

Programming in C++

<https://fan1x.github.io/cpp21.html>
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Programming in C++ - lab 9

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Reminders

- The first large homework: Data aggregation
 - Deadline: 9/12/2021 04:59
- The second large homework
 - Deadline: 2/1/2022 23:59
- Pick a software project
 - Topic must be approved **by 9/12/2021**
 - Send a specification via mail **for approval**

Inheritance comments

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

Homework: Animal Database

- Try to reuse + fix people database (from ReCodex)
- Nice OOP architecture first
 - Make a sketch (~UML style)
- At least 5 types of animals
 - ≥ 2 common attributes
 - ≥ 1 unique attribute
 - Family relations: parent (children)
- Operations
 - `print()`, `print_all()`, `insert`, `sort_by_name/age/type`, `remove_by_name/age/type`
 - `print_family_tree(animal *)`, `set_parent()`, `set_child`, `get_parents()`,
`get_children()`, `get_siblings()`

Programming in C++ - lab 8

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Reminders

- The first large homework: Data aggregation
 - Deadline: 9/12/2021 04:59
- Pick a software project
 - Topic must be approved **by 28/11/2021**
 - Send a specification via mail **for approval**
 - Extended to 9/12/2021
 - First submission: 24/4/2022
 - Final submission: 22/5/2022

Homework Feedback

- Don't use `delete` with smart pointers!
- Prefer `->` to `(*)`.
- Use ``const`` functions
 - For read only things
- `const void print() const`
 - ``const void`` doesn't make sense
- `head = NULL`
 - Use `nullptr` instead

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 &

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

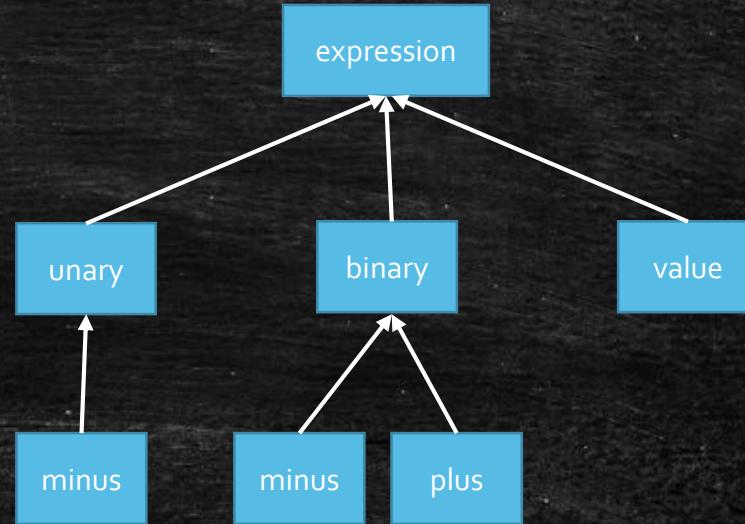
```
class car {};  
class volvo : public car {};  
class skoda : public car {};
```

```
class animal {};  
class dog : public animal {};  
class cat : public animal {};
```

```
class employee {};  
class accountant : public employee {};
```

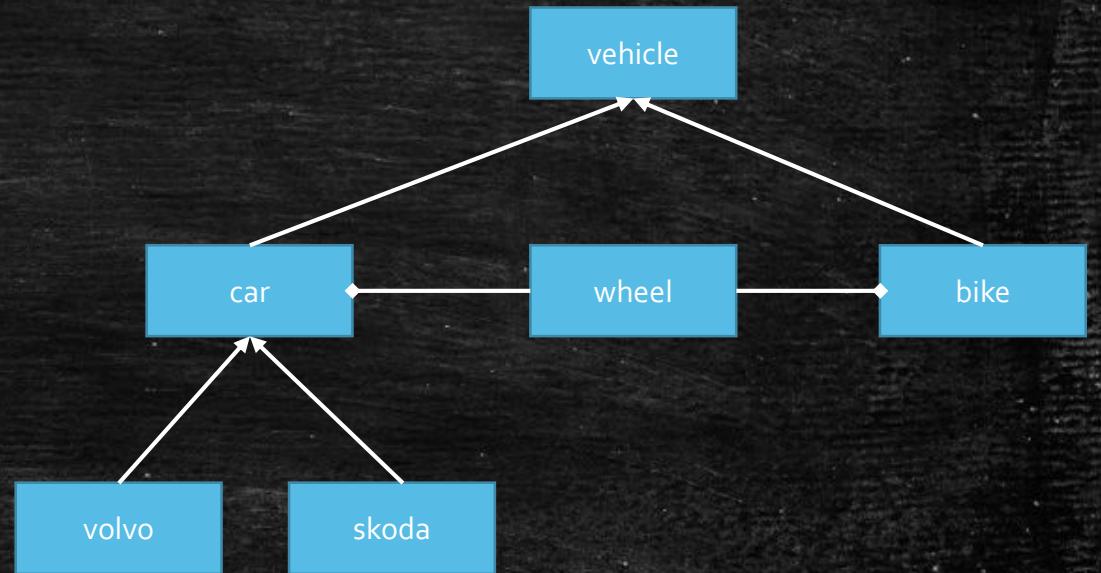
```
class expression {};  
class binary : public expression {};  
class plus : public binary {};
```

```
class object {} // JAVA  
class XYZ : public object {};
```



