

SEMESTER HS2020

C++ Zusammenfassung

Joel Schaltegger
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Lizenz

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1 Introduction to C++

In C++ gibt es keinen Garbage Collector, wie man es aus anderen Sprachen, wie Java oder C# kennt. Warnung: Wenn Code "falsch" geschrieben wurde, kann **Undefined Behavior** auftreten.

1.1 C++ Compilation Process

*.cpp Files

- Also called Implementation File
- For function implementations (can be in .h as well)
- Source of compilation

*.h File

- Also called Header File
- Declarations and definitions to be used in other implementation files

3 Phases of compilation

- Preprocessor Textual replacement of preprocessor directives (include)
- Compiler Translation of C++ code into machine code (source file to object file)
- Linker Combination of object files and libraries into libraries and executables

1.2 Declarations and Definitions

All things with a name that you use in a C++ program must be declared before you can do so.

One Definition Rule

While a program element can be declared several times without problem there can be only one definition of it. This is called the **One Definition Rule** (ODR)!

Include Guard

Include guards ensure that a header file is only included once. Multiple inclusions could violate the One Definition Rule when the header contains definitions.

```
1  #ifndef SAYHELLO_H_
2  #define SAYHELLO_H_
3
4  #include <iosfwd>
5  struct Greeter { /* Some Code */ };
6
7  #endif /* SAYHELLO_H_ */
```

2 Values and Streams

2.1 Variable Definitions

- Defining a variable consists of specifying its type, its variable name and its initial value. E.g. `int x{42};`
- Empty braces mean default initialization. E.g. `double x{};`
- Using `=` for initialization we can have the compiler determine its type. E.g. `auto const i = 5;`

Constants

- Adding the `const` keyword in front of the name makes the variable a single assignment variable, aka a constant. E.g. `int const x{42};`
 - Must be initialized and immutable
- Use the keyword `constexpr` if the variable is required to be fixed at compile time. E.g. `double constexpr pi{3.14159};`

Why should I use `const`?

- A lot of code needs names for values, but often does not intend to change it
- It helps to avoid reusing the same variable for different purposes (code smell)
- It creates safer code, because a `const` variable cannot be inadvertently changed
- It makes reasoning about code easier
- Constness is checked by the compiler
- It improves optimization and parallelization (shared mutable state is dangerous)

Important types for Variable

- `short`, `int`, `long`, `long long` - each also available as unsigned version
- `bool`, `char`, unsigned `char`, signed `char`
- `float`, `double`, `long double`
- `void` is special, it is the type with no values
- class defined: E.g. `std::string`, `std::vector`

2.2 Values and Expressions

Integer to boolean: `0 = False`, every other value = `True`

if `(a < b < c)` → zuerst wird `a < b` ausgewertet (true oder false). Dann wird der Boolean mit einem `int` (`c`) verglichen. Der Bool wird dafür implizit in 0 oder 1 gecastet.

Literal Example	Type	Value
'a'	char	Letter a, value: 97
'\n'	char	<NL> character, value: 10
'\x0a'	char	<NL> character, value: 10
1	int	1
42L	long	42
5LL	long long	5
<code>int{}</code> (not really a literal)	int	0 (default value)
1u	unsigned int	1
42ul	unsigned long	42
5ull	unsigned long long	5
020	int	16 (octal 20)
0x1f	int	31 (hex 1F)
0XFULL	unsigned long long	15 (hex F)
0.f	float	0
.33	double	0.33
1e9	double	1000000000 (10 ⁹)
42.E-12L	long double	0.00000000042 (42*10 ⁻¹²)
.3l	long double	0.3
"hello"	char const [6]	Array of 6 chars: h e l l o <NUL>
"\012\n\\"	char const [4]	Array of 4 chars: <NL> <NL> \ <NUL>

2.3 Strings and Sequences

`std::string` is C++'s type for representing sequences of `char` (which is often only 8 bit) and are mutable. That means, we can modify the content. (Vergleich zu Java: Dort würde ein neues String Objekt erstellt werden)

Grundsätzlich werden Strings also als `char const[]` abgespeichert. Mit dem namespace `std::literals` hat man die Option hinter dem String eine `'s'` anzufügen, um das Objekt effektiv als String zu speichern. z.B. `"ab"s`

toUpper Iterator

```
1 void toUpper(std::string & value) {
2     transform(cbegin(value), cend(value), begin(value), ::toupper);
3 }
```

2.4 Input and Output Streams

Functions taking a stream object must take it as a reference, because they provide a side effect to the stream (i.e., output characters).

