# Introduction to C++ STL (Standard Template Library)

Giulio Ermanno Pibiri
giulio.pibiri@di.unipi.it

27/09/2017

# What is the C++ STL?

Alexander Stepanov

The Standard Template Library (**STL**) is a **C++** framework consisting in **template-based** classes and algorithms that implement mostly used data structures and common tasks.

# What is the C++ STL?

Alexander Stepanov

The Standard Template Library (STL) is a C++ framework consisting in **template-based** classes and algorithms that implement mostly used data structures and common tasks.

Roughly speaking:

16 containers (data structures)

~90 algorithms

+ utilities

# Why we care about STL

- Because we will use `C++` in this course.
- You do not have to re-invent the wheel.
- Learn more about `C++`.

# Why we care about STL

- Because we will use **C++** in this course.
- You do not have to re-invent the wheel.
- Learn more about **C++**.

My advice: **be skeptic**.
Measure first, then conclude.

# Why we care about STL

- Because we will use **C++** in this course.
- You do not have to re-invent the wheel.
- Learn more about **C++**.

Robert Sedgewick

My advice: **be skeptic**.
Measure first, then conclude.

"Use a data structure (or an algorithm) once you know its performance".

# Why we care about STL

- Because we will use **C++** in this course.
- You do not have to re-invent the wheel.
- Learn more about **C++**.

Robert Sedgewick

My advice: **be skeptic**.
Measure first, then conclude.

"Use a data structure (or an algorithm) once you know its performance".

You **must** consult sources like:
[http://www.cplusplus.com/](http://www.cplusplus.com/)
[http://en.cppreference.com/](http://en.cppreference.com/)

# STL goal

**Generic** programming: code once, re-use many times.

Increase correctness.

Wider range of uses.

# STL goal

**Generic** programming: code once, re-use many times.

Increase correctness.
Wider range of uses.

↓

**C++ templates**

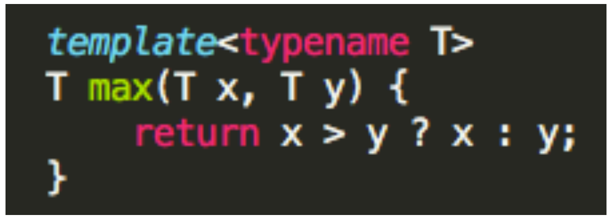
# STL goal

**Generic** programming: code once, re-use many times.

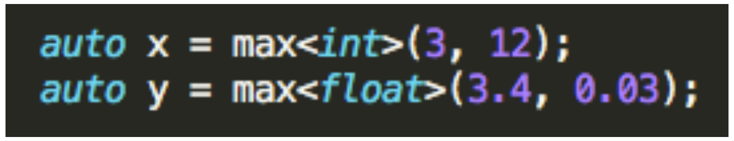
Increase correctness.
Wider range of uses.

**C++ templates**

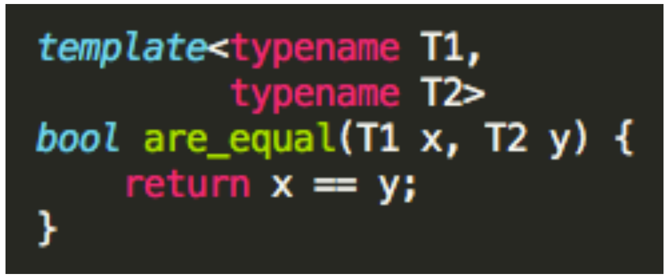
**function** templates



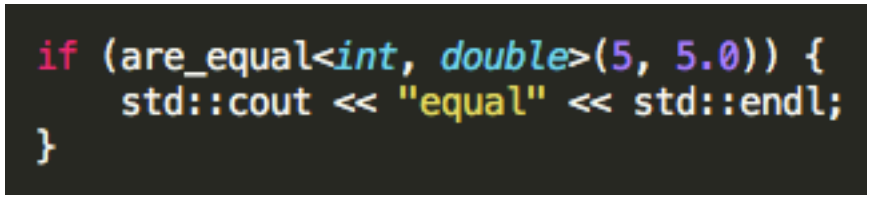
```
template<typename T>
T max(T x, T y) {
    return x > y ? x : y;
}
```



```
auto x = max<int>(3, 12);
auto y = max<float>(3.4, 0.03);
```



```
template<typename T1,
         typename T2>
bool are_equal(T1 x, T2 y) {
    return x == y;
}
```



```
if (are_equal<int, double>(5, 5.0)) {
    std::cout << "equal" << std::endl;
}
```

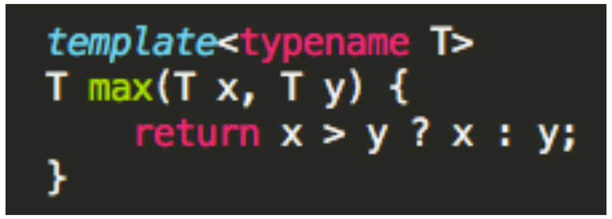
# STL goal

**Generic** programming: code once, re-use many times.

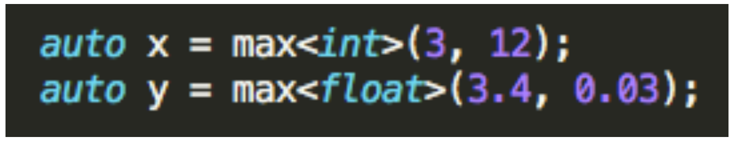
Increase correctness.
Wider range of uses.

**C++ templates**

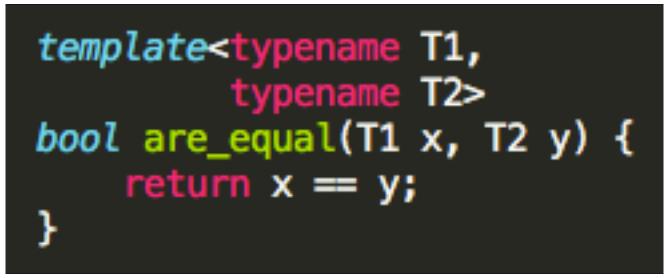
**function** templates



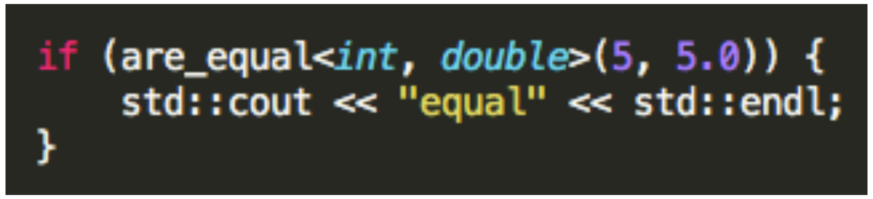
```
template<typename T>
T max(T x, T y) {
    return x > y ? x : y;
}
```



```
auto x = max<int>(3, 12);
auto y = max<float>(3.4, 0.03);
```

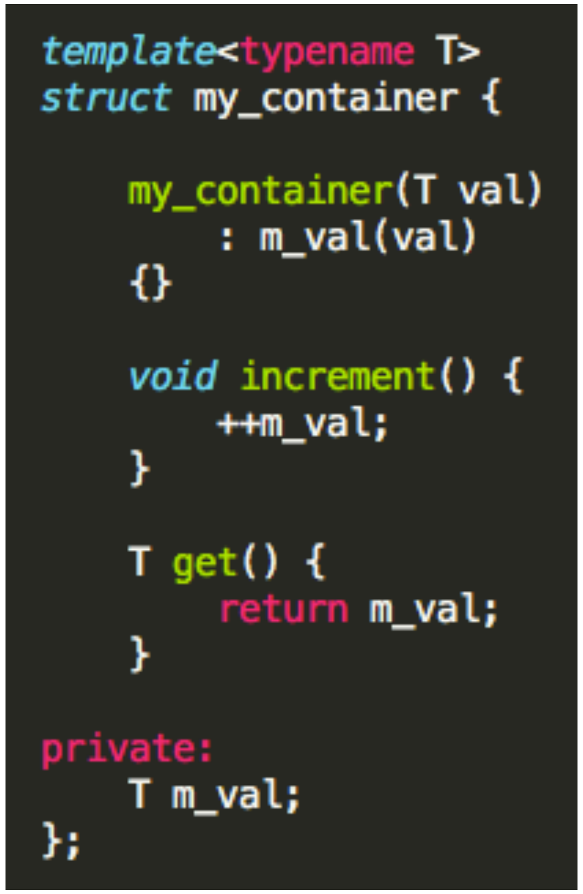


```
template<typename T1,
         typename T2>
bool are_equal(T1 x, T2 y) {
    return x == y;
}
```



```
if (are_equal<int, double>(5, 5.0)) {
    std::cout << "equal" << std::endl;
}
```

**class** templates



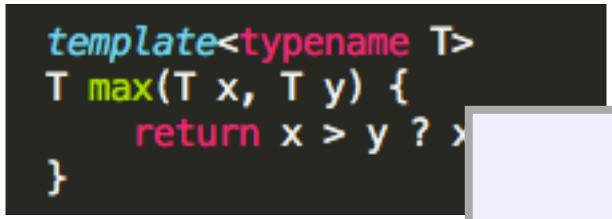
```
template<typename T>
struct my_container {

    my_container(T val)
        : m_val(val)
    {}

    void increment() {
        ++m_val;
    }

    T get() {
        return m_val;
    }

private:
    T m_val;
};
```

# STL goal

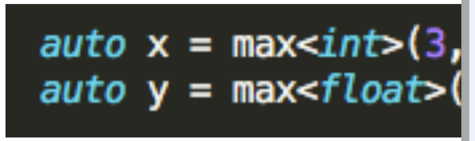
**Generic** programming: code once, re-use many times.

Increase correctness.
Wider range of uses.

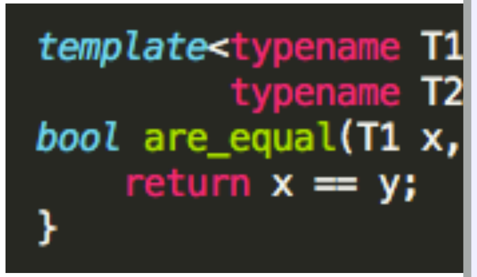
**function** templates ← **C++ templates** → **class** templates



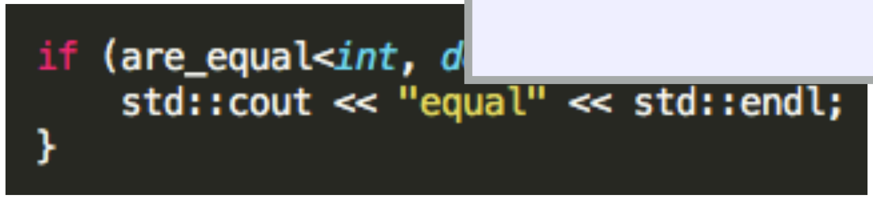
```
template<typename T>
T max(T x, T y) {
    return x > y ? x
}
```



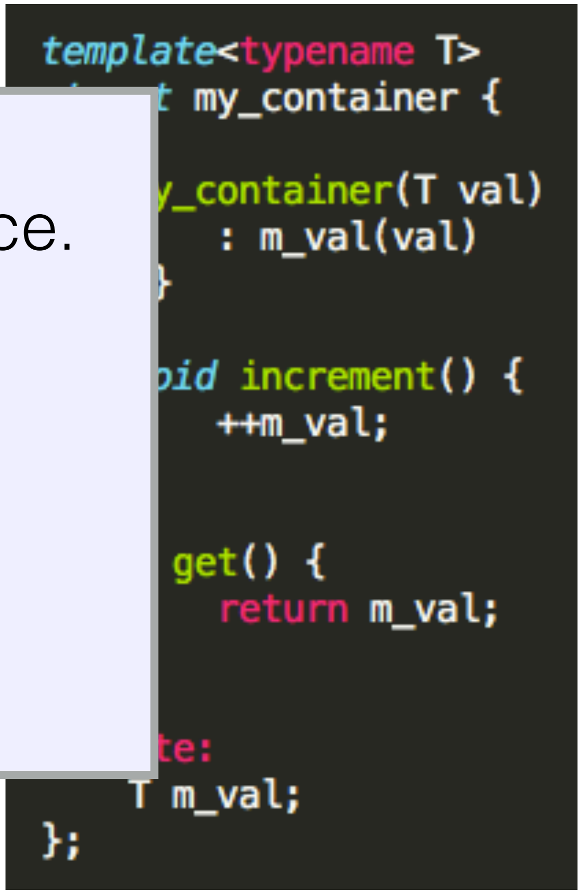
```
auto x = max<int>(3,
auto y = max<float>(
```



```
template<typename T1
         typename T2
bool are_equal(T1 x,
    return x == y;
}
```



```
if (are_equal<int, d
    std::cout << "equal" << std::endl;
}
```



```
template<typename T>
       t my_container {

   y_container(T val)
       : m_val(val)
   }

   oid increment() {
       ++m_val;

    get() {
       return m_val;

   te:
       T m_val;
};
```

Trade-off between reusability and performance.

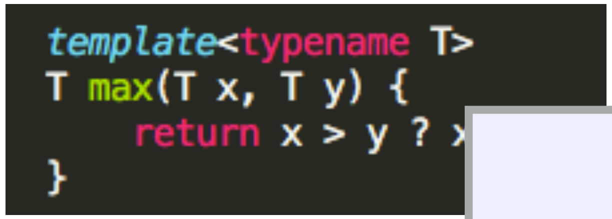
**Experiment** by yourself.
Try to understand **why**.

# STL goal

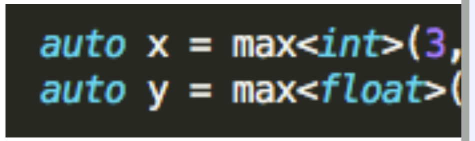
**Generic** programming: code once, re-use many times.

Increase correctness.
Wider range of uses.

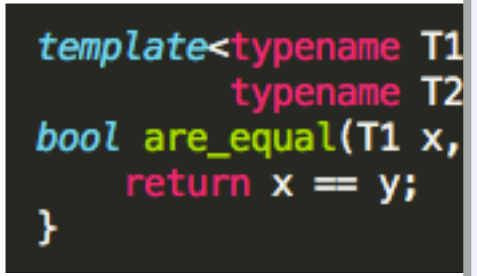
**function** templates ← **C++ templates** → **class** templates



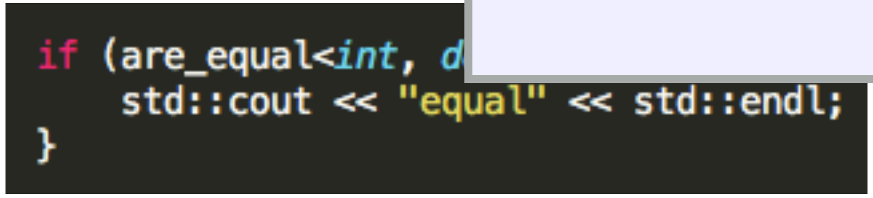
```
template<typename T>
T max(T x, T y) {
    return x > y ? x
}
```



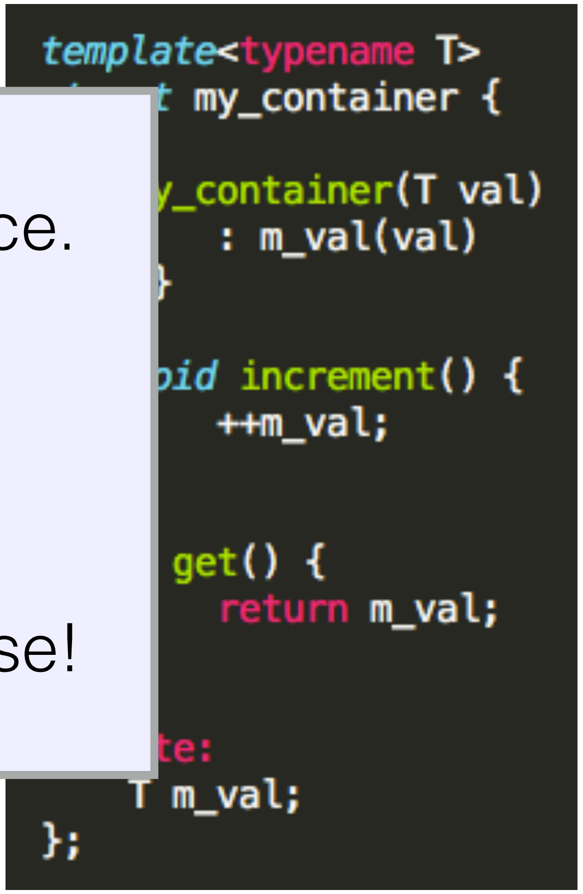
```
auto x = max<int>(3,
auto y = max<float>(
```



```
template<typename T1
         typename T2
bool are_equal(T1 x,
    return x == y;
}
```



```
if (are_equal<int, d
    std::cout << "equal" << std::endl;
}
```



```
template<typename T>
      t my_container {

  y_container(T val)
      : m_val(val)
  }

  oid increment() {
      ++m_val;


   get() {
      return m_val;


  te:
      T m_val;
};
```

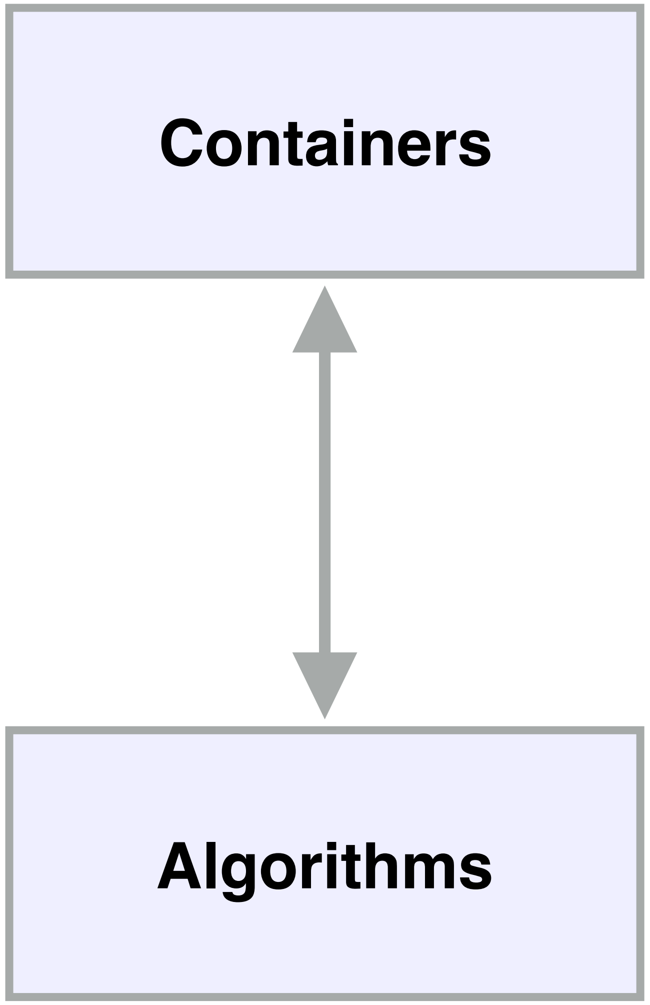
Trade-off between reusability and performance.

**Experiment** by yourself.
Try to understand **why**.

Indeed one of the goals of ours for this course!

