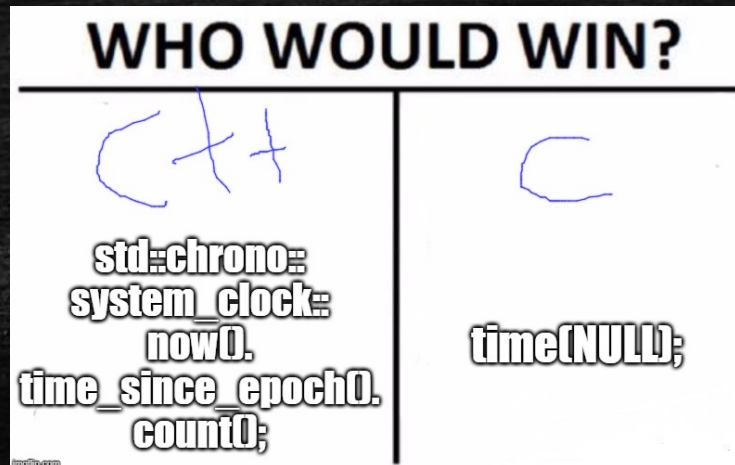

Code Requirements – Readability

- 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[]`



Me when I realized that I can't pass 2D arrays to functions in C/C++ as `int a[]`:



"Pointers are a nuisance"

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 😊



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

"It was only supposed to be a joke, I never thought people would take the book seriously. Anyone with half a brain can see that object-oriented programming is counter-intuitive, illogical and inefficient."

-- Stroustrup C++ 'interview' (<https://www-users.cs.york.ac.uk/susan/joke/cpp.htm>)



Working Environment

- 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, ...

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/>
- ...

Learning C++

- C++ in 100 seconds: <https://youtu.be/MNeX4EGtR5Y>
- C++ in 31h: https://youtu.be/8jLOx1hD3_o

Hello World

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

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


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

All the STL
constructs live
inside 'std'
namespace

Write to
standard output
(screen)

Read from
standard input
(keyboard)

Compilation

- `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

```
#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>
```

Include the whole
std namespace

```
using namespace std;
```

Passing the
argument by
(const) reference

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

Number of
arguments

Arguments of the
program on the
command line

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

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

- 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)`

Homeworks

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 string to <something>
4. A simple calculator (only for operations + -)
 - ``calc.exe 1+2+3-4`` → ``2``
 - to Gitlab
 - The previous programs are not needed, they should give you a lead