

C++ basics

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Contents

Type safety	2	String streams	11
constexpr	2	Vectors	12
Type casting	2	Enumerations	13
Functions	2	Classes	13
Namespaces	3	Operator overloading	14
Random numbers	3	Copy constructor	15
Arrays	4	Inheritance	15
Pointers	4	Polymorphism	16
C-Strings	5	Exceptions	18
Input-output streams	5	Templates	19
Files	8	Iterators	20
Strings	10	Containers	21
		Algorithms	22

In the following code snippets, the standard I/O library and namespace are always used:

```
#include <iostream>
using namespace std;
```

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Type safety

⇒ Universal and uniform initialisation prevents narrowing conversions from happening:

```
// safe conversions
double x {54.21};
int a {2342};

// unsafe conversions (compile error!)
int y {x};
char b {a};
```

constexpr

There are two options:

⇒ **constexpr** must be known at compile time:

```
constexpr int max = 200;
constexpr int c = max + 2;
```

⇒ **const** variables don't change at runtime. They cannot be declared as **constexpr** because their value is not known at compile time:

```
// the value of n is not known at compile time
const int m = n + 1;
```

Type casting

⇒ Use **static_cast** for normal casting:

```
// int 15 to double 15.0
double num;
num = static_cast<double>(15);
```

Functions

⇒ With default trailing arguments only in the function declaration:

```
// if year is omitted, then year = 2000
void set_birthday(int day, int month, int year=2000);
```

⇒ Omitting the name of an argument if not used anymore in the function definition:

```
// argument year is not used anymore in the function definition
// (doesn't break legacy code!)
void set_birthday(int day, int month, int) { ...}
```

⇒ With read-only, read-write and copy-by-value parameters:

```
// day input parameter passed by const reference (read-only)  
// month output parameter to be changed by the function (read-write)  
// year input parameter copied-by-value  
void set_birthday(const int& day, int& month, int year);
```

⇒ Use a function for initialising an object with a complicated initialiser (we might not know exactly when the object gets initialised):

```
const Object& default_value()  
{  
    static const Object default(1,2,3);  
    return default;  
}
```

Namespaces

⇒ **using** declarations for avoiding fully qualified names:

```
// use string instead of std::string  
using std::string;  
  
// use cin, cout instead of std::cin, std::cout  
using std::cin;  
using std::cout;
```

⇒ **using namespace** directives for including the whole namespace:

```
using namespace std;
```

Random numbers

```
#include <cstdlib>  
#include <ctime>  
  
// seed the generator  
srand( time(0) );  
  
// integer random number between 0 and RAND_MAX  
int n = rand();
```

Arrays

⇒ Range-based **for** statement:

```
// changes the values and outputs 3579  
int arr[] = {2, 4, 6, 8};  
  
for (int& x : arr)  
    x++;  
  
for (auto x : arr)  
    cout << x;
```

Pointers

⇒ Simple object:

```
// simple pointer to double  
double *d = new double(5.123);  
  
// delete the storage on the freestore  
delete d;
```

⇒ Dynamic array:

```
// dynamic array of 10 doubles  
double *dd = new double[10];  
  
// delete the storage on the freestore  
delete [] dd;
```

⇒ Dynamic matrix:

```
// dynamic matrix of 5 x 5 doubles memory allocation  
double **m = new double*[5];  
for (int i=0; i<5; i++)  
    m[i] = new double[5];  
  
// memory initialization  
for (int i=0; i<5; i++)  
    for (int j=0; j<5; j++)  
        m[i][j] = i*j;  
  
// memory deallocation  
for (int i=0; i<5; i++)  
    delete[] m[i];  
delete[] m;
```

