Contents

1   Terminology

1.1   Expression

```
1  int foo{1}, bar{2};
2
3  int r = foo + bar;
4  // 'foo + bar' is an expression
5  // 'foo' itself is also an expression
```

1.2   Statement

```
1  void if_statement() {
2    if (true) {} // valid statement
3  }
4
5  void adding_two_ints() {
6    int three = 1 + 2; // '1 + 2' is a statement
7  }
8
9  void calling_a_function() {
10   adding_two_ints(); // calling the function adding_two_ints() is a statement
11 }
12
13 void executable_part_of_a_function() {
14   // the entire code between { } is a statement
15 }
```

1.3   Declaration

```
1  // a declaration gives the compiler information about the signature of a function.
2  // that way, it will know the return type, the name and the parameters of the
3  // function.
4  // however it does not matter to the compiler what the implementation looks like.
5  int this_is_a_declaration(int a, char b);
```

1.4   Definition

```
1  // this is the definition of the previously declared function.
2  // it implements the logic of the function in between {}
3  // a definition is always also a declaration. in this example, the previous
4  // declaration is actually not necessary.
5  int this_is_a_declaration(int a, char b) {
6    // implementation logic goes here
7  }
```

1.5   Parameter and Argument

```
1  // parameter
2  void call_me(int a) { } // 'a' is a parameter
3
4  // argument
5  void call_it() {
6    call_me(1); // '1' is the argument for the call to call_me()
7  }
```

1.6   Predicate

```
1  #include <iostream>
2  #include <vector>
3  #include <algorithm>
4  #include <iterator>
5
6  // a predicate is something that delivers a boolean value on a certain input.
7  // we differ between unary predicates, which take one argument, and binary
8  // predicates, which take two arguments.
9  // in C++, we can represent predicates with the following constructs:
10
11  // a struct overriding the call-operator
12  struct odd_s {
13    bool operator() (int n) {
14      return (n % 2);
15    }
16  };
17
18  // a function
19  bool odd_f(int n) {
20    return (n % 2);
21  }
22
23  // a lambda
24  auto odd_l = [](int n){ return (n % 2); };
25
26  void predicate() {
27    using namespace std;
28
29    vector<int> src{1, 2, 3, 4, 5, 6};
30
31    copy_if(src.begin(), src.end(), ostream_iterator<int>{cout}, odd_f);
32    copy_if(src.begin(), src.end(), ostream_iterator<int>{cout}, odd_l);
33    copy_if(src.begin(), src.end(), ostream_iterator<int>{cout}, odd_s{});
34
35    // output
36    // 135135135
37  }
```

2   Basic Concepts

2.1   Functions

2.1.1   A good function ...

- does exactly one thing (also known as high cohesion)

- has a name that describes its behaviour

- has only few parameters (up to 3 is preferable, no more than 5)

- consists of only a few lines of code

- does not contain deeply nested constructs (if/else, loops etc.)

- guarantees a clear result (also known as contract)

2.1.2   return statement

```cpp
1   #include <iostream>
2
3   int wild_function() {
4     // the compiler automatically returns 1 if we dont define a return statement
5   }
6
7   void return_statement() {
8     std::cout << "wild_function(): " << wild_function() << std::endl;
9
10    // output
11    // wild_function(): 1
12  }
```

2.1.3   function as argument

```cpp
1   double maybe(double d) {
2   }
3
4   // we can define functions as parameters with the following syntax:
5   void call_me(double f(double)) {
6     f(1);
7   }
8
9   void function_as_argument() {
10    call_me(maybe);
11
12    // we can also pass in a lambda with the same signature:
13    auto for_sure = [](double d) {return .0;};
14    call_me(for_sure);
15  }
```

2.2 Exceptions

- Exceptions in C++ have very small overhead. They don't provide additional information such as a stack trace or source code location

- Everything that is copyable can be thrown

- All exceptions are unchecked

2.2.1 Throwing Anything

```cpp
#include <string>
#include <sstream>

void throwing_anything() {
  try {
    throw 1;
  } catch (int i) {}

  try {
    throw "char";
  } catch (char const * i) {}


  try {
    throw std::string{"string"};
  } catch (std::string str) {}

  // we can not throw a stream because streams are not copyable
  // throw std::istringstream{"stream"};
  //                                        ^  error (...)
}
```

2.2.2 Throwing Standard Exceptions

```cpp
#include <stdexcept>

void throwing_std_exceptions() {
  try {
    throw std::logic_error{"something weird happend"};
  } catch (std::logic_error e) {}
}

// other exceptions include
//
// std::logic_error
// std::domain_error
// std::invalid_argument
// std::length_error
// std::out_of_range
// std::runtime_error
// std::range_error
// std::overflow_error
// std::underflow_error
```

2.2.3 Function Followed By Try-Catch

```cpp
// a functions definition can directly be implemented with a try-catch block
void function_followed_by_try_catch()
try {
  // useful implementation that may cause exception goes here
} catch(int i) {

}
```

2.3   Operator Overloading

2.3.1   Basic Example

```cpp
#include <iostream>

struct Age {
  Age(int age) : data{age} {}

  bool operator<(Age const& comparable) const {
    //                ^---                  ^--- not a requirement, but good practice
    //                                           for operators which dont change the state
    return data < comparable.data;
  }

  int data;
};

// an operator can also be defined outside of the types context.
// note that the member 'data' must be public in order to access it.
bool operator<=(Age& a, Age& b) {
  return a.data < b.data;
}

void basic_example() {
  Age a1{20};
  Age a2{30};

  std::cout << std::boolalpha << "20 < 30: " << (a1 < a2) << std::endl;
  std::cout << std::boolalpha << "20 <= 30: " << (a1 <= a2) << std::endl;
  // using the operator with a function call:
  std::cout << std::boolalpha << "20 < 30: " << (a1.operator<(a2)) << std::endl;
  // output
  // 20 < 30: true
  // 20 <= 30: true
  // 20 < 30: true

  // greater than is unimplemented, using it causes a compiler error:
  // std::cout << std::boolalpha << "20 > 30: " << (a1 > a2) << std::endl;
  //                                               ^ error: (...)
}
```

2.3.2   less than comparable

```
1   #include <vector>
2   #include <string>
3   #include <iostream>
4
5   #include <boost/operators.hpp>
6
7   // we can inherit from boosts less_than_comparable and implement the less-than
8   // operator to have all other operators ready for our type:
9   struct Number : private boost::less_than_comparable<Number> {
10    Number(int n) : data{n} {}
11
12    bool operator<(Number const& comparable) const {
13      data < comparable.data;
14    }
15
16    private: int data;
17  };
18
19  void boost_less_than_comparable() {
20    Number n1{0};
21    Number n2{1};
22
23    // we can now call all the comparation operators:
24    n1 < n2;
25    n1 > n2;
26
27    // heres an outline of how boost can simulate each operators behaviour with the
28    // less-than operator:
29    //
30    // operator    simulation with <
31    // ------------------------------
32    // a > b        (b < a)
33    // a >= b      !(a < b)
34    // a <= b      !(b < a)
35    // a == b      !(a < b) && !(b < a)
36    // a != b      !(a == b)
37  }
```

2.3.3   Increment Postfix vs. Prefix

```cpp
#include <iostream>

struct Inc {
  void operator++() {
    std::cout << "this is the prefix increment" << std::endl;
  }

  // we must use a dummy parameter of type int so the compiler can differ between the
  // pre- and postfix increment operators. the dummy parameter doesnt have any
  // specific value:
  void operator++(int dummy) {
    std::cout << "this is the postfix increment" << std::endl;
  }
};

void increment_postfix_vs_prefix() {
  Inc i{};
  ++i;
  i++;

  // output
  // this is the prefix increment
  // this is the postfix increment
}
```

2.4 Enums

2.4.1 Enums Are Integers

```cpp
#include <iostream>

void enums_are_integers() {
  enum season { Spring, Summer, Autumn, Winter };
  //              0       1       2       3

  int summer = Summer;
  std::cout << "summer: " << summer << std::endl;
  std::cout << "Summer + Winter: " << Summer + Winter << std::endl;

  // output
  // summer: 1
  // Summer + Winter: 4

  // increment or decrement does not work however:
  //
  // Spring++;
  //       ^  error: no operator++(int) declared for postfix ++ [-fpermissive]
}
```

2.4.2 Indices Can Be Defined

```cpp
#include <iostream>

void indices_can_be_defined() {
  enum season { Spring = 10, Summer, Autumn, Winter };
  //            10          11      12      13
  std::cout << "Spring: " << Spring << std::endl;
  std::cout << "Winter: " << Winter << std::endl;
  // output
  // Spring: 10
  // Winter: 13

  enum brand { Feldschloesschen = 1, Calanda, Quoellfrisch,
  //           1                      2        3
               Budweiser = 10, Heineken, SanMiguel };
  //           10              11        12

  std::cout << "Feldschloesschen: " << Feldschloesschen << std::endl;
  std::cout << "Calanda: " << Calanda << std::endl;
  std::cout << "Quoellfrisch: " << Quoellfrisch << std::endl;
  std::cout << "Budweiser: " << Budweiser << std::endl;
  std::cout << "Heineken: " << Heineken << std::endl;
  std::cout << "SanMiguel: " << SanMiguel << std::endl;
  // output
  // Feldschloesschen: 1
  // Calanda:          2
  // Quoellfrisch:     3
  // Budweiser:        10
  // Heineken:         11
  // SanMiguel:        12
}

// enum class d_o_w
//   Was ist der Unterschied? Bezeichner sind nicht in einem bestimmten Scope drin
//   und global verwendbar.
```

2.4.3 Casting

```cpp
void casting() {
  enum season { Spring, Summer, Autumn, Winter };
  //               0       1       2       3

  int summer = Summer;

  season favourite_season{Winter};
  std::cout << "favourite_season: " << favourite_season << std::endl;
  // output
  // favourite_season: 3

  // favourite_season = 1;
  //                    ^  error: invalid conversion from int to casting()::season

  favourite_season = static_cast<season>(1);
  std::cout << "favourite_season: " << favourite_season << std::endl;

  // output
  // favourite_season: 1
}
```

2.4.4 Operator Overloading

```cpp
#include <iostream>

enum Belt { Yellow, Orange, Green, Blue, Brown, Black };
//           0       1       2      3      4      5

Belt operator++(Belt &belt) {
  int tmp = (belt + 1) % (Black + 1);
  belt = static_cast<Belt>(tmp);
  return belt;
}

void operator_overloading() {
  Belt belt{Brown};

  std::cout << "belt: " << belt << std::endl;
  ++belt;
  std::cout << "belt: " << belt << std::endl;
  ++belt;
  std::cout << "belt: " << belt << std::endl;

  // output
  // belt: 4
  // belt: 5
  // belt: 0

  // calling this directly does not work
  // ++Green;
  // ^  error: no match for operator++ in ++(Belt)2u
}
```

2.4.5 Example: Toggle Button

```cpp
#include <ostream>
#include <stdexcept>

struct ToggleButton {

  void hit_button() {
    state = static_cast<State>((state + 1) % 3);
  }

  void print(std::ostream &out) const {
    if (state == State::OFF) {
      out << "OFF";
    } else if (state == State::ON) {
      out << "ON";
    } else if (state == State::BLINK) {
      out << "Blink";
    } else {
      throw std::invalid_argument {"Unkown state"};
    }
  }

private:

  enum State : short {
    OFF, ON, BLINK
  };

  State state { State::OFF };

};

std::ostream& operator<<(std::ostream &out, ToggleButton const &button) {
  button.print(out);
  return out;
}
```

```
1   #include "toggle_button.h"
2
3   void toggle_button_demo() {
4     ToggleButton button{};
5
6     std::cout << "button: " << button << std::endl;
7
8     button.hit_button();
9
10    std::cout << "button: " << button << std::endl;
11
12    button.hit_button();
13
14    std::cout << "button: " << button << std::endl;
15
16    button.hit_button();
17
18    std::cout << "button: " << button << std::endl;
19
20    // output
21    // button: OFF
22    // button: ON
23    // button: Blink
24    // button: OFF
25  }
```

2.5 Lambdas

2.5.1 Basic Examples

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

void nothing() {
  auto gapin_void = [ ]( ){ };
  //                 ^ ------------ captures
  //                   ^ --------- parameters
  //                      ^ ------ implementation

  gapin_void(); // calling a lambda is syntactically similar to calling a function
}

void say_hi() {
  auto hello_thing = [](std::string thing) {
    std::cout << "hello " << thing << "!" << std::endl;
    return true;
  };

  bool result = hello_thing("world");

  std::cout << "result: " << result << std::endl;

  // output
  // hello world!
  // result: 1
}
```

2.5.2 Function Objects

```cpp
#include <iostream>
#include <functional>

void auto_vs_function() {
  // in the previous example we saw how the lambda was assigned to a variable of
  // type auto. we can also use std::function<signature>:
  std::function<void(double)> p1 = [](double a){  };
  std::function<double(double)> p2 = [](double a){ return .0; };

  // checking if something was assigned to a function instance:
  if (p1) {
    std::cout << "p1 does something" << std::endl;
  }

  // output
  // p1 does something
}
```

2.5.3   Capturing

```
1   void capture_for_internal_use() {
2     int magic_number = 8616;
3
4     // if we want to use previously declared variables inside a lambda, we have to
5     // capture them. otherwise, a compiler error will occur:
6     auto capturer = [magic_number]() {
7       //                         ^--- capturing magic_number
8
9       int copy = magic_number;
10
11      // trying to change magic_number causes a compiler error
12      // magic_number = 9548;
13      //              ^   error: assignment of read-only variable magic_number
14    };
15    capturer();
16  }
```

```
1   #include <string>
2   #include <iostream>
3
4   void capture_with_write_access() {
5     std::string name{"batman"};
6
7     std::cout << name << std::endl;
8
9     auto change = [&name]() {
10      name = "spiderman";
11    };
12
13    change();
14
15    std::cout << name << std::endl;
16
17    // output
18    // batman
19    // spiderman
20  }
```

```
1   #include <string>
2
3   std::string PIE{"omnom"};
4
5   void capture_everything_by_reference() {
6     double PI = 3.141;
7
8     auto wicked_lambda = [&]() {
9       PIE = "mjam";
10      PI = 3.142;
11    };
12
13    wicked_lambda();
14  }
15
16  void capture_everything_by_value() {
17    double PI = 3.141;
18
19    auto wicked_lambda = [=]() {
20      PIE = "mjam";
21      // PI = 3.142;
22      //        ^  error: assignment of read-only variable PI
23    };
24
25    wicked_lambda();
26  }
```

```
1   void mutable_demo() {
2     int n = 1;
3
4     // if we wanted to change a captured variable inside a lambda, we have to define
5     // the lambda mutable. note that this is different to using the ampersand syntax,
6     // since the changes wont be reflected to the outside.
7     auto lambda = [n]() mutable {
8       n = 2;
9
10      // if we didnt specify mutable, the following compiler error would occur:
11      //  ^  error: assignment of read-only variable n
12    };
13
14    // n has only been changed inside the lambda
15    std::cout << "n: " << n << std::endl;
16
17    // output
18    // n: 1
19  }
```

3   Classes

3.1   Inheritance

3.1.1   constructor calls