Reading from Input

- Reading into a `std::string` always works. Unless the stream is already `!good()` → Spaces werden übersprungen (neues String-Objekt)!
- Reading into other types (e.g. `int`) has no error recovery. A wrong input puts the stream into status fail and the characters remain in the input.
- Post-read check: `if (in » age) { ... }`
- Multiple subsequent reads are possible: `if (in » symbol » count) { ... }`
- Remove fail flag: `in.clear()`
- Ignore one char: `in.ignore();`
- Helpfull for reading: `while (in.good())` um die Leseoperationen setzen.

Robust reading of an int value

```
1 // Use an std::istringstream as intermediate stream
2 int inputAge(std::istream & in)
3 {
4     std::string line{}
5     while (getline(in, line)) {
6         std::istringstream is{line};
7         int age{-1};
8         if (is >> age) {
9             return age;
10        }
11    }
12    return -1;
13 }
```

Stream States

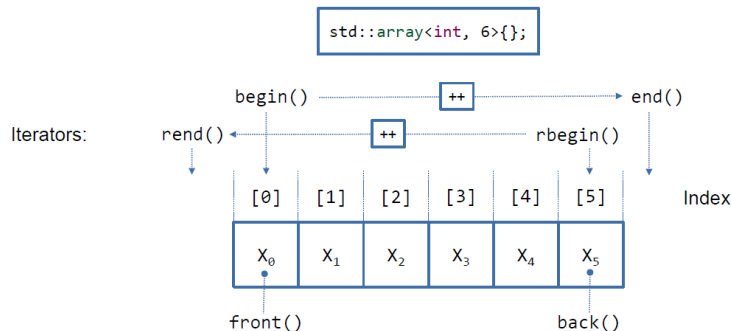
State Bit Set	Query	Entered
<none>	<code>is.good()</code>	initial <code>is.clear()</code>
failbit	<code>is.fail()</code>	formatted input failed
eofbit	<code>is.eof()</code>	trying to read at end of input
badbit	<code>is.bad()</code>	unrecoverable I/O error

3 Sequences and Iterators

3.1 Std::array and std::vector

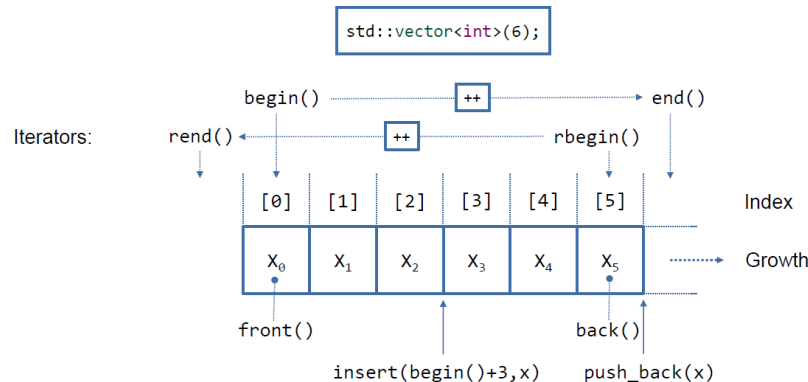
Array

- C++'s `std::array<T, N>` is a fixed size Container
 - T is a template type parameter. N is a positive integer parameter
- `std::array` can be initialized with a list of elements
 - The size of an array must be known at compile time and cannot be changed
 - Otherwise it contains N default constructed elements: `std::array<int, 5> emptyArray`
- The size is bound to the array object and can be queried using `.size()`
- Avoid plain C Array whenever possible: `int arr []{1, 2, 3, 4, 5};`