C-Strings

⇒ Legacy strings from C:

```
#include <cstring>
#include <cstdlib>

// C-string for max 10 characters
// long string + null char '\0'
const int SIZE = 10 + 1;
char msg[SIZE] = "Hello!";

// correct looping over C-strings
int i = 0;
while ( msg[i] != '\0' && i < SIZE)
{
    // process msg[i]
}

// safe string copy, at most 10 characters are copied
strncpy(msg, srcStr, 10);

// safe string compare, at most 10 characters are compared
strncmp(msg, srcStr, 10);

// safe string concatenation, at most 10 characters are concatenated
strncat(msg, srcStr, 10);

// from C-string to int, long, float
int    n = atoi("567");
long   n = atol("1234567");
double n = atof("12.345");
```

Input-output streams

⇒ Input stream **cin**, output stream **cout**, error stream **cerr**:

```
int number;
char ch;

// read a number followed by a character
// from standard input (keyboard)
// (ignores whitespaces, newlines, etc.)
cin >> number >> ch;

// write on standard output (display)
cout << number << "_" << ch << endl;

// write error message on standard error (display)
cerr << "Wrong_input!\n";
```

⇒ Integer format manipulators: once a manipulator is set, it stays until another one is set, i.e. manipulators are *sticky*.

```
#include <iomanip>

// set decimal, octal, or hexadecimal notation,
// and show the base, i.e. 0 for octal and 0x for hexadecimal
cout << showbase;
cout << dec << 1974 << endl;
cout << oct << 1974 << endl;
cout << hex << 1974 << endl;
cout << noshowbase;

// values can be read from input in decimal, octal
// or hexadecimal format previous unsetting
// of all the flags
cin.unsetf(ios::dec);
cin.unsetf(ios::oct);
cin.unsetf(ios::hex);

// now val can be inserted in any format
cin >> val;
```

⇒ Floating point format manipulators: once a manipulator is set, it stays until another one is set, i.e. manipulators are *sticky*.

```
#include <iomanip>

// set default, fixed, or scientific notation
cout << defaultfloat << 1023.984;
cout << fixed << 1023.984;
cout << scientific << 1023.984;

// set precision
cout << setprecision(2) << 1023.984;

// set character text width
cout << setw(10);

// set left or right alignment
cout << left << 1023.984;
cout << right << 1023.984;

// always show decimal point and zeros
cout << showpoint << 0.532;

// always show plus sign
cout << showpos << 3.64;
```

⇒ Single characters read and write:

```
// read any character from cin (doesn't skip spaces, newlines, etc.)
char nextChar;
```

```

cin.get(nextChar);

// write a character to cout
cout.put(nextChar)

// read a whole line of 80 chars
char line[80+1];
cin.getline(line,81);

// put back nextChar to cin, nextChar will be the next
// char read by cin.get()
cin.putback(nextChar);

// put back the last char got from cin.get() to cin
cin.unget();

```

⇒ If the input pattern is unexpected, it is possible to set the state of **cin** to failed:

```

try
{
    // check for unexpected input
    char ch;
    if ( cin >> ch && ch != expected_char )
    {
        // put back last character read
        cin.unget();

        // set failed bit
        cin.clear(ios_base::failbit);

        // throw an exception or deal with failed stream
        throw runtime_error("Unexpected_input");
    }
}
catch (runtime_error e)
{
    cerr << "Error!_" << e.what() << "\n";

    // check for failure
    if (cin.fail())
    {
        // clear failed bit
        cin.clear();

        // read wrong input
        string wrong_input;
        cin >> wrong_input;

        cerr << "Got_" << wrong_input[0] << "'\n";
    }
    // End of file (eof) or corrupted state (bad)
    else return 1;
}

```

Files

⇒ Accessed by means of **ifstream** (input) or **ofstream** (output) objects:

```
#include <fstream>

// open input file
ifstream in_stream {"infile.dat"};
// open output file
ofstream out_stream {"outfile.dat"};
```

⇒ Files can be also opened explicitly (not recommended):

```
#include <fstream>

// input file
ifstream in_stream;
// output file
ofstream out_stream;

// open files
in_stream.open("infile.dat");
out_stream.open("outfile.dat");
```