# STL basic model

## Separation of concerns



16

Containers

**Store** data;
do not know
about algorithms.

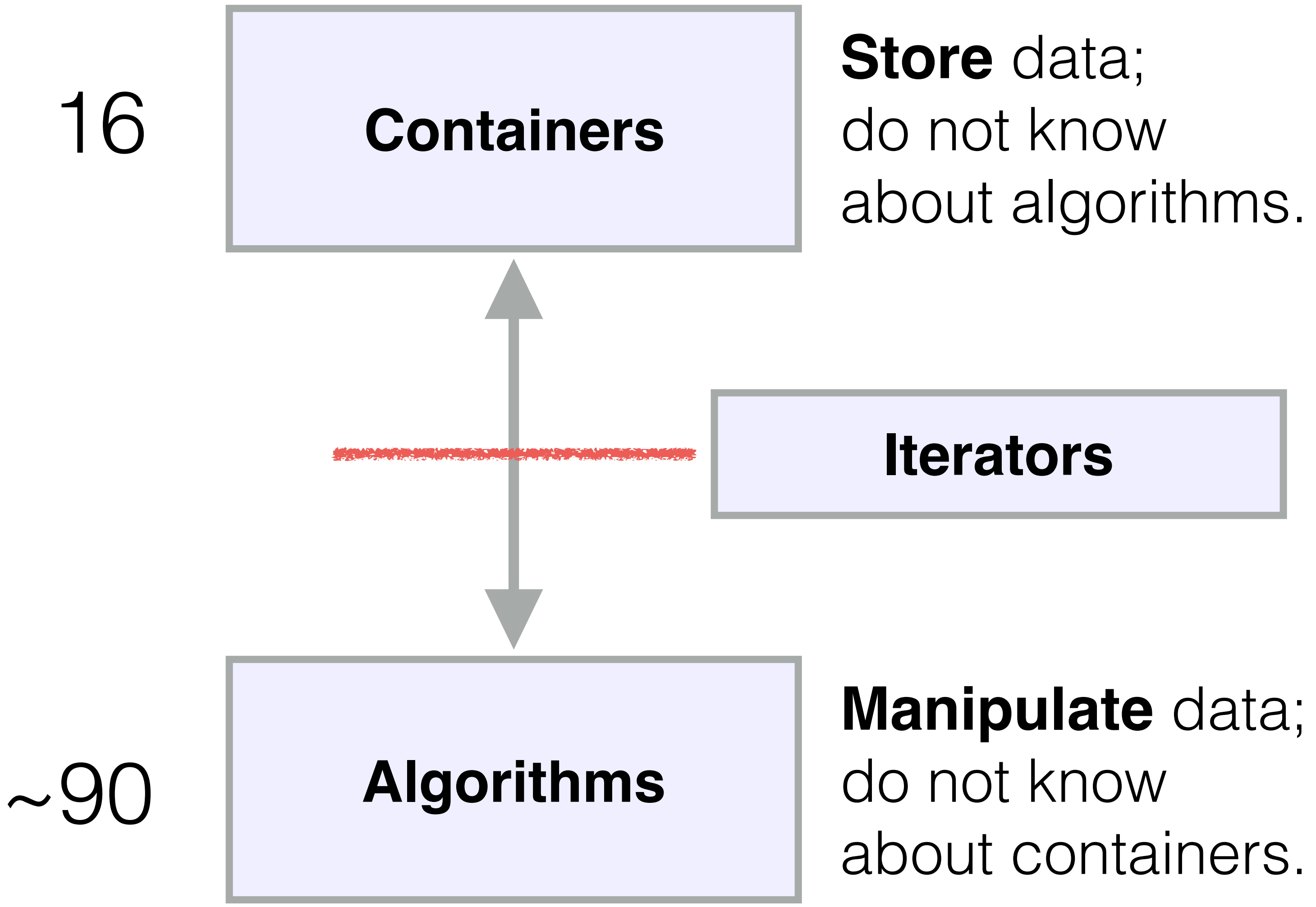
~90

Algorithms

**Manipulate** data;
do not know
about containers.

# STL basic model

## Separation of concerns

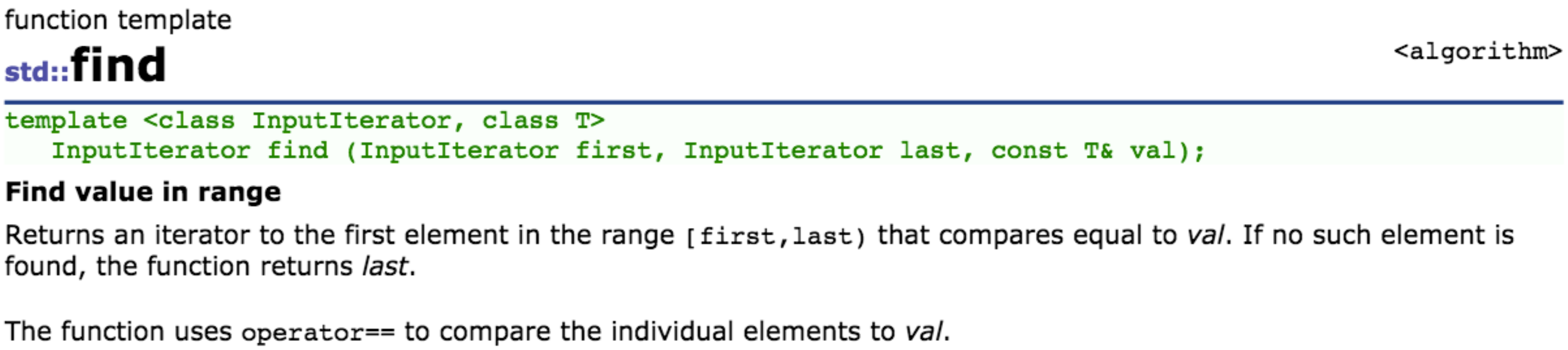


**Store** data;
do not know
about algorithms.

**Manipulate** data;
do not know
about containers.

# An example

[source: http://www.cplusplus.com]



function template

**std::find**

<algorithm>

```
template <class InputIterator, class T>
   InputIterator find (InputIterator first, InputIterator last, const T& val);
```

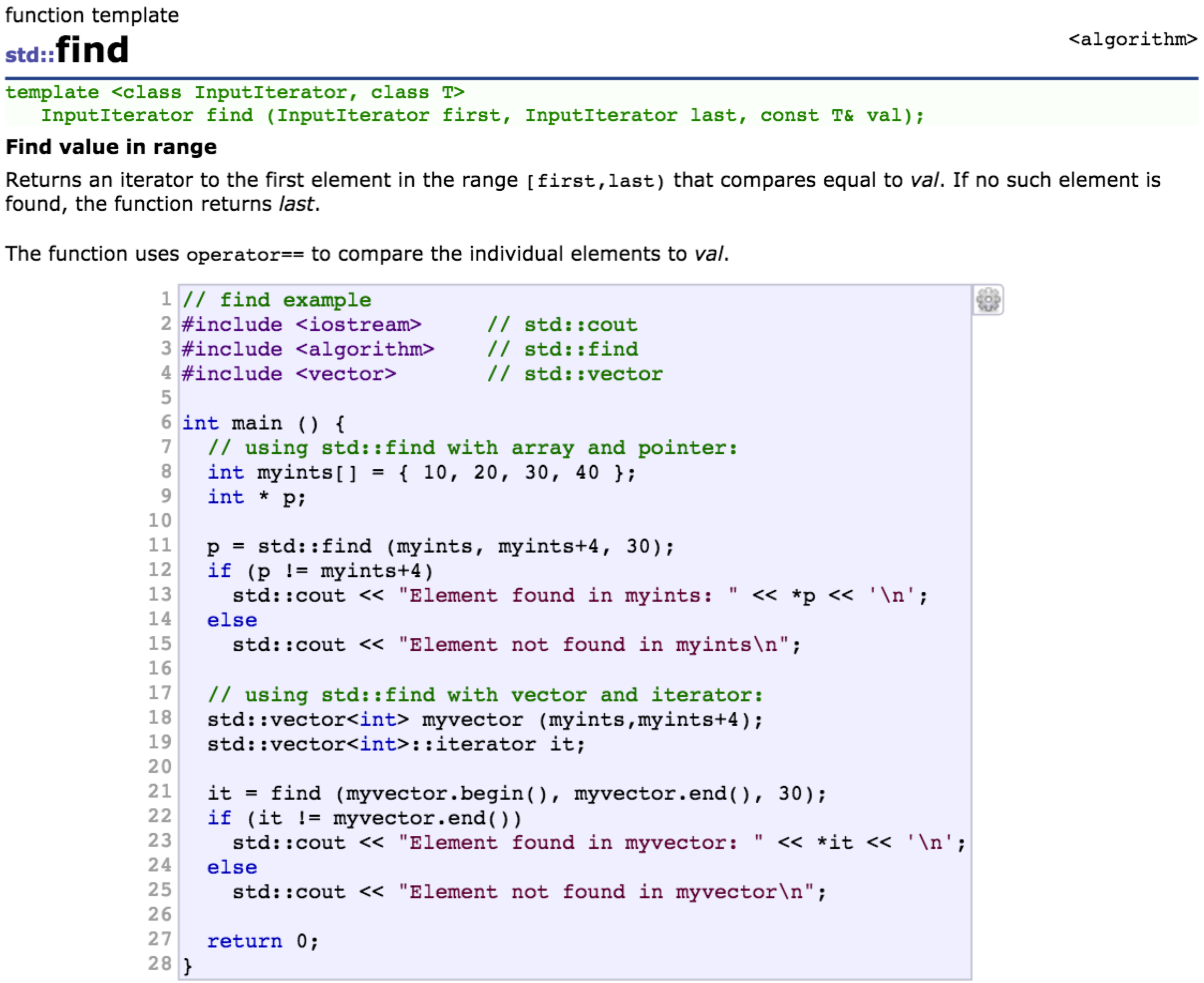
**Find value in range**

Returns an iterator to the first element in the range `[first,last)` that compares equal to *val*. If no such element is found, the function returns *last*.

The function uses `operator==` to compare the individual elements to *val*.

# An example

[source: http://www.cplusplus.com]



function template

## std::find

<algorithm>

```
template <class InputIterator, class T>
   InputIterator find (InputIterator first, InputIterator last, const T& val);
```

**Find value in range**

Returns an iterator to the first element in the range `[first,last)` that compares equal to *val*. If no such element is found, the function returns *last*.

The function uses `operator==` to compare the individual elements to *val*.

```
// find example
#include <iostream>     // std::cout
#include <algorithm>    // std::find
#include <vector>       // std::vector

int main () {
  // using std::find with array and pointer:
  int myints[] = { 10, 20, 30, 40 };
  int * p;

  p = std::find (myints, myints+4, 30);
  if (p != myints+4)
    std::cout << "Element found in myints: " << *p << '\n';
  else
    std::cout << "Element not found in myints\n";

  // using std::find with vector and iterator:
  std::vector<int> myvector (myints,myints+4);
  std::vector<int>::iterator it;

  it = find (myvector.begin(), myvector.end(), 30);
  if (it != myvector.end())
    std::cout << "Element found in myvector: " << *it << '\n';
  else
    std::cout << "Element not found in myvector\n";

  return 0;
}
```

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.

```
vector
deque
list
```

```
set
multiset
map
multimap
```

```
stack
queue
priority_queue
```

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.

**sequential**

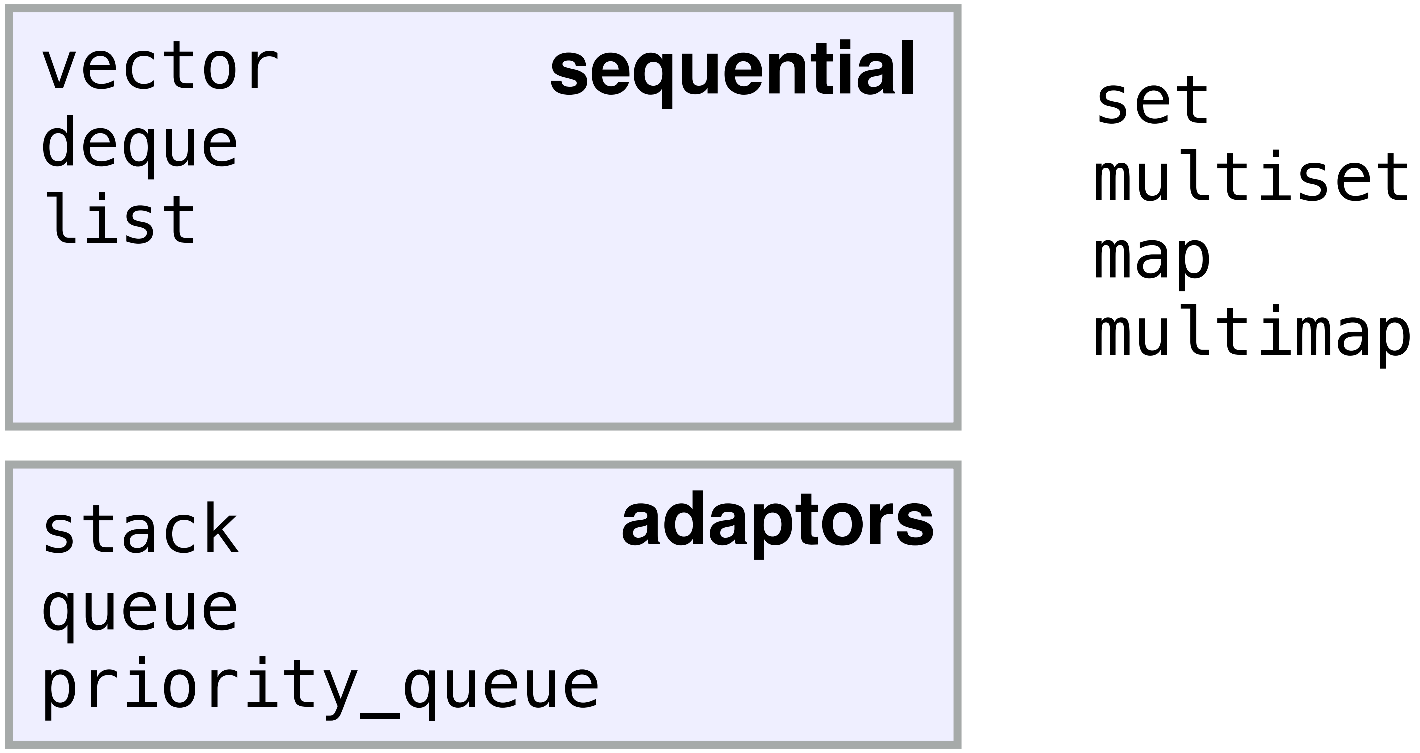
```
vector
deque
list
```

```
set
multiset
map
multimap
```

```
stack
queue
priority_queue
```

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.



**sequential**

```
vector
deque
list
```

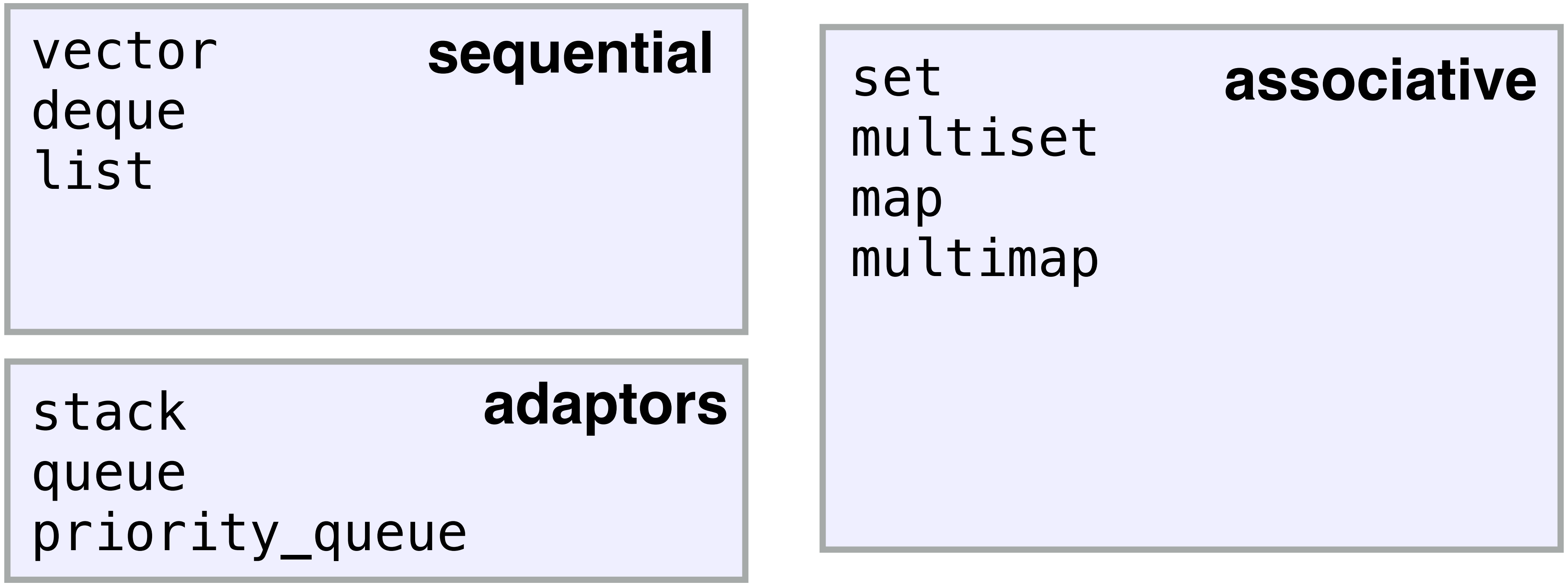
**adaptors**

```
stack
queue
priority_queue
```

```
set
multiset
map
multimap
```

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.



**sequential**

`vector`
`deque`
`list`

**adaptors**

`stack`
`queue`
`priority_queue`

**associative**

`set`
`multiset`
`map`
`multimap`

# Containers

A container is a holder object that stores a **collection** of other objects (its elements). These are implemented as **class templates**.
The container manages the **storage space** for its elements and provides member functions to access them, either directly or through iterators.

+ 6 containers with `C++11`

**sequential**

```
vector
deque
list
array
forward_list
```

**adaptors**

```
stack
queue
priority_queue
```

**associative**

```
set
multiset
map
multimap
unordered_set
unordered_multiset
unordered_map
unordered_multimap
```

# Sequential containers

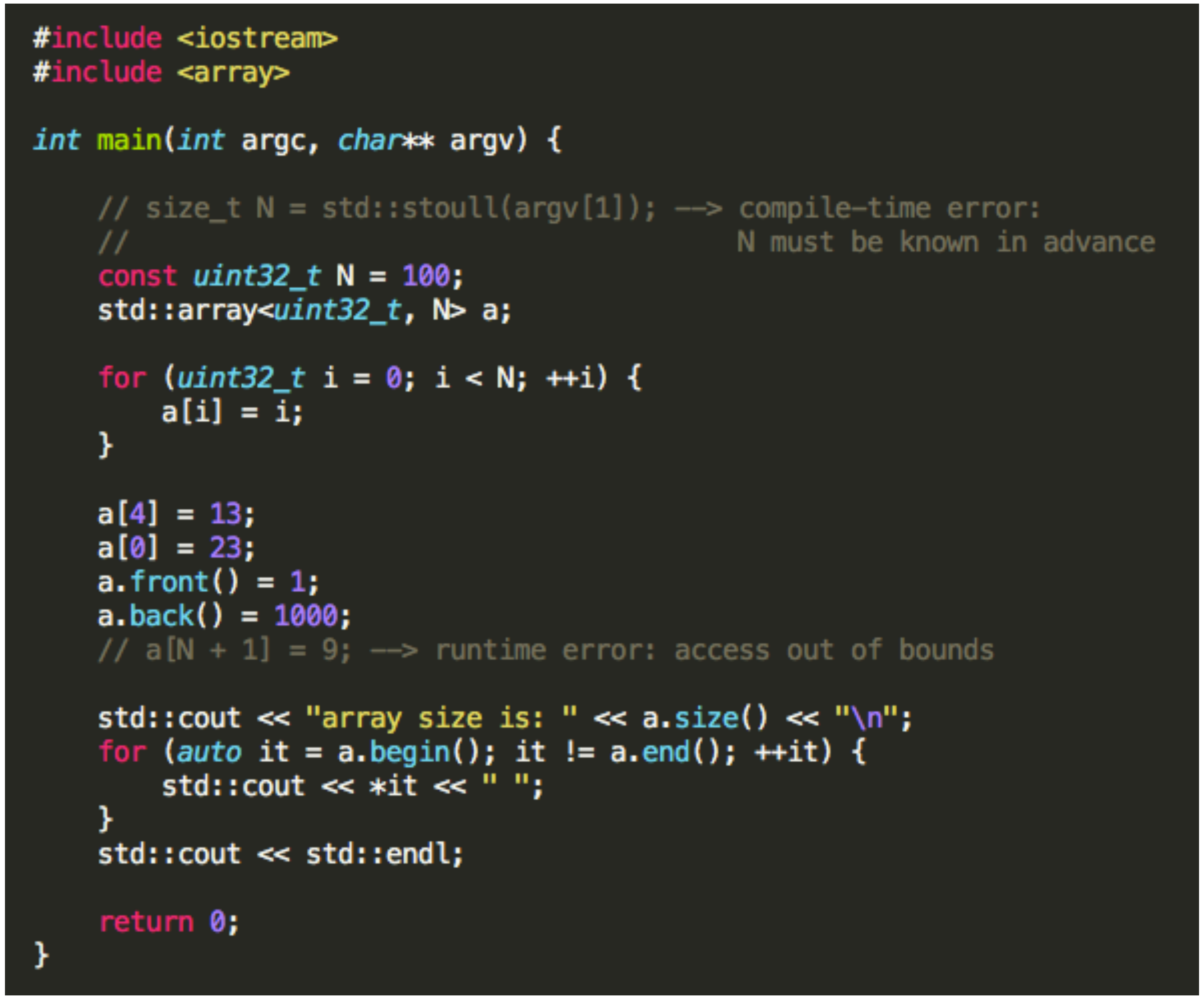
random access: O(1)
other operations: O(N)

class template

**std::array** C++11

`template < class T, size_t N > class array;`

Arrays are **fixed-size** sequence containers: they hold a specific number of elements ordered in a strict linear sequence. A wrap class around the an ordinary array declared with the language's bracket syntax ( **[]** ).