Vector

- C++'s `std::vector<T>` is a Container: contains its elements of type T (no need to allocate them)
 - `java.util.ArrayList<T>` is a collection = keeps references to T objects
 - T is a template parameter
- `std::vector` can be initialized with a list of elements
 - Otherwise it is empty: `std::vector<double> vd{ };`
 - Other construction means might need parentheses (legacy)
- When an initializer is given, the element type can be deduced! `std::vector{1, 2, 3, 4, 5};`



Parenthesis at definition allow providing initial size, when type of elements is a number:
`std::vector<string> words{6};` → Um sicher zu gehen die Grösse mit runden Klammern angeben.

Für beide Datentypen:

Element access using subscript operator `[]` or `at()`:

`at` throws an exception and `[]` has undefined behavior on invalid access.

Speicherort:

Generell werden alle Elemente einer Klasse auf dem Stack abgelegt. So auch der Vector. Fügt man dem Vector ein Element hinzu, wird davon eine unabhängige Kopie auf dem Heap erstellt. Der Vector referenziert auf das neue Objekt.

3.2 Iteration

Element Iteration (Range-Based for-Loop)

	const: • element cannot be changed	non-const: • element can be changed
reference: • element in vector is accessed	<pre>for (auto const & cref : v) { std::cout << cref << '\n'; }</pre>	<pre>for (auto & ref : v) { ref *= 2; }</pre>
copy: • loop has own copy of the element	<pre>for (auto const ccopy : v) { std::cout << ccopy << '\n'; }</pre>	<pre>for (auto copy : v) { copy *= 2; std::cout << copy << '\n'; }</pre>

Iteration with Iterators

```
1 // Changing the element in a non-const container is possible in this way
2 for (auto it = std::begin(v); it != std::end(v); ++it) {
3     std::cout << (*it)++ << ", ";
4 // Guarantee to just have read-only access with std::cbegin() and std::cend()
5 for (auto it = std::cbegin(v); it != std::cend(v); ++it) {
6     std::cout << *it << ", ";
7 }
```

3.3 Iterators with Algorithms

```
1 // Counting values: std::count
2 size_t count_blanks (std::string s) {
3     return std::count(s.begin(), s.end(), ' ');
4 }
5 // Summing up all values in a vector: std::accumulate
6 std::vector<int> v{5, 4, 3, 2, 1};
7 std::cout << std::accumulate(std::begin(v), std::end(v), 0) << " = sum\n";
8
9 // Number of elements in range: std::distance
10 void printDistanceAndLength (std::string s) {
11     std::cout << "distance: " << std::distance(s.begin(), s.end()) << '\n';
12     std::cout << "in a string of length: " << s.size() << '\n';
13 }
14
15 // std::for_each
16 void printAll(std::vector<int> v) {
17     std::for_each(cbegin(v), std::cend(v), print);
18 }
19 // std::for_each with Lambda
20 void printAll(std::vector<int> v, std::ostream & out) {
21     std::for_each(cbegin(v), std::cend(v), [&out](auto x) {
22         out << "print: " << x << '\n';
23     });
24 }
25 // std::copy (target needs to be an iterator too. target.end() would not work)
26 std::vector<int> source{1, 2, 3}, target{};
27 std::copy(source.begin(), source.end(), std::back_inserter target(target));
28
29 // Filling a vector with std::fill
30 std::vector<int> v(10);
31 std::fill(std::begin(v), std::end(v), 2);
32 // Or even easier:
33 std::vector v(10, 2);
34
35 // std::generate()
36 std::vector<double> powerOfTwos(5);
37 double x{1.0};
38 std::generate(powerOfTwos.begin(), powerOfTwos.end(), [&x] {return x *= 2.0; });
39 // std::generate_n
40 std::vector<double> powerOfTwos();
41 double x{1.0};
```

```

42 std::generate(std::back_inserter(powerOfTwos), 5, [&x] {return x *= 2.0; });
43
44 // fills a range with subsequent values (1,2,3,...): std::iota()
45 std::vector<int> v(100);
46 std::iota(std::begin(v), std::end(v), 1);
47
48 // std::find(), std::find_if() - If no match exists the end of the range is returned
49 auto zero_it = std::find(std::begin(v), std::end(v), 0);
50 if (zero_it == std::end(v)) { std::cout << "no zero found \n"; }
51 // std::count_if()
52 std::cout << std::count_if(begin(v), end(v), [](int x) { return isEven(x); }) << " even numbers\n";

