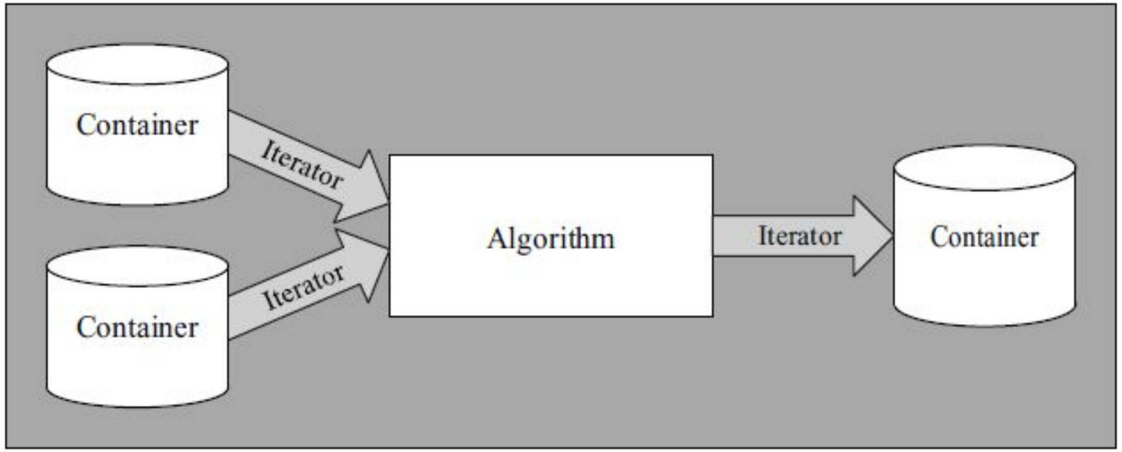
C++ Course 6: Containers + Miscellanea 2

2020 by Oleksiy Grechnyev

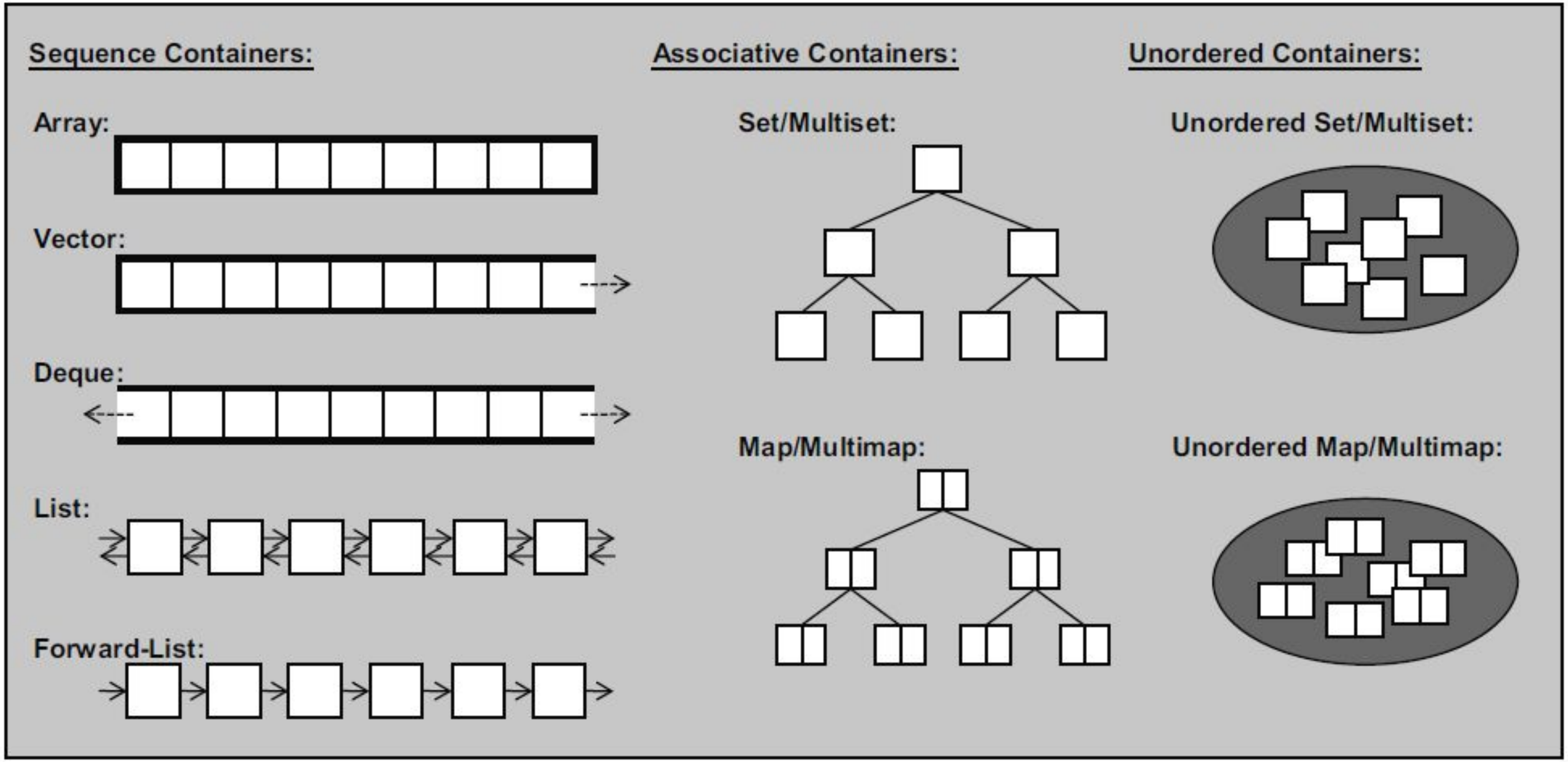
Standard Template Library (STL)



1. **Container** : A data class : **vector, array, map, set, ...**
2. **Iterator** : An object which iterates over a container (sort of a smart pointer)
3. **Algorithm**: A polymorphic algorithm : **sort, find, reverse, transform, copy, move** ...
4. **Function Objects + Lambda expressions**: Often used as arguments in algorithms

STL = Object Oriented + Generic + Functional programming

STL containers



Built-in arrays (C-arrays) : Don't use them!

```
int a[12];  // Array of size 12
double b[3] = {0.1, 1.2, 2.3};
string weapons[] = {"Sword", "Axe", "Bow"};   // Size can be omitted if initialized
constexpr int SIZE = 1024*1024*16;    // SIZE must be constexpr
char buffer[SIZE];
char cString[] = "This is a null-terminated C-string";   // Automatically ended with \0
double matrix[10][10];      // Multidimensional
```

Arrays are indexed by the [] operator, starting from 0, no range checks (seg fault !!!)

```
for (int i=0; i<12; ++i)
        a[i] = i*i;
```

Arrays can be implicitly converted to pointers.

```
char * message = cString;
```

Size of an array (number of elements), does not work with pointers !

```
int size = sizeof a / sizeof (int);
```

Extra slides : C-arrays

std::array : C++ array of fixed (compile time) size

```
array<string, 5> aS1{"Karen", "Lucia", "Anastasia", "Margaret", "Alice"};
array<int, 100> aI;
aI.fill(17);                                    // Fill with the value 17
constexpr int SIZE = 1024*1024*16;
array<double, SIZE> aD;         // Size must be constexpr (compile time) !
auto aStr = std::experimental::make_array("Red", "Green", "Blue");
```

Possible implementation of **array**: thin wrapper around C-array:

```
template <typename T, size_t SIZE>
class array{
public:
        ...                             // Methods, operators
private:
        T myData[SIZE];     // The build-in array
}; // Note: std::array does not allocate any heap memory (stack overflow risk).
```