```cpp
#include <iostream>

struct Furniture {
  Furniture() { std::cout << "furniture created" << std::endl; }
  ~Furniture() { std::cout << "furniture destroyed" << std::endl; }
};

struct Table : Furniture {
  Table() { std::cout << "table created" << std::endl; }
  ~Table() { std::cout << "table destroyed" << std::endl; }
};

struct WoodenTable : Table {
  WoodenTable() { std::cout << "wooden table created" << std::endl; }
  ~WoodenTable() { std::cout << "wooden table destroyed" << std::endl; }
};

void constructor_calls() {
  // the constructor of the base class is called first.
  // the constructor of the derived class is called last.
  // this order is reversed at the destruction of the object.
  WoodenTable wooden_table{};

  std::cout << "---" << std::endl;

  // output
  // furniture created
  // table created
  // wooden table created
  // ---
  // wooden table destroyed
  // table destroyed
  // furniture destroyed
}
```

3.1.2 calling super constructors

```cpp
struct Furniture {
  Furniture() { std::cout << "furniture created" << std::endl; }
};

struct Table : Furniture {
  Table() { std::cout << "table created" << std::endl; }
};

struct WoodenTable : Table {

  // we can call a constructor of the direct base class
  WoodenTable() : Table{} {
    std::cout << "wooden table created" << std::endl;
  }

  // if we try to call a constructor from the base type Furniture, we get a
  // compiler error:
  // WoodenTable() : Furniture{} {
  //                 ^  error: type Furniture is not a direct base of WoodenTable
  // }

  // we can also delegate an other constructor of the same type. the delegation is
  // called first:
  WoodenTable(int i) : WoodenTable{(double) i} {
    std::cout << "wooden table created with " << i << std::endl;
  }

  WoodenTable(double i) {
    std::cout << "doing more " << i << std::endl;
  }

};

void calling_super_constructors() {
  // calling the constructor which calls the constructor of the direct base:
  WoodenTable table1{};
  // furniture created
  // table created
  // wooden table created

  // calling the constructor which delegates to a constructor in the same type.
  // note how the delegation is called first:
  WoodenTable table2{0};
  // furniture created
  // table created
  // doing more 0
  // wooden table created with 0
}
```

3.1.3   pure virtual function

```
1   struct Drink {
2     // a pure virtual function can be compared to an abstract method in Java.
3     // as soon as a class contains this kind of function, the type becomes abstract
4     // and can not be instantiated.
5     // we can declare pure virtual functions with the following syntax:
6     virtual void prepare() = 0;
7   };
8
9   struct Beer : Drink {
10    void prepare() {}
11  };
12
13  struct Rivella : Drink {
14    // we dont have to implement prepare() here.
15    // however, the type Rivella will remain abstract.
16  };
17
18  void pure_virtual_function() {
19    // trying to instantiate an object of abstract type Drink causes an error:
20    // Drink drink{};
21    //              ^   error: cannot allocate an object of abstract type 'Drink'
22
23    // we cant instantiate an object of type Rivella because it is abstract:
24    // Rivella rivella{};
25    //                  ^   error: cannot allocate an object of abstract type 'Rivella'
26
27    Beer beer{};
28  }
```

3.1.4   object slicing

```cpp
#include <iostream>

namespace example_1 {
  struct Creature {
    void walk() {}
  };

  struct Ork : Creature {
    void grunt() {}
  };

  void object_slicing() {
    // creatures can walk
    Creature creature{};
    creature.walk();

    // orks can walk and grunt
    Ork ork{};
    ork.walk();
    ork.grunt();

    // here we make a copy of the ork instance.
    // since we declare copy_of_ork to be of type Creature, only the part of that
    // type is copied. copy_of_ork therefore can not grunt. this is called object
    // slicing:
    Creature copy_of_ork = ork;
    copy_of_ork.walk();
    // copy_of_ork.grunt();
    //               ^   error: 'struct Creature' has no member named 'grunt'
  }
}
```

3.1.5   object slicing with reference and virtual

```
1   namespace example_2 {
2     struct Creature {
3       void walk() { std::cout << "creature is walking" << std::endl; }
4       virtual void grunt() { std::cout << "creature is grunting" << std::endl;}
5     };
6
7     struct Ork : Creature {
8       void walk() { std::cout << "ork is walking" << std::endl; }
9       void grunt() { std::cout << "ork is grunting" << std::endl; }
10    };
11
12    void object_slicing() {
13      Ork ork{};
14      Creature  ork_c = ork;  // a copy of ork.
15                              // contains the implementations of Creature only.
16      Creature& ork_r = ork;  // a reference to an Ork object.
17                              // delegates member calls to the implementations of
18                              // Creature unless the member is declared virtual.
19      Creature* ork_p = &ork; // a pointer to an Ork object. behaves the same way
20                              // as the reference.
21
22      // the following gets called on type Ork, as expected
23      ork.walk();      // ork is walking
24      ork.grunt();     // ork is grunting
25
26      // the following gets called on type Creature due to object slicing
27      ork_c.walk();    // creature is walking
28      ork_c.grunt();   // creature is grunting
29
30      // the following calls depend on whether the implementations are virtual or not.
31      // if not defined virtual, the behaviour is the same as with object slicing.
32      // if defined virtual, the calls are delegated to the original type Ork.
33      ork_r.walk();    // creature is walking
34      ork_r.grunt();   // ork is grunting
35
36      ork_p->walk();   // creature is walking
37      ork_p->grunt();  // ork is grunting
38    }
39  }
```

3.1.6   member hiding problem

```cpp
#include <iostream>

struct Vehicle {
  void accelarate(int amount) {}
  void repair() {}
  void refuel() const { std::cout << "refueling vehicle" << std::endl; }
};

struct Toeff : Vehicle {
  // because we overload the accelarate function in a derived class, we have to
  // make the functions from the base class available with the following statement:
  using Vehicle::accelarate;

  void accelarate() {}
  void refuel() { std::cout << "refueling toeff" << std::endl; }
};

void member_hiding_problem() {
  Toeff t{};

  // calling a function from base type Vehicle
  t.repair();

  // calling accelarate defined in type Toeff
  t.accelarate();

  // calling accelarate defined in type Vehicle
  // this is only possible because using Vehicle::accelarate;
  t.accelarate(1);

  // if the using statement is not defined, the following compiler error is raised:
  // t.accelarate(1);
  //              ^   error: no matching function for call to Toeff::accelarate(int)

  // the const keyword wont hide overloaded functions. the function of the derived
  // class is called:
  t.refuel(); // output: refueling toeff

}
```

3.1.7 humming bird

```cpp
#include <iostream>

struct Animal {
  void makeSound() { std::cout << "---\n";}
  virtual void move() { std::cout << "---\n";}

  Animal() { std::cout << "animal born\n";}
  ~Animal() { std::cout << "animal died\n";}
};

struct Bird : Animal {
  virtual void makeSound() { std::cout << "chirp\n";}
  void move() { std::cout << "fly\n";}

  Bird() { std::cout << "bird hatched\n";}
  ~Bird() { std::cout << "bird crashed\n";}
};

struct Hummingbird :  Bird {
  void makeSound() { std::cout << "peep\n";}
  virtual void move() { std::cout << "hum\n";}

  Hummingbird() { std::cout << "hummingbird hatched\n";}
  ~Hummingbird() { std::cout << "hummingbird died\n";}
};

void humming_bird() {
  std::cout << "(a)---------------------------\n";
  Hummingbird hummingbird;
  Bird        bird = hummingbird; // ACTHUNG: es wird eine Kopie erstellt, das heisst
                                  // der konstruktor wird nicht aufgeerufen!
  Animal &    animal = hummingbird;
  // Animal       animal2 = hummingbird;

  std::cout << "(b)---------------------------\n";
  hummingbird.makeSound();
  bird.makeSound();
  animal.makeSound();

  std::cout << "(c)---------------------------\n";
  hummingbird.move();
  bird.move();
  animal.move();
  // animal2.move();

  std::cout << "(d)---------------------------\n";
}

// animal born
// bird hatched
// hummingbird hatched
// (b)---------------------------
// peep
// chirp
// ---
// (c)---------------------------
// hum
// fly
// hum
// (d)---------------------------
// bird crashed
```

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4 Immutability

4.1 Const Function Parameters

```
1   // The parameter a is passed to this function as a reference and can be modified
2   // inside it.
3   void i_can_change_you(int& a) {
4     a++;
5   }
6
7   // This function declares its parameter as a reference and const. Const means that
8   // this parameter can not be modified inside the function.
9   // However, it is possible to pass in a non-const variable.
10  void i_cannot_change_you(const int& a) {
11    // a++;
12    // ^  error: increment of read-only reference 'a'
13  }
14
15  int test_i_cannot_change_you() {
16    // passing a non-const object to a function that declares the parameter const is
17    // possible:
18    int a = 1;
19    i_cannot_change_you(a);
20  }
21
22  // This function declares its parameter not as a reference and const. Const still
23  // means that the object can not be modified, however this makes less sense than in
24  // the previous example since this parameter is passed by value and therefore is a
25  // copy anyways.
26  void i_cannot_change_you_inside(const int a) {
27    // a ++;
28    // ^  error: increment of read-only parameter 'a'
29  }
30
31  // The previous function declaration is the same as the following, which would be
32  // ambiguous:
33  // void i_cannot_change_you_inside(int a) {
34  //       ^  error: redefinition of 'void i_cannot_change_you_inside(int)'
35  // }
```

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4.2 Const Return Values

```cpp
struct Dog {
  int age = 0;

  const int& getAge() {
    return age;
  }

  int& getMutableAge() {
    return age;
  }
};

void const_return_values() {
  Dog dog{};

  // variables declared const can not be modified
  const int& age = dog.getAge();
  // not possible:
  // age = 6;
  //     ^  error: assignment of read-only reference 'age'

  // not possible:
  // int& age = dog.getAge();
  //                     ^  error: invalid initialization of reference of type
  //                        'int&' from expression of type 'const int'

  int& muatable_age = dog.getMutableAge();

  // possible:
  muatable_age = 6;
}
```

4.3 Const Objects

```
1   void init_demo() {
2     // if we define a variable const, it must be initialized:
3     // const int number;
4     //            ^  error: uninitialized const number [-fpermissive]
5
6     const int number{0};
7   }
8
9   struct Cat {
10
11     int age;
12
13     void increaseAge() {
14       age++;
15     }
16
17     // Because this function is declared const, it is not possible to modify members
18     // of Cat.
19     // Also, it is not possible to call member functions that are NOT declared const.
20     void growUp() const {
21       // age++;
22       // ^  error: increment of member 'Cat::age' in read-only object
23
24       // increaseAge();
25       // ^  error: no matching function for call to 'Cat::increaseAge() const'
26     }
27
28     // Functions can be overloaded with the const keyword:
29     // The non-const version will be called if the object itself is not const.
30     // The const version will be called if the object itself is const.
31     void notAmbiguous() {}
32
33     void notAmbiguous() const {}
34
35   };
36
37   void const_functions() {
38     Cat cat{};
39     const Cat const_cat{};
40
41     // calling a const function on a non const object is possible:
42     cat.growUp();
43
44     // calling a non-const function on a const object is not possible:
45     // const_cat.increaseAge();
46     //            ^  error: no matching function for call to Cat::increaseAge() const
47
48     // calling functions overloaded with the const keyword depends on whether the
49     // object is const itself:
50     cat.notAmbiguous();
51     const_cat.notAmbiguous();
52   }
```

4.4 Const Values And Pointers

```
1  void value_is_const() {
2    const int value = 5;
3
4    // This pointer points to a variable of type const int. The pointer itself is not
5    // const and can be modified:
6    const int * value_p = &value;
7    value_p++;
8
9    // Changing the value which is pointed by the pointer is not possible:
10   // *value_p = 6;
11   //          ^   error: assignment of read-only location '* value_p'
12
13   // We can define a pointer of type const int eventhough it does not point to a
14   // const variable:
15   int not_const = 5;
16   const int * not_const_p = &not_const;
17
18   // *not_const_p = 6;
19   //              ^   error: assignment of read-only location * not_const_p
20 }
21
22 void pointer_is_const() {
23   int value = 5;
24
25   // This pointer is const and can not be modified:
26   int* const value_p = &value;
27   // value_p++;
28   //        ^   error: increment of read-only variable 'value_p'
29 }
30
31 void pointer_and_value_are_const() {
32   const int value = 5;
33
34   // Here we define a pointer which both points to a const variable and is const
35   // itself:
36   const int* const value_p = &value;
37   // *value_p = 6;
38   //          ^   error: assignment of read-only location '*(const int*)value_p'
39   // value_p++;
40   //        ^   error: increment of read-only variable 'value_p'
41
42   // Also note that putting the asterisk at the right place is critical:
43   // const int const *value_p = &value;
44   // ^   error: duplicate 'const'
45 }
```

5   Streams

5.1   Handling Invalid Input

5.1.1   Escape After Fail

```cpp
#include <iostream>
#include <sstream>

int get_age(std::istream& in) {
  int age{-1};

  while (!in.eof()) {
    if (in >> age) {
      return age;
    }

    std::cout << "in.good(): " << in.good() << std::endl; // in.good(): 0
    std::cout << "in.fail(): " << in.fail() << std::endl; // in.fail(): 1

    // at this point we have to read the remaining content of in so eof file is
    // reached and the while loop is escaped:
    in.clear();
    std::string line{};
    std::getline(in, line);
  }

  return -1;
}

void reading_integers() {
  std::istringstream in{"24 a 25"};

  int age;

  age = get_age(in);
  std::cout << "age: " << age << std::endl; // age: 24

  age = get_age(in);
  std::cout << "age: " << age << std::endl; // age: -1

  std::cout << "in.eof(): " << in.eof() << std::endl; // in.eof(): 1
}
```

5.1.2   Continue After Fail

```
1   #include <iostream>
2   #include <sstream>
3
4   int get_age_2(std::istream& in) {
5     int age{-1};
6
7     while (!in.eof()) {
8       if (in >> age) {
9         return age;
10      }
11
12      // read the invalid sequence then continue
13      in.clear();
14      std::string invalid_sequence{};
15      in >> invalid_sequence;
16    }
17
18    return -1;
19  }
20
21  void reading_integers_2() {
22    std::istringstream in{"24 a 25     "};
23
24    int age;
25
26    age = get_age_2(in);
27    std::cout << "age: " << age << std::endl; // age: 24
28
29    age = get_age_2(in);
30    std::cout << "age: " << age << std::endl; // age: 25
31
32    age = get_age_2(in);
33    std::cout << "age: " << age << std::endl; // age: -1
34
35    std::cout << "in.eof(): " << in.eof() << std::endl; // in.eof(): 1
36  }
```

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5.2 Manipulators

5.2.1 boolalpha

```cpp
#include <iostream>

void boolalpha_demo() {
  std::cout << true << std::endl;
  std::cout << std::boolalpha << true << std::endl;
  std::cout << true << std::endl;
  std::cout << 1 << std::endl;
  std::cout << 0 << std::endl;
  std::cout << std::noboolalpha << true << std::endl;