```

3.4 Iterators for I/O

- `std::ostream_iterator<T>`
 - outputs values of type T to the given `std::ostream`
 - No `end()` marker needed for output, it ends when the input range ends
- `std::istream_iterator<T>`
 - reads values of type T from the given `std::istream`
 - End iterator is the default constructed `std::istream_iterator<T>{}`
 - It ends when the Stream is no longer good()

Shorter types with the keyword `using`.

```

1 // Copy Strings from standard input to standard output
2 // Skips white space !!
3 using input = std::istream_iterator<string>;
4 input eof{};
5 input in{std::cin};
6 std::ostream_iterator<string> out{std::cout, " "};
7 std::copy(in, eof, out);
8
9 // std::istreambuf_iterator<char> uses std::istream::get to get every character
10 // Only works with char-like types
11 using input = std::istreambuf_iterator<char>;
12 input eof{};
13 input in{std::cin};
14 std::ostream_iterator<char> out{std::cout, " "};
15 std::copy(in, eof, out);
16
17 // Fill a vector from a stream (copy with back_inserter)
18 using input = std::istream_iterator<int>;
19 input eof{};
20 std::vector<int> v{};
21 std::copy(input{std::cin}, eof, std::back_inserter(v));
22
23 // Fill a vector from a stream (directly from two iterators)
24 using input = std::istream_iterator<int>;
25 input eof{};
26 std::vector<int> const v{input{std::cin}, eof};

```

4 Functions and Exceptions

4.1 Functions

	const: • Parameter cannot be changed	non-const: • Parameter can be changed
reference: • Argument on call-site is accessed	<pre>void f(std::string const & s) { //no modification //efficient for large objects }</pre>	<pre>void f(std::string & s) { //modification possible //side-effect also at call-site }</pre>
copy: • Function has its own copy of the parameter	<pre>void f(std::string const s) { //no modification //used for maximum constness }</pre>	<pre>void f(std::string s) { //modification possible //side-effect only locally }</pre>

When to use & and const Parameters:

- Value Parameter:
 - Default case
- Reference Parameter
 - When side-effect is required at call-site
- Const-Reference Parameter
 - Possible optimization, when type is large (costly to copy) and no side effects desired at call site
 - For non-copyable objects
- Const Value Parameter
 - The coding style guide of your project this might prefer this over non const value parameters
 - Could prevent changing the parameter in the function inadvertently

Function Overloading

The same function name can be used for different functions if parameter number or types differ

→ Functions cannot be overloaded just by their return type

→ If only the parameter type is different there might be ambiguities

Default Arguments

- A function declaration can provide default arguments for its parameters from the right.
 - E.g: `void incr(int & var, unsigned delta = 1);`
- Implicit overload of the function with fewer parameters
 - If n default arguments are provided, n+1 versions of the function are declared
- Default arguments can be omitted when calling the function

Functions as Parameters

Functions are "first class" objects in C++

→ You can pass them as argument, or keep them in reference variables.

```

1 // As Argument (No Lambdas/Captures before function allowed)
2 void applyAndPrint(double x, double f(double)) {
3     std::cout << "f(" << x << ") = " << f(x) << '\n'; }
4
5 // As reference variable
6 double (&h)(double);
7
8 // std::function: template for Lambdas --> #include <functional>
9 void applyAndPrint(double x, std::function<double(double)> f) {
10    std::cout << "f(" << x << ") = " << f(x) << '\n'; }
11 int main() {
12     double factor{3.0};
13     auto const multiply = [factor](double value) { // Lambda Function
14         return factor * value; };
15     applyAndPrint(1.5, multiply);

```

4.2 Failing Functions

What should you do, if a function cannot fulfill its purpose?