Creating std::array : more options

You can use type alias:

```
using SArray = array<string, 5>;
SArray aS1{"Karen", "Lucia", "Anastasia", "Margaret", "Alice"}; // List creation
SArray aS2 = {"Maria", "Nel", "Sophia", "Clair", "Mirage"};  // This is also OK
SArray aS3;
aS3 = aS1;                  // Copy array
aS1.swap(aS2);        // Swap arrays
swap(aS1, aS2);        // Swap arrays (the same)
```

Get a raw pointer to the data (underlying built-in array):

```
string * rawData = aS1.data();
```

Create an **std::array** object out of a built-in array (NOT from pointer !):

```
string a[] = {"Maria", "Nel", "Sophia", "Clair", "Mirage"};
auto aS4 = std::experimental::to_array(a);
```

std::array of funny types

Pointers (but NOT references) :

```
int i1 = 13, i2 = 17, i3 = 666;
array <int *, 3> aPtr{&i1, &i2, &i3};               // Pointers
array <const int *, 3> aCPtr{&i1, &i2, &i3};   // Pointers to const
```

Constants : Some other containers (e.g. **std::vector**) don't allow this:

```
array<const string, 5> cNames{"Maria", "Nel", "Sophia", "Clair", "Mirage"};
```

unique_ptr or **shared_ptr** objects (fine with other containers):

```
array<unique_ptr<int>, 2> uAr {
        make_unique<int>(17),
        make_unique<int>(666)
};
```

Built-in arrays of fixed size:

```
array<int[17], 3> aa;
```

Indexing std::array

array <int, 12> a;

a.at(i)	: Element **i** (Checks boundaries, throws **std::out_of_range**)
a[i]	: Element **i** (No checks, seg fault !)
a.front()	: First element
a.back()	: Last element
a.size()	: Number of elements

Set/modify array elements:

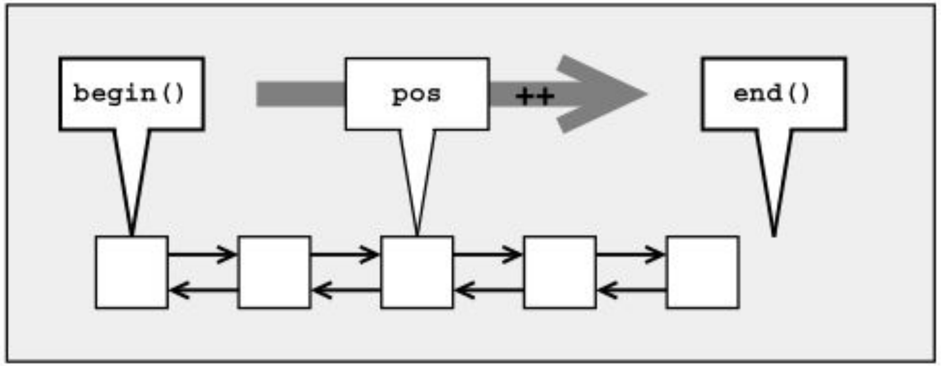
```
for (int i = 0; i < a.size(); ++i)
        a.at(i) = i*i;
```

Print the array:

```
for (int i = 0; i < a.size(); ++i)          // Using []
        cout << a[i] << " ";
for (int elem : a)                          // Using range for
        cout << elem << " ";
```

Iterators

- *Iterators* are objects (smart pointers) that iterate over container elements.
- This includes containers without numerical index (**std::set**, **std::list**).
- Iterators have operators ***** and **->** defined (like pointers). ***iter** is the container element the iterator points at.
- All iterators support operators **++** , **==** , **!=**, **=**.
- Some iterators support operators **--** , **+**, **-** , **<**, **>**, **+=**, **-=**.



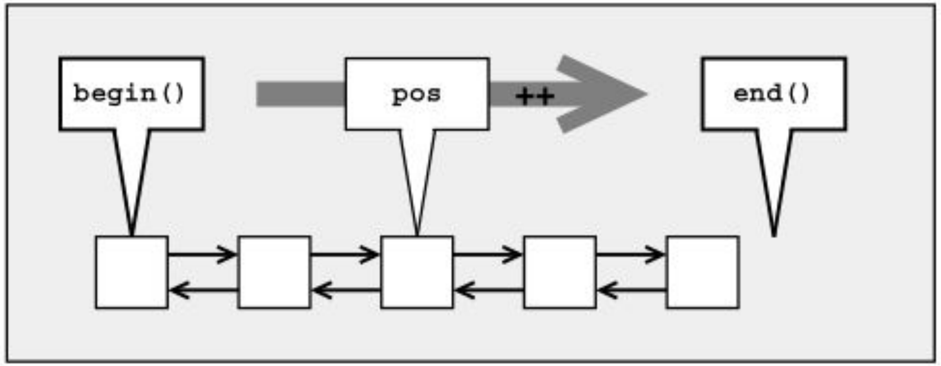
begin() and end()

a**.begin()** or **begin(**a**)** is the iterator to the first element of a container **a**.

a**.end()** or **end(**a**)** is the iterator *past the last* element of a container **a**.

a**.end()** is not a valid element!
a**.begin() ==** a**.end()** for an empty container.

Only functional form **begin(**a**)**, **end(**a**)** can be used for C-arrays !



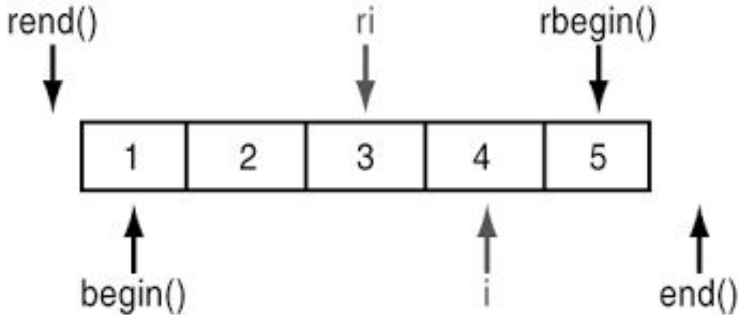
const and reverse iterators, for loop

Normal version	: **a.begin(), a.end()**
const version	: **a.cbegin(), a.cend()**
Reverse version	: **a.rbegin(), a.rend()** all except **forward_list**
Reverse **const** version	: **a.crbegin(), a.crend()** all except **forward_list**

Iterators in a **for** loop (same syntax for all containers !):

```
for (auto it = a.begin(); it != a.end(); ++it)
      *it *= *it;   // Square each element of the container
```

Range **for** is based on iterators! Use range **for** whenever possible!



Iterator arithmetics (std::array, std::vector, ...)

Index to iterator:

```
auto it = a.begin() + index;
```

Iterator to index:

```
size_t index  = it - a.begin();
```

More operations:

```
int diff  = it2 - it1;          // Distance between two iterators
if (it1 < it2) ..               //  Compare two iterators
it += 5;                          // Move forward by 5 elements
it -=  2;                         // Move back by 2 elements
it =  a.end() - 1;                // Element before last
```

Iterator classes of **std::array** (usually **auto** is used):

array::iterator, array::const_iterator,

array::reverse_iterator, array::const_reverse_iterator

Templates to print any container (even built-in array !)

With range **for** (uses iterators under the hood !):

```
template <typename C>
void print(const C & c){
    for (const auto & e : c)  // Duck typing ! Will not compile if C is not a container !
        cout << e << " ";
    cout << endl;
}
```

With iterators:

```
template <typename C>
void print2(const C & c){
    for (auto it = begin(c); it != end(c); ++it)
        cout << *it << " ";
    cout << endl;
}
```

Iterators, ranges, and algorithms

C++ algorithms use a range given by 2 iterators : **first**, **last**.