  // Output:
  // 1
  // true
  // true
  // 1
  // 0
  // 1
}
```

5.2.2 skipws

```cpp
#include <iostream>
#include <sstream>

void skipws_demo() {
  // Only has effect on istream
  char a, b, c;

  std::istringstream in{"  123"};
  in >> std::skipws >> a >> b >> c;
  std::cout << a << b << c << std::endl;
  // output: 123

  in.seekg(0); // reset stream to read from beginning
  in >> std::noskipws >> a >> b >> c;
  std::cout << a << b << c << std::endl;
  // output:   1

  std::cout << std::skipws << "   abc   def" << std::endl; // no effect
}
```

5.2.3 uppercase

```cpp
#include <iostream>

void uppercase_demo() {
  // makes hexadecimal representations uppercase.
  // attention: non numeric types will NOT be uppercase!
  // the following example shows no effect:
  std::cout << std::uppercase << "abc" << std::endl << std::nouppercase;
  // Output:
  // abc

  // Output integers as hex values:
  std::cout << std::showbase << std::hex;
  std::cout << std::uppercase << 77 << std::endl;
  std::cout << std::nouppercase << 77 << std::endl;

  // Output:
  // 0X4D
  // 0x4d
}
```

5.2.4 oct, hex, dec

```cpp
#include <iostream> // std::cout, std::dec, std::hex, std::oct

void oct_hex_dec() {
  int n = 29;
  std::cout << std::dec << n << std::endl;
  // the setting persists for subsequent calls
  std::cout << std::hex << n << std::endl;
  std::cout << n << std::endl;
  std::cout << std::oct << n << std::endl;
  std::cout << n << std::endl;

  // output
  // 29
  // 1d
  // 1d
  // 35
  // 35
}
```

5.2.5   setw

```cpp
#include <iostream>
#include <iomanip> // std::setw

void std_cout_width() {
  // setting the width on an output stream determines the minimum count of characters
  // the output shall have:
  std::cout.width(4);
  std::cout << "ab" << std::endl;

  // this setting will be consumed by the first output to the stream. the next
  // output will not have the width set anymore:
  std::cout << "ab" << std::endl;

  //output
  //    ab
  // ab
}

void setw() {
  // we can use setw(n) as a shortcut to width(n):
  std::cout << std::setw(4) << "ab" << std::endl;
  std::cout << "ab" << std::endl;

  //output
  //    ab
  // ab
}
```

5.2.6   left, right, internal

```
1   #include <iostream>
2
3   void left_right_internal() {
4     int n = -1;
5
6     // using std::left or std::right will align the output to the left or right if a
7     // width has been specified:
8     std::cout.width(6);
9     std::cout << std::left << n << std::endl;
10
11    std::cout.width(6);
12    std::cout << std::right << n << std::endl;
13
14    // std::internal can be used for negative numbers.
15    // for non-numerical values it is equivalent to right:
16    std::cout.width(6);
17    std::cout << std::internal << n << std::endl;
18
19    // output
20    // -1
21    //     -1
22    // -    1
23  }
```

5.2.7   setprecision, scientific, fixed

```cpp
#include <iostream> // setprecision, scientific, fixed

double PI = 3.14159;

void setprecision() {

  // setprecision sets the maximum digits to display.
  // the number is automatically rounded.
  std::cout << std::setprecision(5) << PI << std::endl;
  // setprecision will persist for subsequent outputs to the stream
  std::cout << PI << std::endl;

  // output
  // 3.1416
  // 3.1416
}

void scientific() {
  std::cout << std::scientific << 10000000.0 << std::endl;

  std::cout << std::setprecision(0);

  std::cout << std::scientific << 10000000.0 << std::endl;

  // output
  // 1.000000e+07
  // 1e+07
}

void fixed() {
  // expands the output to a minimum of digits.
  std::cout << std::fixed << 1.1 << std::endl;
  // 1.100000

  std::cout << std::fixed << std::setprecision(3) << 1.0 << std::endl;
  std::cout << std::fixed << PI << std::endl;
  // 1.000
  // 3.142
}
```

6   Iterators

6.1   Insert Iterators

6.1.1   Insert iterator

```cpp
#include <iterator>
#include <vector>
#include <algorithm>
#include "util.h"

void insert_iterator() {
  std::vector<int> incomplete{1, 4, 5};
  print("incomplete", incomplete);

  std::vector<int>::iterator it = incomplete.begin();
  it++; // we have to insert after the first entry, so lets increment by one
  std::insert_iterator<std::vector<int>> insert_iterator{incomplete, it};

  std::vector<int> addition{2, 3}; // this is the content we want to insert
  std::copy(addition.begin(), addition.end(), insert_iterator);

  print("complete", incomplete);

  // output
  // incomplete:   {1, 4, 5}
  // complete:     {1, 2, 3, 4, 5}
}
```

6.1.2   Back insert iterator

```cpp
#include <iterator>
#include <vector>
#include <algorithm>
#include "util.h"

void back_insert_iterator() {
  std::vector<int> incomplete{5, 4};
  print("incomplete", incomplete);

  std::vector<int> addition{3, 2, 1};
  std::copy(addition.begin(), addition.end(), std::back_inserter(incomplete));

  print("complete", incomplete);

  // output
  // incomplete:   {5, 4}
  // complete:     {5, 4, 3, 2, 1}
}
```

6.1.3   Front insert iterator

```
1   #include <iterator>
2   #include <list>
3   #include <algorithm>
4   #include "util.h"
5
6   void front_insert_iterator() {
7     std::list<int> incomplete{4, 5};
8     print("incomplete", incomplete);
9
10    std::vector<int> addition{3, 2, 1};
11    std::copy(addition.begin(), addition.end(), std::front_inserter(incomplete));
12
13    print("complete", incomplete);
14
15    // output
16    // incomplete:    {4, 5}
17    // complete:      {1, 2, 3, 4, 5}
18  }
```

6.2   Stream Iterators

6.2.1   Iterate over strings

```cpp
#include <sstream>
#include <iterator>
#include <iostream>

void iterate_over_strings() {
  using namespace std;

  istringstream in{"ill iterate until youre dizzy"};

  copy(istream_iterator<string>{in}, istream_iterator<string>{},
       ostream_iterator<string>{cout, "-"});

  // output
  // ill-iterate-until-youre-dizzy
}
```

6.2.2   Iterate over ints

```cpp
#include <sstream>
#include <iterator>
#include <iostream>

void iterate_over_ints() {
  using namespace std;

  istringstream in{"1 2 3"};

  copy(istream_iterator<int>{in}, istream_iterator<int>{},
       ostream_iterator<int>{cout, ""});

  // output
  // 123
}
```

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6.2.3   Iterate over your own types

```cpp
#include <string>
#include <algorithm>

struct Word {

  void read(std::istream& in) {
    in >> data;
    std::transform(data.begin(), data.end(), data.begin(), toupper);
  }

  void write(std::ostream& os) const {
    os << data;
  };

private:

  std::string data;

};

std::istream& operator>>(std::istream& in, Word& r) {
  r.read(in);
  return in;
}

std::ostream& operator<<(std::ostream& out, Word const& r) {
  r.write(out);
  return out;
}


void iterate_over_your_own_types() {
  using namespace std;

  istringstream in{"ill iterate until youre dizzy"};

  copy(istream_iterator<Word>{in}, istream_iterator<Word>{},
       ostream_iterator<Word>{cout, " "});

  // output
  // ILL ITERATE UNTIL YOURE DIZZY
}
```

6.2.4   Count Chars

```cpp
#include <iostream>
#include <sstream> // istringstream
#include <iterator>
#include <algorithm>

void count_all_chars_skip_whitespaces() {
  std::istringstream in{"ab c d !?  &*"};

  // istream_iterator<char> will iterator through every char in the stream, except
  // white spaces.
  using Iterator = std::istream_iterator<char>;
  Iterator begin{in};
  Iterator end{};

  // we could also use the count_if algorithm and use a lamda that always returns
  // true. distance is more elegant, however a bit abstract:
  int count = std::distance(begin, end);

  std::cout << "count: " << count << std::endl; // count: 8
}

void count_all_chars() {
  std::istringstream in{"ab c d !?  &*"};

  // using a istreambuf_iterator avoids skipping white spaces.
  using Iterator = std::istreambuf_iterator<char>;
  Iterator begin{in};
  Iterator end{};

  int count = std::distance(begin, end);

  std::cout << "count: " << count << std::endl; // count: 13
}
```

6.2.5   Count Specific Chars

```cpp
void count_specific_chars() {
  std::istringstream in{"oppa gangnam style"};

  using Iterator = std::istream_iterator<char>;
  Iterator begin{in};
  Iterator end{};

  int count = std::count(begin, end, 'a');

  std::cout << "count: " << count << std::endl; // count: 3
}
```

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6.2.6   Count Words

```cpp
void count_words() {
  std::istringstream in{"oppa gangnam style :D"};

  // this iterator will read char sequences that are separated by white spaces:
  using Iterator = std::istream_iterator<std::string>;
  Iterator begin{in};
  Iterator end{};

  int count = std::distance(begin, end);

  std::cout << "count: " << count << std::endl; // count: 4
}
```

6.3   Custom Iterators

6.3.1   Line Iterator

```cpp
#include <iostream>
#include <iterator>
#include <algorithm>
#include <sstream>
#include <boost/operators.hpp>

namespace {
  std::istringstream empty{};
}

struct LineIterator : boost::input_iterator_helper<LineIterator, std::string> {

  LineIterator() : in(empty) {
    in.clear(std::ios_base::eofbit);
  }

  explicit LineIterator(std::istream &in) : in(in) {
    read_next_line();
  }

  bool operator==(LineIterator const &r) const {
    return !in.good() && !r.in.good();
  }

  value_type operator*() const {
    return current_line;
  }

  LineIterator &operator ++() {
    read_next_line();
    return *this;
  }

private:

  void read_next_line() {
    getline(in, current_line);
  }
  std::istream &in;
  std::string current_line;
};
```

```
1   #include "line_iterator.h"
2
3   void line_iterator_demo() {
4     std::istringstream in{"first line\nsecond line"};
5     LineIterator li{in};
6
7     std::cout << "*li: " << *li << std::endl;
8     li++;
9     std::cout << "*li: " << *li << std::endl;
10
11    // output
12    // *li: first line
13    // *li: second line
14  }
15
16  int main() {
17    line_iterator_demo();
18  }
```

6.3.2   My Ostream Iterator

```cpp
#include <iostream>
#include <iterator>
#include <algorithm>

struct MyOstreamIterator
: std::iterator<std::output_iterator_tag, int>  {

  explicit MyOstreamIterator(std::ostream& out) : out{&out} {}

  MyOstreamIterator& operator =(const int value) {
    *out << value;
    return *this;
  }

  MyOstreamIterator& operator *() { return *this; }
  MyOstreamIterator& operator ++() { return *this; }
  MyOstreamIterator& operator ++(int) { return *this; }

private:

  std::ostream* out;

};

void my_ostream_iterator_demo() {
  MyOstreamIterator moi{std::cout};

  moi = 1;
  moi = 20;
  moi = 300;

  // output
  // 120300
}
```

6.3.3   Square Iterator

```cpp
#include <iterator>

struct SquareIterator : std::iterator<std::input_iterator_tag, int>
{
  explicit SquareIterator(int start=0) : value{start} {}

  bool operator ==(SquareIterator const &r) const {
    return value == r.value;
  }

  bool operator !=(SquareIterator const &r) const {
    return !(*this == r);
  }

  value_type operator *() const {
    return value * value;
  }

  SquareIterator& operator ++() {
    ++value;
    return *this;
  }

  SquareIterator operator ++(int) {
    auto old = *this;
    ++(*this);
    return old;
  }

private:

  int value;

};
```

```cpp
#include "square_iterator.h"

#include <iostream>
#include <algorithm>

void square_iterator_demo() {

  SquareIterator begin{2};
  SquareIterator end{6};

  std::for_each(begin, end, [](int sqr) {
    std::cout << "sqr: " << sqr << std::endl;
  });

  // output
  // sqr: 4
  // sqr: 9
  // sqr: 16
  // sqr: 25
}

int main() {
  square_iterator_demo();
}
```

6.3.4   Prime Iterator

```cpp
#include <iostream>
#include <vector>
#include <array>
#include <algorithm>
#include <boost/iterator/counting_iterator.hpp>
#include <boost/iterator/filter_iterator.hpp>

bool is_divisable(int x, int divisor) {
  return !(x % divisor);
}

bool is_prime(unsigned x) {
  if (x % 2 == 0 || x < 3) return false;
  return std::none_of(boost::make_counting_iterator(2u),
                      boost::make_counting_iterator(x),
                      [x](unsigned divisor) { return is_divisable(x, divisor); });
}

void prime_iterator() {
  auto counting = boost::make_counting_iterator(1);
  auto countingEnd = boost::make_counting_iterator(40);

  auto prime_iterator = boost::make_filter_iterator(is_prime, counting);
  auto prime_iterator_end = boost::make_filter_iterator(is_prime, countingEnd);

  std::copy(prime_iterator, prime_iterator_end,
            std::ostream_iterator<int>{std::cout, " "});

  // output
  // 3 5 7 11 13 17 19 23 29 31 37
}
```

6.4 Iterator Semantics

6.4.1 Iterator

```cpp
#include <iostream>
#include <iterator>
#include <vector>

void iterator() {
  std::vector<int> v{0, 1, 2, 3, 4};

  // 0 1 2 3 4
  // ^ v.begin()

  // 0 1 2 3 4
  //           ^ v.end()

  // 0 1 2 3 4
  //         ^ --v.end()

  std::cout << "*v.begin():   " << *v.begin()   << std::endl;
  std::cout << "*v.end():     " << *v.end()     << std::endl;
  std::cout << "*(--v.end()): " << *(--v.end()) << std::endl;

  // output
  // *v.begin():   0
  // *v.end():     (undefined behaviour)
  // *(--v.end()): 4
}
```

6.4.2   Reverse Iterator

```
1   void reverse_iterator() {
2     std::vector<int> v{10, 11, 12, 13, 14};
3
4     // 10 11 12 13 14
5     //             ^ v.rbegin()
6
7     // 10 11 12 13 14
8     //          ^ v.rbegin() + 1
9
10    //   10 11 12 13 14
11    // ^ v.rend()
12
13    //     10 11 12 13 14
14    // ^ v.rend() + 1
15
16    // 10 11 12 13 14
17    // ^ v.rend() - 1
18
19    std::vector<int>::reverse_iterator rbegin = v.rbegin();
20    std::vector<int>::reverse_iterator rend = v.rend();
21
22    std::cout << "*rbegin:       " << *rbegin       << std::endl;
23    std::cout << "*(rbegin + 1): " << *(rbegin + 1) << std::endl;
24    std::cout << "*rend:         " << *rend         << std::endl;
25    std::cout << "*(rend + 1):   " << *(rend + 1)   << std::endl;
26    std::cout << "*(rend - 1):   " << *(rend - 1)   << std::endl;
27
28    // output
29    // *rbegin:       14
30    // *(rbegin + 1): 13
31    // *rend:         (undefined behaviour)
32    // *(rend + 1):   (undefined behaviour)
33    // *(rend - 1):   10
34  }
```

7 Containers

7.1 Vector

7.1.1 Initialization

```cpp
#include <vector>

void initialization() {
  // with initializer list
  std::vector<int> ve1{1, 2, 3};

  // with capacity
  // elements are zero-initialized
  std::vector<int> ve2(3);
}
```

7.1.2 Accessing Elements