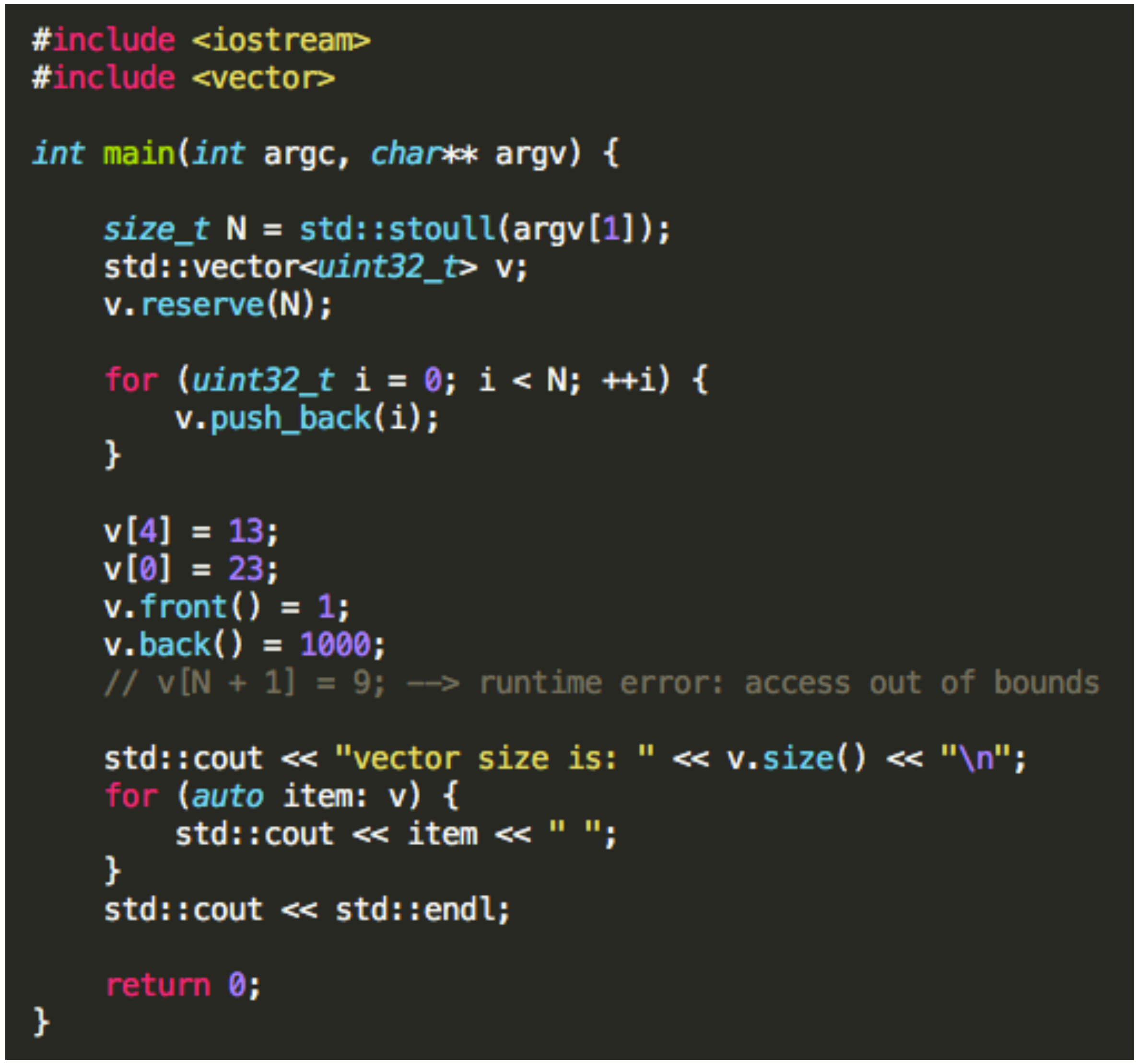
```
#include <iostream>
#include <array>

int main(int argc, char** argv) {

    // size_t N = std::stoull(argv[1]); --> compile-time error:
    //                                      N must be known in advance
    const uint32_t N = 100;
    std::array<uint32_t, N> a;

    for (uint32_t i = 0; i < N; ++i) {
        a[i] = i;
    }

    a[4] = 13;
    a[0] = 23;
    a.front() = 1;
    a.back() = 1000;
    // a[N + 1] = 9; --> runtime error: access out of bounds

    std::cout << "array size is: " << a.size() << "\n";
    for (auto it = a.begin(); it != a.end(); ++it) {
        std::cout << *it << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

class template

**std::vector**

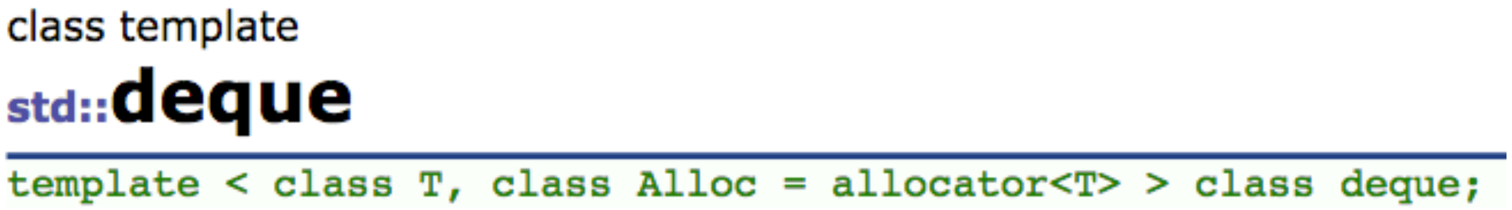
`template < class T, class Alloc = allocator<T> > class vector;`

Just like arrays, vectors use contiguous storage locations for their elements but unlike arrays, **their size can change dynamically**, with their storage being handled automatically by the container.



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

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    v[4] = 13;
    v[0] = 23;
    v.front() = 1;
    v.back() = 1000;
    // v[N + 1] = 9; --> runtime error: access out of bounds

    std::cout << "vector size is: " << v.size() << "\n";
    for (auto item: v) {
        std::cout << item << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

# Sequential containers



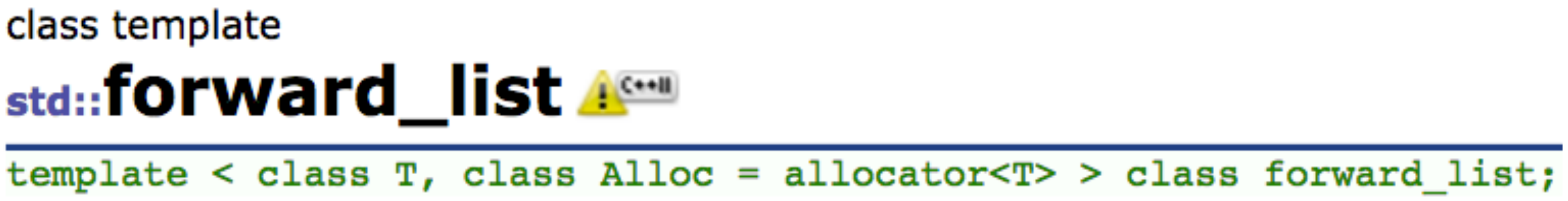
class template

## std::deque

```
template < class T, class Alloc = allocator<T> > class deque;
```

Deque is a **d**ouble-**e**nded **que**ue. Double-ended queues are sequence containers with dynamic sizes that can be expanded or contracted on **both ends** (either its front or its back). Behaviour similar to that of vectors.

random access: O(1)
other operations: O(N)

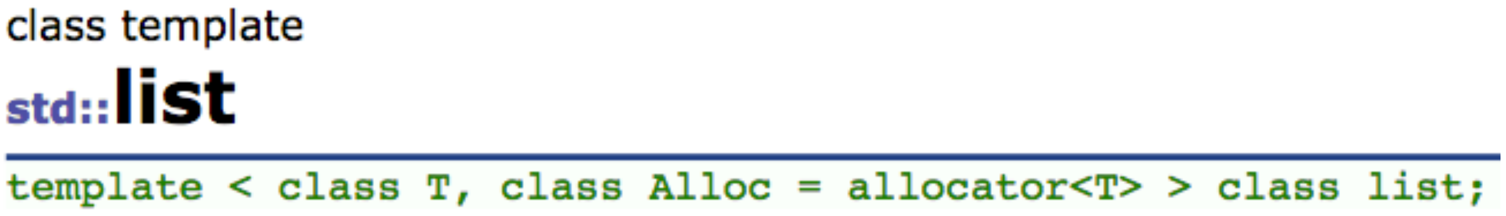


class template

## std::forward_list

```
template < class T, class Alloc = allocator<T> > class forward_list;
```

Forward lists are implemented as **singly-linked lists**. Singly linked lists can store each of the elements they contain in **different and unrelated storage locations**. The ordering is kept by the association to each element of a link to the next element in the sequence.



class template

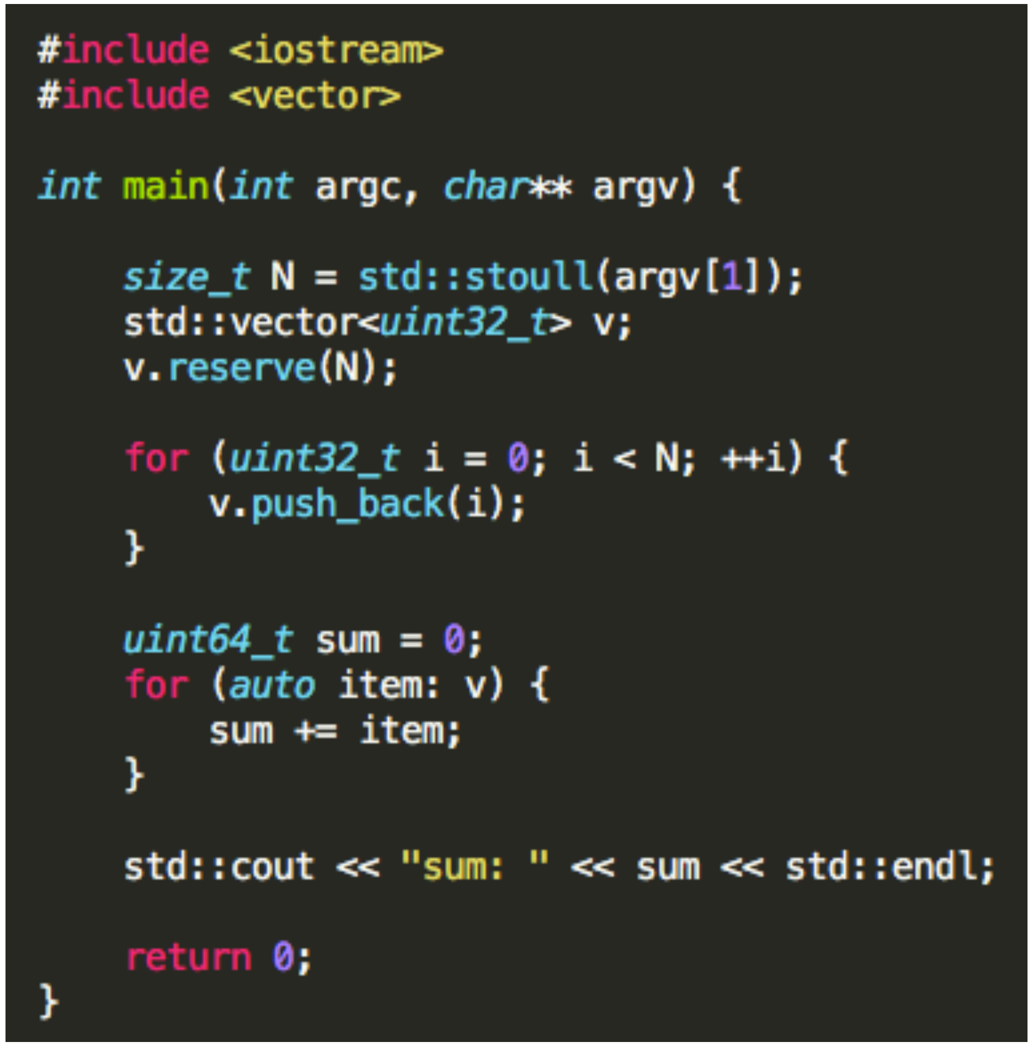
## std::list

```
template < class T, class Alloc = allocator<T> > class list;
```

List containers are implemented as **doubly-linked lists**.

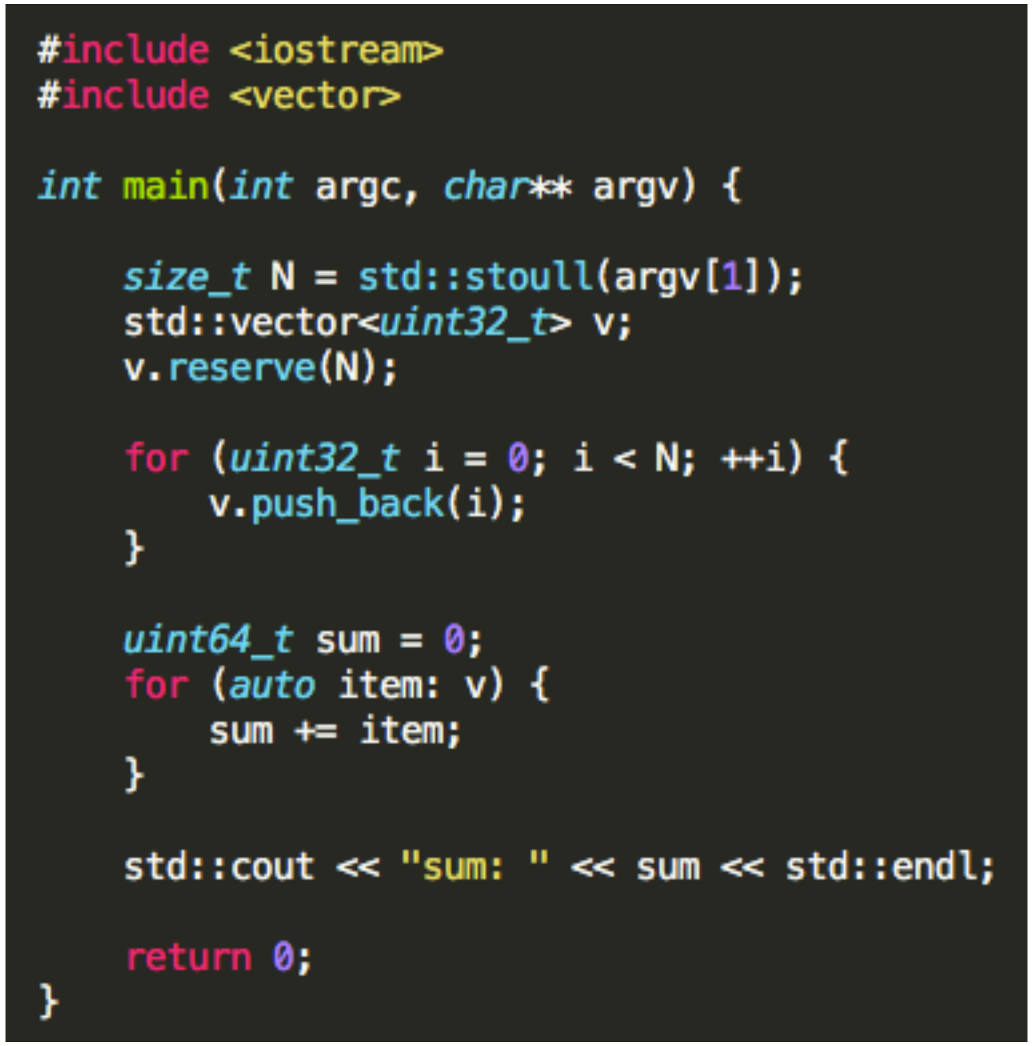
random access: O(N)
insert/delete: O(1)

# Sequential containers

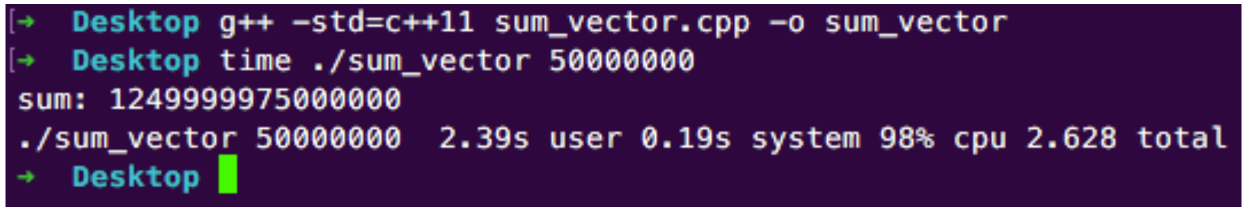