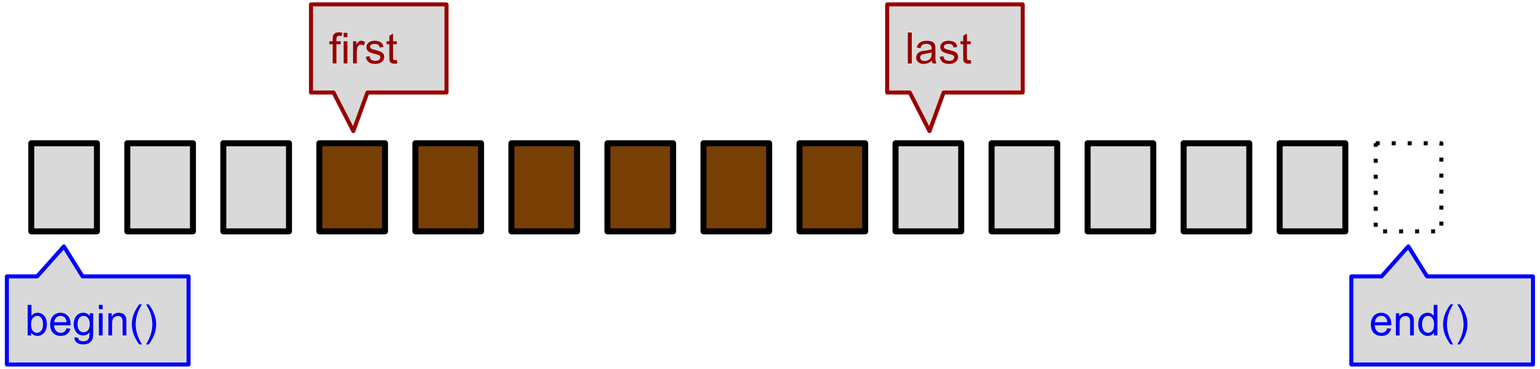
first : The first element of the range

last : The element past the last

Use **begin()**, **end()** to include the entire container in the range.

The algorithms are *polymorphic templates* (work with any container !)

This is basically a *slice* (a bit ugly syntax though)



Algorithms 1

Sort a container.

```
sort(first, last);
sort(a.begin(), a.end());       // The entire container
sort(begin(a), end(a));         // This form can be used for built-in arrays
```

Reverse a container.

```
reverse(first, last);
```

Random order.

```
shuffle(first, last, rng);      // rng = Random Number Generator
```

Find min and max elements (Returns iterator !).

```
auto minEl = min_element(first, last);
auto maxEl = max_element(first, last);
cout << "min = " << *minEl << ", max = " << *maxEl << endl;
```

Algorithms 2

Fill with a value : **fill(first, last, value);**

```
fill(a.begin(), a.end(), 13);     // Fill container a with value 13
```

Copy elements. : **copy(first, last, dest_first);**

```
copy(a1.begin(), a1.end(), a2.begin());    // Copies a1 to a2
```

Generate with a function. **generate(first, last, fun);**

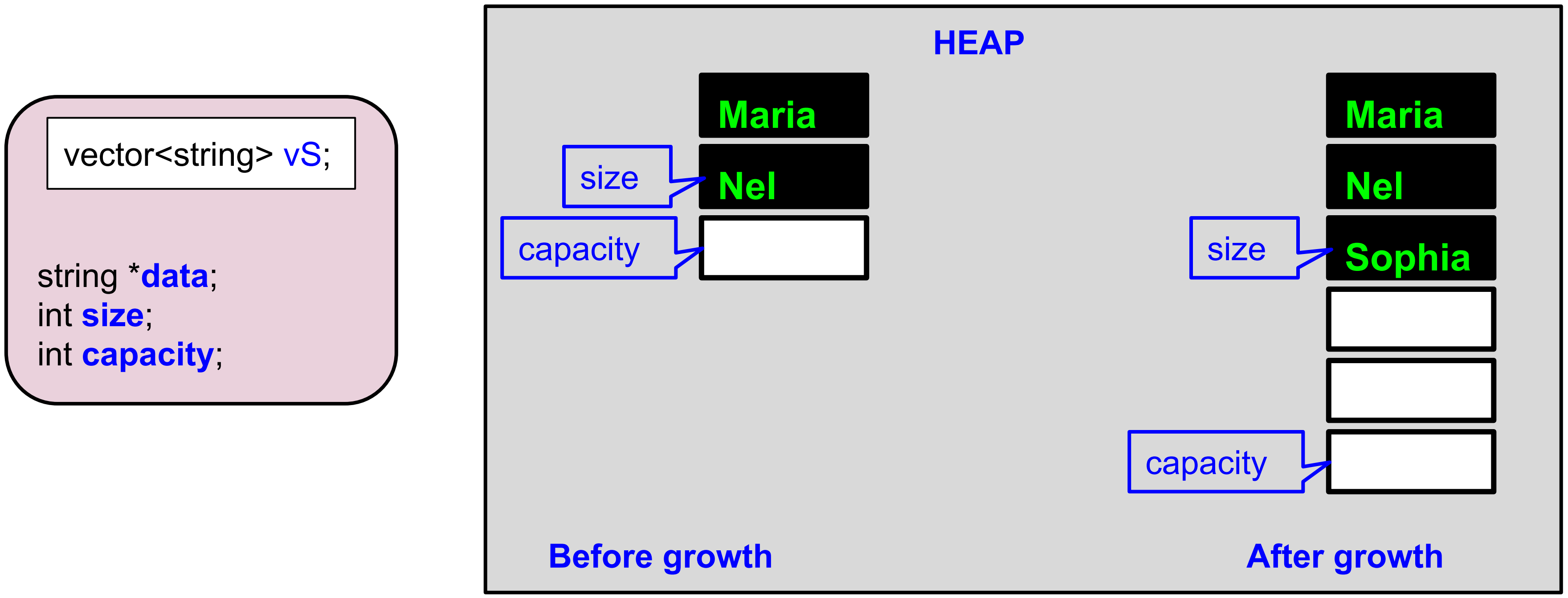
```
int n = 0;
generate(al4.begin(), al4.end(), [&n](){return n++;});   // 0, 1, .., 11
```

Apply a function to each element: **for_each(first, last, fun);**

```
for_each(a.begin(), a.end(), [](int &n){n*=3;});   // Multiply each element by 3
```

Extra slides: Algorithms

std::vector : A dynamic array. THE C++ container.



size Number of objects in container

capacity Number of reserved slots in the heap. It grows automatically if needed!

Creating std::vector

```
vector<int> vl1;                          // Empty vector
vl1.push_back(17);                        // Add elements to an empty vector
vl1.push_back(19);
vl1.push_back(26);
vector<int> vl2(10);                      // vector of 10 elements
vector<int> vl3(10, 13);                  // vector of 10 elements equal to 13
vector<int> vl4{10, 13};                  // vector of two elements : 10, 13
vector<int> vl5 = {2, 3, 7, 11, 13, 17, 19, 23};        // List assignment constructor
vector<string> vS{"Maria", "Nel", "Sophia", "Clair", "Mirage"};        // List constructor
```

move() and **swap()** are very good for vectors !

Fast and slow operations:

Fast: access elements with **[]**, **move()** and **swap()**

Medium: access elements with **.at()**, adding to the end (**push_back**, **emplace_back**)

Slow: insert/delete in the middle

How to fill std::vector with data?