- Ignore the error and provide potentially **undefined behavior**
- Return a standard result to cover the error
- Return an error code or error value
- Provide an error status as a side-effect
- Throw an exception

Ignore the error:

- Relies on the caller to satisfy all preconditions
- Most efficient implementation (no unnecessary checks)
- Simple for implementer, harder for caller
- Should be done consciously and consistently!

Return standard result:

- Reliefs the caller from the need to care if it can continue with the default value
- Can hide underlying problems
- Often better if caller can specify its own default value

Error Value

- Only feasible if result domain is smaller than return type
- E.g: Error Value for strings: `std::string::npos`
- Optional as return type can contain no value.
→ `#include <optional>`
E.g: `std::optional<std::string>`
- caller side: has to check with: `var.has_value()`

Error Status

- Requires reference parameter
- Alternative: Global Variable (BAD decision)
- E.g: `std::istream's` states (`good()`, `fail()`) is changed as a side-effect of input

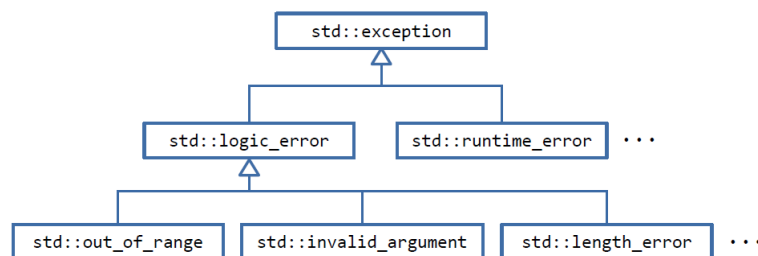
Exceptions

- Prevent execution of invalid logic by throwing an exception

4.3 Exceptions

Principle: Throw by value, catch by const reference.

Functions can be declared to explicitly not throw an exception with the keyword `noexcept`
`#include <stdexcept>`



```

1 // Throw an Exception
2 if (x < 0) {
3     throw std::invalid_argument{"square_root imaginary"};
4 }
5
6 // Catch an Exception
7 try {
8     throwingCall();
9 } catch (type const & e) { /* Handle type exception */
10 } catch (type2 const & e) { /* Handle type2 exception */
11 } catch (...) { /* Handle other exception types */
12 } // Caught exceptions can be rethrown with throw;
13
14 //CUTE
15 void testSquareRootNegativeThrows() {
16     ASSERT_THROWS(square_root(-1.0), std::invalid_argument);
17 }
  
```

5 Woche05

6 Woche06

7 Woche07

8 Woche08

9 Woche09

10 Woche10

11 Woche11

12 Woche12

13 Woche13

14 Anhang

14.1 Übungen Woche XX

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Includes

```
1 // Only the declaration for input and output streams
2 #include <iosfwd>
3
4 // Implementation of input stream
5 #include <istream>
6
7 // Implementation of output stream
8 #include <ostream>
9
10 // Declaration of both streams and additionally std::cout, std::cin, std::cerr
11 #include <iostream>
12
13 // Functions: std::tolower(c), std::isupper(c)
14 #include <cctype>
15
16 // Strings
17 #include <string>
18
19 // Arrays
20 #include <array>
21
22 // Vectors (ArrayList)
23 #include <vector>
24
25 // Iterators: std::count, std::accumulate, std::distance, std::for_each
26 #include <iterator>
27
28 // std::iota
29 #include <numeric>
30
31 // function template, which allows passing lambdas (with capture)
32 #include <functional>
```