```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

# Sequential containers

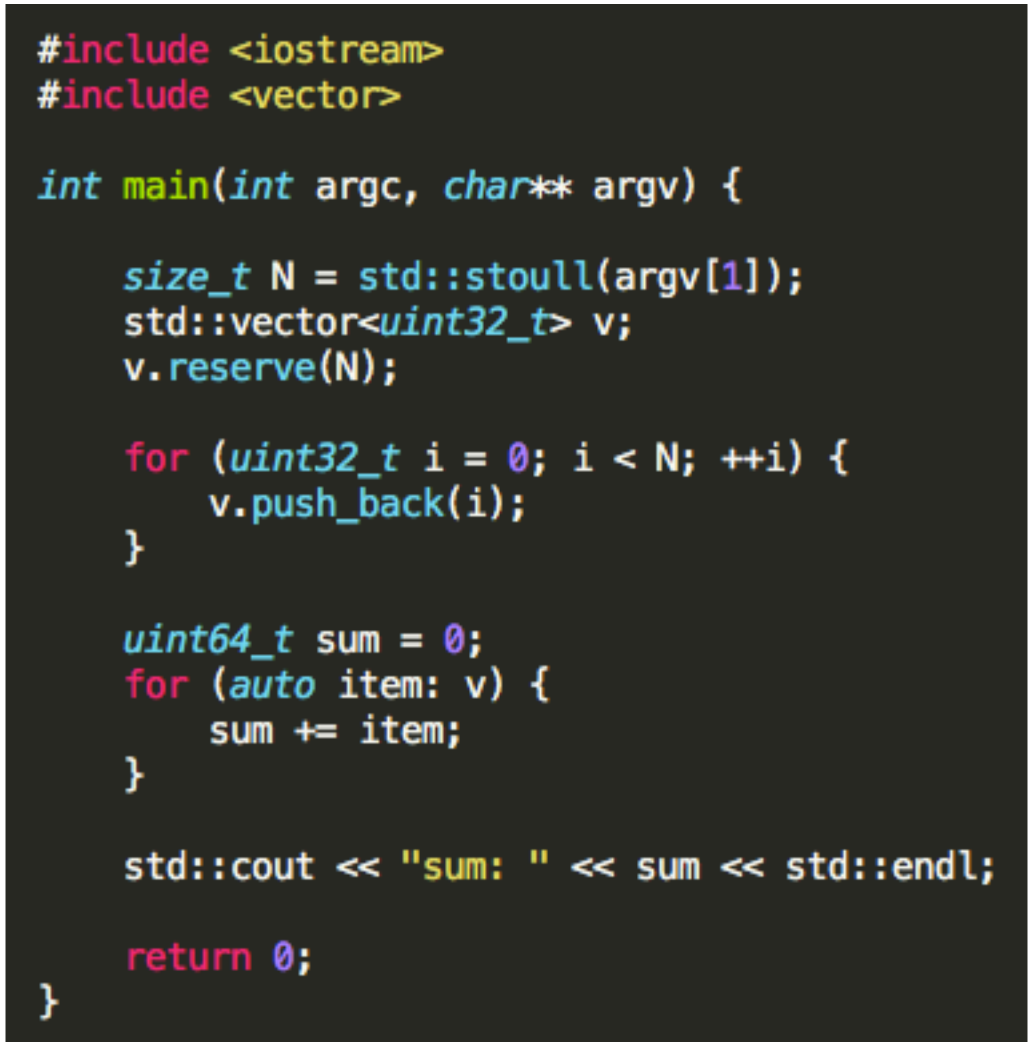


```
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

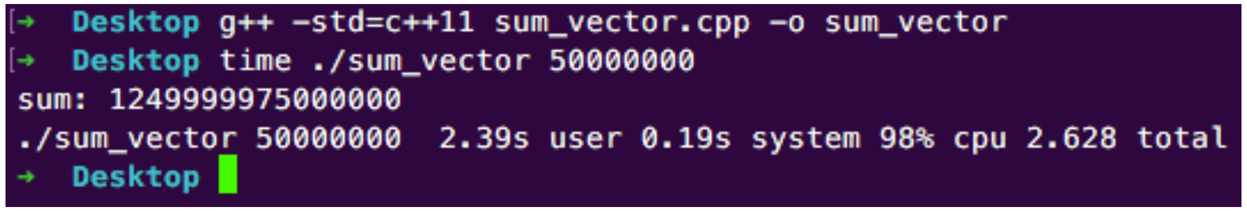


```
[→  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
[→  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
→  Desktop █
```

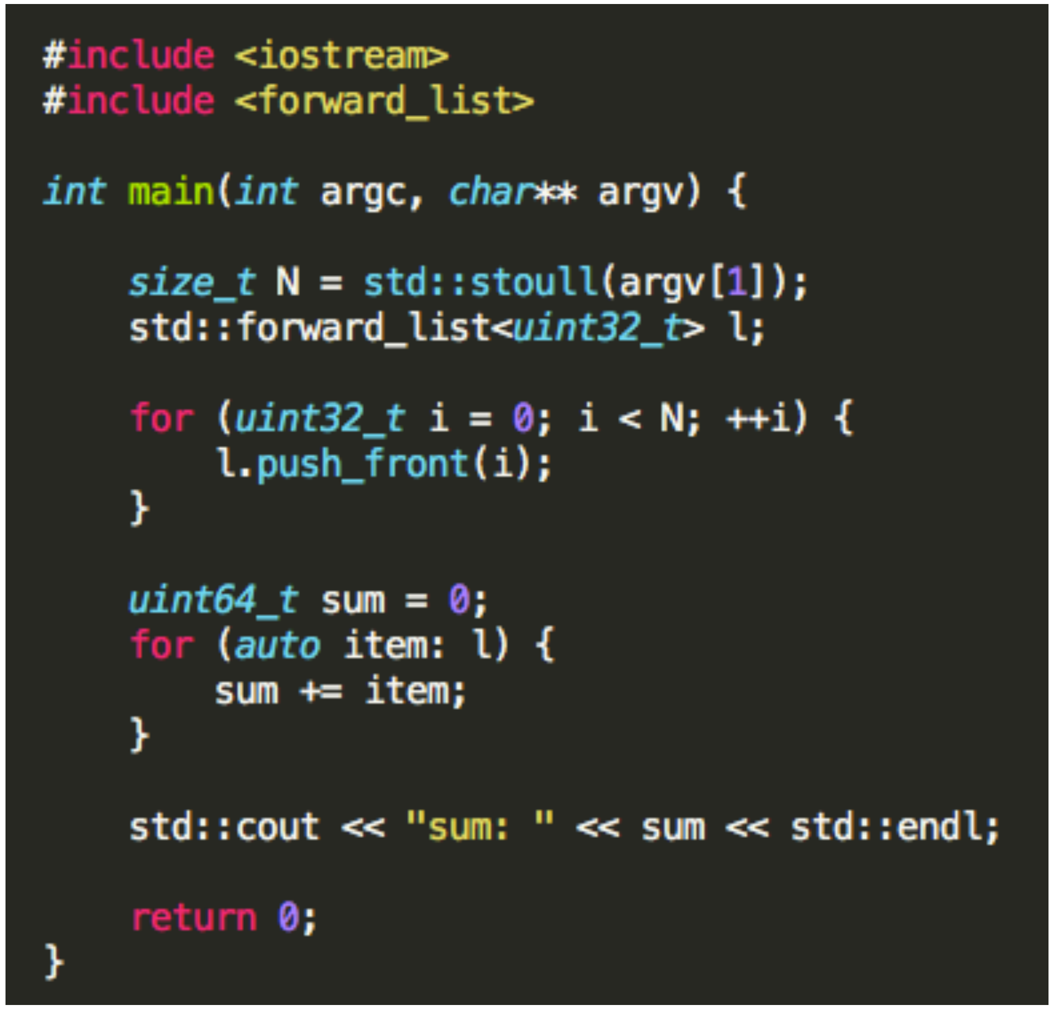
# Sequential containers



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

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

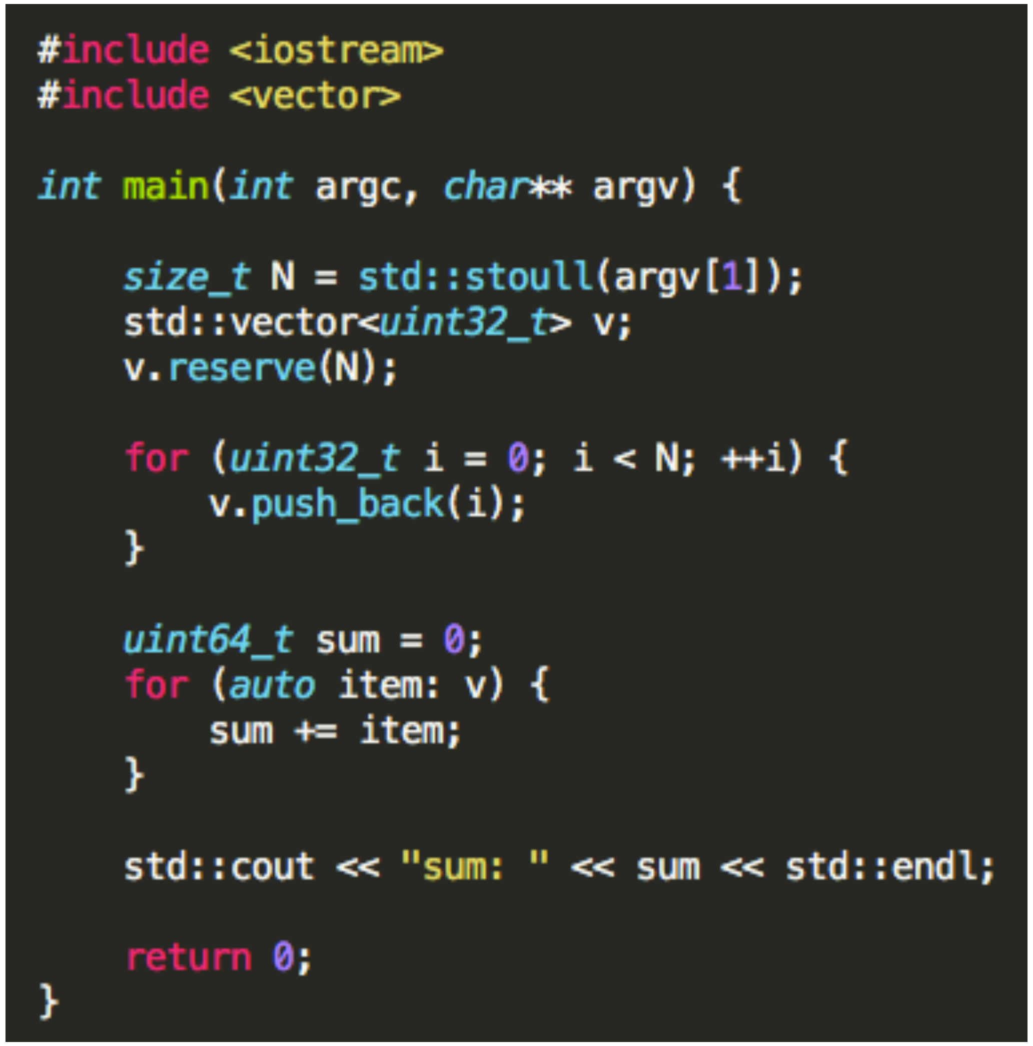


```
[→  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
[→  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
→  Desktop
```

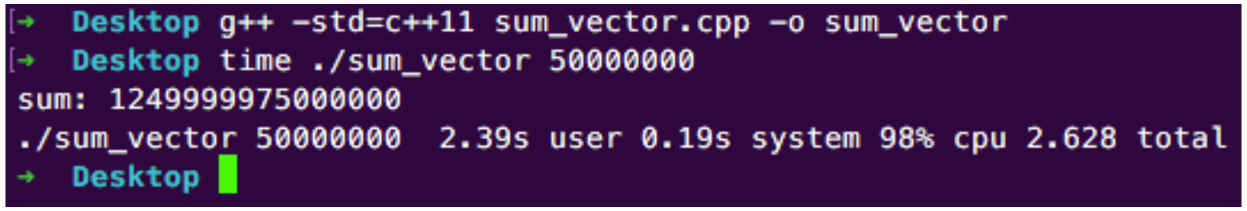


```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

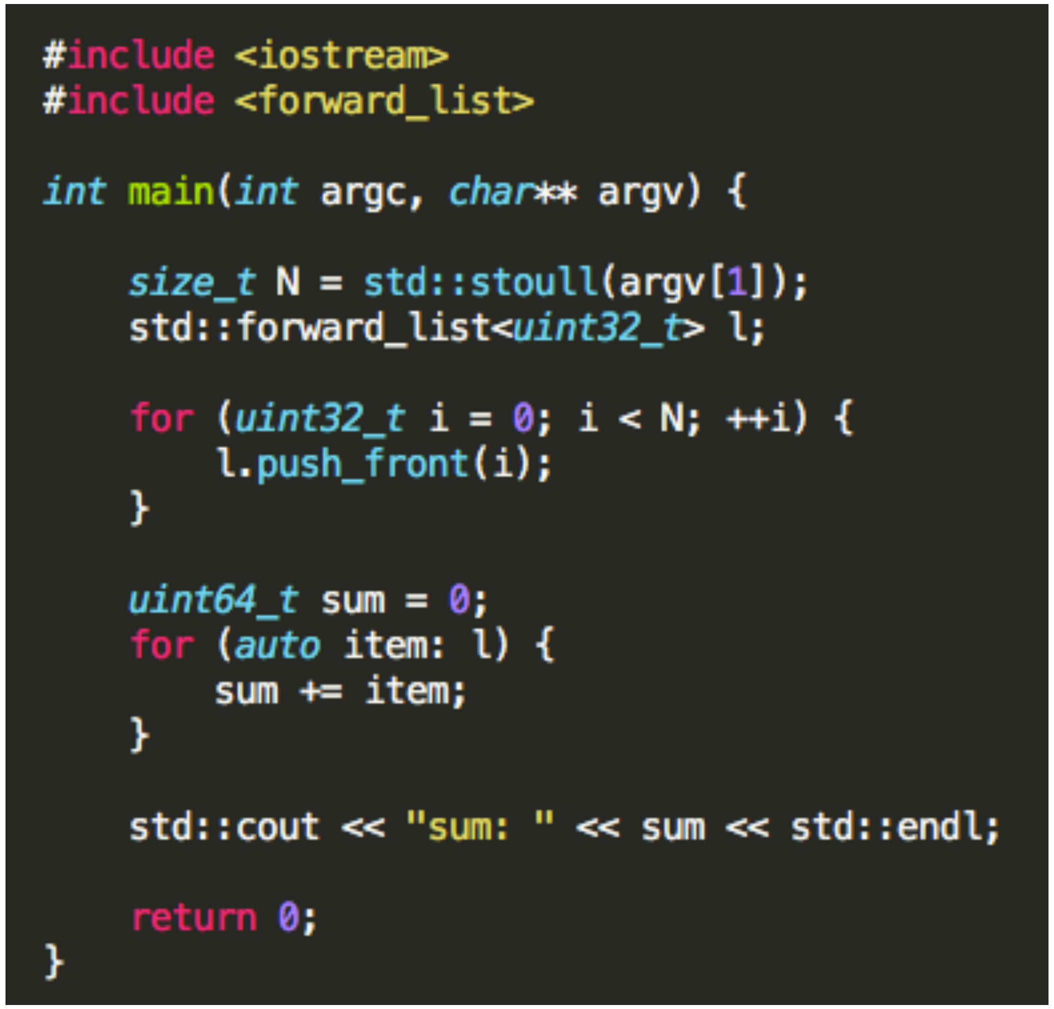
# Sequential containers



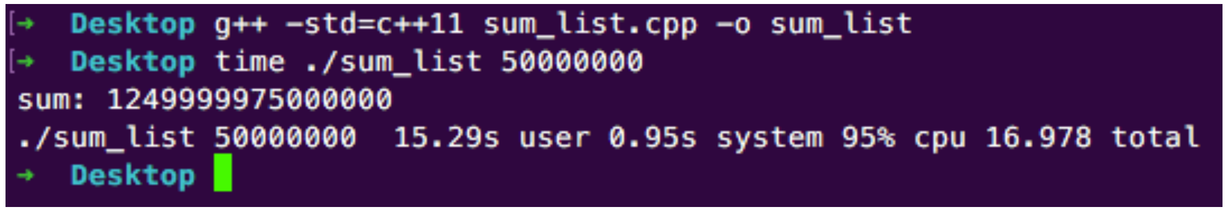
```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



```
[➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
[➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop 
```

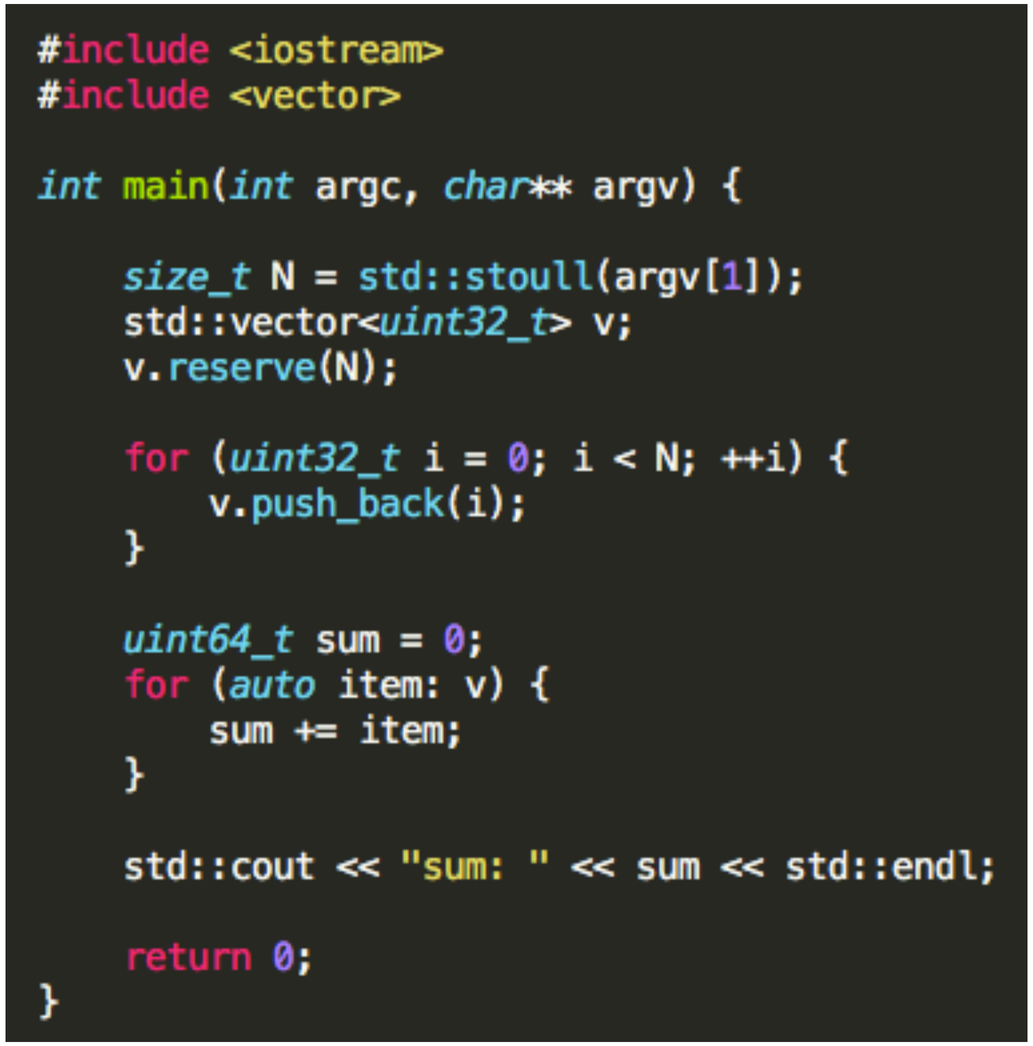


```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

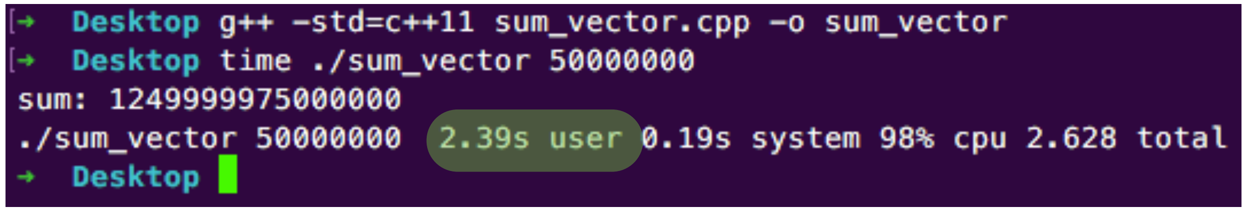


```
[➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
[➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop 
```