Indexing : Default Ctor, string Ctor, move assignment :

```
vector<Tjej> vT(5);                          // Default constructor 5 times !!!
for (int i=0; i < 5; ++i)
     vT.at(i) = Tjej("Tjej #" + to_string(i));
```

push_back : string Ctor, move Ctor :

```
vector<Tjej> vT;                              // Empty vector
for (int i=0; i < 5; ++i)
     vT.push_back(Tjej("Tjej #" + to_string(i)));
```

emplace_back : string Ctor. New objects are constructed in-place !

```
vector<Tjej> vT;                              // Empty vector
for (int i=0; i < 5; ++i)
     vT.emplace_back("Tjej #" + to_string(i));
```

But what the hell is going on (Tjej = logging class) ???

```
Ctor Tjej #0
Ctor Tjej #1
Move Ctor Tjej #0
Dtor
Ctor Tjej #2
Move Ctor Tjej #0
Move Ctor Tjej #1
Dtor
Dtor
Ctor Tjej #3
Ctor Tjej #4
Move Ctor Tjej #0
Move Ctor Tjej #1
Move Ctor Tjej #2
Move Ctor Tjej #3
Dtor
Dtor
Dtor
Dtor
```

std::vector capacity growth

```
vector<int> v;
for (int i = 0; i <= 40; ++i) {
        cout << "size = " << v.size() << ", capacity = " << v.capacity() << endl;
        v.push_back(i);
}
```

```
size = 0, capacity = 0
size = 1, capacity = 1
size = 2, capacity = 2
size = 3, capacity = 4
size = 4, capacity = 4
size = 5, capacity = 8
...
size = 9, capacity = 16
...
size = 17, capacity = 32
...
size = 33, capacity = 64
...
```

size vs capacity

SIZE operations:

v.size();	// Get size
v.clear();	// Delete all elements
v.resize(17);	// Change size (delete elements or create empty ones)

CAPACITY operations:

v.capacity();	// Get capacity
v.reserve(1000);	// Reserve storage (grow in size to given capacity)
v.shrink_to_fit();	// Trim capacity to size

Use **reserve()** before **push_back** / **emplace_back** !

Is growth a COPY or MOVE operation ?

If move constructor is **noexcept** : prefer MOVE !

Otherwise prefer COPY !

Don't forget **noexcept** in your move Ctor!

Extra slides: Insert and delete elements in the middle (slow !)

deque, set, unordered_set, multiset, unordered_multiset

std::deque : Like **vector**, but with fast **push_front()**, **emplace_front()**, **pop_front()**
std::set : Tree set. Sorted. Uses **operator<** or **less()** to compare.
std::unordered_set : Hash set. Unsorted. Uses function **hash()** .
std::multiset, **std::unordered_multiset** : Multisets can keep multiple copies.

```
set<int> s{1, 22, 2, 3, 19, 1, 3, 8, 12, 19, 22};        // Repeated, unsorted
```
Contains : 1 2 3 8 12 19 22
Look for element in the set:
```
int i = s.count(22);          // Returns 0 or 1 (or number of copies)
auto pos = s.find(22);    // Returns iterator or s.end() if not found
```

Insert and delete:
```
s.insert(5);
s.emplace(7);
s.insert({11, 13, 17, 19, 23});
s.erase(8);
```

map, unordered_map, multimap, unordered_multimap

map<K, V> is a container of **pair<const K, V>** :

```
map<string, int> m1{
            {"Maria Traydor", 19},
            {"Nel Zelpher", 23}
};
m1.insert({"Mirage Koas", 27});                // Create a new entry
m1.insert(make_pair("Sophia Esteed", 19));
m1.emplace("Peppita Rossetti", 14);
m1["Clair Lasbard"] = 25;                      // Create OR change

m1["Mirage Koas"] -= 1;                        // Create OR change
m1.at("Nel Zelpher") -= 1;                     // Change only
for (auto & p : m1)                            // Change with a range for
         p.second += 1;                        // p is pair<const string, int>
```

map operations

Check if a key exists:

```
m1.count("Nel Zelpher");                    // Returns 0 or 1
```

Access an element by key:

```
auto pos = m1.find("Nel Zelpher");  // Returns iterator, dereference if needed !
string s1 = m1["Maria Traydor"];    // Does not work on const map!
string s2 = m1.at("Nel Zelpher");   // Throws exception if key is not found
```

Delete an entry (by iterator):

```
m1.erase(pos);
```

Delete an entry (by key):

```
m1.erase("Mirage Koas");
```

Number of entries in a map:

```
m1.size();
```

Extra slide: Template to print a map

C strings and C++ strings (std::string)

C-strings: 0-terminated string : **char*** or **char []**

C-string literal: **"Hello"** : type **const char [7]**

C++ strings: **std::string** . Use this, don't use C-strings!

C++ string literals (C++ 14) : **"World"s** : Warning! Temporary objects, like **std::string(...)** !

H	**e**	**l**	**l**	**l**	**o**	**\0**

basic_string<T> : A **vector**-like container for primitive types only, **char_traits**

Note : C++ strings are *mutable* (unlike Java, Python, ...) !

using string = basic_string<char>; : UTF-8 string (works with IO streams)

using u16string = basic_string<char16_t>; : UTF-16 string

using u32string = basic_string<char32_t>; : UTF-32 string

using wstring = basic_string<wchar_t>; : Don't use this

Strings are real simple, see the EXTRA SLIDES

Do it yourself: C string operations, Regular Expressions

std::string 101

Create **std::string** from C-string literal :

```
string s1("Big [REDACTED]");
```

Concatenate with **+**, **+=** :

```
s1 += " Gun";
```

Create a 0-terminated C-string (**const char ***) from **std::string** :

```
const char * c1 = s1.c_str();
```

Find a substring, then remove it :

```
string s2 = "[REDACTED] ";
int pos = s1.find(s2);
if (pos != string::npos){
        // Remove the substring from s1 if found. std::string is mutable !
        s1.erase(pos, s2.size());
}
```

std::string_view (C++ 17)

std::string_view is a **std::string**-like interface to *existing* bytes in memory

std::string_view works like a slice (pointer + length) to *existing* string, has no text of its own !

Create from a C-string:

```
const char * c1 = "Take a look to the sky just before you die";
string_view sv1(c1);   // Whole 0-terminated string
string_view sv2(c1 + 12, 10);  // Substring
```

Create from a **std::string** :

```
string s3{"It is the last time you will"};
string_view sv3(s3);   // Whole string
string_view sv4 = string_view(s3).substr(10, 9);  // Substring
```

Warning ! The underlying **string** must be kept alive while you use **string_view**!

```
string_view sv(string("Error !!! Dangling pointer to a temporary !!!"));
```

Do it yourself: std::valarray

C++ and unicode : use UTF-8 ! And no locales !

1. Your code (*.h, *.cpp) must be in UTF-8 (string literals !).
2. Use **string** (not **wstring** !) for strings in UTF-8.
3. Use **cin**, **cout**, **ifstream**, **ofstream** with files in UTF-8.
4. Works fine with files, linux console.
5. Some trouble with windows console:
   Output: type **chcp 65001** in the console
   Input: I could not fix
6. Could be fixed with windows API if really needed.
7. GUI libraries have their own unicode support, e.g. **ustring** in gtkmm, **QString** in Qt.
8. Use C++ 11 **u16string** and **char16_t** if needed. UTF8 <-> UTF16 conversion!
9. Ignore the forum posts with locales, **wchar**, **wstring**, **wmain()**, **_tmain()**.

```
cout << "Український текст із літерами ґҐ !"  << endl;  // UTF-8 string literals
cout << "Svenska bokstäver ÅåÖöÄä !" << endl;
cout << "Hiragana :  あ , い , う , え , お " << endl;
```

Using UTF-16 : char16_t and u16string

char16_t is a type for a UTF-16 character

```
char16_t c1 = u'Ї', c2 = 0x456;
```

u16string is **basic_string<char_16_t>** :

```
u16string us2 = u"ЇїЄєҐґÅåÖöÄä";                    // UTF-8 string literal converted to UTF-16
u16string us3{0x414, 0x456, 0x432, 0x43a, 0x430};   // Numerical UTF-16 values
u16string us4{u'Ї', u'ж' , u'a', u' ', u'å', u'ö', u'ä'};     // List of UTF-16 chars
```

UTF-8 <-> UTF-16 conversion: **from_bytes(), to_bytes()** (deprecated ? WTF ???):

```
wstring_convert<codecvt_utf8_utf16<char16_t>, char16_t> cvt;   // Converter object
string s1 = "Український текст!";                  // UTF-8 string
u16string us1 = cvt.from_bytes(s1);                // Convert UTF-8 to UTF-16 !
cout << "us1 = " << cvt.to_bytes(us1) << endl;     // Convert UTF-16 to UTF-8 !

for (char16_t c : us2)                             // Iterate over UTF-16 chars
    cout << cvt.to_bytes(c) << "  " << hex << (int)c << dec << endl;
```

Time your code execution

Time your code with **system_clock** or **high_resolution_clock** :

```
auto t1 = std::chrono::system_clock::now();
// Some code you want to time
auto t2 = std::chrono::system_clock::now();
```

We want duration in milliseconds (Note: uses **std::chrono::duration** template):

Difference **t2 - t1** is **std::chrono::duration** in some unknown time units. Cast it to ms!

```
int dMs = std::chrono::duration_cast<std::chrono::milliseconds>(t2 - t1).count();
```

Where **std::chrono::milliseconds** is duration template in ms integer units.