```cpp
#include <vector>

void accessing_elements() {
  std::vector<int> ve1(3);

  // we can use at() or the []-operator to access elements in a vector
  ve1.at(1);
  ve1[1];

  // the difference lies in the behaviour of when trying to access an element with
  // an index that is out of range:

  // the following code would throw 'std::out_of_range'
  // ve1.at(3);

  // the following code is undefined behaviour and does not throw an exception
  // ve1[3];
}
```

7.1.3 Assigning Values

```cpp
#include <iostream>
#include <vector>

void assigning_values() {
  std::vector<int> ve1{3, 2, 1};

  ve1[1] = 10; // OK

  // the following line tries to access an invalid index and is undefined behaviour
  // ve1[3] = 30;
}

void using_front() {
  std::vector<int> ve1{3, 2, 1};

  // because front() returns a reference, we can also assign values to it
  std::cout << ve1.front() << std::endl;
  ve1.front() = 4;
  std::cout << ve1.front() << std::endl;
  // Output:
  // 3
  // 4

  // there is also a const version of front();
  const int f = ve1.front();

  // the opposite to front() is back()
}
```

7.1.4 Appending Values

```cpp
#include <vector>

void appending_values() {
  std::vector<int> ve1(3);
  ve1.push_back(0);
  ve1.push_back(1);
  ve1.push_back(2);

  // At this point, the vector will automatically resize.
  ve1.push_back(3);
}
```

7.1.5 Iterating Elements

```cpp
#include <vector>

void iteration_with_read_only_access() {
  std::vector<int> v{1, 2, 3};
  for (auto const i : v) {
    std::cout << i << " ";

    // i++;
    // ^  error: increment of read-only variable i
  }
  std::cout << '\n';

  // Output:
  // 1 2 3
}

void iteration_with_reference() {
  std::vector<int> v{1, 2, 3};
  for (auto &i : v) {
    i++;
    std::cout << i << " ";
  }
  std::cout << '\n';

  // Output
  // 2 3 4
}
```

8   Algorithms

8.1   Modifying

8.1.1   Copy

```
#include "util.h"

#include <algorithm>
#include <vector>

void copy_directly() {
  std::vector<int> src{1, 2, 3, 4};

  // note that the size of dest must be at least the size of src to avoid
  // undefined behaviour:
  std::vector<int> dest(4);

  std::copy(src.begin(), src.end(), dest.begin());

  print("src", src);
  print("dest", dest);

  // output
  // src:  1 2 3 4
  // dest: 1 2 3 4
}

void copy_with_back_inserter() {
  std::vector<int> src{5, 6, 7, 8};
  std::vector<int> dest{};

  // using a back_inserter here makes sure that dest is being resized if required:
  std::copy(src.begin(), src.end(), std::back_inserter(dest));

  print("src", src);
  print("dest", dest);

  // output
  // src:  5 6 7 8
  // dest: 5 6 7 8
}
```

8.1.2 Move

```cpp
#include "util.h"

#include <algorithm>
#include <vector>
#include <string>

void move_integers() {
  std::vector<int> numbers{1, 2, 3, 4};
  std::vector<int> copied_numbers;

  std::move(numbers.begin(), numbers.end(), std::back_inserter(copied_numbers));

  print("numbers", numbers);
  print("copied_numbers", copied_numbers);

  // moving the elements depends on the move semantics of the given type.
  // in this case, we are moving ints. the move semantics of ints keeps the original
  // values in the vector:
  //
  // numbers:        1 2 3 4
  // copied_numbers: 1 2 3 4
}

void move_strings() {
  std::vector<std::string> strings{"a", "b", "c"};
  std::vector<std::string> copied_strings;

  std::move(strings.begin(), strings.end(), std::back_inserter(copied_strings));

  print("strings", strings);
  print("copied_strings", copied_strings);

  // move semantics of string actually moves the elements from one vector to the
  // other:
  //
  // strings:        "" "" ""
  // copied_strings: "a" "b" "c"
}
```

8.1.3 Transform

```cpp
#include "util.h"

#include <algorithm>
#include <vector>

void unary_transform() {
  std::vector<int> numbers{1, 2, 3, 4};

  std::transform(numbers.begin(), numbers.end(),
                 numbers.begin(),
                 [](int n) { return n + 10; });

  print("numbers", numbers);

  // output
  // 11 12 13 14
}

void binary_transform() {
  std::vector<int> numbers1{1, 2, 3, 4};
  std::vector<int> numbers2{4, 3, 2, 1};

  std::transform(numbers1.begin(), numbers1.end(),
                 numbers2.begin(), numbers2.begin(),
                 [](int n1, int n2) { return n1 + n2; });

  print("numbers2", numbers2);

  // output
  // 5 5 5 5
}
```

8.2   Partitioning

8.2.1   Partitioning

```
#include "util.h"

#include <algorithm>
#include <vector>

void partition() {
  std::vector<int> v{1, 2, 3, 4, 5, 6, 7, 8};

  print("before", v);

  // puts all the even numbers into the first half of the vector and all the odd
  // numbers into the second half
  std::partition(v.begin(), v.end(), [](int n) { return !(n % 2); });

  print("after", v);

  // output
  // before: 1 2 3 4 5 6 7 8
  // after:  8 2 6 4 5 3 7 1
}

// makes sure the relative order of the elements is preserved
void stable_partition() {
  std::vector<int> v{1, 2, 3, 4, 5, 6, 7, 8};

  print("before", v);

  std::stable_partition(v.begin(), v.end(), [](int n) { return !(n % 2); });

  print("after", v);

  // output
  // before: 1 2 3 4 5 6 7 8
  // after:  2 4 6 8 1 3 5 7
}

// besides these there are the following algorithms handling partitioning:
//
// is_partitioned(v.begin(), v.end(), unary_predicate)
//
// partition_copy(v.begin(), v.end(), dest1.begin(), dest2.begin(), unary_predicate)
//
// forward_iterator = partition_point(v.begin(), v.end(), unary_predicate)
```

8.3   Numeric

8.3.1   Accumulate

```
1   void accumulate_demo() {
2     std::vector<int> v{1, 2, 3, 4, 5};
3
4     int sum = std::accumulate(v.begin(), v.end(), 10);
5     std::cout << "sum: " << sum << std::endl;
6
7     int fac = std::accumulate(v.begin(), v.end(), 1, std::multiplies<int>());
8     //                                            ^ multiplication with 0 = 0!
9     std::cout << "fac: " << fac << std::endl;
10
11    // output
12    // sum: 25
13    // fac: 120
14  }
```

8.3.2   Adjacent Difference

```
1   void adjacent_difference_demo() {
2     std::vector<int> v{1, 2, 3, 4, 5, 6, 7, 8, 9};
3
4     std::vector<int> d1{};
5     std::vector<int> d2{};
6
7     std::adjacent_difference(v.begin(), v.end(), std::back_inserter(d1));
8     std::adjacent_difference(v.begin(), v.end(), std::back_inserter(d2),
9                              std::plus<int>());
10
11    std::copy(d1.begin(), d1.end(), std::ostream_iterator<int>{std::cout, " "});
12    std::cout << std::endl;
13    std::copy(d2.begin(), d2.end(), std::ostream_iterator<int>{std::cout, " "});
14
15    // output
16    // 1 1 1 1 1 1 1 1 1
17    // 1 3 5 7 9 11 13 15 17
18  }
```

8.3.3 Inner Product

```
1  void inner_product_demo() {
2    std::vector<int> v1{1,   2,   3};
3    //                  *   *   *
4    std::vector<int> v2{4,   5,   6};
5    //                  4 + 10 + 18   = 32
6
7    int res = std::inner_product(v1.begin(), v1.end(), v2.begin(), 0);
8
9    std::cout << "res: " << res << std::endl;
10
11   // output
12   // res: 32
13 }
```

8.3.4 Partial Sum

```
1  void partial_sum_demo() {
2    // 1 =                  1
3    // 1 + 2 =              3
4    // 1 + 2 + 3 =          6
5    // 1 + 2 + 3 + 4 =     10
6    // 1 + 2 + 3 + 4 + 5 = 15
7
8    std::vector<int> v{1, 2, 3, 4, 5};
9    std::vector<int> r(5);
10
11   std::partial_sum(v.begin(), v.end(), r.begin());
12
13   std::copy(r.begin(), r.end(), std::ostream_iterator<int>(std::cout, " "));
14
15   // output
16   // 1 3 6 10 15
17 }
```

8.4   Misc

8.4.1   Fill Vector With Squares

```cpp
#include <iostream>
#include <iterator>
#include <vector>
#include <algorithm>
#include <numeric>

void fill_vector_with_squares() {
  // create vector containing only ones
  std::vector<int> v(10, 1);

  // this will make the vector contain the values from 1 to 10
  std::partial_sum(v.begin(), v.end(), v.begin());

  // square every item in v
  std::transform(v.begin(), v.end(), v.begin(), [](int i) { return i * i; });

  // print it
  std::copy(v.begin(), v.end(), std::ostream_iterator<int>{std::cout, " "});

  // output
  // 1 4 9 16 25 36 49 64 81 100
}
```

8.4.2 Is Palindrome

```cpp
#include <iostream>
#include <cctype>
#include <iterator>
#include <string>
#include <algorithm>

bool are_equal(char a, char b) {
  return tolower(a) == tolower(b);
}

bool is_palindrome(std::string word) {
  return std::equal(word.cbegin(),
                    word.cbegin() + word.length() / 2,
                    word.crbegin(),
                    are_equal);
}

void is_palindrome_demo() {
  std::cout << std::boolalpha;
  std::cout << is_palindrome("Rihanna") << std::endl;
  std::cout << is_palindrome("Anna") << std::endl;
  std::cout << is_palindrome("abcba") << std::endl;
  std::cout << is_palindrome("trugtimeinesohellehoseniemitgurt") << std::endl;

  // output
  // false
  // true
  // true
  // true
}
```

8.4.3   Multiplication Table

```
#include <iomanip> // std::setw

void multiplication_table() {
  std::vector<int> numbers(20, 1);

  // generate a list containing the values from 1 to 20.
  // could also be done with iota which would be much easier lol.
  std::transform(numbers.begin(), numbers.end()-1, numbers.begin()+1, numbers.begin()+1,
                 [](int a, int b) { return a + b; });

  std::for_each(numbers.begin(), numbers.end(), [&numbers](int i) {
    std::for_each(numbers.begin(), numbers.end(), [&i](int j) {
      std::cout << std::setw(4) << i * j;
    });
    std::cout << '\n';
  });

  // output
  //
  //    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15   16   17   18   19   20
  //    2    4    6    8   10   12   14   16   18   20   22   24   26   28   30   32   34   36   38   40
  //    3    6    9   12   15   18   21   24   27   30   33   36   39   42   45   48   51   54   57   60
  //    4    8   12   16   20   24   28   32   36   40   44   48   52   56   60   64   68   72   76   80
  //    5   10   15   20   25   30   35   40   45   50   55   60   65   70   75   80   85   90   95  100
  //    6   12   18   24   30   36   42   48   54   60   66   72   78   84   90   96  102  108  114  120
  //    7   14   21   28   35   42   49   56   63   70   77   84   91   98  105  112  119  126  133  140
  //    8   16   24   32   40   48   56   64   72   80   88   96  104  112  120  128  136  144  152  160
  //    9   18   27   36   45   54   63   72   81   90   99  108  117  126  135  144  153  162  171  180
  //   10   20   30   40   50   60   70   80   90  100  110  120  130  140  150  160  170  180  190  200
  //   11   22   33   44   55   66   77   88   99  110  121  132  143  154  165  176  187  198  209  220
  //   12   24   36   48   60   72   84   96  108  120  132  144  156  168  180  192  204  216  228  240
  //   13   26   39   52   65   78   91  104  117  130  143  156  169  182  195  208  221  234  247  260
  //   14   28   42   56   70   84   98  112  126  140  154  168  182  196  210  224  238  252  266  280
  //   15   30   45   60   75   90  105  120  135  150  165  180  195  210  225  240  255  270  285  300
  //   16   32   48   64   80   96  112  128  144  160  176  192  208  224  240  256  272  288  304  320
  //   17   34   51   68   85  102  119  136  153  170  187  204  221  238  255  272  289  306  323  340
  //   18   36   54   72   90  108  126  144  162  180  198  216  234  252  270  288  306  324  342  360
  //   19   38   57   76   95  114  133  152  171  190  209  228  247  266  285  304  323  342  361  380
  //   20   40   60   80  100  120  140  160  180  200  220  240  260  280  300  320  340  360  380  400
}
```

8.4.4   Sum Numbers

```cpp
#include <numeric>    // accumulate
#include <sstream>

void sum_integers() {
  std::istringstream in{"1 2 3"};

  using Iterator = std::istream_iterator<int>;
  Iterator begin{in};
  Iterator end{};

  int sum = 0;

  sum = std::accumulate(begin, end, 0);
  std::cout << "sum: " << sum << std::endl; // sum: 6
}

void sum_floats() {
  std::istringstream in{"1.1 2.2 3.3"};

  using Iterator = std::istream_iterator<double>;
  Iterator begin{in};
  Iterator end{};

  double sum = 0;

  sum = std::accumulate(begin, end, .0);
  //                                      ^--- we have to pass in a double, otherwise result
  //                                           will be integer!
  std::cout << "sum: " << sum << std::endl; // sum: 6.6
}
```

8.4.5 Word List

```cpp
1   #include <algorithm>
2   #include <iostream>
3   #include <sstream>
4   #include <iterator>
5   #include <set>
6
7   struct Comparator {
8     bool operator() (const std::string& a, const std::string& b) const {
9       return std::lexicographical_compare(a.begin(), a.end(), b.begin(), b.end(),
10                        [](char x, char y) {return tolower(x) < tolower(y);});
11    }
12  };
13
14  void word_list() {
15    using Iterator = std::istream_iterator<std::string>;
16
17    std::istringstream in{"this is a test this is A TEST THIS IS"};
18
19    std::set<std::string, Comparator> list(Iterator{in}, Iterator{});
20
21    std::copy(list.begin(), list.end(), std::ostream_iterator<std::string>{std::cout, "\n"});
22
23    // output (note how set automatically sorts its content)
24    // a
25    // is
26    // test
27    // this
28  }
```

9 Bind

9.1 Examples

```cpp
#include <functional> // std::bind, std::placeholders
#include <cmath>       // sqrt
#include <iostream>

using namespace std::placeholders;

// x + y
void example_1() {
  auto e = std::bind(std::plus<double>(), _1, _2);

  std::cout << "1 + 2 = " << e(1, 2) << std::endl;

  // output
  // 1 + 2 = 3
}

// (2 * x) - (y / 3)
void example_2() {
  auto e = std::bind(std::minus<double>(),
                     std::bind(std::multiplies<double>(), 2, _1),
                     std::bind(std::divides<double>(), _2, 3));

  std::cout << "(2 * 2) - (6 / 3) = " << e(2, 6) << std::endl;

  // output
  // (2 * 2) - (6 / 3) = 2
}

// (x * x) % y
void example_3() {
  auto e = std::bind(std::modulus<int>(),
                     std::bind(std::multiplies<double>(), _1, _1), _2);

  std::cout << "(4 * 4) % 5 = " << e(4, 5) << std::endl;