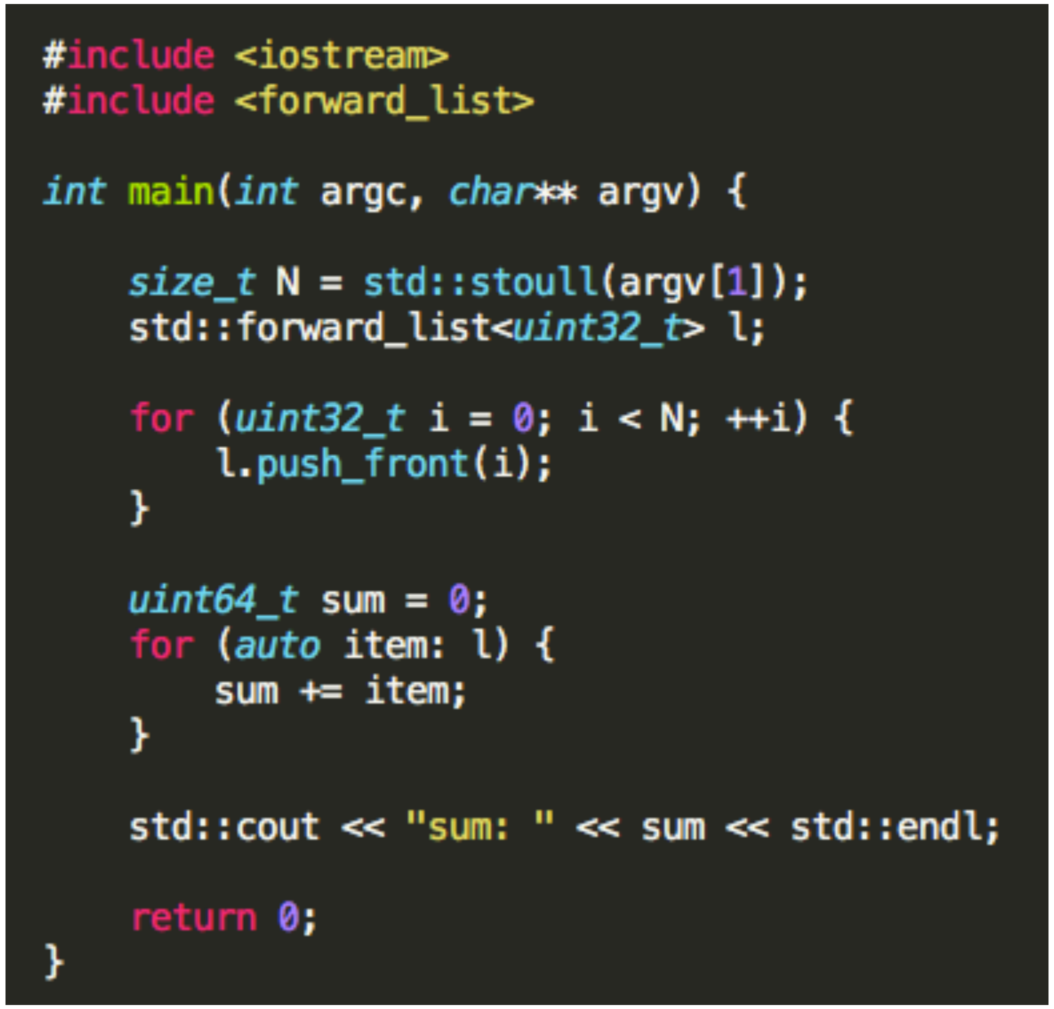
# Sequential containers



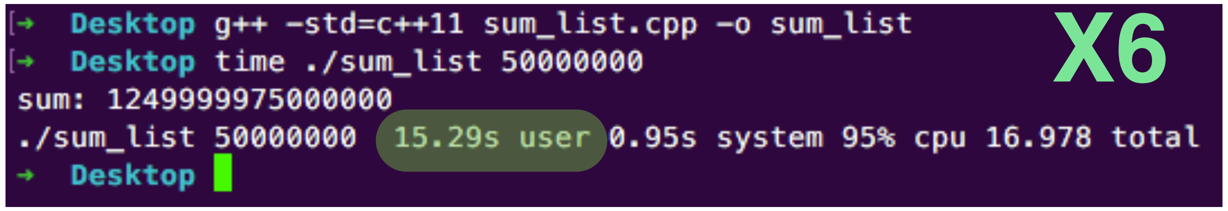
```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



```
➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop 
```



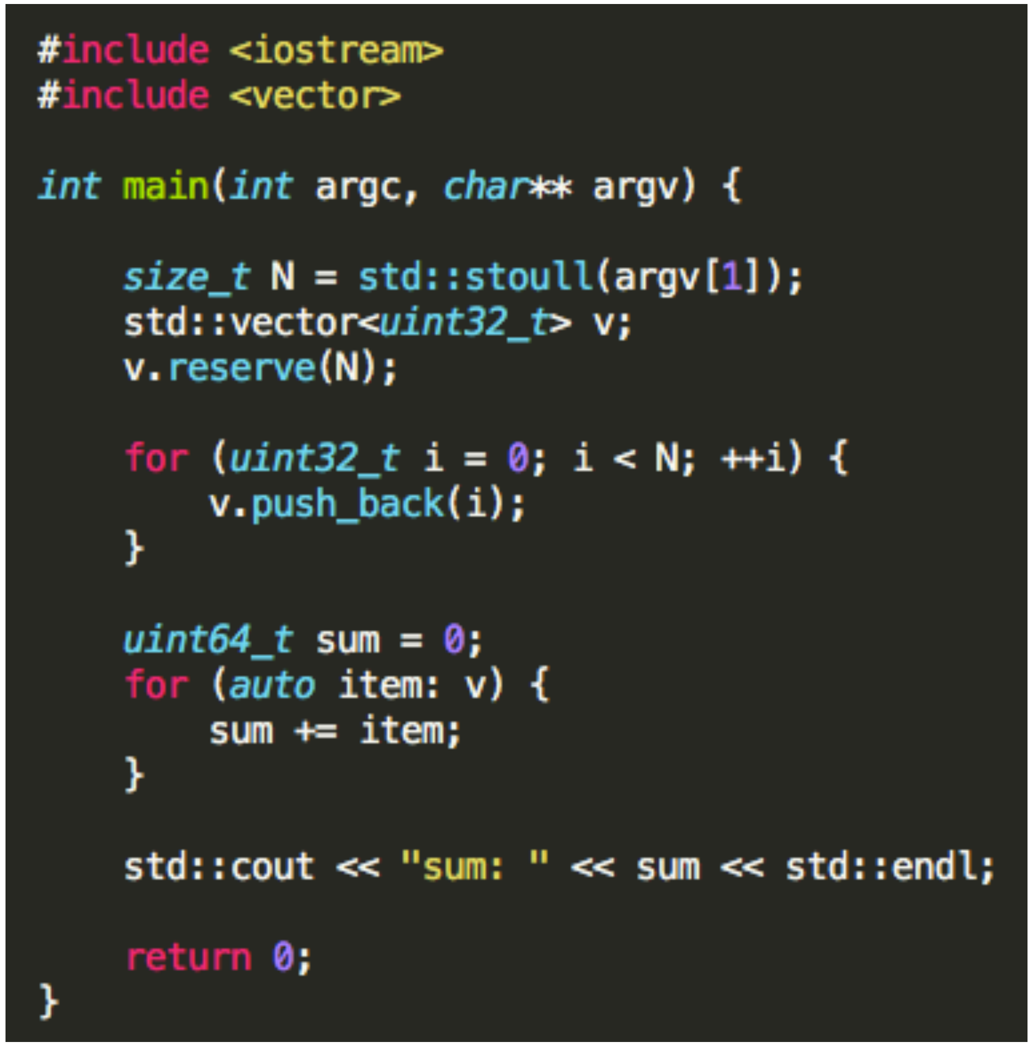
```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



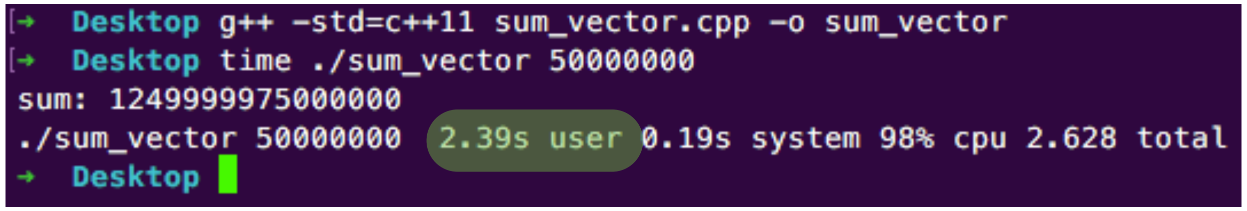
```
➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop 
```

X6

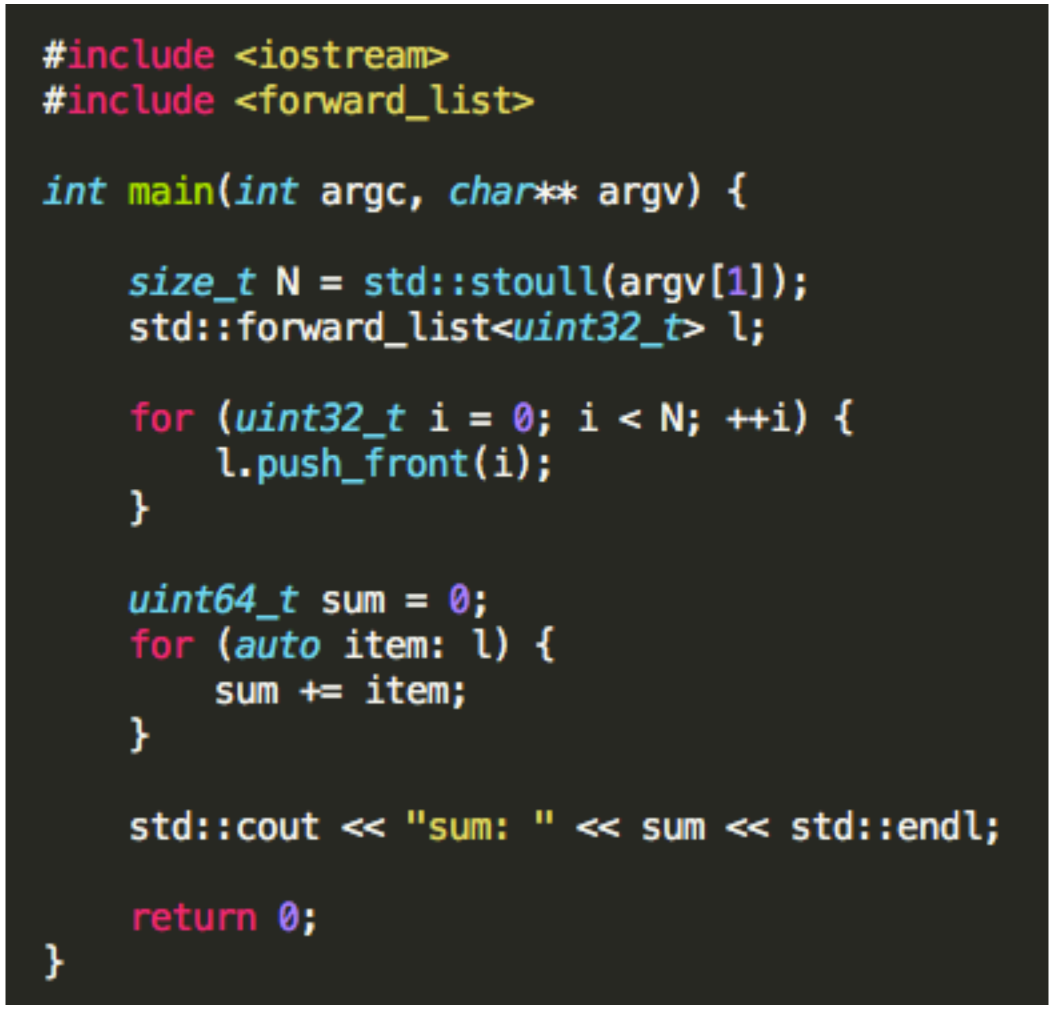
# Sequential containers



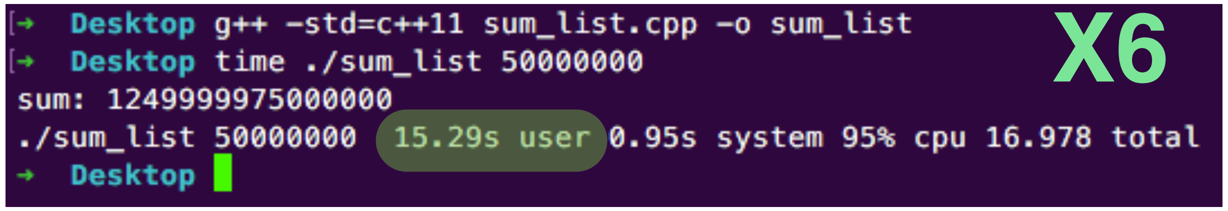
```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



```
➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop
```

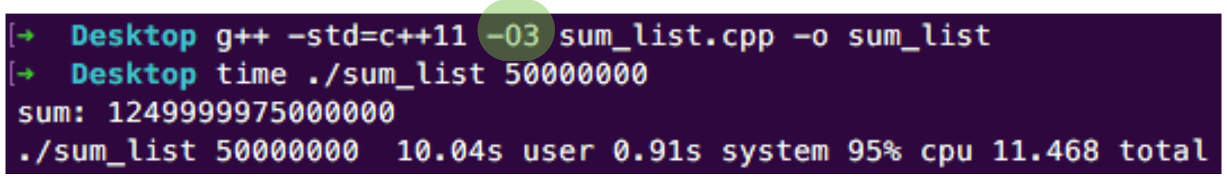


```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



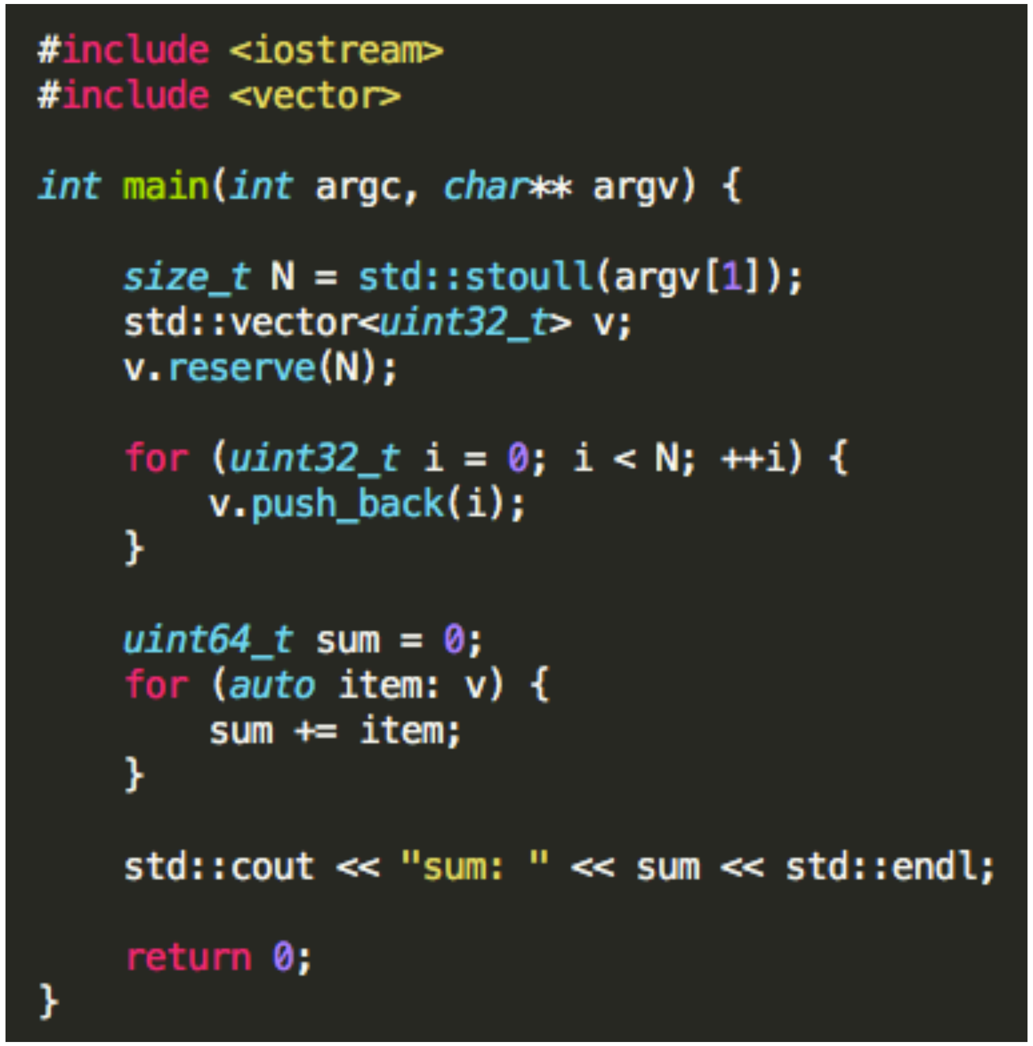
```
➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop
```

X6

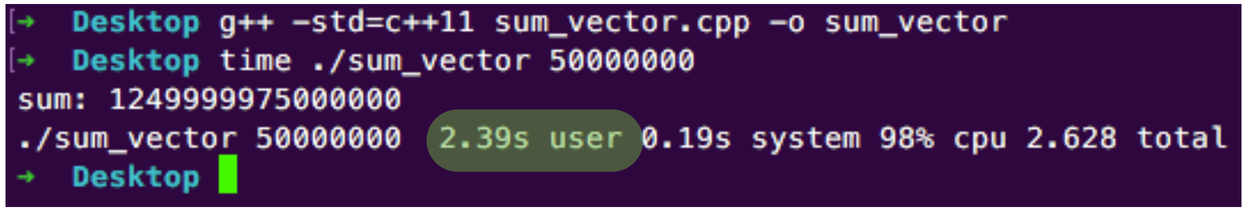


```
➜  Desktop g++ -std=c++11 -O3 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  10.04s user 0.91s system 95% cpu 11.468 total
```