The method **count()** returns numerical value of the **duration** object.

I prefer duration in **double** seconds:

```
using DSeconds = std::chrono::duration<double>;   // Double duration of 1 second units
double dS = DSeconds(t2 - t1).count(); // No need for cast here, because double is 'exact'
```

Extra slides: C++ date and time, ratio, duration

Random numbers

Create random number generator from a seed:

```
mt19937 mt(seed);
```

Or use system time as a seed:

```
mt19937 mt(time(NULL));
```

Create a distribution:

```
uniform_int_distribution<int> uiD(-2, 4);    // Integer -2 to 4 INCLUSIVE
```

Use this distribution with the random engine:

```
for (int i = 0; i < 20; ++i)
        cout << uiD(mt) << endl;
```

Pseudorandom engines (templates with parameters) :

linear_congruential_engine, mersenne_twister_engine, subtract_with_carry_engine

Many pre-configured types: **mt19937, mt19937_64** (good), **minstd_rand** (fast)

Random distributions

Uniform integer distribution from n1 to n2 inclusive :

```
uniform_int_distribution<int> uiD(n1, n2);
```

Uniform real distribution from a to b :

```
uniform_real_distribution<double> urD(a, b);
```

Normal (Gaussian) distribution with mean and sigma :

```
normal_distribution<double> nD(mean, sigma);
```

Random boolean values with probability p :

```
bernoulli_distribution bD(p);
```

MANY other distributions !

Do it yourself: C random numbers: rand(), srand()

Library of the day: RapidJSON (Very Fast Header-only JSON parser)

Let us parse a JSON file hero.json :

```
{
    "name" : "Reimi Saionji",
    "age" : 19,
    "weapons" : ["Short Bow", "Eldarian Bow", "Torch Bow", "Hunting Bow",
"Earthsoul Bow"]
}
```

In CMakeLists.txt :

```
...
# Copy the file to build directory at the "cmake .." stage
file(COPY hero.json DESTINATION .)

# RapidJSON
find_package(RapidJSON REQUIRED)
message("RAPIDJSON_INCLUDE_DIRS = ${RAPIDJSON_INCLUDE_DIRS}")
include_directories(${RAPIDJSON_INCLUDE_DIRS})
...
```

Library of the day: RapidJSON (Very Fast Header-only JSON parser)

```cpp
ifstream inFile("hero.json");            // Open json file
rapidjson::IStreamWrapper isw(inFile);   // Create rapidjson wrapper
rapidjson::Document d;                   // Create the document (DOM)
if (d.ParseStream(isw).HasParseError())  // Parse the stream
    throw runtime_error("Parse Error !");

if (d.HasMember("name") && d["name"].IsString())    // Read a field
    cout << "name = " << d["name"].GetString() << endl;
if (d.HasMember("age") && d["age"].IsInt())    // int or double ?
    cout << "age = " << d["age"].GetInt() << endl;
else if (d.HasMember("age") && d["age"].IsDouble())
    cout << "age = " << d["age"].GetDouble() << endl;

if (d.HasMember("weapons") && d["weapons"].IsArray()) {    // Array
    cout << "weapons =\n";
    for (const rapidjson::Value & v : d["weapons"].GetArray() ) {
        if (v.IsString())
            cout << v.GetString() << endl;
    }
}
```

Thank you for your attention !

title

text

References and Pointers to array

Do not confuse with pointer to array *element*. Array type must be of fixed size !

```
int a[12];
int (& aRef1) [12] = a;
int (* aPtr1) [12] = &a;
```

Create a type alias:

```
using ArrayType = int [12];
ArrayType & aRef2 = a;
ArrayType * aPtr2 = &a;
```

Template to get array size:

```
template <typename T, size_t SIZE>
size_t getArraySize(const T (&) [SIZE]) { return SIZE; }
```

Arrays can be printed with a range for:

```
for (int i : a) cout << i << " ";
```

Dynamic arrays (pointers actually)

How do we create an array of dynamic size?

We cannot, use pointers instead:

```
int size = 1024;                 // Not constexpr
int * data = new int[size];
for (int i=0; i<size; ++i)
      data[i] = i*i;             // We can use operator[] with pointers
delete [] data;                  // Array delete
```

It is possible to use **unique_ptr** (but not **shared_ptr** !) :

```
unique_ptr<int[]> data2(new int[size]);
```

Pointers are not real arrays!

You cannot use range **for, begin(), end(),** or our **getArraySize()** for pointers !

Absolutely no way to tell the size !

sizeof(data) returns pointer size (8 bytes) and not array size !

Pointers as array iterators

A C-style Array (NOT class) :

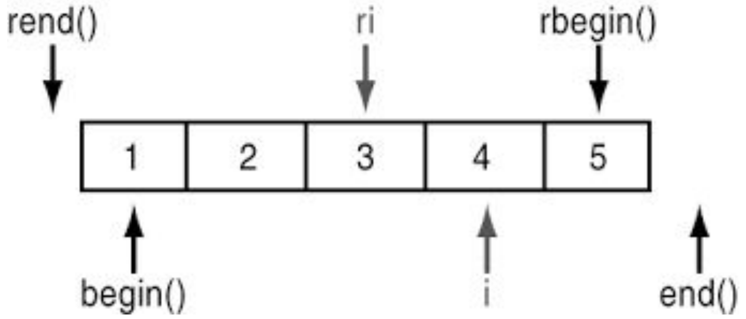
```
const string names[] = {"Karen", "Lucia", "Anastasia", "Margaret", "Alice"};
```

Print it with pointers :

```
const string * eit = names + 5;    // Position just after the last element
for (const string * it = names; it != eit; ++it)
     cout << *it << " ";
```

Or using C++ iterator style (only works with real array, not pointers !):

```
for (auto it = begin(names); it != end(names); ++it)
     cout << *it << " ";
```



What's wrong with built-in arrays? They are C legacy.

1. They cannot be copied.
2. They cannot be returned from a function.
3. They cannot be passed to a function by value. Converted to pointer !!!

void fun(int a[]) {...}   // Converted to **int** * pointer !
void fun(int a[37]) {...}   // Converted to **int** * pointer, size is ignored !

4. No **size()** method !
5. Must be of fixed size.
6. Array types in templates and containers are trouble.
7. Pointer is NOT an array. No range **for, begin(), end()** for pointers !

Don't use arrays, use *container classes* instead !

