

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_; }

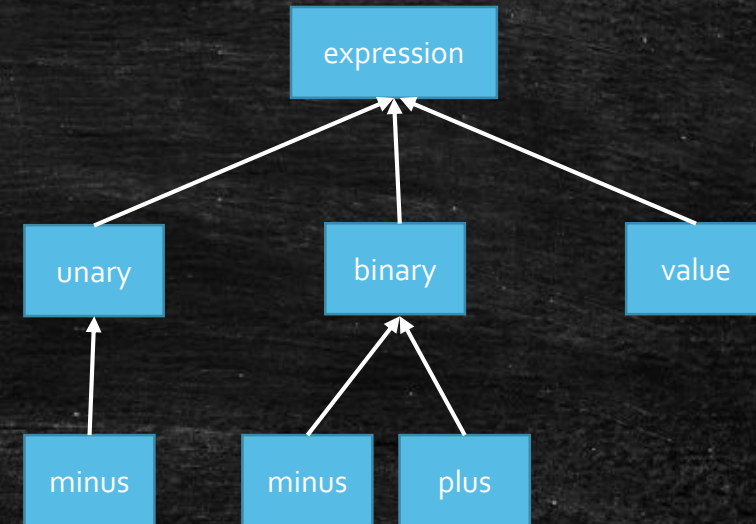
protected:
    size_t size_;
};

class vector_int : public container { ... };
class list_int : public container { ... };

int main() {
    vector_int vi;
    cout << vi.size();
}
```

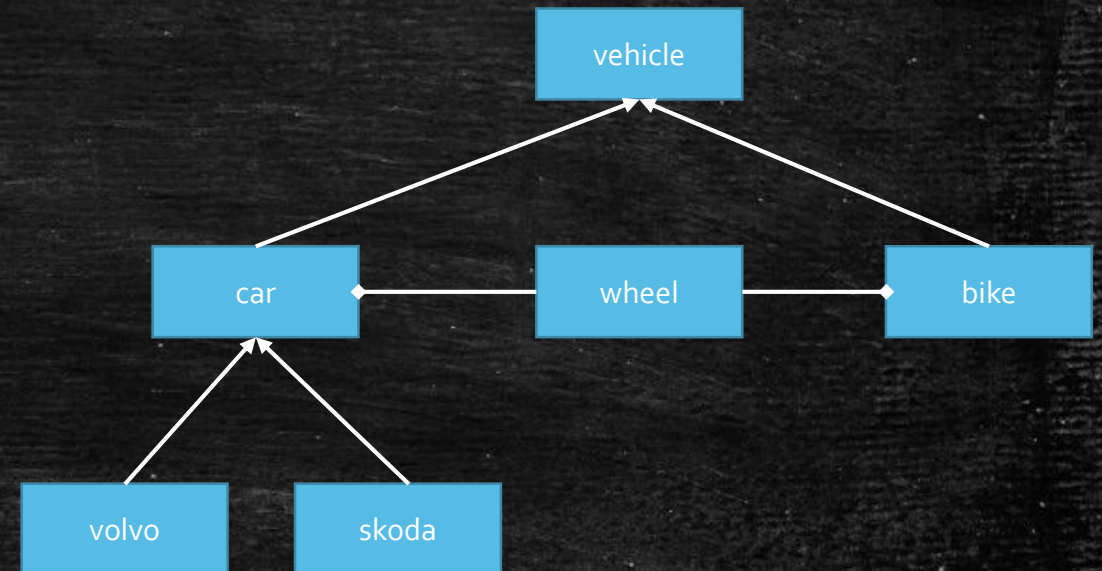

Inheritance Examples

```
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"]  
}
```


Programming in C++ - lab 7

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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)
....		
100	2	i
101		
102	100	pi
103		
104	102	ppi
105		
....		

operator*

✱ ✱

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?

Programming in C++ - lab 6

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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://recodex.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:
18

```
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
}
```


Programming in C++ - lab 3

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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 a 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=z1knw5ag6p8nipop1i7iciga6a
 - 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
- Cleanness, 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++

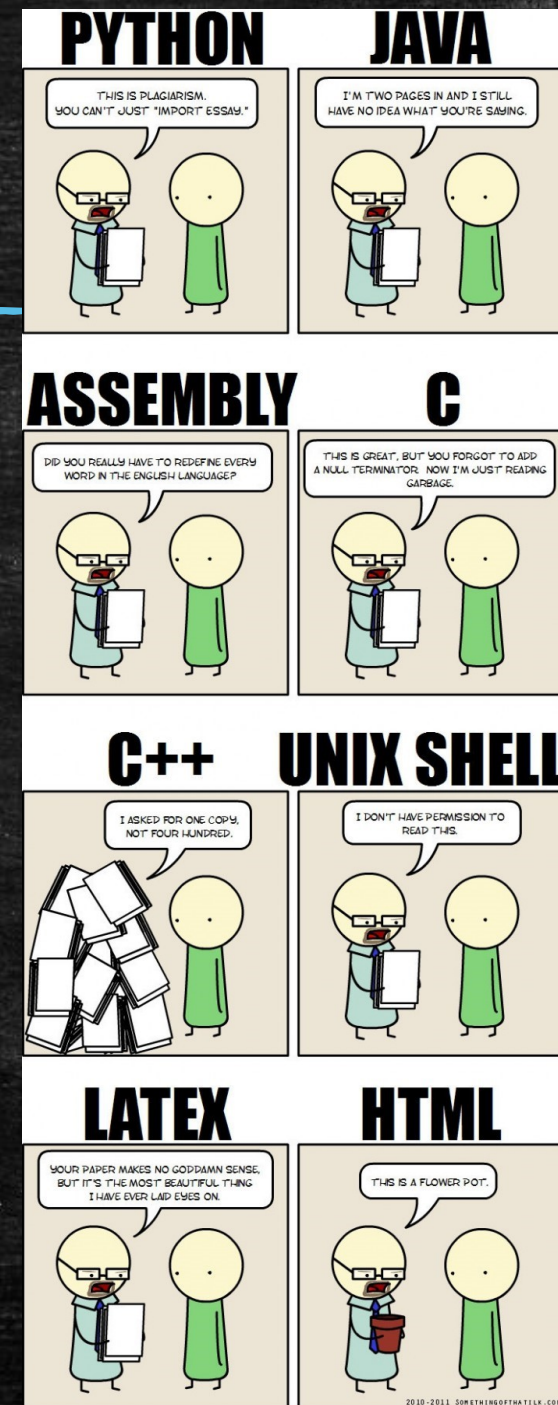
"C makes it easy to shoot yourself in the foot. C++ makes it harder, but when you do, it blows away your whole leg."

-- 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/...>
 - 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.gnu.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 the libraries
which implements the
used STL constructs
(string, cin, cout)

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

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

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

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) { ... }

int main(int argc, char** argv) {
    vector<string> arg(argv, argv+argc);
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        cout << "Usage: myprg [OPTION]... [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