Inheritance vs. Composition

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



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"]  
}
```

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Homework feedback

- Great work 😊
- Automated translation
 - Try all translation/languages
 - Take a word, find the language and translate the rest

Large homework - Data Aggregation

- In ReCodex
- Deadline: 12/9/2021 (Thursday) 4:59
- 15 points (10p + 5p)
 - Functionality: max 10 points
 - Code culture: max 5 points
 - ~points_for_functionality/2

Dynamic allocation

- Use smart pointers (no raw `T*` 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
- Getting an address of an object
 - `&x`
- Smart pointers
 - `get()`
- To access the values through a pointer
 - `operator*`, `operator->`



Pointers in Memory

```
int main() {  
    int i = 2;  
    int *pi = &i;  
    int **ppi = &pi;  
    cout << i; // 2  
    cout << pi; // 102  
    cout << *pi; // 2  
    cout << ppi; // 104  
    cout << *ppi; // 102  
    cout << **ppi; // 2  
}
```

Address	Value	(Variable)	operator*
....			
100	2	i	
101			*
102	100	pi	**
103			*
104	102	ppi	*
105			
....			



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

Notes on Dynamic Allocation

- Prefer static/automatic storage
- 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 ->
            }
        }
        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>

Homeworks: 1. Finish the LL

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

Homeworks: 2. 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 allocations of arrays, no LL
- **Q:** How many owners does it need?

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Homework feedback

- Plagiarism
- Passing large objects by (const-) reference
- Using const functions
- Warnings/cannot compile with another compiler
- Using named constants instead of any number
- Function decomposition
- “Too complex solution”
 - `vector<vector<string>>`
 - `map<string, tuple<int, int, int>>`

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()`, ...

Homeworks: 1. 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;
};
```

Homeworks: 2. Simple People Database

- A simple people database
 - In Recodex: <https://recode.mff.cuni.cz/>

Programming in C++ - lab 5

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Homework feedback

- Lack of responsibility ☹
 - Lots of missed deadlines
 - Not working homeworks
 - No communication
- Summing program
 - Used forbidden functions/constructs
- Integer matrix
 - const functions

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;
```

Homework: TicTacToe 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

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Homework feedback

const with Classes

```
class Person {  
    const string name;  
    uint8_t age;  
public:  
    Person(const string &name, uint8_t age) : name(name), age(age) {}  
  
    void inc_age() {  
        ++age;  
    }  
  
    uint8_t get_age() const {  
        return age;  
    }  
  
    const string &get_name() const {  
        return name;  
    }  
};
```

Homeworks

1. Create a verbose class C and show its usage
 - Prints identifier on each call to a class special method
2. Use the verbose class in another verbose class and show its usage
 - Usage:
 - a single C
 - a vector of Cs
 - Show usage – insert things into it
3. Finish the summing program
4. Finish/Fix Matrix for Integers

Summing Program

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

```
class C {  
    /* CAN ADD MORE ATTRIBUTES */  
    int value;  
  
    void print() const {  
        cout << value << "\n";  
    }  
  
public:  
    /* IMPLEMENT SPECIAL FUNCTIONS */  
};  
  
class D {  
    std::vector<C> cs;  
    /* CANNOT ADD MORE ATTRIBUTES */  
public:  
    /* IMPLEMENT SPECIAL FUNCTIONS */  
};  
  
int main(int argc, char *argv[]) {  
    int first, last;  
    cin >> first >> last;  
    cout << "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  
}
```

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Down to operator