Exception: Array of constants:

const string names[] = {"Karen", "Lucia", "Anastasia", "Margaret", "Alice"};

Algorithms 3

Find first occurrence of an element. Returns last if not found.

```
find(first, last, value);
```

Find example:

```
array<int, 12> a{0, 1, 4, 9, 16, 25, 36, 49, 64, 81, 100, 121};
it1 = find(a.begin(), a.end(), 16);
it2 = find(a.begin(), a.end(), 64);

if (it1 == a.end() || it2 == a.end())    // Check if found
        throw runtime_error("Not found !!!");

if (it1 > it2)              // Check the order !
                swap(it1, it2);
reverse(it1, it2 + 1);    // Reverse from 16 to 64 inclusive !
```

Dangers of using iterators

When using algorithms, **last** must be reachable from **first** by operator **++** !

```
sort(first, last);
```

For example:

```
++ ++ ++ ++ ++ first == last
```

Otherwise BAD error! Difficult to diagnose!

```
array<int, 12> a1, a2;
...
sort(a1.begin(), a1.end());             //  OK
sort(a1.end(), a1.begin());             //  Error ! Wrong order !
sort(a1.begin(), a2.end());             //  Error ! Iterators of different arrays !
```

insert()/emplace() in the middle of vector

```
vector<int> v{1, 2, 3, 4, 5};

auto pos = find(v.cbegin(), v.cend(), 3);  // Find position of 3
pos = v.insert(pos, 17);                  // Insert BEFORE 3
pos = v.insert(pos, {21, 22});            // Insert list before 17
pos = v.emplace(pos, 33);                 // Emplace BEFORE 21
// insert() returns iterator to the 1st new element !

// 1 2 33 21 22 17 3 4 5

for (auto it = v.cbegin(); it != v.cend(); ++it)
    if (*it > 20 && *it < 30)
        it = v.insert(it, 49) + 1;        // Insert 49 BEFORE 21, 22
// 1 2 33 49 21 49 22 17 3 4 5

// it -> 21
// insert 17 before 21, it -> 17
// +1 : it -> 21
// ++it : iy -> 22
```

erase() : delete elements

```
vector<int> v{0, 1, 2, 3, 4, 5, 6, 7, 8, 9};

auto pos = find(v.cbegin(), v.cend(), 2);       // Find 2
pos = v.erase(pos);                            // Erase 2, pos -> 3
pos = v.erase(pos, pos+3);                     // Erase 3, 5, 6
// erase() returns iterator to the element AFTER erased

// 0 1 6 7 8 9

v.assign({0, 1, 2, 3, 4, 5, 6, 7, 8, 9});      // Just like Ctor

// Delete all even numbers in a for loop
for (auto it = v.cbegin(); it != v.cend(); ++it)
    if (*it % 2 == 0)
        it = v.erase(it) - 1;                  // -1 to negate ++it

// 1 3 5 7 9
```

Templates to print a map

With range **for** :

```
template <typename M>
void printMap(const M & m){
    for (const auto & e : m)
        cout << e.first << " : " << e.second << endl;
}
```

With iterators:

```
template <typename M>
void printMap2(const M & m){
    for (auto it = m.begin(); it != m.end(); ++it)
        cout << it->first << " : " << it->second << endl;
}
```

Creating strings : constructors, assign

```
string s0;                      // Empty string
```

From literals, char and C-strings :

```
string s1("Bastard Sword");                    // "Bastard Sword"
string s2 = "Heavy Crossbow";                  // "Heavy Crossbow"
string s3(18, 'Z');                            // "ZZZZZZZZZZZZZZZZZZ"
string s4("Mary Had a Little Lamb", 8);        // "Mary Had"   (length)
string s5("Mary Had a Little Lamb" + 5, 12);   // "Had a Little"
```

From strings object:

```
string s6(s1, 8);                              // "Sword"   (start pos)
string s7(s2, 6, 5);                           // "Cross"   (start pos, length)
```

assign() : change an existing strings object:

```
s3.assign(s2, 6, 5);                           // "Cross"
```

String operations

substr() : Substring (works just like constructors from **string**) :

```
string s1 = "Take a look to the sky just before you die";
string s2 = s1.substr(7);                 // "look to the sky just before you die"
string s3 = s1.substr(7, 11);             // "look to the"
```

Length of a **string** :

```
s1.size() == s1.length() == 42
```

Convert to a C-string (0-terminated) :

```
const char * cS1 = s1.c_str();
```

The temporary C-string lives only as long as **s1** is alive and not modified !

Raw data (might be not 0-terminated in theory, in reality identical to **c_str()**) :

```
const char * raw = s1.data();
```

Container operations

Modify with a range **for** :

```
for (char & c : s)
        c = toupper(c);
```

Print with iterators :

```
for (auto it = s.cbegin(); it != s.cend(); ++it)
        cout << *it;
cout << endl;
```

Sort using algorithm:

```
sort(s.begin(), s.end());
```

capacity, reserve, shrink_to_fit

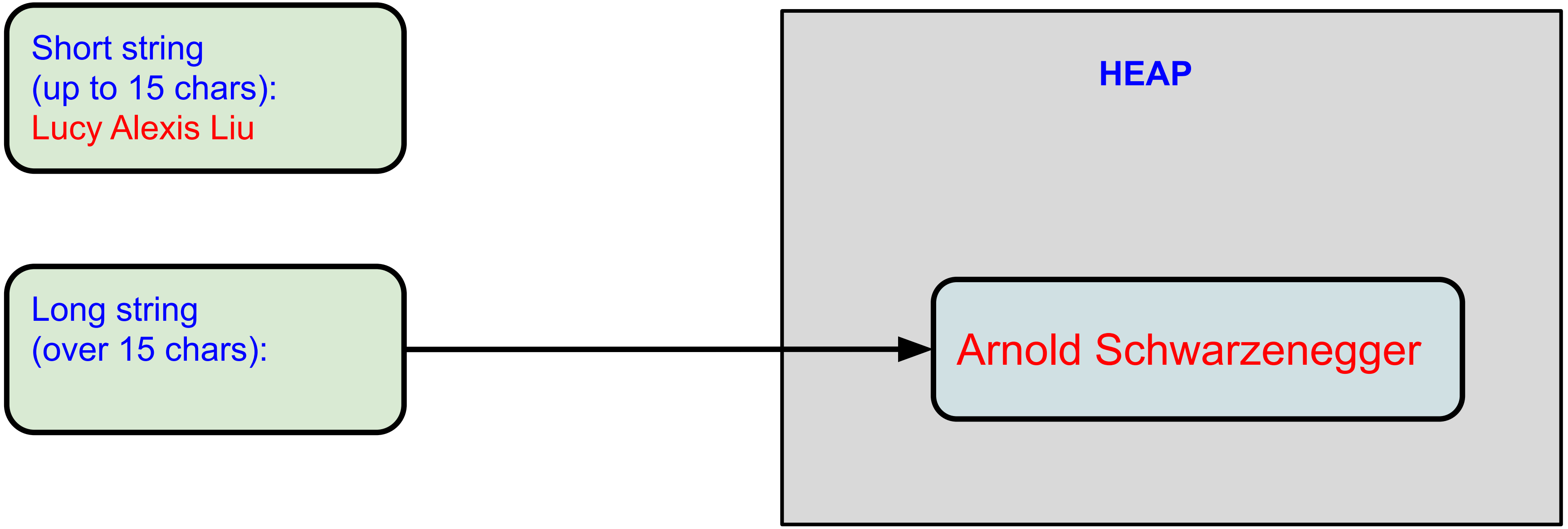
Capacity operations:

```
s.capacity();                          // return capacity
s.reserve(100);                        // reserve capacity
s.shrink_to_fit();                     // Trim capacity to size
for (int i = 0; i < 65; ++i){
        cout << "size = " << s.size() << " , capacity = " << s.capacity() << endl;
        s.push_back('Z');
}   // Growth : 15, 30, 60, 120 ...
```

Size operations:

```
s.size();                              // return size, also s.length()
s.empty();                             // return true if empty
s.clear();                             // return size
s.resize(27);                          // resize
s.resize(127, 'Z');                    // resize filling with 'Z'
```

In-place and heap strings



Short strings are stored in the **string** object (initial/minimal **capacity()** = 15)