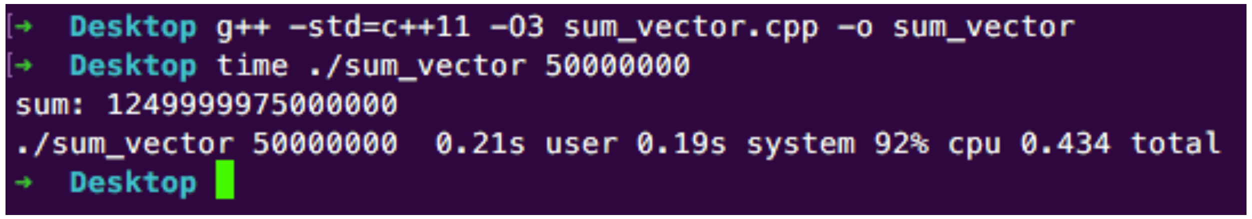
# Sequential containers



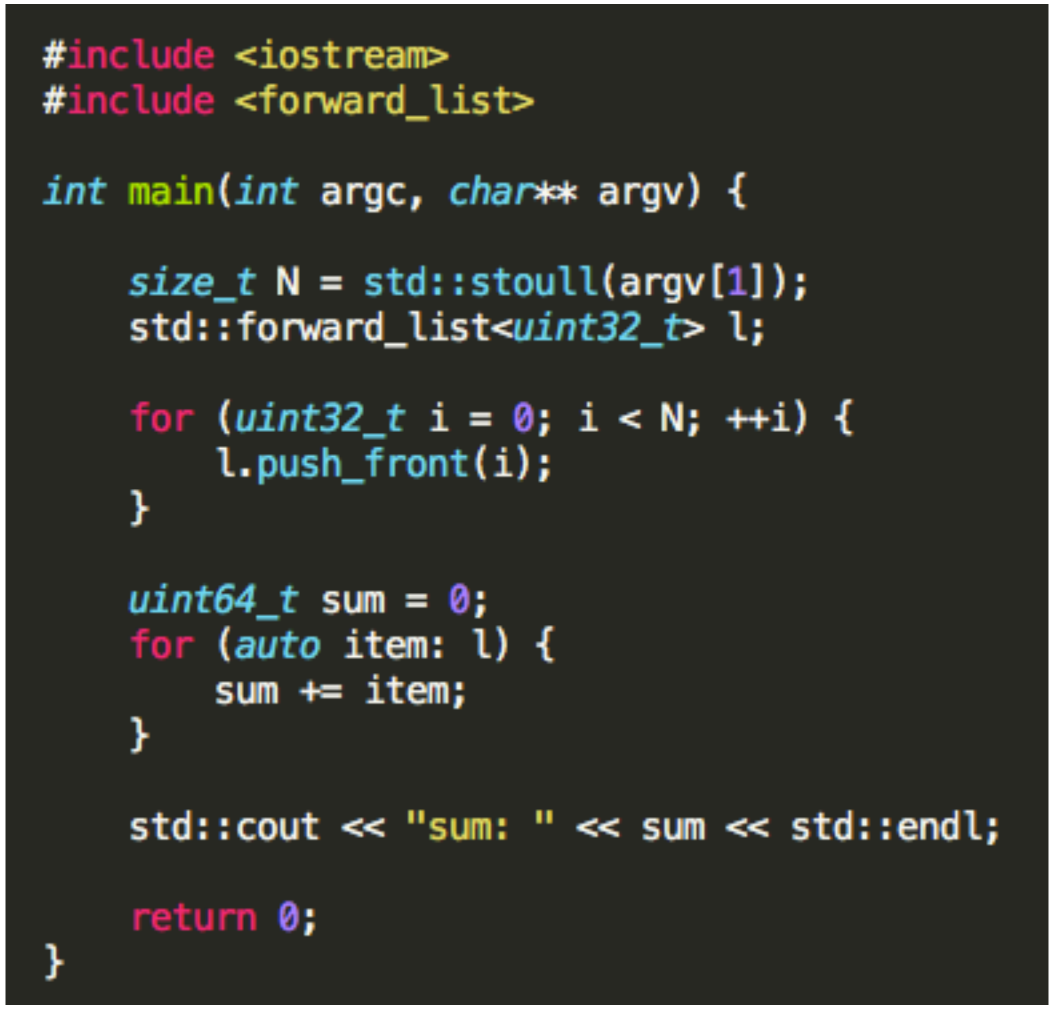
```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



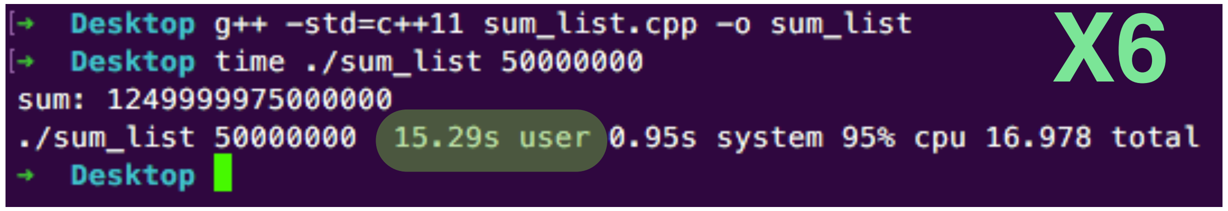
```
→  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
→  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
→  Desktop
```



```
→  Desktop g++ -std=c++11 -O3 sum_vector.cpp -o sum_vector
→  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  0.21s user 0.19s system 92% cpu 0.434 total
→  Desktop
```

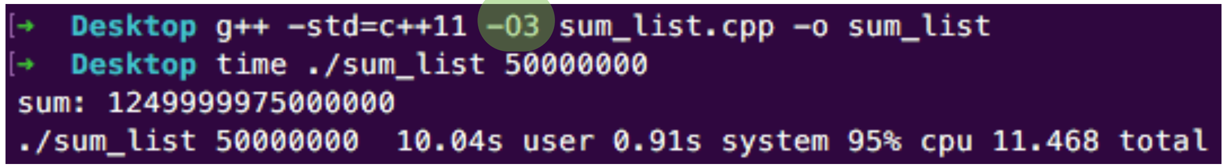


```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



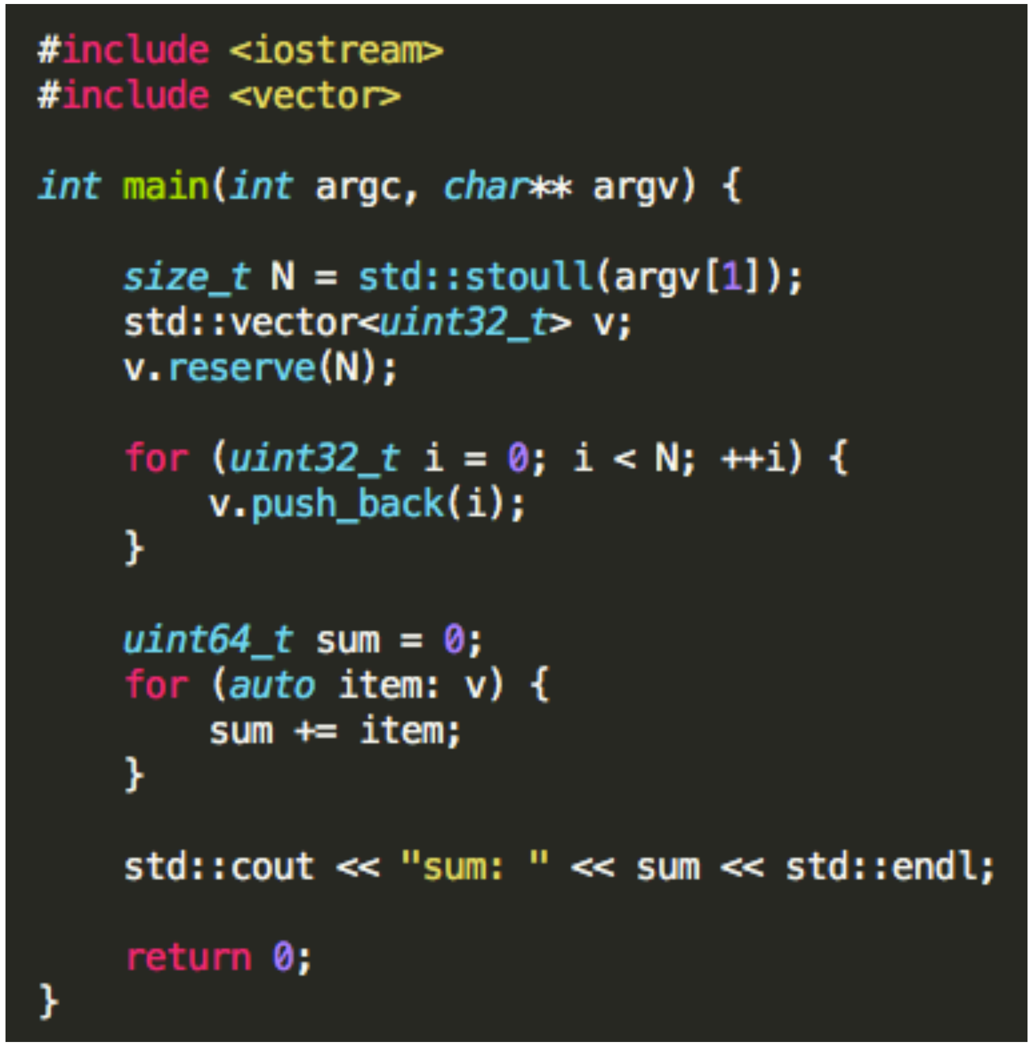
X6

```
→  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
→  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
→  Desktop
```

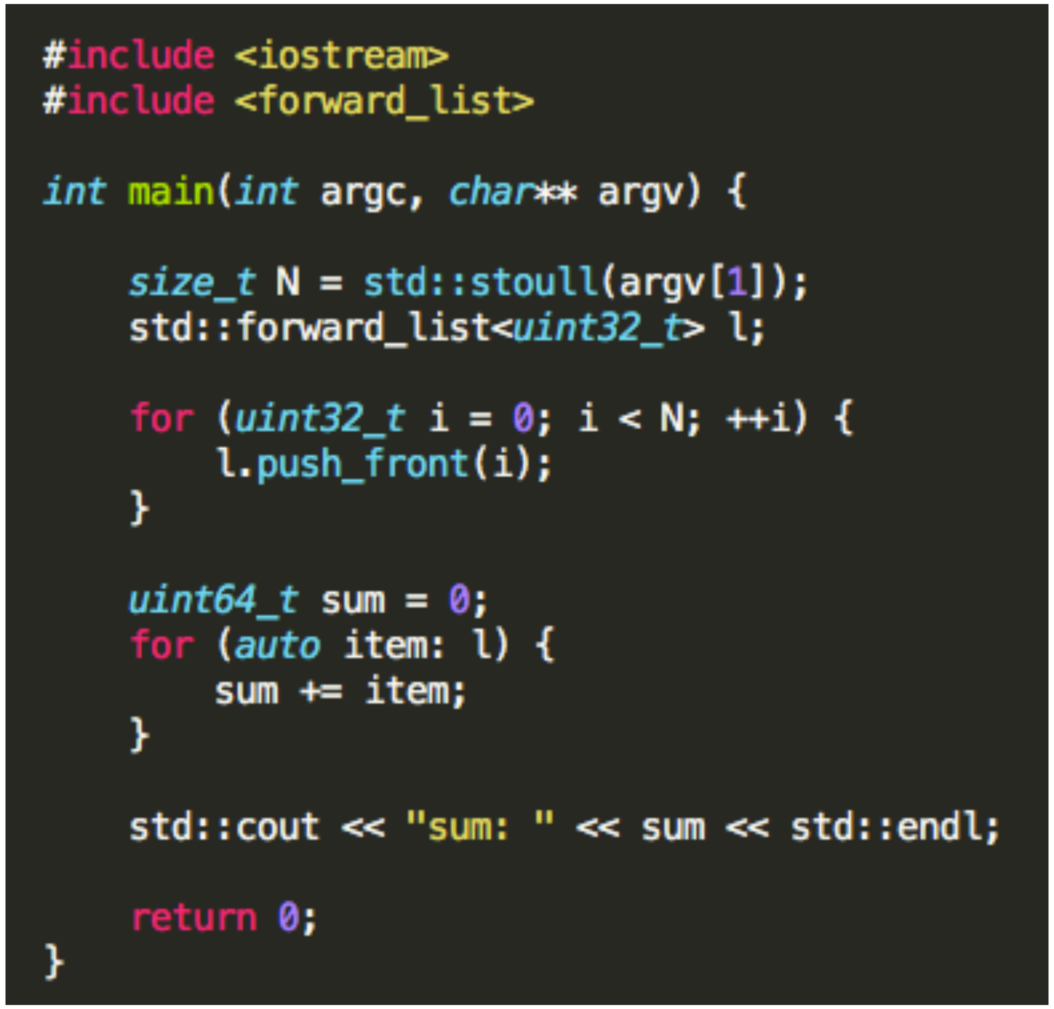


```
→  Desktop g++ -std=c++11 -O3 sum_list.cpp -o sum_list
→  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  10.04s user 0.91s system 95% cpu 11.468 total
```

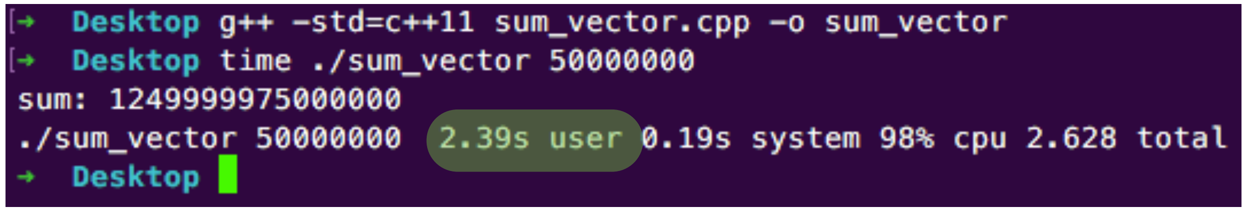
# Sequential containers



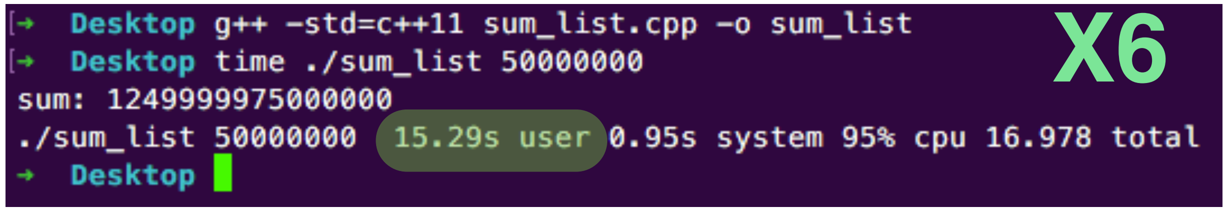
```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; ++i) {
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```



```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

    for (uint32_t i = 0; i < N; ++i) {
        l.push_front(i);
    }

    uint64_t sum = 0;
    for (auto item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

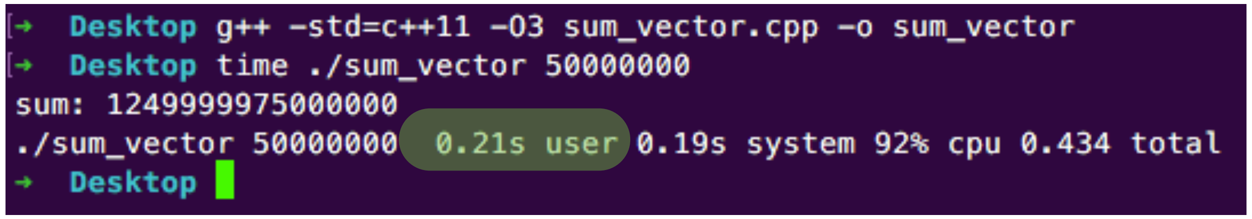


```
➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop
```

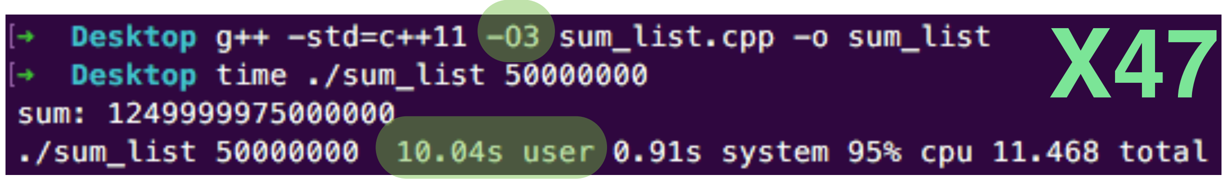


```
➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop
```

X6



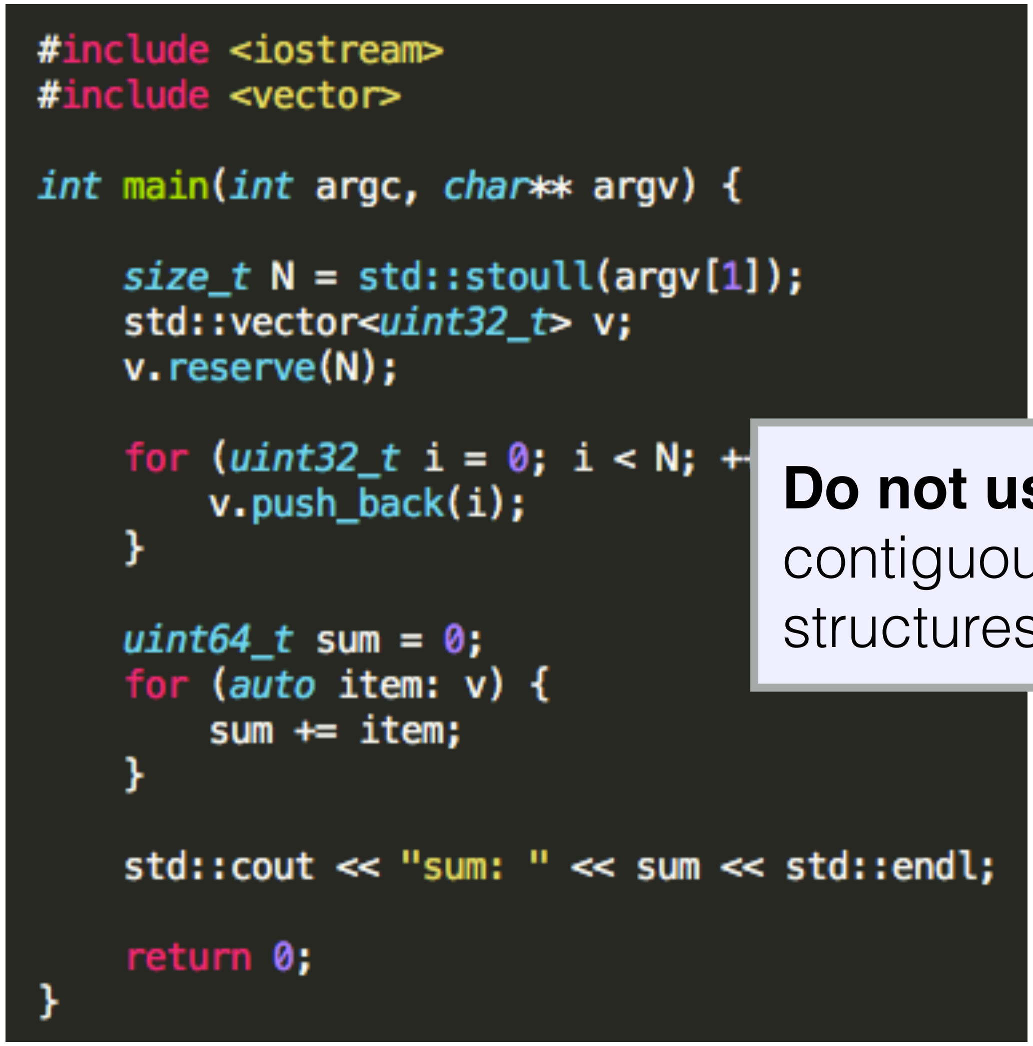
```
➜  Desktop g++ -std=c++11 -O3 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  0.21s user 0.19s system 92% cpu 0.434 total
➜  Desktop
```



```
➜  Desktop g++ -std=c++11 -O3 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  10.04s user 0.91s system 95% cpu 11.468 total
```