  // output
  // (4 * 4) % 5 = 1
}

// sqrt(x * x)
void example_4() {
  auto e = std::bind(sqrt, std::bind(std::multiplies<double>(), _1, _1));

  std::cout << "sqrt(4 * 4) = " << e(4) << std::endl;

  // output
  // sqrt(4 * 4) = 4
}
```

10   Templates

10.1   Function Templates

10.1.1   median

```cpp
#include <iostream>
#include <vector>
#include <algorithm>

template<typename T>
T median(T a, T b, T c) {
  std::vector<T> list{a, b, c};
  std::sort(list.begin(), list.end());
  return list.at(1);
}

void median_demo() {
  std::cout << "median(2, 3, 1): " << median(2, 3, 1) << std::endl;

  // output
  // median(2, 3, 1): 2
}
```

10.1.2   rotate 3 arguments

```cpp
template<typename T>
void rotate_3_arguments(T& a, T& b, T& c) {
  T tmp = a;
  a = b;
  b = c;
  c = tmp;
}

void rotate_3_arguments_demo() {
  int a{0}, b{1}, c{2};
  rotate_3_arguments(a, b, c);
  std::cout << "a: " << a << std::endl;
  std::cout << "b: " << b << std::endl;
  std::cout << "c: " << c << std::endl;

  // output
  // a: 1
  // b: 2
  // c: 0
}
```

10.1.3   read line

```cpp
#include <string>
#include <sstream>

void read_line(std::istream& in) {
  std::cout << "doing absolutely nothing!" << std::endl;
}

template<typename HEAD, typename...ARGS>
void read_line(std::istream& in, HEAD& head, ARGS &...args) {
  in >> head;
  read_line(in, args...);
}

void read_line_demo() {
  int a, b, c;
  std::string input{"1 2 3"};
  std::istringstream in{input};

  read_line(in, a, b, c);

  std::cout << "a: " << a << std::endl;
  std::cout << "b: " << b << std::endl;
  std::cout << "c: " << c << std::endl;

  // output
  // a: 1
  // b: 2
  // c: 3
}

  // if (sizeof...(args)) {
  //   read_line(in, args...);
  // }
```

10.1.4   read line 2

```cpp
#include <iostream>
#include <sstream>

void read_line_2(std::istream& in, std::string& str) {
  getline(in, str);
}

template<typename HEAD, typename...ARGS>
void read_line_2(std::istream& in, HEAD& head, ARGS &...args) {
  in >> head;
  read_line_2(in, args...);
}

void read_line_2_demo() {
  std::istringstream in{"1 some rest 123 \n 2 the rest\n"};
  std::string rest{};
  int first{};

  read_line_2(in,first,rest);

  std::cout << first << std::endl;
  std::cout << rest << std::endl;

  read_line_2(in,first,rest);

  std::cout << first << std::endl;
  std::cout << rest << std::endl;

  // output
  // 1
  //  some rest 123
  // 2
  //  the rest
}
```

10.1.5   calling unimplemented functions

```
1   struct Lea {
2     void call() {
3     }
4   };
5
6   struct Julia {
7   };
8
9   template<typename T>
10  void call_me(T girl) {
11    girl.call();
12  }
13
14  void calling_unimplemented_functions() {
15    Lea lea{};
16    Julia julia{};
17
18    // will call call() on lea
19    call_me(lea);
20
21    // calling call_me() with julia will cause a compiler error:
22    //
23    // call_me(julia);
24    //         ^  error: struct Julia has no member named call
25  }
```

10.1.6   int and double dilemma

```
1   template<typename T>
2   void take_two(T one, T two) {
3   }
4
5   void int_and_double_dilemma() {
6     // the argument types to the following call to take_two() will be recoginzed by the
7     // compiler as an integer followed by a double:
8     //
9     // take_two(1, 2.2);
10    //                ^   error: no matching function for call to take_two(int, double)
11
12    // here are two solutions how to avoid this:
13
14    // with static_cast
15    take_two(static_cast<double>(1), 2.2);
16
17    // by specifying template argument
18    take_two<double>(1, 2.2);
19  }
```

10.1.7   string fallacy

```
1  #include <string>
2
3  template<typename T>
4  void compare(T const& one, T const& two) {
5  }
6
7  void string_fallacy() {
8    // the following does not compile. at first it looks like we are passing strings
9    // to the function. however, the compiler will recognize the arguments as char
10   // arrays:
11   //
12   // compare("shorter", "longer");
13   //                         ^   error: no matching function for call to
14   //                             compare(const char [8], const char [7])
15
16   // this works because both arguments have the same size:
17   compare("one", "two");
18
19   // if we want the arguments to be passed as strings, we can do the following:
20   compare<std::string>("shorter", "longer");
21 }
```

10.2   Class Templates

10.2.1   class template specialization

```cpp
// this example is currently incomplete. remove it?

#include <iostream>
#include <string>

template<typename T>
struct Versatile;

// we can specialize a templated class with the following syntax:
template<>
struct Versatile<std::string> {
  void print() {
    // std::cout << "string: " << data << std::endl;
//                               ^  error: data was not declared in this scope %bamprog%
  }
};

template<typename T>
struct Versatile {

  Versatile(T t) : data{t} {}

  void print() {
    std::cout << "number: " << data << std::endl;
  }

protected: T data;

};

void class_template_specialization() {
  Versatile<int> vint{1};
  vint.print();

  Versatile<double> vdou{1.1};
  vdou.print();

  Versatile<std::string> vstr{};
  vstr.print();

  // output
  // number: 1
  // number: 1.1
  // string: str
}
```

10.2.2   prohibited construction

```
1   #include <string>
2
3   // we can prohobit the creation of templated types with partial specializations by
4   // deleting the destructors in the specialized type. The compiler prohibits the
5   // creation of objects of types which dont have a destructor.
6   // the following two specialiations will prohibit creating instances of
7   // Restrictive<char> and Restrictive<T*>.
8
9   template<typename T>
10  struct Restrictive {
11  };
12
13  // prohibit Restrictive<char>
14  template<>
15  struct Restrictive<char> {
16    ˜Restrictive() = delete;
17  };
18
19  // prohibit Restrictive<T*>
20  template<typename T>
21  struct Restrictive<T*> {
22    ˜Restrictive() = delete;
23  };
24
25  void prohibited_construction() {
26    Restrictive<int> ints{};
27    Restrictive<std::string> strings{};
28
29    // Restrictive<char> chars{};
30    //                          ^  error: use of deleted function
31
32    // Restrictive<int*> pints{};
33    //                         ^  error: use of deleted function
34
35    // Restrictive<char*> pchars{};
36    //                           ^  error: use of deleted function
37  }
```

10.2.3   vector delegator

```
1   #include <vector>
2   #include <string>
3   #include <algorithm>
4   #include <iostream>
5   #include <iterator>
6
7   template<typename T>
8   struct VectorDelegator {
9
10      template<typename ITER>
11      VectorDelegator(ITER a, ITER b) : data(a, b) {}
12
13   private:
14
15      std::vector<int> data{};
16
17   };
18
19   void vector_delegator() {
20      std::vector<int> v{1,2,3};
21
22      VectorDelegator<int> vd{v.begin(), v.end()};
23   }
```

11 References And Pointers

11.1 Basic Examples

11.1.1 Reference on int

```cpp
#include <iostream>

void reference_on_int() {
  int j = 5;
  int& r = j;

  std::cout << "j: " << j << std::endl;
  std::cout << "r: " << r << std::endl;

  j = 6;

  std::cout << "j: " << j << std::endl;
  std::cout << "r: " << r << std::endl;

  r = 7;

  std::cout << "j: " << j << std::endl;
  std::cout << "r: " << r << std::endl;

  // output
  // j: 5
  // r: 5
  // j: 6
  // r: 6
  // j: 7
  // r: 7

}
```

11.1.2 Reference on cat

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

class Cat {
  std::string name;

public:
  Cat(std::string name) : name{name} {}

  void setName(std::string n) {
    name = n;
  }

  std::string getName() {
    return name;
  }
};

void reference_on_cat() {
  Cat cat{"Hector-Pascal"};
  Cat& same_cat = cat;
  Cat other_cat = cat;

  std::cout << "cat.getName(): " << cat.getName() << std::endl;
  std::cout << "same_cat.getName(): " << same_cat.getName() << std::endl;
  std::cout << "other_cat.getName(): " << other_cat.getName() << std::endl;

  same_cat.setName("Luftdruck");

  std::cout << "cat.getName(): " << cat.getName() << std::endl;
  std::cout << "same_cat.getName(): " << same_cat.getName() << std::endl;
  std::cout << "other_cat.getName(): " << other_cat.getName() << std::endl;

  // output
  // cat.getName():       Hector-Pascal
  // same_cat.getName():  Hector-Pascal
  // other_cat.getName(): Hector-Pascal
  // cat.getName():       Luftdruck
  // same_cat.getName():  Luftdruck
  // other_cat.getName(): Hector-Pascal
}
```

11.2   Reference vs. Pointer

```cpp
#include <iostream>
#include <sstream>
#include <string>

struct Exp1 {
  Exp1(std::ostream& out) : out(out) {}

  void write(std::string something) {
    out << something << std::endl;
  }

  std::ostream& out;
};

struct Exp2 {
  Exp2(std::ostream& out) : out(&out) {}
  //                             ^--- address of out
  //
  //                ^--- reference to out

  void write(std::string something) {
    *out << something << std::endl;
  }

  std::ostream* out;
};

void saving_ref_or_p_as_member() {
  Exp1 exp_1{std::cout};
  Exp2 exp_2{std::cout};

  exp_1.write("this comes from exp_1");
  exp_2.write("this comes from exp_2");

  // output
  // this comes from exp_1
  // this comes from exp_2
}
```

11.3   C++ vs. Java

11.3.1   Reference in C++

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

void change(std::string& something) {
  something = "another string";
}

void reference_in_cpp() {
  std::string str = "a string";

  std::cout << "str: " << str << std::endl;

  change(str);

  std::cout << "str: " << str << std::endl;

  // output
  // str: a string
  // str: another string
}
```

11.3.2   Reference in Java

```java
public class ReferenceInJava {

  public static void change(String str) {
    str = "another string";
  }

  public static void main(String[] args) {
    String str = "a string";

    System.out.println(str);

    change(str);

    System.out.println(str);

    // output
    // a string
    // a string
  }

}
```

11.4 Dynamic Heap Memory Management

11.4.1 Unique Pointer

```cpp
#include <iostream>
#include <memory>

std::unique_ptr<int> create_on_heap(int i) {
  return std::unique_ptr<int>{new int{i}};
}

void unique_ptr_demo() {
  // a unique pointer can only exist once. we can not copy it. we can only move the
  // unique pointer to another variable, making the original variable invalid.

  auto p = create_on_heap(10);

  std::cout << std::boolalpha;
  std::cout << "is p valid? " << static_cast<bool>(p) << std::endl;

  auto j = std::move(p);
  // not possible:
  // auto j = p;

  std::cout << "is p valid? " << static_cast<bool>(p) << std::endl;

  // output:
  // is p valid? true
  // is p valid? false
}
```

11.4.2   Shared Pointer

```cpp
#include <iostream>
#include <memory>

struct A {
  A(int n) : n{n} {}
  int n;
};

void shared_ptr_demo() {
  // shared pointers can be copied:

  auto i = std::make_shared<A>(123);

  auto j = i;

  std::cout << "i->n: " << i->n << std::endl;
  std::cout << "(*j).n: " << (*j).n << std::endl;

  // output
  // i->n: 123
  // (*j).n: 123
}
```

12   Compile Time Calculation

12.1   constexpr

```cpp
#include <vector>
#include <iostream>

constexpr int add_at_compile_time(int a, int b) {
  return a + b;
}

void constexpr_demo() {
  // to c will be assigned the value 3 at compile time, because the called function
  // add_at_compile_time() is a constexpr.
  // writing 'int c = 1 + 2;' would be equivalent.
  int c = add_at_compile_time(1, 2);
}
```

12.2   static_assert

```cpp
void static_assert_demo() {
  // with static assert we can do assertions at compile time:
  const int i = 3;
  static_assert(i >= 3, "nooope");

  // if the assertion fails a compilation error is raised:
  // static_assert(i < 3, "nooope");
  // ^  error: static assertion failed: nooope

  // static_assert only works with constant conditions. working with the non-const
  // variable j will fail:
  int j = 3;
  // static_assert(j, "");
  // ^  error: non-constant condition for static assertion
  // ^  error: the value of j is not usable in a constant expression
}
```

12.3   User Defined Literals

```
1  constexpr double operator"" _cm(long double x){
2    return x / 100.;
3  }
4
5  constexpr double operator"" _cm(unsigned long long x){
6    return x / 100.;
7  }
8
9  constexpr double operator"" _m(long double x){
10   return x;
11 }
12
13 constexpr double operator"" _m(unsigned long long x){
14   return x;
15 }
16
17 constexpr double operator"" _km(long double x){
18   return x * 1000;
19 }
20
21 constexpr double operator"" _km(unsigned long long x){
22   return x * 1000;
23 }
24
25 void user_defined_literals() {
26   std::cout << "1_cm: " << 1_cm << " meters" << std::endl;
27   std::cout << "1_km: " << 1_km << " meters" << std::endl;
28
29   // output
30   // 1_cm: 0.01 meters
31   // 1_km: 1000 meters
32 }
```

12.4   Ring5

```
1   struct Ring5 {
2     explicit constexpr
3     Ring5(unsigned x=0u) : val{ x % 5 } {}
4
5     constexpr unsigned value() const { return val; }
6
7     constexpr operator unsigned() const { return val; }
8
9     constexpr bool operator==(Ring5 const &r) const {
10      return val == r.val;
11    }
12
13    constexpr bool operator!=(Ring5 const &r) const {
14      return !(*this == r);
15    }
16
17    // this function can not be constexpr because it changes internal state.
18    Ring5 operator+=(Ring5 const &r) {
19      val = (val + r.value())%5;
20      // this error would be raised if we tried to use constexpr:
21      //                    ^  error: assignment of member val in read-only object
22      return *this;
23    }
24
25    Ring5 operator*=(Ring5 const&r) {
26      val = (val * r.value())%5;
27      return *this;
28    }
29
30    constexpr Ring5 operator+(Ring5 const &r) const {
31      return Ring5{val+r.val};
32    }
33
34    constexpr Ring5 operator*(Ring5 const &r) const {
35      return Ring5{val*r.val};
36    }
37
38  private:
39    unsigned val;
40  };
```

13   Good To Know

This section contains miscellaneous information on C++.

Default floating point type

```cpp
// the default floating point type is double, not float
auto this_is_a_double = 3.141;
```

Assigning floating point to int

```cpp
#include <iostream>

void assigning_floating_point_to_int() {
  // if we assign a floating point to a variable of type integer, it will
  // automatically be casted.
  int autoconverted_to_int = 7.5;

  std::cout << autoconverted_to_int << std::endl;

  // output:
  // 7
}
```

Bool is an integer

```cpp
#include <iostream>

void bool_is_an_integer() {
  std::cout << "5 + true:  " << 5 + true  << std::endl;
  std::cout << "5 + 1:     " << 5 + 1     << std::endl;
  std::cout << "6 + false: " << 6 + false << std::endl;
  std::cout << "6 - 0:     " << 6 - 0     << std::endl;