Long strings are stored in the HEAP

insert(), erase() a substring

Position-based **insert()** , syntax like constructor and **assign()** :

```
string s1 = "Lucy Liu";
s1.insert(5, "Alexis ");                                   // "Lucy Alexis Liu"
s1.insert(0, string("One Gorgeous Two"), 4, 9);    // "Gorgeous Lucy Alexis Liu"
s1.insert(s1.size(), 3, '!');                             // "Gorgeous Lucy Alexis Liu!!!"
```

Iterator-based **insert()** , container syntax :

```
auto pos = s1.begin() + 9;
pos = s1.insert(pos, '?') + 1;                  // "Gorgeous ?Lucy Alexis Liu!!!"
string s2(" Deadly ");
s1.insert(pos, s2.cbegin(), s2.cend());          // "Gorgeous ? Deadly Lucy Alexis Liu!!!"
```

Position and iterator-based **erase()**:

```
s1.erase(0, 18);                                 // "Lucy Alexis Liu!!!"
pos = s1.begin() + 5;
s1.erase(pos, pos + 7);                          // "Lucy Liu!!!"
s1.erase(8);                                     // "Lucy Liu"
```

Concatenate: +, +=, append()

Concatenate with **operator+** :

```
string s1 = string("One ") + "Two " + "Three";
string s2 = "One " + string("Two ") + "Three";
string s3 = "One " + ("Two " + string("Three"));
string s4 = "One " + "Two " + string("Three");
string s5 = "One " + "Two " + "Three";
```

Which lines are OK ? Which are errors?

Concatenate: +, +=, append(), replace()

Concatenate with **operator+** :

```
string s1 = string("One ") + "Two " + "Three";            // OK
string s2 = "One " + string("Two ") + "Three";            // OK
string s3 = "One " + ("Two " + string("Three"));          // OK
string s4 = "One " + "Two " + string("Three");            // Error !!!
string s5 = "One " + "Two " + "Three";                    // Error !!!
```

Concatenate with **append()** and **operator+=** :

```
string s = "Alpha ";                  // "Alpha "
s.append("Beta ");                    // "Alpha Beta "
s.append("Gamma Delta ", 6);          // "Alpha Beta Gamma "
s += "Epsilon ";                      // "Alpha Beta Gamma Epsilon "
```

Modify with **replace()** : works like **erase()** + **insert()** :

```
s.replace(6, 4, "OMEGA");             // "Alpha OMEGA Gamma Epsilon "
```

find()

find() returns position of type **string::size_type** or **string::npos** if not found:

string s("Gorgeous ? Deadly Lucy Alexis Liu!!!");

Search for substring from left or right:

```
s.find("Alex")                  // 23 : Gorgeous ? Deadly Lucy Alexis Liu!!!
s.find("Alexander", 5);         // string::npos : starting position = 5
s.find(" L")                    // 17 : Gorgeous ? Deadly Lucy Alexis Liu!!!
s.rfind(" L")                   // 29 : Gorgeous ? Deadly Lucy Alexis Liu!!!
```

Search for any of the characters:

```
s.find_first_of(".,?!;;")       // 9,  Gorgeous ? Deadly Lucy Alexis Liu!!!
s.find_last_of(".,?!;;")        // 35, Gorgeous ? Deadly Lucy Alexis Liu!!!
s.find_first_not_of(".,?!;;")   // 0,  Gorgeous ? Deadly Lucy Alexis Liu!!!
s.find_last_not_of(".,?!;;")    // 32, Gorgeous ? Deadly Lucy Alexis Liu!!!
```

Search string with iterators and algorithms

returns iterators:

```
string s("Gorgeous ? Deadly Lucy Alexis Liu!!!");
```

Find a character:

```
find(s.cbegin(), s.cend(), 'L')                    // 17 : Gorgeous ? Deadly Lucy Alexis Liu!!!
```

Find with a lambda expression:

```
find(s.cbegin(), s.cend(), [](char c)->bool{
      return set<char>{'?','!', '.', ',', ':', ';'}.count(c);
})                                                 // 9,  Gorgeous ? Deadly Lucy Alexis Liu!!!
```

Search for a substring:

```
const string s2("Alex");                           // 23 : Gorgeous ? Deadly Lucy Alexis Liu!!!
search(s.cbegin(), s.cend(), s2.cbegin(), s2.cend());
```

Search for a first occurrence of a character:

```
const string s3(".,?!;;");                         // 9,  Gorgeous ? Deadly Lucy Alexis Liu!!!
find_first_of(s.cbegin(), s.cend(), s3.cbegin(), s3.cend());
```

Comparing strings:

Compare with **operator==** :

```
string("Mary Ann") == string("Mary Ann")          // OK
string("Mary Ann") == "Mary Ann"                  // OK
"Mary Ann" == string("Mary Ann")                  // OK
"Mary Ann" == "Mary Ann"                          // Compares pointers, not strings !!!!
```

Compare with **compare()** : Returns number <0, 0, or >0:

```
string("abcd").compare("abce")                    // <0
string("abcd").compare("abc")                     // >0
```

Compare two substrings (result == 0):

```
string("Alpha Two Three Tango").compare(6, 9, string("One Two Three Four"), 4, 9)
```

Number-string conversion

```
to_string(0.123456789)                    // "0.123456789"
```

String to int: **int stoi(std::string& str, size_t* pos = 0, int base = 10)**

```
stoi("101")                          // 101
size_t st;
stoi("101", &st)                     // 101, st == 3  (Number of chars read)
stoi("101", nullptr, 2)              // 5, binary
stoi("101", nullptr, 5)              // 26, base 5
stoi("101", nullptr, 8)              // 65, base 8
stoi("101", nullptr, 16)             // 257, base 16
stoi("101", nullptr, 0)              // 101, base 10 (auto base)
stoi("0101", nullptr, 0)             // 65, base 8
stoi("0x101", nullptr, 0)            // 257, base 16
```

Other types: **stof(), stod(), stold(), stol(), stoll(), stoul(), stoull()**

String streams: istringstream, ostringstream, stringstream

We can use strings as IO streams with operators **<<**, **>>**
Use **str()** (getter and setter) to access the underlying string
Useful for sophisticated string formatting

```
istringstream iss("13.98  17.32");
ostringstream oss;
double a, b;
iss >> a >> b;
oss << "a = " << a << " , b = " << b << " , a*b = " << a*b << endl;
cout << "oss.str() = " << oss.str();     // Contents of oss
```

If we want to reuse **iss** -- Если мы хотим снова использовать **iss :**

```
iss.str("3.0 7.0");      // Change the string in iss
iss.clear();             // To avoid failure on EOF !
```

We need **clear()** to clear the EOF bit !

Time and Date in C++

C++ time:

duration

clock

time_point

C time:

Time in seconds: **time_t, time()**

Execution time in milliseconds: **clock_t, clock()**

Calendar: **tm, localtime(), gmtime()**

Print: **ctime(), asctime(), strftime()**

Print (C++): **put_time**

Alternatives:

Boost or HowardHinnant/date

ratio : compile time rational number (fraction n/d)

ratio<n, d> : compile time rational number (fraction n/d)

using R1 = ratio<1, 100>;   // 1/1000

Template with static members only, do not create objects of this type

Numerator **R1::num** , Denominator **R1::den**

The fraction is reduced:

```
ratio<25, 15>              //  5/3
ratio<100, -10>          //  -10/1
ratio_add<ratio<1, 2>, ratio<1, 3>>                       //  5/6
ratio_multiply<ratio<1, 2>, ratio<1, 3>>              //  1/6
ratio_greater<ratio<1, 2>, ratio<1, 3>>::value   //  true
```