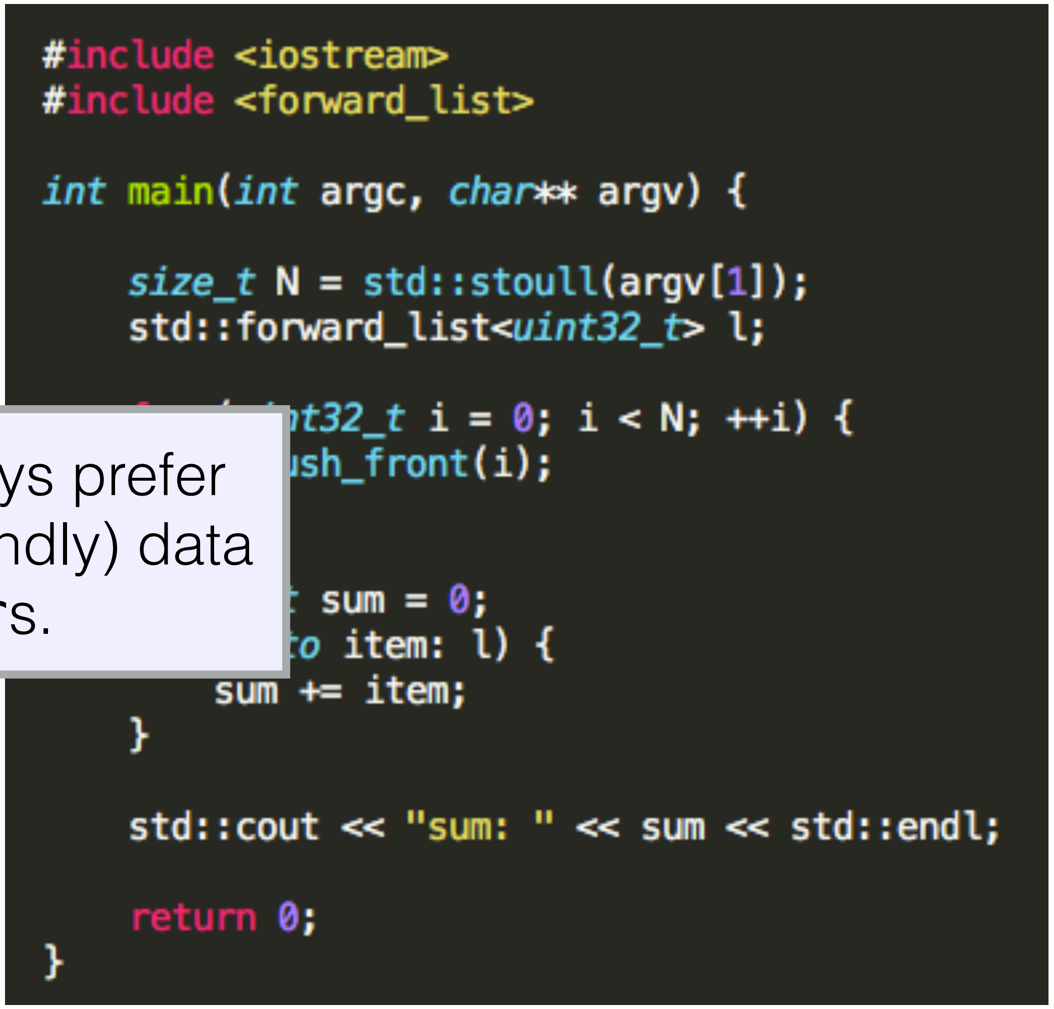
X47

# Sequential containers

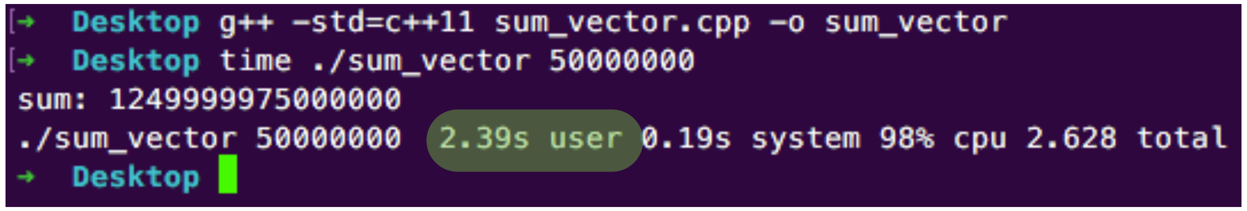


```cpp
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; +
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

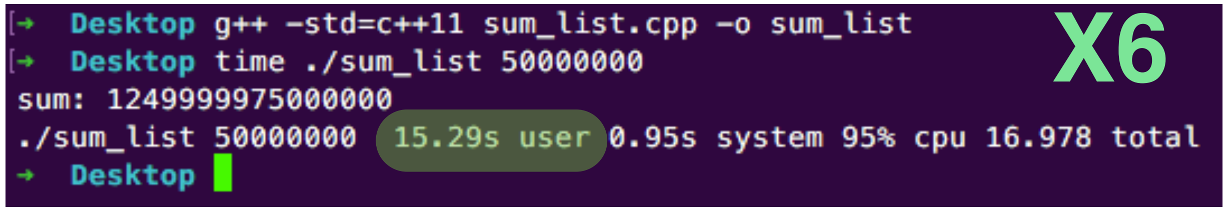
**Do not use lists.** Always prefer contiguous (cache-friendly) data structures, like `vectors`.



```cpp
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

           t32_t i = 0; i < N; ++i) {
           sh_front(i);

             sum = 0;
           o item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

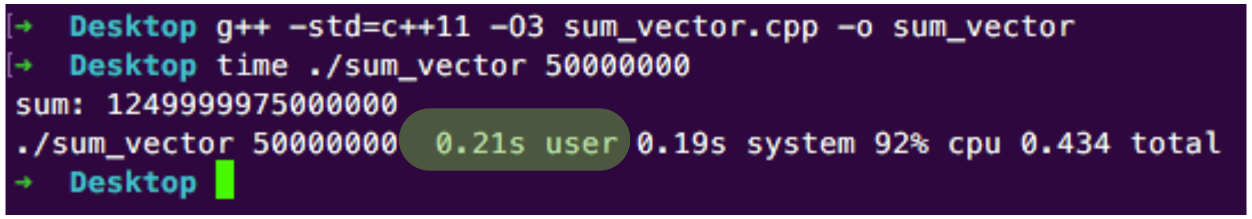


```
➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop
```

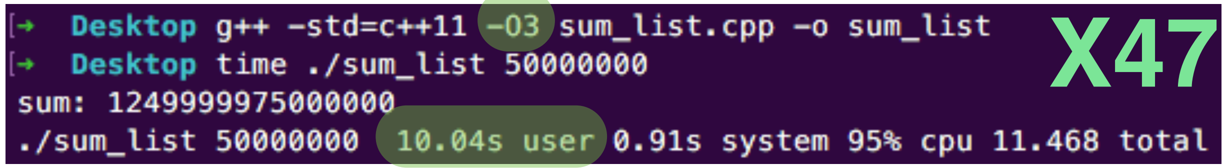


```
➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop
```

X6



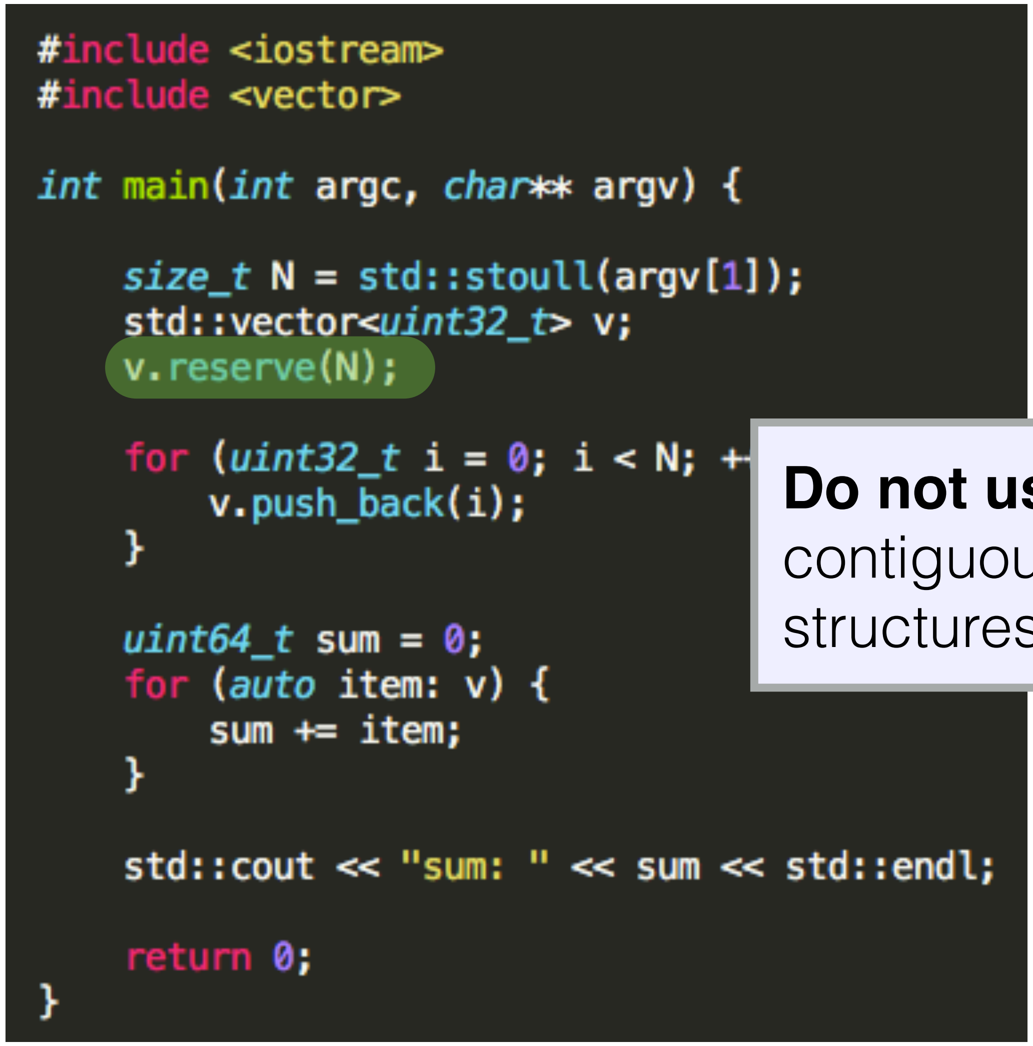
```
➜  Desktop g++ -std=c++11 -O3 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  0.21s user 0.19s system 92% cpu 0.434 total
➜  Desktop
```



```
➜  Desktop g++ -std=c++11 -O3 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  10.04s user 0.91s system 95% cpu 11.468 total
```

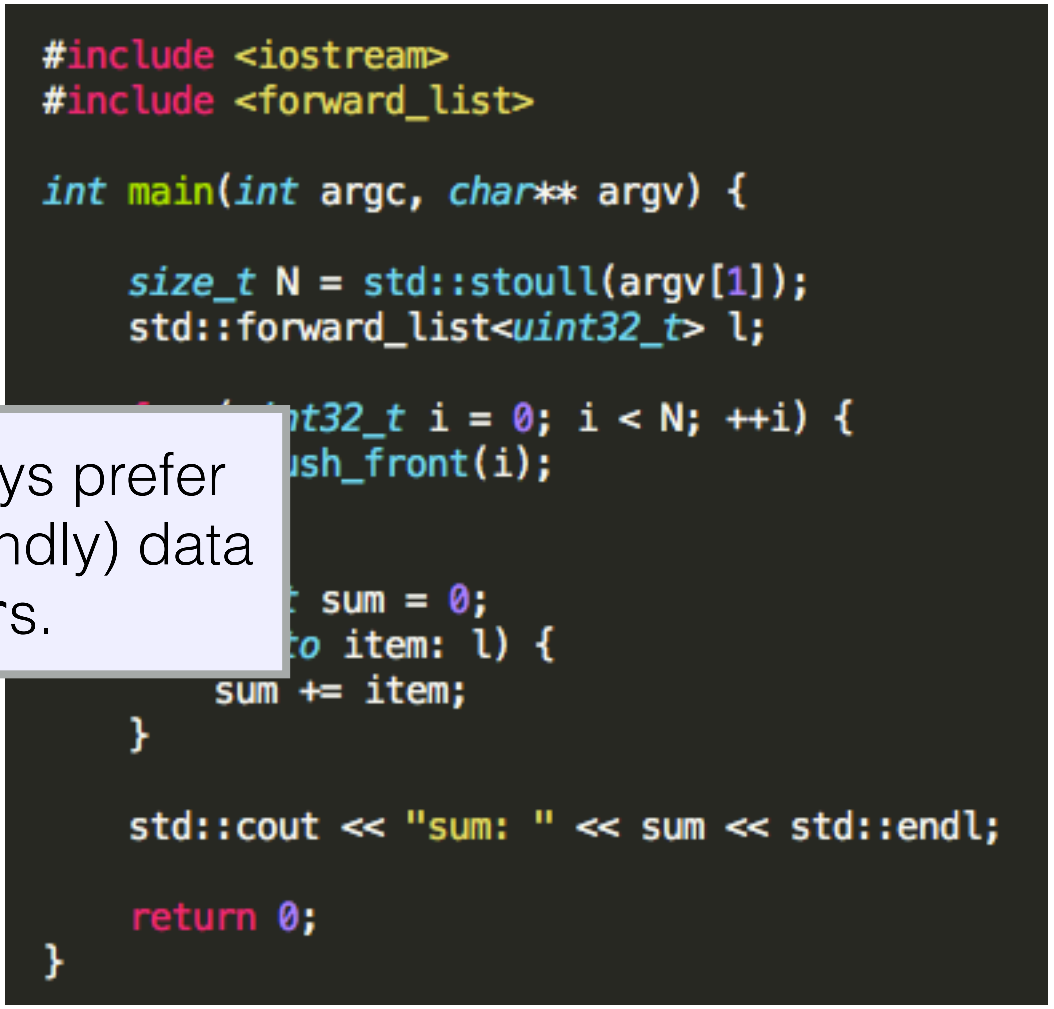
X47

# Sequential containers

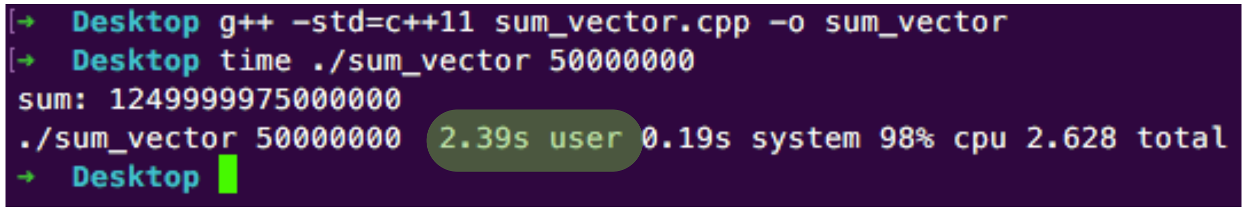


```
#include <iostream>
#include <vector>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::vector<uint32_t> v;
    v.reserve(N);

    for (uint32_t i = 0; i < N; +
        v.push_back(i);
    }

    uint64_t sum = 0;
    for (auto item: v) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

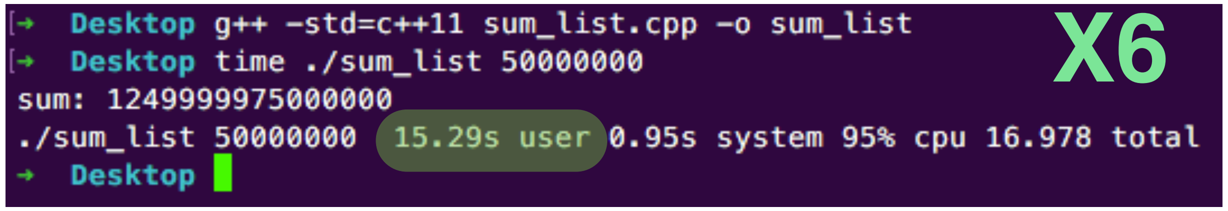
**Do not use lists.** Always prefer contiguous (cache-friendly) data structures, like `vectors`.



```
#include <iostream>
#include <forward_list>

int main(int argc, char** argv) {

    size_t N = std::stoull(argv[1]);
    std::forward_list<uint32_t> l;

             t32_t i = 0; i < N; ++i) {
             ush_front(i);


             t sum = 0;
             to item: l) {
        sum += item;
    }

    std::cout << "sum: " << sum << std::endl;

    return 0;
}
```

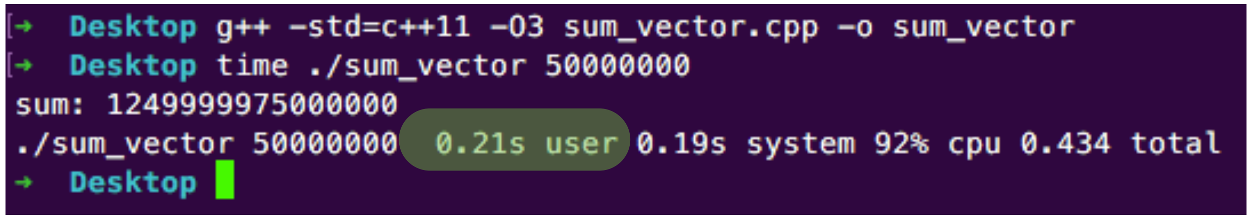


```
➜  Desktop g++ -std=c++11 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  2.39s user 0.19s system 98% cpu 2.628 total
➜  Desktop
```

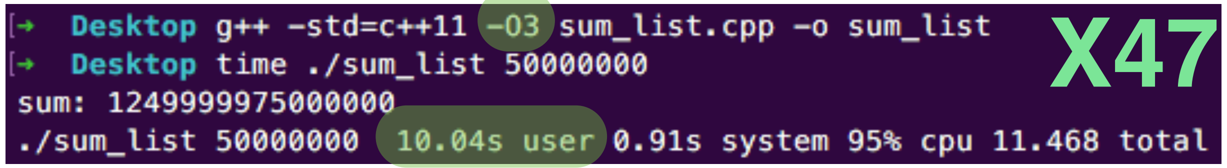


```
➜  Desktop g++ -std=c++11 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  15.29s user 0.95s system 95% cpu 16.978 total
➜  Desktop
```

X6



```
➜  Desktop g++ -std=c++11 -O3 sum_vector.cpp -o sum_vector
➜  Desktop time ./sum_vector 50000000
sum: 1249999975000000
./sum_vector 50000000  0.21s user 0.19s system 92% cpu 0.434 total
➜  Desktop
```

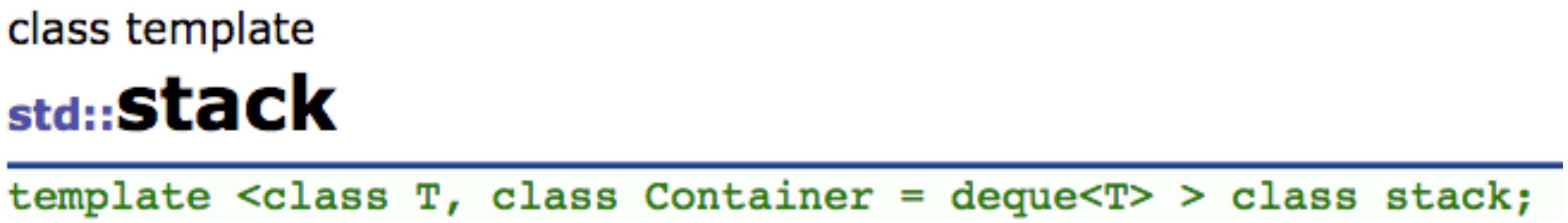


```
➜  Desktop g++ -std=c++11 -O3 sum_list.cpp -o sum_list
➜  Desktop time ./sum_list 50000000
sum: 1249999975000000
./sum_list 50000000  10.04s user 0.91s system 95% cpu 11.468 total
```

X47

# Container adaptors

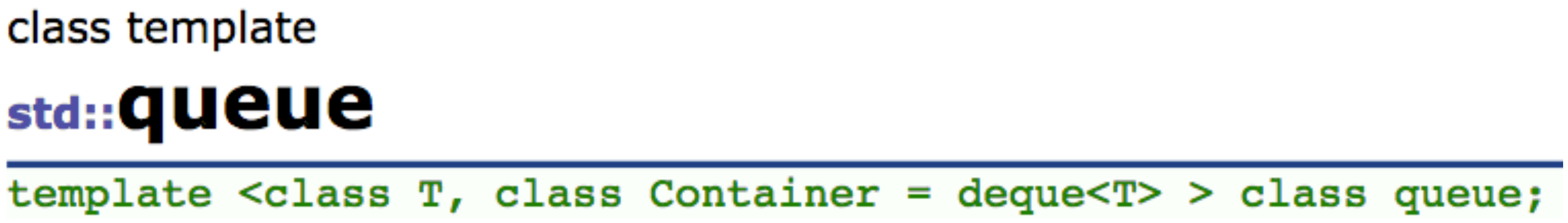
Containers adaptors are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements.



class template

**std::stack**

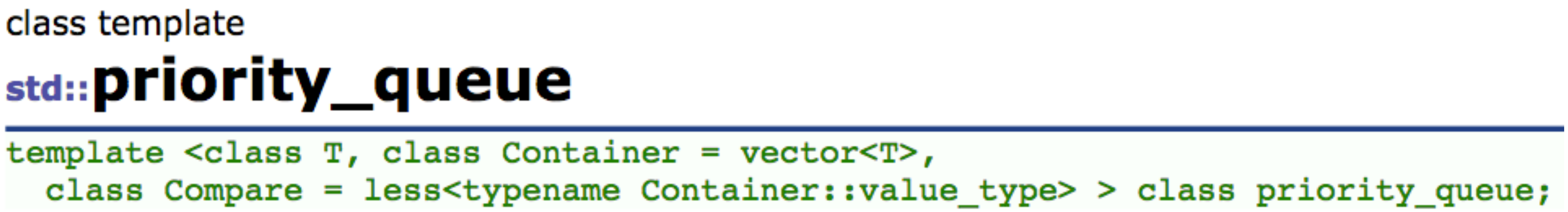
```
template <class T, class Container = deque<T> > class stack;
```



class template

**std::queue**