⇒ When checking for failure, the status flag needs to be cleared in order to continue working with the file:

```
// check for failure on input file
if ( !in_stream )
{
    if ( in_stream.bad() ) error("stream_corrupted!");

    if ( in_stream.eof() )
    {
        // no more data available
    }

    if ( in_stream.fail() )
    {
        // some format data error, e.g. expected
        // an integer but a string was read
        // recovery is still possible

        // set back the state to good
        // before attempting to read again
        in_stream.clear();

        // read again
        string wrong_input;
        in_stream >> wrong_input;
    }
}
```


⇒ As for the standard input, if the input pattern is unexpected, it is possible to set the state of the file to failed and try to recover somewhere else, e.g. by throwing an exception:

```
try
{
    // check for unexpected input
    char ch;
    if ( in_stream >> ch && ch != expected_char )
    {
        // put back last character read
        in_stream.unget();

        // set failed bit
        in_stream.clear(ios_base::failbit);

        // throw an exception or deal with failed stream
        throw runtime_error("Unexpected_input");
    }
}
catch (runtime_error e)
{
    cerr << "Error!_" << e.what() << "\n";

    // check for failure
    if (in_stream.fail())
    {
        // clear failed bit
        in_stream.clear();

        // read wrong input
        string wrong_input;
        in_stream >> wrong_input;

        cerr << "Got_" << wrong_input[0] << "'\n";
    }
    else return 1; // eof or bad
}
```

⇒ Read and write:

```
// read/write data
in_stream >> data1 >> data2;
out_stream << data1 << data2;
```

⇒ Read a line:

```
string line;
getline(in_stream, line);
```

⇒ Ignore input (extract and discard):

```
// ignore up to a newline or 9999 characters
in_stream.ignore(9999, '\n');
```

⇒ Move the file pointer:

```
// skip 5 characters when reading (seek get)
in_stream.seekg(5);
// skip 8 characters when writing (seek put)
out_stream.seekp(8);
```

⇒ Checking for end of file:

```
// the failing read sets the EOF flag but avoids further processing
while ( in_stream >> next )
{
    // process next
}

// check the EOF flag
if ( in_stream.eof() )
    cout << "EOF_reached!" << endl;
```

⇒ When a file object gets out of scope, the file is closed automatically, but explicit close is also possible (not recommended):

```
// explicitly close files
in_stream.close();
out_stream.close();
```

Strings

⇒ Strings as supported by the C++ standard library:

```
#include <string>

// initialization
string s1 = "Hello";
string s2("World");

// concatenation
string s3 = s1 + ",_" + s2;

// read a line
string line;
getline(cin, line);

// access to the ith character (no illegal index checking)
s1[i];

// access to the ith character (with illegal index checking)
s1.at(i);

// append
s1.append(s2);
```

```

// size and length
s1.size();
s1.length();

// substring from position 5 and length 4 characters
string substring;
substring = s4.substr(5,4);

// find (returns string::npos if not found)
size_t pos;
pos = s3.find("World");
if (pos == string::npos)
    cerr << "Error:_String_not_found!\n";

// find starting from position 5
s3.find("l",5);

// C-string
s3.c_str();

// from string to int, long, float
int    n = stoi("456");
long   n = stol("1234567");
double n = stod("12.345");

// from numeric type to string
string s = to_string(123.456);

```

String streams

A string is used as a source for an input stream or as a target for an output stream.

⇒ Input string stream **istringstream**:

```

#include <sstream>

// input string stream
istringstream data_stream{"1.234_-5643.32"};

// read numbers from data stream
double val;
while ( is >> val )
    cout << val << endl;

```

⇒ Output string stream **ostringstream**:

```

#include <sstream>

// output string stream
ostringstream data_stream;

```

```

// the same manipulators of input-output streams
// can be used
data_stream << fixed << setprecision(2) << showpos;
data_stream << 6.432 << "_" << -313.2134 << "\n";

// the str() method returns the string in the stream
cout << data_stream.str();