  // output
  // 5 + true:  6
  // 5 + 1:     6
  // 6 + false: 6
  // 6 - 0:     6
}
```

Initializing variables

```cpp
void initializing_variables() {
  int a{1};      // initialized with 1
  int b{};       // default initialization (in case of int zero)
  int c;         // undefined behaviour
  static int d;  // zero initialized

  std::cout << "a: " << a << std::endl;
  std::cout << "b: " << b << std::endl;
  std::cout << "c: " << c << std::endl;
  std::cout << "d: " << d << std::endl;

  // output
  // a: 1
  // b: 0
  // c: 7
  // d: 0
}
```

Floating points cant be unsigned

```cpp
// unsigned double ud = 1.1;
//                  ^  error: signed or unsigned invalid for ud
// unsigned float  uf = 1.1;
//                  ^  error: signed or unsigned invalid for uf

unsigned int    ui = 1;
```

Literals

```
1   void chars() {
2     char a;
3     a = 'a';
4     a = '\n';
5     a = '\x0a';
6   }
7
8   void integers() {
9     int i =        1;
10    long l =       1L;
11    long long ll = 1LL;
12  }
13
14  void unsigned_integers() {
15    unsigned int ui =        1u;
16    unsigned long ul =       1ul;
17    unsigned long long ull = 1ull;
18  }
19
20  void octal_hex_full() {
21    int octal =      020;
22    int hex =        0x1f;
23    long long full = 0XFULL;
24  }
25
26  void floating_points() {
27    float f =       0.1f;
28    double d1 =     .33;
29    double d2 =     1e9;
30    long double d3 = 42.E-12L;
31    long double d4 = .3l;
32  }
33
34  void char_array() {
35    char a[] = "hello"; // char[6] {'h', 'e', 'l', 'l', 'o', '\0'}
36                        // '\0' terminates the string
37  }
```

Weird string syntax

```
1   void weird_string_syntax() {
2     std::string  s1 = "line1"
3                       "line2"
4                       "line3";
5
6     std::cout << s1 << std::endl;
7
8     // output
9     // line1line2line3
10  }
```

Arithmetics with int and double

```cpp
void arithmetics_with_int_and_double() {
  // doing divisions only with integers will return an integer
  std::cout << "7   / 2:    \t\t" << 7 / 2   << std::endl;
  // as soon as a floating point is involved, the result is a floating point too
  std::cout << "7   / 2.0:  \t\t" << 7 / 2.0 << std::endl;
  std::cout << "7.0 / 2:    \t\t" << 7.0 / 2 << std::endl;

  // output
  // 7   / 2:       3
  // 7   / 2.0:     3.5
  // 7.0 / 2:       3.5

  // assigning the division of two integers to a double variable results in an int
  double x = 7 / 2;
  std::cout << "x: " << x << std::endl;
  // output
  // x: 3
}

void division_by_zero_demo() {
  // division by zero is undefined behaviour. the following code compiles and does
  // not cause an exception at runtime:
  // std::cout << "1 / 0: \t\t" << 1 / 0 << std::endl;
}
```

Unspecified invocation order

```cpp
int get_a() {
  std::cout << "get_a()" << std::endl;
  return 0;
}

int get_b() {
  std::cout << "get_b()" << std::endl;
  return 0;
}

void random_function_name(int a, int b) { }

void unspecified_invocation_order() {
  // if we call functions to pass arguments to another function, we don't know in
  // which order the functions are called.
  random_function_name(get_a(), get_b());

  // output could for example be
  // get_b()
  // get_a()
}
```

Factory function

```
1   #include <stdexcept>
2
3   namespace Galaxy {
4     struct Planet {
5       Planet() = default;
6
7       Planet(int distance) {
8         if (distance < 0) throw std::invalid_argument("");
9       }
10
11      int distance;
12    };
13
14    Planet make_planet(int distance)
15    try {
16      return Planet{distance};
17    } catch(std::invalid_argument e) {
18      return Planet{};
19    }
20  }
```

Ideen:

initializer list

return statement in functions: was tut der compiler, was muss man selbst tun?

14   Appendix

14.1   Algorithm Api

14.1.1   Non-Modifying

```
1   // all_of                Test condition on all elements in range
2   bool all_of (InputIterator first, InputIterator last, UnaryPredicate pred);
3
4   // any_of                Test if any element in range fulfills condition
5   bool any_of (InputIterator first, InputIterator last, UnaryPredicate pred);
6
7   // none_of               Test if no elements fulfill condition
8   bool none_of (InputIterator first, InputIterator last, UnaryPredicate pred);
9
10  // for_each              Apply function to range
11  Function for_each (InputIterator first, InputIterator last, Function fn);
12
13  // find                  Find value in range
14  InputIterator find (InputIterator first, InputIterator last, const T& val);
15
16  // find_if               Find element in range
17  InputIterator find_if (InputIterator first, InputIterator last, UnaryPredicate pred);
18
19  // find_if_not           Find element in range (negative condition)
20  InputIterator find_if_not (InputIterator first, InputIterator last, UnaryPredicate pred);
21
22  // find_end              Find last subsequence in range
23  ForwardIterator1 find_end (ForwardIterator1 first1, ForwardIterator1 last1,
24                             ForwardIterator2 first2, ForwardIterator2 last2);
25  ForwardIterator1 find_end (ForwardIterator1 first1, ForwardIterator1 last1,
26                             ForwardIterator2 first2, ForwardIterator2 last2,
27                             BinaryPredicate pred);
28
29  // find_first_of         Find element from set in range
30  ForwardIterator1 find_first_of (InputIterator first1, InputIterator last1,
31                                  ForwardIterator first2, ForwardIterator last2);
32  ForwardIterator1 find_first_of (InputIterator first1, InputIterator last1,
33                                  ForwardIterator first2, ForwardIterator last2,
34                                  BinaryPredicate pred);
35
36  // adjacent_find         Find equal adjacent elements in range
37  ForwardIterator adjacent_find (ForwardIterator first, ForwardIterator last);
38  ForwardIterator adjacent_find (ForwardIterator first, ForwardIterator last,
39                                 BinaryPredicate pred);
40
```

```
41  // count                    Count appearances of value in range
42  Number count (InputIterator first, InputIterator last, const T& val);
43
44  // count_if                  Return number of elements in range satisfying condition
45  Number count_if (InputIterator first, InputIterator last, UnaryPredicate pred);
46
47  // mismatch                  Return first position where two ranges differ
48  pair<InputIterator1, InputIterator2> mismatch (InputIterator1 first1, InputIterator1 last1,
49                                           InputIterator2 first2);
50  pair<InputIterator1, InputIterator2> mismatch (InputIterator1 first1, InputIterator1 last1,
51                                           InputIterator2 first2, BinaryPredicate pred);
52
53  // equal                     Test whether the elements in two ranges are equal
54  bool equal (InputIterator1 first1, InputIterator1 last1,
55            InputIterator2 first2);
56  bool equal (InputIterator1 first1, InputIterator1 last1,
57            InputIterator2 first2, BinaryPredicate pred);
58
59  // is_permutation            Test whether range is permutation of another
60  bool is_permutation (ForwardIterator1 first1, ForwardIterator1 last1,
61                     ForwardIterator2 first2);
62  bool is_permutation (ForwardIterator1 first1, ForwardIterator1 last1,
63                     ForwardIterator2 first2, BinaryPredicate pred);
64
65  // search                    Search range for subsequence
66  ForwardIterator1 search (ForwardIterator1 first1, ForwardIterator1 last1,
67                        ForwardIterator2 first2, ForwardIterator2 last2);
68  ForwardIterator1 search (ForwardIterator1 first1, ForwardIterator1 last1,
69                        ForwardIterator2 first2, ForwardIterator2 last2,
70                        BinaryPredicate pred);
71
72  // search_n                  Search range for a sequence of elements
73  ForwardIterator search_n (ForwardIterator first, ForwardIterator last,
74                         Size count, const T& val);
75  ForwardIterator search_n (ForwardIterator first, ForwardIterator last,
76                         Size count, const T& val, BinaryPredicate pred);
```

14.1.2   Modifying

```
1   // copy                    Copy range of elements
2   OutputIterator copy (InputIterator first, InputIterator last, OutputIterator result);
3
4   // copy_n                  Copy elements
5   OutputIterator copy_n (InputIterator first, Size n, OutputIterator result);
6
7   // copy_if                 Copy certain elements of range
8   OutputIterator copy_if (InputIterator first, InputIterator last,
9                           OutputIterator result, UnaryPredicate pred);
10
11  // copy_backward           Copy range of elements backward
12  BidirectionalIterator2 copy_backward (BidirectionalIterator1 first,
13                                        BidirectionalIterator1 last,
14                                        BidirectionalIterator2 result);
15
16  // move                    Move range of elements
17  OutputIterator move (InputIterator first, InputIterator last, OutputIterator result);
18
19  // move_backward           Move range of elements backward
20  BidirectionalIterator2 move_backward (BidirectionalIterator1 first,
21                                        BidirectionalIterator1 last,
22                                        BidirectionalIterator2 result);
23
24  // swap                    Exchange values of two objects
25  noexcept (is_nothrow_move_constructible<T>::value && is_nothrow_move_assignable<T>::value);
26  noexcept (noexcept(swap(*a,*b)));
27
28  // swap_ranges             Exchange values of two ranges
29  ForwardIterator2 swap_ranges (ForwardIterator1 first1, ForwardIterator1 last1,
30                                ForwardIterator2 first2);
31
32  // iter_swap               Exchange values of objects pointed by two iterators
33  void iter_swap (ForwardIterator1 a, ForwardIterator2 b);
34
35  // transform               Transform range
36  OutputIterator transform (InputIterator first1, InputIterator last1,
37                            OutputIterator result, UnaryOperation op);
38  OutputIterator transform (InputIterator1 first1, InputIterator1 last1,
39                            InputIterator2 first2, OutputIterator result,
40                            BinaryOperation binary_op);
41
```

```
42   // replace                Replace all values in range with another one
43   void replace (ForwardIterator first, ForwardIterator last,
44                 const T& old_value, const T& new_value);
45
46   // replace_if             Replace all values in range with another one
47   void replace_if (ForwardIterator first, ForwardIterator last,
48                    UnaryPredicate pred, const T& new_value);
49
50   // replace_copy           Copy range replacing value
51   OutputIterator replace_copy (InputIterator first, InputIterator last,
52                                OutputIterator result,
53                                const T& old_value, const T& new_value);
54
55   // replace_copy_if        Copy range replacing value
56   OutputIterator replace_copy_if (InputIterator first, InputIterator last,
57                                   OutputIterator result, UnaryPredicate pred,
58                                   const T& new_value);
59
60   // fill                   Fill range with value
61   void fill (ForwardIterator first, ForwardIterator last, const T& val);
62
63   // fill_n                 Fill sequence with value
64   OutputIterator fill_n (OutputIterator first, Size n, const T& val);
65
66   // generate               Generate values for range with function
67   void generate (ForwardIterator first, ForwardIterator last, Function f);
68
69   // generate_n             Generate values for sequence with function
70   OutputIterator generate_n (OutputIterator first, Size n, Function f);
71
72   // remove                 Remove all values from range and return iterator to the new end
73   ForwardIterator remove (ForwardIterator first, ForwardIterator last, const T& val);
74
75   // remove_if              Remove all values from range and return iterator to the new end
76   ForwardIterator remove_if (ForwardIterator first, ForwardIterator last,
77                              UnaryPredicate pred);
78
79   // remove_copy            Copy range removing all values
80   OutputIterator remove_copy (InputIterator first, InputIterator last,
81                               OutputIterator result, const T& val);
82
83   // remove_copy_if         Copy range removing all values
84   OutputIterator remove_copy_if (InputIterator first, InputIterator last,
85                                  OutputIterator result, UnaryPredicate pred);
86
```

96

```
87   // unique              Remove consecutive duplicates in range and return iterator to new end
88   ForwardIterator unique (ForwardIterator first, ForwardIterator last);
89   ForwardIterator unique (ForwardIterator first, ForwardIterator last,
90                       BinaryPredicate pred);
91
92   // unique_copy          Copy range removing consecutive duplicates
93   OutputIterator unique_copy (InputIterator first, InputIterator last,
94                           OutputIterator result);
95   OutputIterator unique_copy (InputIterator first, InputIterator last,
96                           OutputIterator result, BinaryPredicate pred);
97
98   // reverse              Reverse range
99   void reverse (BidirectionalIterator first, BidirectionalIterator last);
100
101  // reverse_copy         Copy range reversed and return an iterator pointing to the
102  //                      end of the copied range
103  OutputIterator reverse_copy (BidirectionalIterator first,
104                          BidirectionalIterator last, OutputIterator result);
105
106  // rotate               Rotate left the elements in range in such a way that the
107  //                      element pointed by middle becomes the new first element.
108  //                      Return an iterator pointing to the element that now contains
109  //                      the value previously pointed by first.
110  ForwardIterator rotate (ForwardIterator first, ForwardIterator middle,
111                      ForwardIterator last);
112
113  // rotate_copy          Copy range rotated left. Return an output iterator pointing
114  //                      to the end of the copied range.
115  OutputIterator rotate_copy (ForwardIterator first, ForwardIterator middle,
116                          ForwardIterator last, OutputIterator result);
117
118  // random_shuffle       Randomly rearrange elements in range
119  void random_shuffle (RandomAccessIterator first, RandomAccessIterator last);
120  void random_shuffle (RandomAccessIterator first, RandomAccessIterator last,
121                      RandomNumberGenerator&& gen);
122
123  // shuffle              Randomly rearrange elements in range using generator
124  void shuffle (RandomAccessIterator first, RandomAccessIterator last, URNG&& g);
```

14.1.3 Partitions

```cpp
// is_partitioned          Test whether range is partitioned
bool is_partitioned (InputIterator first, InputIterator last, UnaryPredicate pred);

// partition               Partition range in two and return an iterator that points
//                         to the first element of the second group of elements.
ForwardIterator partition (ForwardIterator first,
                           ForwardIterator last, UnaryPredicate pred);

// stable_partition        Partition range in two - stable ordering
BidirectionalIterator stable_partition (BidirectionalIterator first,
                                        BidirectionalIterator last,
                                        UnaryPredicate pred);

// partition_copy          Partition range into two
pair<OutputIterator1, OutputIterator2> partition_copy (
                InputIterator first, InputIterator last,
                OutputIterator1 result_true, OutputIterator2 result_false,
                UnaryPredicate pred);

// partition_point         Get partition point
ForwardIterator partition_point (ForwardIterator first, ForwardIterator last,
                                 UnaryPredicate pred);
```

14.1.4 Sorting