```
void op_downto(int x) {  
    while (x --> 0) {  
        cout << x;  
    }  
}  
  
op_downto(10); // prints 9,8,7,...,1,0
```

Homework feedback

- Enable warnings

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;
};

{

    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 with Classes

```
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; // initialization
```

```
assert(!CountingClass::has_instance() && "No instances");  
{  
    CountingClass cc1;  
    assert(CountingClass::get_num_instances() == 1);  
    {  
        CountingClass cc2 = cc1;  
        assert(CountingClass::get_num_instances() == 2);  
    }  
    assert(CountingClass::get_num_instances() == 1);  
}
```

Homework1: Implement class C

- Can touch only class C
- Don't use `exit()`, `break`, `goto`, ...
- Program writes: 1, 2, 3, ..., 12

```
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";
}
```

Voluntary Homework2: Finish Matrix for Integers

- Correct all issues in the previous HW
- Implement correctly all special methods
- Show usage/test all the methods with assertions
- **Not needed for the next week**

Programming in C++ - lab 2

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Homework Feedback

- Deadlines
 - Communication!
- Use functions
 - Don't put everything into `main()`
 - Function should do a single thing
- Don't put binaries into a repo
 - Source/header files, configs, project files, ...
 - Search what to put into repo on-line
- Use objects/structs
- Use (const) references for large objects

Argument Passing - By Value

- Creates a copy
- Use for small/elementary types (int, double)

```
int max(int x, int y);
```

Argument Passing - By Const-reference

- Doesn't create a copy
- Use for large objects (containers, e.g., vector, string, ...)

```
int find_max(const vector<int> &numbers);
```

Argument Passing - By Reference

- Doesn't create a copy
- Allows to change the passed object
- For output parameters
 - ! Is the function really doing a single things?
 - Could you use `std::pair`?
 - `pair<iterator, bool> map::emplace(...)`

```
void transform(Matrix &matrix);
```

```
pair<size_t, int> find_max(const vector<int> &numbers);
```

Argument Passing - By R-value Reference

- To transfer ownership
- Moves the object into a function
 - the object no longer lives outside the function
- 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));
```

Class/Struct

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

```
class calculator {  
    void sum(); // private by default  
  
public:  
    // change internal attributes, cannot be const  
    void calc(const std::string &expression);  
  
    // doesn't change internals, should be const  
    void print() const;  
  
private:  
    // ...  
};  
};  
  
calculator c; // no need for `new`  
c.calc("1+2*3/4");
```

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

std::vector<T>

```
#include <vector>
int main() {
    std::vector<int> vi{1, 2, 3, 4, 5, 6};
    std::vector<float> vf{5, 0.0f};
    std::cout << vi[3] << " " << vf.at(3) << std::endl;
    std::cout << vi.size();
    vi[3] = 100; vi.at(6) = 600;
    vf.push_back(100.0f); vf.emplace_back(200.0f);
    vf.insert(3, 300.0f); vf.emplace(3, 300.0f);
    vi.pop_back();
    vf.erase(3);
    vi.clear();
    vi.resize(10); vi.reserve(100);
}
```

- Beware of time complexity
- `vector<bool>`

Homework: Matrix for Integers

- `set(x, y, value)`, `get(x, y)`, `print()`
- `set_width()`, `set_height()`, `get_width()`, `get_height()`
- `get_row(x)`, `get_column(x)`
- `get_rows()`, `get_columns()`
- `clear()` – set all values to 0 (zero)
- `fill_with_value(value)` – set all values to a given value
- `reverse()` – reverse values from $[x, y]$ to $[y, x]$
- `is_negative()` – are all numbers in the matrix negative?
- `zero_count()`

Programming in C++ - lab 1

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Basic information

- Email: tomas.faltin@matfyz.cuni.cz
- Lab's web: <https://fan1x.github.io/cpp21.html>
- ZOOM for distance learning
 - <https://cuni-cz.zoom.us/j/94350923737>
 - Credentials in SIS/mail
- Mattermost
 - Invite link:
https://ulita.ms.mff.cuni.cz/mattermost/signup_user_complete/?id=z1knw5aq6p8nipop1i7icq a6a
 - Use ASAP, might expire eventually
 - Channel: `nprgo41-cpp-english`
- Gitlab
 - <https://gitlab.mff.cuni.cz/>
 - <https://gitlab.mff.cuni.cz/teaching/nprgo41/2021-22/eng>