```

Vectors

⇒ Sequence of elements accessed via an index:

```

#include <vector>

// vector with base type int
vector<int> v = {2, 4, 6, 8};

// vector with 10 elements all initialised to 0
vector<int> v(10);

// access to the ith element
cout << v[i];

// add an element
v.push_back(10);

// range-for-loop
for (auto x : v)
    cout << x << endl;

// size
cout << v.size();

// capacity: number of elements currently allocated
cout << v.capacity();

// reserve more capacity e.g. at least 64 ints
v.reserve(64);

```

⇒ Throws an **out_of_range** exception if accessed out of bounds:

```

// out of bounds access
vector<int> v = {2, 4, 6, 8};

try
{
    cout << v[7];
} catch (out_of_range)
{
    // access error!
}

```

Enumerations

⇒ **enum class** defines symbolic constants in the scope of the class:

```
// enum definition
enum class Weekdays
{
    mon=1, tue, wed, thu, fri
};

// usage
Weekdays day = Weekdays::tue;
```

⇒ **ints** cannot be assigned to **enum class** and viceversa:

```
// errors!
Weekdays day = 3;
int d = Weekdays::wed;
```

⇒ A conversion function should be written which uses unchecked conversions:

```
// valid
Weekdays day = Weekdays(2);
int d = int(Weekdays::fri);
```

Classes

⇒ If you give no constructor, the compiler will generate a default constructor that does nothing. If you give at least one constructor, then the C++ compiler will generate no other constructors.

```
class Car
{
public:
    // constructor
    Car(double size);
    // mutators
    void set_engine_size(const double& size);
    // accessors
    double get_engine_size() const;
    // friend function
    friend bool equal(const Car& car1, const Car& car2);
private:
    double engine_liter;
};

// constructor with member initialisation list
// the member variable is immediately initialised before the
// constructor body runs
Car::Car(double size) : engine_liter{size}
{
}
```

```

// parameter passed by reference for efficiency
void Car::set_engine_size(const double& size)
{
    engine_liter = size;
}

// constant member function doesn't change the object
double Car::get_engine_size() const
{
    return engine_liter;
}

// friend function with direct access to private members
bool equal(const Car &car1, const Car &car2)
{
    return car1.engine_liter == car2.engine_liter;
}

```

⇒ Constructor invocations:

```

// all forms call the Car(2000) constructor
Car bmw {2000};
Car bmw = {2000};
Car bmw = Car{2000};

```

Operator overloading

The behaviour is different if overloaded as class members or friend functions.

⇒ As class members:

```

class Euro
{
    // constructor for euro
    Euro(int euro);
    // constructor for euro and cents
    Euro(int euro, int cents);
    // works for Euro(5) + 2, equivalent to
    // Euro(5).operator+( Euro(2) ),
    // doesn't work for 2 + Euro(5), 2 is not a calling object
    // of type Euro !
    Euro operator+(const Euro& amount);
    friend Euro operator+(const Euro& amount1, const Euro& amount2);
private:
    int euro;
    int cents;
};

```

⇒ As friend members:

```

class Euro
{
    // constructor for euro
    Euro(int euro);
    // constructor for euro and cents
    Euro(int euro, int cents);
    // works for every combination int arguments are converted by
    // the constructor to Euro objects
    friend Euro operator+(const Euro& amount1, const Euro& amount2);
    // insertion and extraction operators
    friend ostream& operator<<(ostream& outs, const Euro& amount);
    friend istream& operator>>(istream& ins, Euro& amount);
private:
    int euro;
    int cents;
};

```

Copy constructor

⇒ If not defined, C++ automatically adds the default copy constructor and the default assignment operator. They might not be correct if dynamic variables are used, because class members are simply copied:

```

class Int_list
{
    // constructor with size of the list
    Int_list(int size);
    // copy constructor
    Int_list(Int_list& list);
    // assignment operator
    Int_list& operator=(const Int_list& list);
private:
    int *p;
    int size;
}

// call the copy constructor
// second_list is initialised from first_list
Int_list second_list(first_list);

// call the assignment operator
third_list = first_list;