```
1   // sort                 Sort elements in range
2   void sort (RandomAccessIterator first, RandomAccessIterator last);
3   void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);
4
5   // stable_sort          Sort elements preserving order of equivalents
6   void stable_sort (RandomAccessIterator first, RandomAccessIterator last);
7   void stable_sort (RandomAccessIterator first, RandomAccessIterator last,
8                     Compare comp);
9
10  // partial_sort         Partially sort elements in range.
11  //                      Rearranges the elements in the range [first,last), in such
12  //                      a way that the elements before middle are the smallest elements
13  //                      in the entire range and are sorted in ascending order, while
14  //                      the remaining elements are left without any specific order.
15  void partial_sort (RandomAccessIterator first, RandomAccessIterator middle,
16                     RandomAccessIterator last);
17  void partial_sort (RandomAccessIterator first, RandomAccessIterator middle,
18                     RandomAccessIterator last, Compare comp);
19
20  // partial_sort_copy    Copy and partially sort range
21  RandomAccessIterator partial_sort_copy (InputIterator first,InputIterator last,
22                                          RandomAccessIterator result_first,
23                                          RandomAccessIterator result_last);
24  RandomAccessIterator partial_sort_copy (InputIterator first,InputIterator last,
25                                          RandomAccessIterator result_first,
26                                          RandomAccessIterator result_last, Compare comp);
27
28  // is_sorted            Check whether range is sorted
29  bool is_sorted (ForwardIterator first, ForwardIterator last);
30  bool is_sorted (ForwardIterator first, ForwardIterator last, Compare comp);
31
32  // is_sorted_until      Find first unsorted element in range
33  ForwardIterator is_sorted_until (ForwardIterator first, ForwardIterator last);
34  ForwardIterator is_sorted_until (ForwardIterator first, ForwardIterator last,
35                                   Compare comp);
36
37  // nth_element          Rearranges the elements in the range [first,last) in such
38  //                      a way that the element at the nth position is the element
39  //                      that would be in that position in a sorted sequence.
40  void nth_element (RandomAccessIterator first, RandomAccessIterator nth,
41                    RandomAccessIterator last);
42  void nth_element (RandomAccessIterator first, RandomAccessIterator nth,
43                    RandomAccessIterator last, Compare comp);
```

14.1.5 Binary Search

```
// these algorithms support operation on SORTED ranges

// lower_bound          Return iterator to lower bound
//                      10 10 10 20 20 20 30 30
//                      ^
ForwardIterator lower_bound (ForwardIterator first, ForwardIterator last,
                             const T& val);
ForwardIterator lower_bound (ForwardIterator first, ForwardIterator last,
                             const T& val, Compare comp);

// upper_bound          Return iterator to upper bound
//                      10 10 10 20 20 20 30 30
//                                      ^
ForwardIterator upper_bound (ForwardIterator first, ForwardIterator last,
                             const T& val);
ForwardIterator upper_bound (ForwardIterator first, ForwardIterator last,
                             const T& val, Compare comp);

// equal_range          Get subrange of equal elements
pair<ForwardIterator,ForwardIterator> equal_range (ForwardIterator first,
                                                   ForwardIterator last,
                                                   const T& val);
pair<ForwardIterator,ForwardIterator> equal_range (ForwardIterator first,
                                                   ForwardIterator last,
                                                   const T& val, Compare c);

// binary_search        Test if value exists in sorted sequence
bool binary_search (ForwardIterator first, ForwardIterator last, const T& val);
bool binary_search (ForwardIterator first, ForwardIterator last, const T& val, Compare comp);
```

14.1.6 Other

```
1  // lexicographical_compare   Lexicographical less-than comparison
2  bool lexicographical_compare (InputIterator1 first1, InputIterator1 last1,
3                                InputIterator2 first2, InputIterator2 last2);
4  bool lexicographical_compare (InputIterator1 first1, InputIterator1 last1,
5                                InputIterator2 first2, InputIterator2 last2,
6                                Compare comp);
7
8  // next_permutation            Transform range to next lexicographically greater
9  //                             permutation. Returns true if the function could rearrange
10 //                             the object as a lexicographicaly greater permutation.
11 //                             Otherwise, the function returns false to indicate that
12 //                             the arrangement is not greater than the previous, but
13 //                             the lowest possible (sorted in ascending order).
14 bool next_permutation (BidirectionalIterator first,
15                        BidirectionalIterator last);
16 bool next_permutation (BidirectionalIterator first,
17                        BidirectionalIterator last, Compare comp);
18
19 // prev_permutation            Transform range to next lexicographically smaller
20 //                             permutation.
21 bool prev_permutation (BidirectionalIterator first,
22                        BidirectionalIterator last );
23 bool prev_permutation (BidirectionalIterator first,
24                        BidirectionalIterator last, Compare comp);
```

14.1.7 Numeric

```
1  // these algorithms are for numeric values only
2
3  // accumulate                        Accumulate values in range
4  T accumulate (InputIterator first, InputIterator last, T init);
5  T accumulate (InputIterator first, InputIterator last, T init,
6               Function f);
7
8  // adjacent_difference               Compute adjacent difference of range
9  OutputIterator adjacent_difference (InputIterator first, InputIterator last,
10                                      OutputIterator result);
11 OutputIterator adjacent_difference (InputIterator first, InputIterator last,
12                                      OutputIterator result, BinaryOperation binary_op);
13
14 // inner_product                     Compute cumulative inner product of range
15 T inner_product (InputIterator1 first1, InputIterator1 last1,
16                  InputIterator2 first2, T init);
17 T inner_product (InputIterator1 first1, InputIterator1 last1,
18                  InputIterator2 first2, T init,
19                  BinaryOperation1 binary_op1,
20                  BinaryOperation2 binary_op2);
21
22 // partial_sum                       Compute partial sums of range
23 OutputIterator partial_sum (InputIterator first, InputIterator last,
24                             OutputIterator result);
25 OutputIterator partial_sum (InputIterator first, InputIterator last,
26                             OutputIterator result, BinaryOperation binary_op);
27
28 // iota                              Store increasing sequence
29 void iota (ForwardIterator first, ForwardIterator last, T val);
```

14.1.8 Functional

14.1.9 Arithmetic

```
1   // plus                    Addition function object class
2   T operator() (const T& x, const T& y) const {return x+y;
3   }
4
5   // minus                   Subtraction function object class
6   T operator() (const T& x, const T& y) const {return x-y;}
7
8   // multiplies              Multiplication function object class
9   T operator() (const T& x, const T& y) const {return x*y;}
10
11  // divides                 Division function object class
12  T operator() (const T& x, const T& y) const {return x/y;
13  }
14
15  // modulus                 Modulus function object class
16  T operator() (const T& x, const T& y) const {return x%y
17    ;}
18
19  // negate                  Negative function object class
20  T operator() (const T& x) const {return -x;}
```

14.1.10 Comparison

```
1   // equal_to                Function object class for equality comparison
2   bool operator() (const T& x, const T& y) const {return x==y;}
3
4   // not_equal_to            Function object class for non-equality comparison
5   bool operator() (const T& x, const T& y) const {return x!=y;}
6
7   // greater                 Function object class for greater-than inequality comparison
8   bool operator() (const T& x, const T& y) const {return x>y;}
9
10  // greater_equal           Function object class for greater-than-or-equal-to comparison
11  bool operator() (const T& x, const T& y) const {return x>=y;}
12
13  // less                    Function object class for less-than inequality comparison
14  bool operator() (const T& x, const T& y) const {return x<y;}
15
16  // less_equal              Function object class for less-than-or-equal-to comparison
17  bool operator() (const T& x, const T& y) const {return x<=y;}
```

14.1.11   Bit Operations

```
1   // bit_and               Bitwise AND function object class
2   T operator() (const T& x, const T& y) const {return x&y;}
3
4   // bit_or                Bitwise OR function object class
5   T operator() (const T& x, const T& y) const {return x|y;}
6
7   // bit_xor               Bitwise XOR function object class
8   T operator() (const T& x, const T& y) const {return x^y;}
9
10  // logical_and           Logical AND function object class
11  bool operator() (const T& x, const T& y) const {return x&&y ;}
12
13  // logical_not           Logical NOT function object class
14  bool operator() (const T& x) const {return !x;}
15
16  // logical_or            Logical OR function object class
17  bool operator() (const T& x, const T& y) const {return x||
18     y;}
```

14.2   Container Api

14.2.1   Array

```
1  #include <array>
2
3  // Capacity:
4  // empty                    Test whether container is empty
5  // size                     Return size
6  // max_size                 Return maximum size
7
8  // Element access:
9  // front                    Access first element by reference
10 // back                     Access last element by reference
11 // operator[]               Access element
12 // at                       Access element
13 // data                     Access data
14
15 // Modifiers:
16 // swap                     Swap content (list& x)
17 // fill                     Fill all elements of array with the passed value
```

14.2.2   List

```
1   #include <list>
2
3   // Capacity:
4   // empty                    Test whether container is empty
5   // size                     Return size
6   // max_size                 Return maximum size
7
8   // Element access:
9   // front                    Access first element by reference
10  // back                     Access last element by reference
11
12  // Modifiers:
13  // assign                   Assign new content to container
14  //                          range, fill or initializer list
15  // emplace_front            Construct and insert element at beginning
16  // push_front               Insert element at beginning
17  // pop_front                Delete first element (returns nothing)
18  // emplace_back             Construct and insert element at the end
19  // push_back                Add element at the end
20  // pop_back                 Delete last element (returns nothing)
21  // emplace                  Construct and insert element
22  //                          (IteratorToPosition, Args...)
23  // insert                   Insert elements
24  //                          (Iterator, single_element, fill, range, move, initializerlist)
25  // erase                    Erase elements (effectively reduces container size)
26  //                          (IteratorToPosition) or (Begin, End)
27  // swap                     Swap content (list& x)
28  // resize                   Change size to n elements (deletes overflow elements at the end)
29  // clear                    Clear content (size will be 0)
30
31  // Operations:
32  // splice                   Transfer elements from list to list
33  // remove                   Remove elements with specific value
34  // remove_if                Remove elements fulfilling condition
35  // unique                   Remove duplicate consecutive values
36  // merge                    Merge sorted lists
37  // sort                     Sort elements in container
38  // reverse                  Reverse the order of elements
```

14.2.3   Map

```
1  #include <set>
2
3  // Capacity:
4  // empty                    Test whether container is empty
5  // size                     Return size
6  // max_size                 Return maximum size
7
8  // Element access:
9  // none
10
11 // Modifiers:
12 // emplace                  Construct and insert element
13 //                          (IteratorToPosition, Args...)
14 // insert                   Insert elements
15 //                          (Iterator, single_element, fill, range, move, initializerlist)
16 // erase                    Erase elements (effectively reduces container size)
17 //                          (IteratorToPosition) or (Begin, End)
18 // swap                     Swap content (list& x)
19 // clear                    Clear content (size will be 0)
20
21 // Operations:
22 // find                     Get iterator to element by passing a value
23 // count                    Count elements with a specific key by passing a value
24 // lower_bound              Return iterator to lower bound by passing a value
25 // upper_bound              Return iterator to upper bound by passing a value
26 // equal_range              Get range of equal elements by passing a value
```

14.2.4   Set

```
1   // Capacity:
2   // empty                   Test whether container is empty
3   // size                    Return size
4   // max_size                Return maximum size
5
6   // Element access:
7   // operator[]              Access element
8   // at                      Access element
9
10  // Modifiers:
11  // emplace                 Construct and insert element
12  //                         (IteratorToPosition, Args...)
13  // insert                  Insert elements
14  //                         (Iterator, single_element, fill, range, move, initializerlist)
15  // erase                   Erase elements (effectively reduces container size)
16  //                         (IteratorToPosition) or (Begin, End)
17  // swap                    Swap content (list& x)
18  // clear                   Clear content (size will be 0)
19
20  // Operations:
21  // find                    Get iterator to element by passing a value
22  // count                   Count elements with a specific key by passing a value
23  // lower_bound             Return iterator to lower bound by passing a value
24  // upper_bound             Return iterator to upper bound by passing a value
25  // equal_range             Get range of equal elements by passing a value
```

14.2.5 Vector

```
1   #include <vector>
2
3   // Capacity:
4   // empty                  Test whether container is empty
5   // size                   Return size
6   // max_size               Return maximum size
7   // resize                 Change size
8   // capacity               Return size of allocated storage capacity
9   // reserve                Request a change in capacity
10  // shrink_to_fit          Shrink to fit
11
12  // Element access:
13  // front                  Access first element by reference
14  // back                   Access last element by reference
15  // operator[]             Access element
16  // at                     Access element
17  // data                   Access data
18
19  // Modifiers:
20  // assign                 Assign new content to container
21  //                        range, fill or initializer list
22  // emplace_back           Construct and insert element at the end
23  // push_back              Add element at the end
24  // pop_back               Delete last element (returns nothing)
25  // emplace                Construct and insert element
26  //                        (IteratorToPosition, Args...)
27  // insert                 Insert elements
28  //                        (Iterator, single_element, fill, range, move, initializerlist)
29  // erase                  Erase elements (effectively reduces container size)
30  //                        (IteratorToPosition) or (Begin, End)
31  // swap                   Swap content (list& x)
32  // clear                  Clear content (size will be 0)
```

14.3   Random Code

14.3.1   PIMPL idiom

```cpp
#ifndef PERSON_H_
#define PERSON_H_
#include <memory>
#include <string>
#include <vector>
#include <iosfwd>

class Person {
  std::shared_ptr<class PersonImpl> person;

  Person(std::shared_ptr<class PersonImpl> person) :
    person { person } {}

public:
  Person(std::string name);
  Person(std::string name, Person father, Person mother);
  ~Person();
  void addChild(Person child);
  std::string getName() const;
  Person findChild(std::string name) const;
  void killChild(Person child);
  void killMe();
  operator bool() const;
  void print(std::ostream &out) const;
};

#endif /* PERSON_H_ */
```

```cpp
1   #include "Person.h"
2   #include <iostream>
3   #include <algorithm>
4   #include <functional>
5
6   using PersonPtr=std::shared_ptr<class PersonImpl>;
7   using WeakPersonPtr=std::weak_ptr<class PersonImpl>;
8
9   class PersonImpl : public std::enable_shared_from_this<PersonImpl> {
10    std::string name;
11    WeakPersonPtr father; // don't lock parent objects
12    WeakPersonPtr mother;
13    std::vector<PersonPtr> children;
14
15    PersonPtr myLock() {
16      try {
17        auto me=shared_from_this(); // throws when called from dtor!
18        return me;
19      } catch(std::bad_weak_ptr const &ex){}
20      std::cout << "++++already dead? " << name<< '\n';
21      return PersonPtr{}; // already dead
22    }
23
24  public:
25    PersonImpl(std::string name,PersonPtr father,PersonPtr mother)
26    :name{name},father{father},mother{mother}{
27      // can not do shared_from_this here!
28      //no if(father) father->addChild(shared_from_this());
29    }
30
31    ~PersonImpl() {
32      std::cout << "killing me: "<< name << '\n';
33      //killMe(); // can not call shared_from_this() in dtor!
34    }
35
36    void addChild(PersonPtr child){
37      children.push_back(child);
38    }
39
40    std::string getName() const {
41      return name;
42    }
43
```