Predefined ratios:

atto, femto, pico, nano, micro, milli, centi, deci
deca, hecto, kilo, mega, giga, tera, peta, exa

std::chrono::duration

duration<Rep, Period> is a template for time intervals
Rep is a numerical type (**int, unsigned long long, double**)
Period is a time unit represented as **ratio** of seconds

```
using DMinutes = duration<double, ratio<60>>;          // 60/1
using DSeconds = duration<double>;                     // 1/1
using DDays = duration<double, ratio<60*60*24>>;       // 60*60*24/1
using DHours = duration<double, ratio<60*60>>;         // 60*60/1
```

Examples from cppreference.com :

```
constexpr auto year = 31556952ll;       // seconds in average Gregorian year
using Shakes = duration<int, ratio<1, 100000000>>;
using Jiffies = duration<int, centi>;                  // centi = 1/100
using Microfortnights = duration<float, ratio<14*24*60*60, 1000000>>;
using Nanocenturies = duration<float, ratio<100*year, 1000000000>>;
```

std::chrono::duration operations

Predefined durations :

nanoseconds, microseconds, milliseconds, seconds, minutes, hours

Declaring variables :

```
seconds s148(148);            //148 int seconds
minutes m1(1);                //1 int minute
DSeconds ds1_3(1.3);          //1.3 double seconds
```

Adding and subtracting durations (uses common denominator !):

```
auto dur1 = minutes(1) + seconds(3) - milliseconds(247);
```

Using literals (**operator""h** etc.):

```
using namespace std::chrono_literals;
auto dur2 = 1h + 10min + 42s;
auto dur3 = 1s + 234ms + 567us + 890ns;
```

count() , duration_cast

count() returns numerical value of a duration :

```
minutes m15(15);       // 15 minutes
m15.count();           // Returns 15 (in minutes !)
```

duration_cast<D> casts to a duration type **D** :

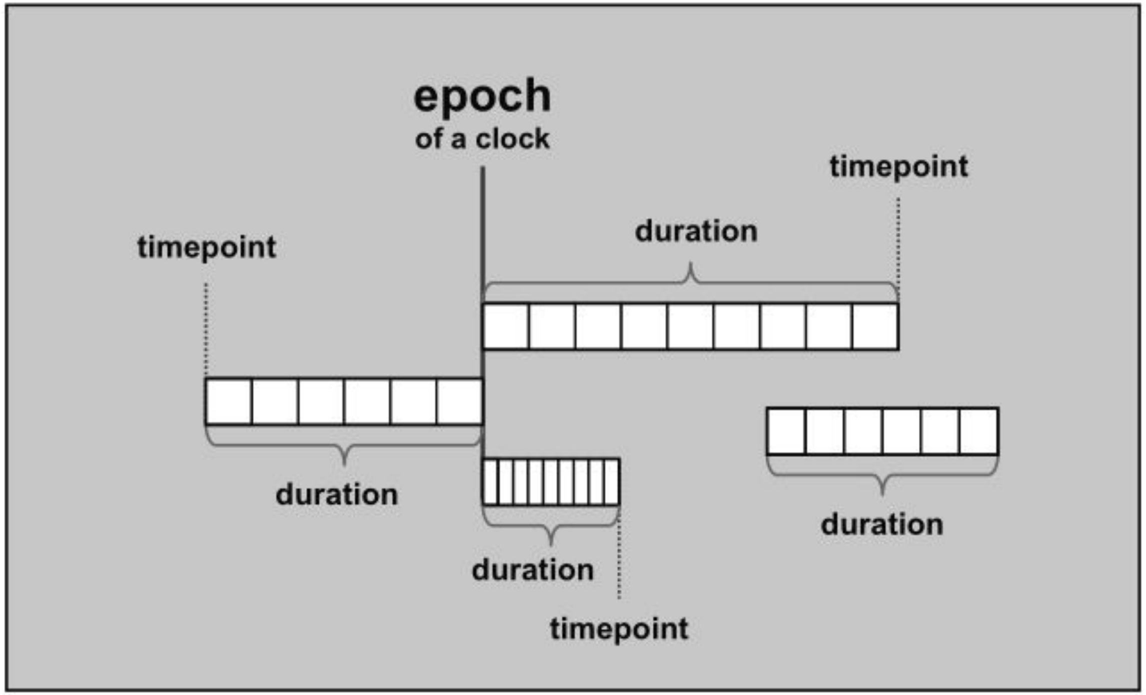
```
cout << "148 seconds = " << DMinutes(s148).count() << " DMinutes" << endl;
cout << "148 seconds = " << duration_cast<minutes>(s148).count() << " minutes" << endl;
cout << "1.3 seconds = " << duration_cast<milliseconds>(ds1_3).count() <<
                        " milliseconds" << endl;
cout << "dur1 = " << milliseconds(dur1).count() << " milliseconds" << endl;
cout << "dur2 = " << seconds(dur2).count() << " seconds" << endl;
cout << "dur3 = " << DSeconds(dur3).count() << " DSeconds" << endl;
```

duration_cast is needed if there is a *precision loss*

Note: float/double are treated is exact, which they are not, no need for cast

Clocks

system_clock	: Normal clock
steady_clock	: Never adjusted
high_resolution_clock	: Shortest time unit



Time execution of a method

```
auto t1 = high_resolution_clock::now();          // time_point 1
int result = fun(17);                // Method to time
auto t2 = high_resolution_clock::now();          // time_point 2

nanoseconds dNS = duration_cast<nanoseconds>(t2-t1);
using DSeconds = duration<double>;
DSeconds dS = duration_cast<DSeconds >(t2-t1);

cout << "Timing(nanoseconds) : " << dNS.count() << endl;
cout << "Timing(seconds) : " << dS.count() << endl;
```

Sleep for a time interval:

```
this_thread::sleep_for(milliseconds(2600));
```

C time routines and calendars

time_t Integer type to store time in seconds since epoch (1970)

```
time_t t1 = time(nullptr);            // C function to get time
```

Get **time_t** from a C++ **time_point** :

```
system_clock::time_point tP2 = system_clock::now();     // auto can be used
time_t t2 = system_clock::to_time_t(tP2);   // Convert to time_t
```

Different ways to print a **time_t** variable:

```
cout << "put_time(localtime()) : " << put_time(localtime(&t1), "%c %Z") << endl;
cout << "put_time(gmtime()) : " << put_time(gmtime(&t1), "%c %Z") << endl;   // GMT !

cout << "asctime(localtime()) : " << asctime(localtime(&t1));
cout << "ctime : " << ctime(&t1);                          // Short for asctime(localtime(&t1))
cout << "asctime(gmtime()) : " << asctime(gmtime(&t1));   // GMT !
```

tm : a C structure for time+date

localtime(), gmtime() return ***tm** :

```
tm tM1 = *localtime(&t1);      // Copy from static buffer to tM1

cout << "put_time(&tM1) = " << put_time(&tM1, "%c %Z") << endl;

cout << "tM1.tm_year = " << tM1.tm_year << endl;
cout << "tM1.tm_mon = " << tM1.tm_mon << endl;
cout << "tM1.tm_mday = " << tM1.tm_mday << endl;
cout << "tM1.tm_hour = " << tM1.tm_hour << endl;
cout << "tM1.tm_min = " << tM1.tm_min << endl;
cout << "tM1.tm_sec = " << tM1.tm_sec << endl;
cout << "tM1.tm_wday = " << tM1.tm_wday << endl;
cout << "tM1.tm_yday = " << tM1.tm_yday << endl;
cout << "tM1.tm_isdst = " << tM1.tm_isdst << endl;
```

tm : a C structure for time+date

localtime(), gmtime() return ***tm** :

```
put_time(&tM1) = 10/03/17 16:59:13 FLE Daylight Time
tM1.tm_year = 117
tM1.tm_mon = 9
tM1.tm_mday = 3
tM1.tm_hour = 16
tM1.tm_min = 59
tM1.tm_sec = 13
tM1.tm_wday = 2
tM1.tm_yday = 275
tM1.tm_isdst = 1
```

Use external libraries such as Boost or HowardHinnant/date !