```

Inheritance

⇒ Constructors, destructor, private member functions, copy constructor and assignment operator are not inherited! Derived classes get the default ones if they are not explicitly provided but are present in the base class.

```
// a simple book class
class Book
{
public:
    Book(string t, int p);
    void print(ostream& os);
protected:
    int pages;
    string title;
};
```

⇒ Redefinition of function members:

```
// a simple textbook class
class Textbook : public Book
{
public:
    Textbook(string t, int p, string s);
    // redefinition of print() from the base class
    void print(ostream& os);
protected:
    string subject;
};
```

⇒ **protected** members can be accessed by derived function members:

```
// has access to protected members of the base class
void Textbook::print(ostream& os)
{
    os << "The_title_of_this_textbook_is_" << title
        << "_and_the_textbook_has_" << pages << "_pages." << endl;
    os << "The_subject_is_" << subject << "_" << endl;
}
```

⇒ With redefinition, no polymorphism!

```
TextBook a_Math_Textbook("Calculus",1200,"Real_variables");
Book *a_book = &a_Math_Textbook;

// call Book::print() not Textbook::print()!
a_book->print(cout);
```

Polymorphism

⇒ **virtual** allows for late binding, i.e. polymorphism. Function members are overridden in the derived class. Note: Destructors should also be declared **virtual**. When derived objects are referenced by base class pointers, the destructor of the derived class is called if it is declared virtual.


```

// a simple book class
class Book
{
public:
    Book(string t, int p);
    virtual ~Book();
    void print(ostream& os);
protected:
    int *pages;
    string *title;
};

Book::Book(string t, int p)
{
    pages = new int(p);
    title = new string(t);
}

Book::~~Book()
{
    delete pages;
    delete title;
}

// a simple textbook class
class Textbook : public Book
{
public:
    Textbook(string t,int p, string s);
    virtual ~Textbook();
    // overriding of print() from the base class
    virtual void print(ostream& os);
protected:
    string *subject;
};

Textbook::Textbook(string t, int p, string s) : Book(t, p)
{
    subject = new string(s);
}

Textbook::~~Textbook()
{
    delete subject;
}

TextBook a_Math_Textbook("Calculus",1200,"Real_variables");
Book *a_book = &a_Math_Textbook;

// call Textbook::print() !
a_book->print(cout);

```

Exceptions

⇒ The value thrown by **throw** can be of any type.

```
// exception class
class My_exception
{
public:
    My_exception(string s);
    virtual ~My_exception();
    friend ostream& operator<<(ostream& os, const My_exception& e);
protected:
    string msg;
};

try
{
    throw My_exception("error");
}
catch (My_exception& e)
{
    // error stream
    cerr << e;
}
// everything else
catch (...)
{
    exit(1);
}
```

⇒ The standard library defines a hierarchy of exceptions. For example **runtime_error** can be thrown when runtime errors occur:

```
try
{
    throw runtime_error("unexpected_result!");
}
catch (runtime_error& e)
{
    // error stream
    cerr << "runtime_error:_" << e.what() << "\n";
    return 1;
}
```

⇒ Functions throwing exceptions should list the exceptions thrown in the exception specification list. These exceptions are not caught by the function itself!

```
// exceptions of type DivideByZero or OtherException are
// to be caught outside the function. All other exceptions
// end the program if not caught inside the function.
void my_function( ) throw (DivideByZero, OtherException);

// empty exception list, i.e. all exceptions end the
```

```

// program if thrown but not caught inside the function.
void my_function( ) throw ( );

// all exceptions of all types treated normally.
void my_function( );

```

Templates

Function templates:

⇒ C++ does not need the template declaration. The template function definition is included directly.

```

// generic swap function
template<class T>
void swap(T& a, T& b)
{
    T temp = a;

    a = b;
    b = temp;
}

int a, b;
char c, d;

// swaps two ints
swap(a, b);

// swaps two chars
swap(c, d);

```

Class templates:

⇒ Methods are defined as template functions. Note the declaration of the templated friend operator.

```

template<class T>
class A_list
{
    // constructor with size of the list
    A_list(int size);
    // destructor
    ~A_list();
    // copy constructor
    A_list(A_list<T>& b);
    // assignment operator
    A_list<T>& operator=(const A_list<T>& b);
    // friend insertion operator
    template <class TT>
    friend ostream& operator<<(ostream& outs, const A_list<TT>& rhs);
private:
    T *p;
    int size;
}

```

```

// constructor definition
template<class T>
A_list<T>::A_list(int size)
{
    p = new T[size];
}

// variable declaration
A_list<double> list;

```

Iterators

⇒ An iterator is a generalization of a pointer. Different containers have different iterators.

```

#include <vector>

vector<int> v = {1,2,3,4,5};
// mutable iterator
vector<int>::iterator e;

// bidirectional access
e = v.begin();
++e;
// print v[1]
cout << *e << endl;
--e;
// print v[0]
cout << *e << endl;

// random access
e = v.begin();
// print v[3]
cout << e[3] << endl;

// change an element
e[3] = 9;

// constant iterator (only read)
vector<int>::constant_iterator c;

// print out the vector content (read only)
for (c = v.begin(); c != v.end(); c++)
    cout << *c << endl;

// not allowed
// c[2] = 2;

// reverse iterator
vector<int>::reverse_iterator r;

// print out the vector content in reverse order

```

```
for (r = v.rbegin(); r != v.rend(); r++)  
    cout << *r << endl;
```

Containers

⇒ Sequential containers: **list**

```
#include <list>  
  
list<double> data = {1.32,-2.45,5.65};  
  
// adds elements  
data.push_back(9.23);  
data.push_front(-3.94);  
  
// bidirectional iterator, no random access  
list<double>::iterator e;  
  
// erase  
e = data.begin();  
++e;  
data.erase(e);  
  
// print out the content  
for (e = data.begin(); e != data.end(); e++)  
    cout << *e << endl;
```

⇒ Adapter containers: **stack**

```
#include <stack>  
  
stack<double> numbers;  
  
// push on the stack  
numbers.push(5.65);  
numbers.push(-3.95);  
numbers.push(6.95);  
  
// size  
cout << numbers.size()  
  
// read top data element  
double d = numbers.top();  
  
// pop top element  
numbers.pop();
```

⇒ Associative containers: **set**

```

#include <set>

set<char> letters;

// inserting elements
letters.insert('a');
letters.insert('d');
// no duplicates!
letters.insert('d');
letters.insert('g');

// erase
letters.erase('a');

// const iterator
set<char>::const_iterator c;
for (c = letters.begin(); c != letters.end(); c++)
    cout << *c << endl;

```

⇒ Associative containers: **map**

```

#include <string>
#include <map>
#include <utility>

// initialization
map<string,int> dict = { {"one",1}, {"two",2} };
pair<string,int> three("three",3);

// insertion
dict.insert(three);
dict["four"] = 4;
dict["five"] = 5;

// iterator
map<string,int>::iterator two;

// find
two = dict.find("two");

// erase
dict.erase(two);

// ranged loop
for (auto n : dict)
    cout << "(" << n.first << ", " << n.second << ")" << endl;

```

Algorithms

⇒ Provided by the C++ standard library:

```
#include <vector>
#include <algorithm>

vector<int> v = {6,2,7,13,4,3,1};
vector<int>::iterator p;

// find
p = find(v.begin(),v.end(),13);

// merge sort
sort(v.begin(),v.end());

// binary search
bool found;
found = binary_search(v.begin(), v.end(), 3);

// reverse
reverse(v.begin(),v.end());
```

References

- [1] Walter Savitch. *Problem Solving with C++*, 10th edition. Pearson Education, 2018
- [2] Bjarne Stroustrup. *Programming: Principles and Practice Using C++*, 2nd edition. Addison Wesley, 2015
- [3] Josh Lospinoso. *C++ Crash Course: A Fast-Paced Introduction*, 1st edition. No Starch Press, 2019