```
44    PersonPtr findChild(std::string name) const {
45      using namespace std::placeholders;
46      auto finder=[name](PersonPtr const &person){
47        return person->getName() == name;
48      };
49      auto it=find_if(children.begin(),children.end(),finder);
50      if (it != children.end()) return *it;
51      return nullptr;
52    }
53
54    void killChild(PersonPtr child) {
55      if (child){
56        children.erase(find(children.begin(),children.end(),child));
57        //if (child->father == ) ?
58      }
59    }
60
61    void killMe() {
62      // here shared_from_this is possible
63      auto me=myLock();
64      if (!me) return; // already dead
65      auto realfather=father.lock();
66      if (realfather) realfather->killChild(me);
67      auto realmother=mother.lock();
68      if (realmother) realmother->killChild(me);
69      children.clear();
70    }
71
72    void print(std::ostream &out) const {
73      out << "Person: "<< name ;
74      auto realfather=father.lock();
75      out << "    "<< (realfather?realfather->getName():"orphan");
76      auto realmother=mother.lock();
77      out << "    "<< (realmother?realmother->getName():"orphan");
78      out << "\n    ";
79      for(auto const &child:children){
80        out << child->name << ", ";
81      }
82      out << '\n';
83    }
84
```

```
85    static PersonPtr makePerson(std::string name,
86                   PersonPtr father={},
87                   PersonPtr mother={}){
88      auto res =  std::make_shared<PersonImpl>(name,father,mother);
89      if (father) father->addChild(res);
90      if (mother) mother->addChild(res);
91      return res;
92    }
93  };
94
95  Person::Person(std::string name) :
96    person { PersonImpl::makePerson(name) } {
97  }
98
99  Person::Person(std::string name, Person father, Person mother) :
100   person { PersonImpl::makePerson(name, father.person, mother.person) } {
101 }
102
103 Person::~Person() {}
104
105 void Person::addChild(Person child) { person->addChild(child.person); }
106 std::string Person::getName() const { return person->getName(); }
107 Person Person::findChild(std::string name) const {
108   auto result = person->findChild(name);
109   return Person { result };
110 }
111
112 void Person::killChild(Person child) {
113   person->killChild(child.person);
114 }
115 void Person::killMe() {
116   person->killMe();
117 }
118
119 void Person::print(std::ostream &out) const {
120   person->print(out);
121 }
122
123 Person::operator bool() const {
124   return person.get();
125 }
```

14.3.2   Word

```cpp
#ifndef WORD_H_
#define WORD_H_

#include <iosfwd>
#include <string>

#include <boost/operators.hpp>

struct Word : boost::less_than_comparable<Word>, boost::equality_comparable<Word> {
  Word():data{} {}
  Word(std::string);

  bool isValid() { return !data.empty(); }
  void read(std::istream&);
  void write(std::ostream& os) const { os << data; };

  bool operator<(Word const& r) const { return toLower() < r.toLower(); }
  bool operator==(Word const& r) const { return toLower() == r.toLower(); }
  std::string operator+(std::string const& r) const { return data + r; }
private:
  std::string data;
  std::string toLower() const;
};

std::istream& operator>>(std::istream&, Word&);
std::ostream& operator<<(std::ostream&, Word const&);

#endif
```

```cpp
#include "word.h"

#include <istream>
#include <ostream>
#include <string>
#include <algorithm>
#include <sstream>

Word::Word(std::string word):data{} {
  std::istringstream in{word};
  read(in);
}

void Word::read(std::istream& in) {
  data.clear();

  char c{};
  while(in.get(c)) {
    if(std::isspace(c) && !isValid()) continue;

    if(std::isalpha(c)) {
      data.push_back(c);
    } else {
      break;
    }
  }
}

std::string Word::toLower() const {
  std::string lowered{data};
  std::transform(lowered.begin(), lowered.end(), lowered.begin(), tolower);
  return lowered;
}

std::istream& operator>>(std::istream& l, Word& r) {
  r.read(l);
  return l;
}

std::ostream& operator<<(std::ostream& l, Word const& r) {
  r.write(l);
  return l;
}
```

14.3.3   Ring

```
1   struct Ring5 {
2
3     explicit constexpr Ring5(unsigned x=0u) : val{ x % 5 } {}
4
5     constexpr unsigned value() const {
6       return val;
7     }
8
9     constexpr operator unsigned() const {
10      return val;
11    }
12
13    constexpr bool operator==(Ring5 const &r) const {
14      return val == r.val;
15    }
16
17    constexpr bool operator!=(Ring5 const &r) const {
18      return !(*this == r);
19    }
20
21    Ring5 operator+=(Ring5 const &r) {
22      val = (val + r.value()) % 5;
23      return *this;
24    }
25
26    Ring5 operator*=(Ring5 const&r) {
27      val = (val * r.value()) % 5;
28      return *this;
29    }
30
31    constexpr Ring5 operator+(Ring5 const &r) const {
32      return Ring5{val+r.val};
33    }
34
35    constexpr Ring5 operator*(Ring5 const &r) const {
36      return Ring5{val*r.val};
37    }
38
39  private:
40
41    unsigned val;
42
43  };
```

14.3.4   Sack

```cpp
#ifndef SACK_H_
#define SACK_H_

#include<vector>
#include<map>
#include <iterator>

template <typename T, template<typename...> class C=std::vector>
class Sack
{
    using SackType=C<T>;
    using size_type=typename SackType::size_type;
    SackType theSack{};

public:
    Sack(std::initializer_list<T> const &items) :
      theSack(items) {
    }

    bool empty() const {
      return theSack.empty();
    }

    size_type size() const {
      return theSack.size();
    }

    void putInto(T const &item) {
      theSack.push_back(item);
    }

    T getOut() {
      if (empty()) {
        throw std::logic_error{"empty Sack"};
      }

      auto index = static_cast<size_type>(rand() % size());

      T retval { theSack.at(index) };
      theSack.erase( theSack.begin() + index);
      return retval;
    }
};
#endif /* SACK_H_ */
```

```cpp
template <typename T>
class Sack<T, std::map> {
  using SackType = std::map<T, unsigned>;
  using size_type=typename SackType::size_type;
  SackType theSack{};

public:
  bool empty() {
    return theSack.empty();
  }

  size_type size() {
    size_type total = 0;
    for (std::pair<T, unsigned> pair : theSack) {
      total += pair.second;
    }

    return total;
  }

  void putInto(T const &item) {
    theSack[item]++;
  }

  T getOut() {
      if (empty()) {
        throw std::logic_error{"empty Sack"};
      }

      auto index = static_cast<size_type>(rand() % size());

      std::pair<T, unsigned> element = *std::next(theSack.begin(), index);

      if (element.second == 1) {
        theSack.erase(element.first);
      } else {
        theSack[element.first] = element.second -1;
      }
      return element.first;
  }
};
```

14.3.5   Highlander

```
1   #ifndef LIMITNUMBEROFINSTANCES_H_
2   #define LIMITNUMBEROFINSTANCES_H_
3
4   #include <stdexcept>
5
6   template <typename TOBELIMITED, unsigned int maxNumberOfInstances>
7   class LimitNofInstances {
8
9     static unsigned int counter;
10
11  protected:
12
13    void checkNofInstances() {
14      if(counter == maxNumberOfInstances) throw std::logic_error("too many instances");
15    }
16    LimitNofInstances() {
17      checkNofInstances();
18      ++counter;
19    }
20    ~LimitNofInstances() {
21      --counter;
22    }
23    LimitNofInstances(const LimitNofInstances &other){
24      checkNofInstances();
25      ++counter;
26    }
27  };
28
29  template <typename TOBELIMITED, unsigned int maxNumberOfInstances>
30  unsigned int
31  LimitNofInstances<TOBELIMITED,maxNumberOfInstances>::counter(0);
32
33  #endif /* LIMITNUMBEROFINSTANCES_H_ */
34
35  // using it:
36  class One : LimitNofInstances<One, 1>{ /*...*/};
```

14.3.6 dynArray

```
1   #ifndef DYNARRAY_H_
2   #define DYNARRAY_H_
3
4   #include <vector>
5
6   template<typename T>
7   struct dynArray {
8
9     using DynArrayType = std::vector<T>;
10    using size_type = typename DynArrayType::size_type;
11    using value_type = typename DynArrayType::value_type;
12    using iterator = typename DynArrayType::iterator;
13    using const_iterator = typename DynArrayType::const_iterator;
14    using allocator_type = typename DynArrayType::allocator_type;
15
16    // Constructors
17
18    explicit dynArray(const allocator_type& alloc = allocator_type()):container{alloc} {}
19    explicit dynArray(size_type n):container{n} {}
20    explicit dynArray(size_type n, value_type const& val, allocator_type const& alloc = allocator_type
21
22    template<class InputIterator>
23    dynArray(InputIterator first, InputIterator last, allocator_type const& alloc = allocator_type()):
24
25    dynArray(dynArray const& x):container{x.container} {}
26    dynArray(dynArray const& x, allocator_type const& alloc):container{x.container, alloc} {}
27    dynArray(std::initializer_list<value_type> il, allocator_type const& alloc = allocator_type()):con
28
29    // Iterators
30
31    iterator begin() {
32      return container.begin();
33    }
34
35    const_iterator begin() const {
36      return container.begin();
37    }
38
39    iterator end() {
40      return container.end();
41    }
42
43    const_iterator end() const {
44      return container.end();
45    }
46
```

```
47    iterator rbegin() {
48      return container.rbegin();
49    }
50
51    const_iterator rbegin() const {
52      return container.rbegin();
53    }
54
55    iterator rend() {
56      return container.rend();
57    }
58
59    const_iterator rend() const {
60      return container.rend();
61    }
62
63    const_iterator cbegin() const {
64      return container.cbegin();
65    }
66
67    const_iterator cend() const {
68      return container.cend();
69    }
70
71    const_iterator crbegin() const {
72      return container.crbegin();
73    }
74
75    const_iterator crend() const {
76      return container.crend();
77    }
78
79    // Capacity
80
81    size_type size() const {
82      return container.size();
83    }
84
```

```cpp
85    void resize(size_type n) {
86      container.resize(n);
87    }
88
89    void resize(size_type n, const value_type& val) {
90      container.resize(n, val);
91    }
92
93    size_type capacity() const {
94      return container.capacity();
95    }
96
97    bool empty() const {
98      return container.empty();
99    }
100
101   // Element access
102
103   value_type& operator[](int n) {
104     return container[normalize_index(n)];
105   }
106
107   value_type const& operator[](int n) const {
108     return container[normalize_index(n)];
109   }
110
111   value_type& at(int n) {
112     return container.at(normalize_index(n));
113   }
114
115   value_type const& at(int n) const {
116     return container.at(normalize_index(n));
117   }
118
119   value_type& front() {
120     return container.front();
121   }
122
123   value_type const& front() const {
124     return container.front();
125   }
126
```

```
127    value_type& back() {
128      return container.back();
129    }
130
131    value_type const& back() const {
132      return container.back();
133    }
134
135    // Modifiers
136
137    void push_back(value_type const& val) {
138      container.push_back(val);
139    }
140
141    void push_back(value_type&& val) {
142      container.push_back(val);
143    }
144
145    void pop_back() {
146      container.pop_back();
147    }
148
149    iterator erase(iterator position) {
150      return container.erase(position);
151    }
152
153    iterator erase(iterator first, iterator last) {
154      return container.erase(first, last);
155    }
156
157    void clear() {
158      container.clear();
159    }
160
161    // Allocator
162
163    allocator_type get_allocator() const {
164      return container.get_allocator();
165    }
166
```

```
167   private:
168
169     DynArrayType container;
170
171     int normalize_index(int n) const {
172       return (n < 0) ? size()+n : n;
173     }
174
175   };
176
177   // Factories
178
179   template <typename T>
180   dynArray<T> makeDynArray(std::initializer_list<T> list) {
181     return dynArray<T>{list};
182   }
183
184   #endif /* DYNARRAY_H_ */
```

14.4   Dec to Hex to Oct

```
1   // DEC
2   //   0:   1    2    3    4    5    6    7    8    9   10
3   //  10:  11   12   13   14   15   16   17   18   19   20
4   //  20:  21   22   23   24   25   26   27   28   29   30
5   //  30:  31   32   33   34   35   36   37   38   39   40
6   //  40:  41   42   43   44   45   46   47   48   49   50
7   //  50:  51   52   53   54   55   56   57   58   59   60
8   //  60:  61   62   63   64   65   66   67   68   69   70
9   //  70:  71   72   73   74   75   76   77   78   79   80
10  //  80:  81   82   83   84   85   86   87   88   89   90
11  //  90:  91   92   93   94   95   96   97   98   99  100
12
13  // HEX
14  //   0:   1    2    3    4    5    6    7    8    9    a
15  //  10:   b    c    d    e    f   10   11   12   13   14
16  //  20:  15   16   17   18   19   1a   1b   1c   1d   1e
17  //  30:  1f   20   21   22   23   24   25   26   27   28
18  //  40:  29   2a   2b   2c   2d   2e   2f   30   31   32
19  //  50:  33   34   35   36   37   38   39   3a   3b   3c
20  //  60:  3d   3e   3f   40   41   42   43   44   45   46
21  //  70:  47   48   49   4a   4b   4c   4d   4e   4f   50
22  //  80:  51   52   53   54   55   56   57   58   59   5a
23  //  90:  5b   5c   5d   5e   5f   60   61   62   63   64
24
25  // OCT
26  //   0:   1    2    3    4    5    6    7   10   11   12
27  //  10:  13   14   15   16   17   20   21   22   23   24
28  //  20:  25   26   27   30   31   32   33   34   35   36
29  //  30:  37   40   41   42   43   44   45   46   47   50
30  //  40:  51   52   53   54   55   56   57   60   61   62
31  //  50:  63   64   65   66   67   70   71   72   73   74
32  //  60:  75   76   77  100  101  102  103  104  105  106
33  //  70: 107  110  111  112  113  114  115  116  117  120
34  //  80: 121  122  123  124  125  126  127  130  131  132
35  //  90: 133  134  135  136  137  140  141  142  143  144
```

```
1   //   d    h    o
2   //
3   //   1    1    1      2    2    2      3    3    3      4    4    4      5    5    5
4   //   6    6    6      7    7    7      8    8    10     9    9    11     10   a    12
5   //   11   b    13     12   c    14     13   d    15     14   e    16     15   f    17
6   //   16   10   20     17   11   21     18   12   22     19   13   23     20   14   24
7   //   21   15   25     22   16   26     23   17   27     24   18   30     25   19   31
8   //   26   1a   32     27   1b   33     28   1c   34     29   1d   35     30   1e   36
9   //   31   1f   37     32   20   40     33   21   41     34   22   42     35   23   43
10  //   36   24   44     37   25   45     38   26   46     39   27   47     40   28   50
11  //   41   29   51     42   2a   52     43   2b   53     44   2c   54     45   2d   55
12  //   46   2e   56     47   2f   57     48   30   60     49   31   61     50   32   62
13  //   51   33   63     52   34   64     53   35   65     54   36   66     55   37   67
14  //   56   38   70     57   39   71     58   3a   72     59   3b   73     60   3c   74
15  //   61   3d   75     62   3e   76     63   3f   77     64   40   100    65   41   101
16  //   66   42   102    67   43   103    68   44   104    69   45   105    70   46   106
17  //   71   47   107    72   48   110    73   49   111    74   4a   112    75   4b   113
18  //   76   4c   114    77   4d   115    78   4e   116    79   4f   117    80   50   120
19  //   81   51   121    82   52   122    83   53   123    84   54   124    85   55   125
20  //   86   56   126    87   57   127    88   58   130    89   59   131    90   5a   132
21  //   91   5b   133    92   5c   134    93   5d   135    94   5e   136    95   5f   137
22  //   96   60   140    97   61   141    98   62   142    99   63   143    100  64   144
```