Communication is the key

- Don't be afraid to ask
 - 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
- Be proactive

Labs credit

- Submitted homeworks before Monday midnight (to Gitlab)
 - Even if not attending!
 - Won't be graded, for a feedback
- Two large homeworks in ReCodex (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 28/11/2021
 - First submission: 24/4/2022
 - Final submission: 22/5/2022
 - **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
 - Be consistent within the code – keep a single code style
- Cleanliness, readability
 - Code doesn't contain commented/dead parts
 - Code should be readable on its own
- Safe, modern
 - E.g., prefer `std::vector<int>` to `new int[]`
- Working
 - OFC, if the code is not working, all the above points are not that important, but they will help you with debugging at least ☺

Why C++

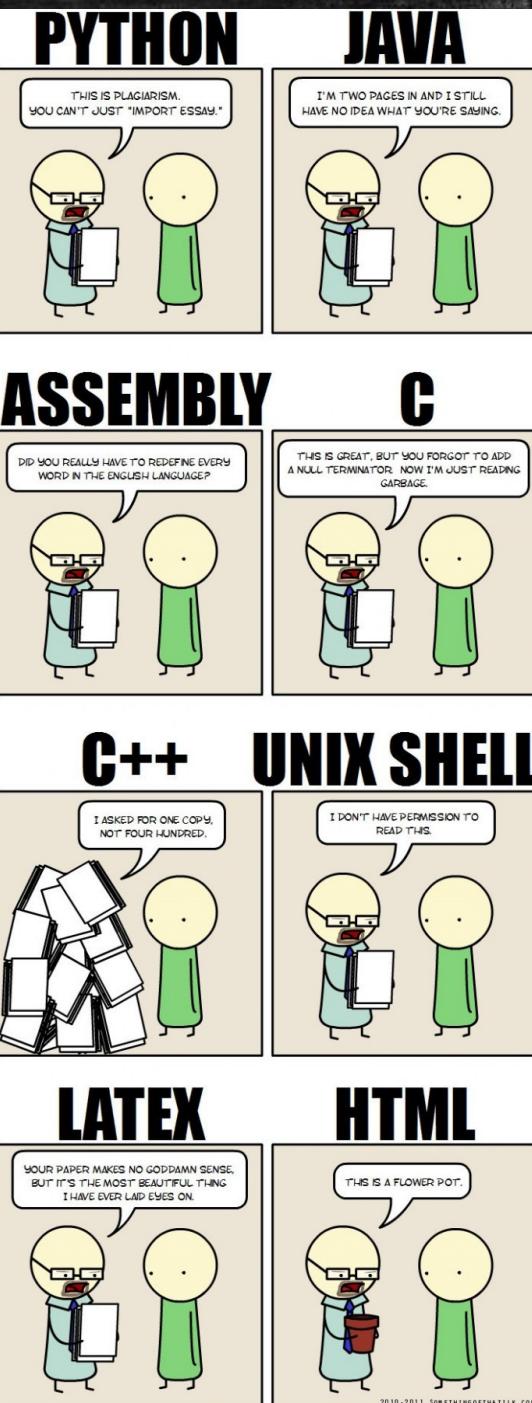
"C makes it easy to shoot yourself in the foot. C++ makes it harder, but when you do, it blows away your whole leg."

-- 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>)

C++ != speed, C++ ~ control



Working Environment

- Use anything you like ☺
- IDEs
 - Visual Studio
 - License for students at [https://portal.azure.com/...](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://gcc.godbolt.org/>
- ...

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

Read from standard input (keyboard)

Write to standard output (screen)

All the STL constructs live inside 'std' namespace

More Complex Program

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

using namespace std;

int length(const string& s) { ... }

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

int main(int argc, char** argv) {
    vector<string> arg(argv, argv+argc);
    if (arg.size() > 1 && arg[1] == "--help") {
        cout << "Usage: myprg [OPT]... [FILE]..." << endl;
        return 8;
    }
    pretty_print(arg);
    return 0;
}
```

More Complex Program

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

using namespace std;

int length(const string& s) { ... }

void pretty_print(const vector<string>& a) { ... }

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        cout << "Usage: myprg [OPT]... [FILE]..." << endl;
        return 8;
    }
    pretty_print(arg);
    return 0;
}
```

Include the whole
std namespace

Passing the
argument by
(const) reference

Arguments of the
program on the
command line

Transform the
arguments into C++
array of strings

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