```
template <class T, class Container = deque<T> > class queue;
```



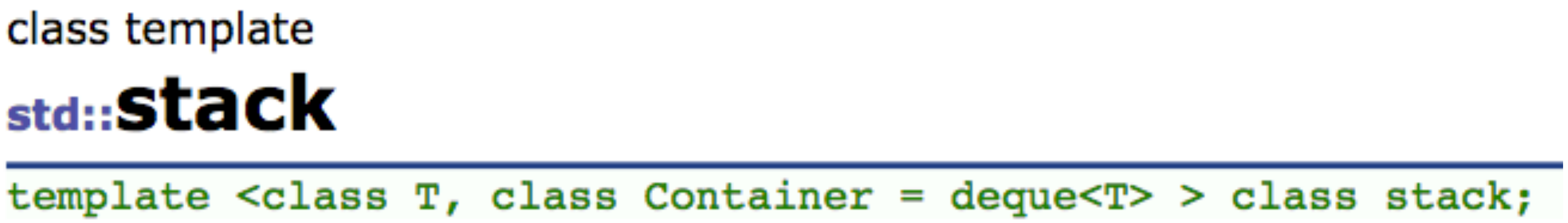
class template

**std::priority_queue**

```
template <class T, class Container = vector<T>,
  class Compare = less<typename Container::value_type> > class priority_queue;
```

# Container adaptors

Containers adaptors are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements.

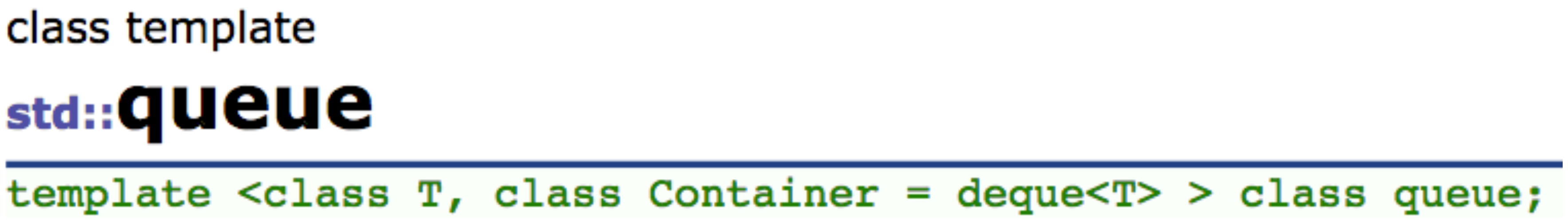


class template

## std::stack

```
template <class T, class Container = deque<T> > class stack;
```

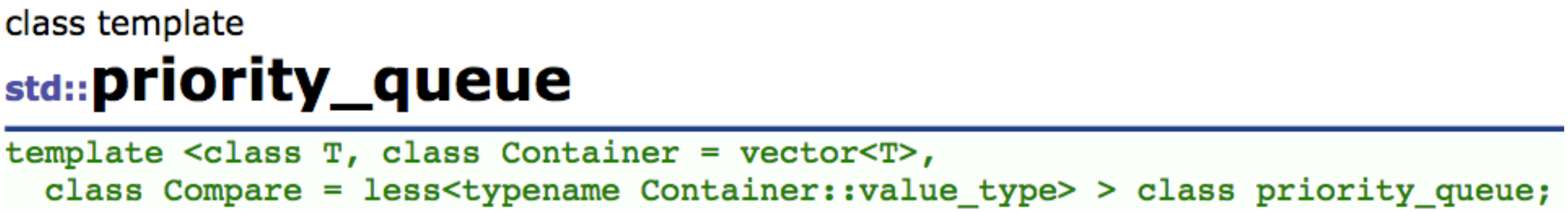
**LIFO** policy
push/pop: O(1)



class template

## std::queue

```
template <class T, class Container = deque<T> > class queue;
```



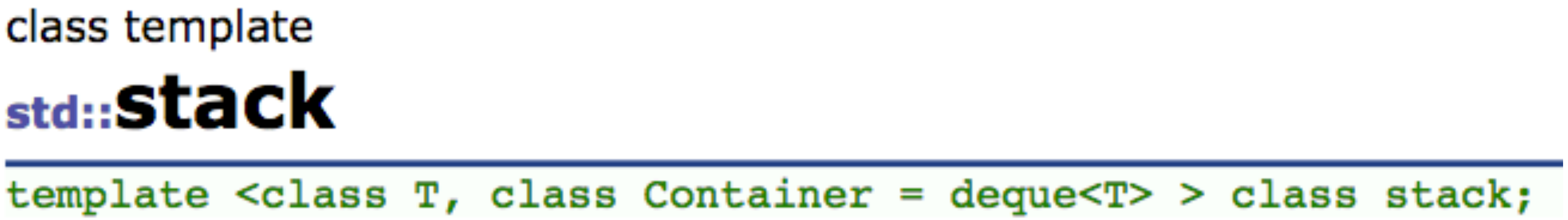
class template

## std::priority_queue

```
template <class T, class Container = vector<T>,
  class Compare = less<typename Container::value_type> > class priority_queue;
```

# Container adaptors

Containers adaptors are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements.

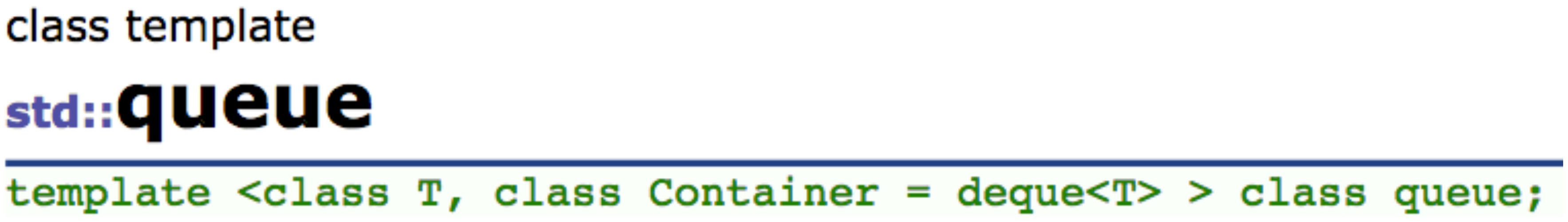


class template

std::**stack**

```
template <class T, class Container = deque<T> > class stack;
```

**LIFO** policy
push/pop: O(1)

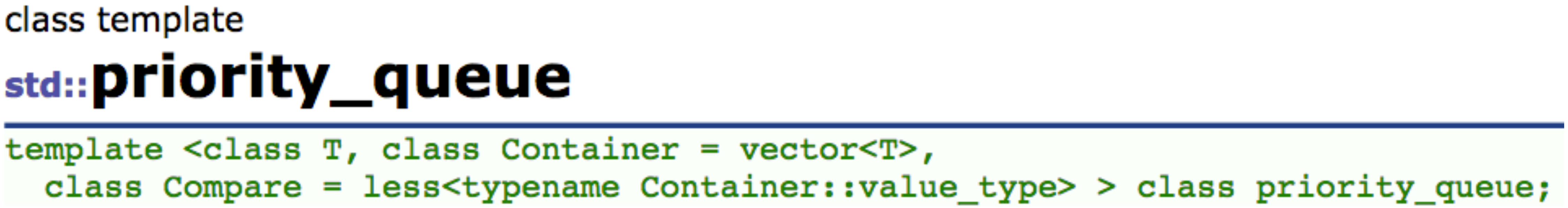


class template

std::**queue**

```
template <class T, class Container = deque<T> > class queue;
```

**FIFO** policy
push/pop: O(1)



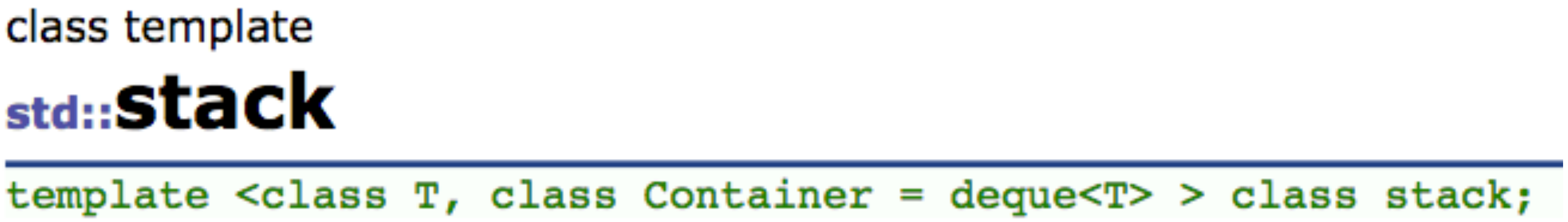
class template

std::**priority_queue**

```
template <class T, class Container = vector<T>,
  class Compare = less<typename Container::value_type> > class priority_queue;
```

# Container adaptors

Containers adaptors are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements.

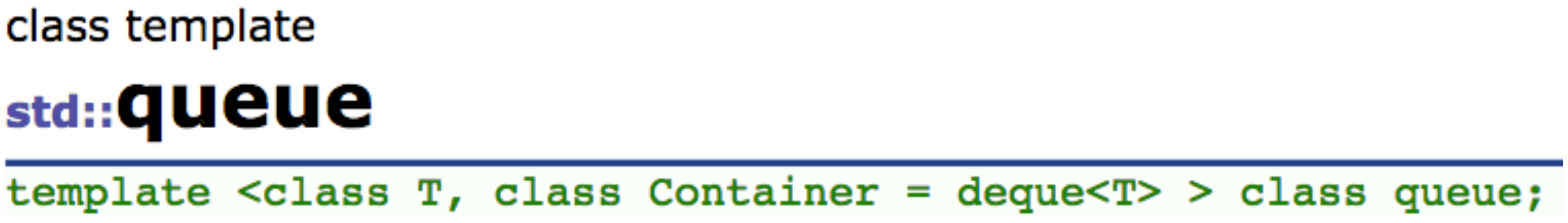


class template

std::**stack**

```
template <class T, class Container = deque<T> > class stack;
```

**LIFO** policy
push/pop: O(1)

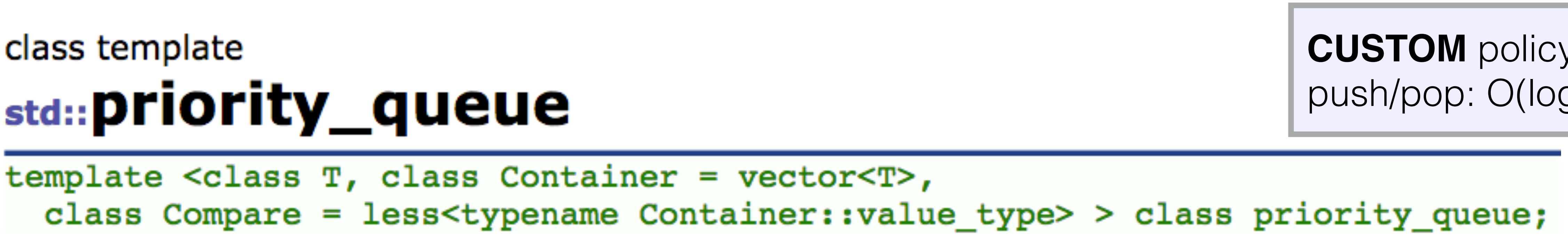


class template

std::**queue**

```
template <class T, class Container = deque<T> > class queue;
```

**FIFO** policy
push/pop: O(1)



class template

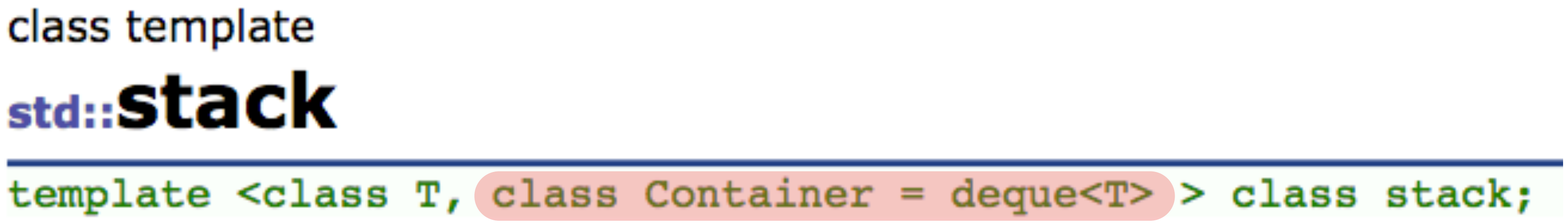
std::**priority_queue**

```
template <class T, class Container = vector<T>,
  class Compare = less<typename Container::value_type> > class priority_queue;
```

**CUSTOM** policy
push/pop: O(log N)

# Container adaptors

Containers adaptors are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements.

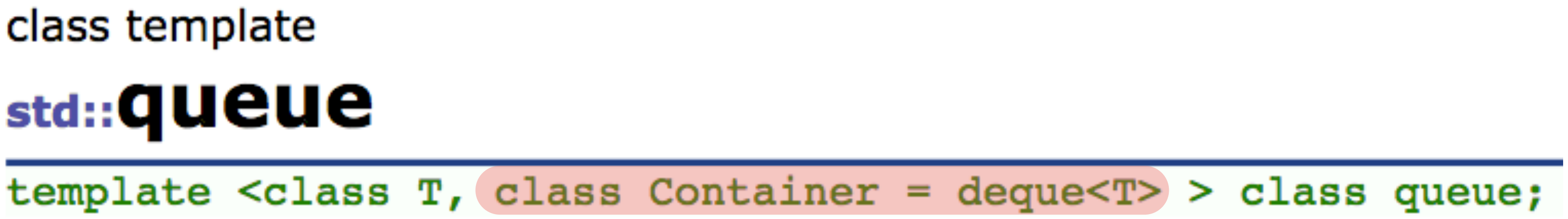


class template

std::**stack**

```
template <class T, class Container = deque<T> > class stack;
```

**LIFO** policy
push/pop: O(1)

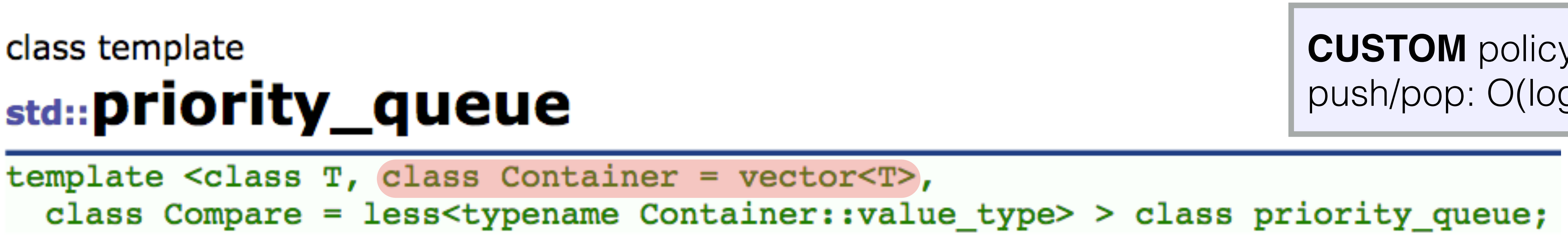


class template

std::**queue**

```
template <class T, class Container = deque<T> > class queue;
```

**FIFO** policy
push/pop: O(1)



class template

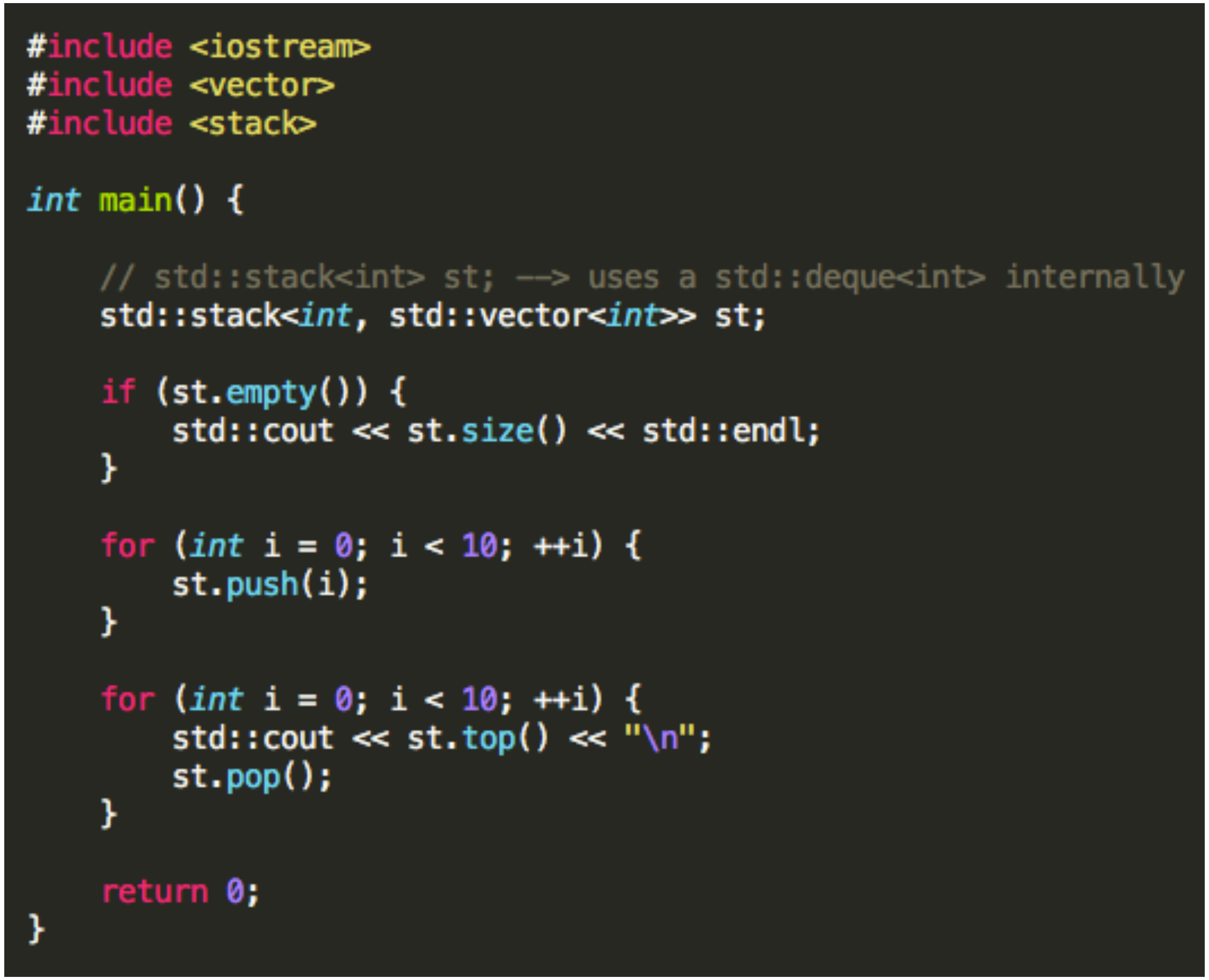
std::**priority_queue**

```
template <class T, class Container = vector<T>,
  class Compare = less<typename Container::value_type> > class priority_queue;
```

**CUSTOM** policy
push/pop: O(log N)

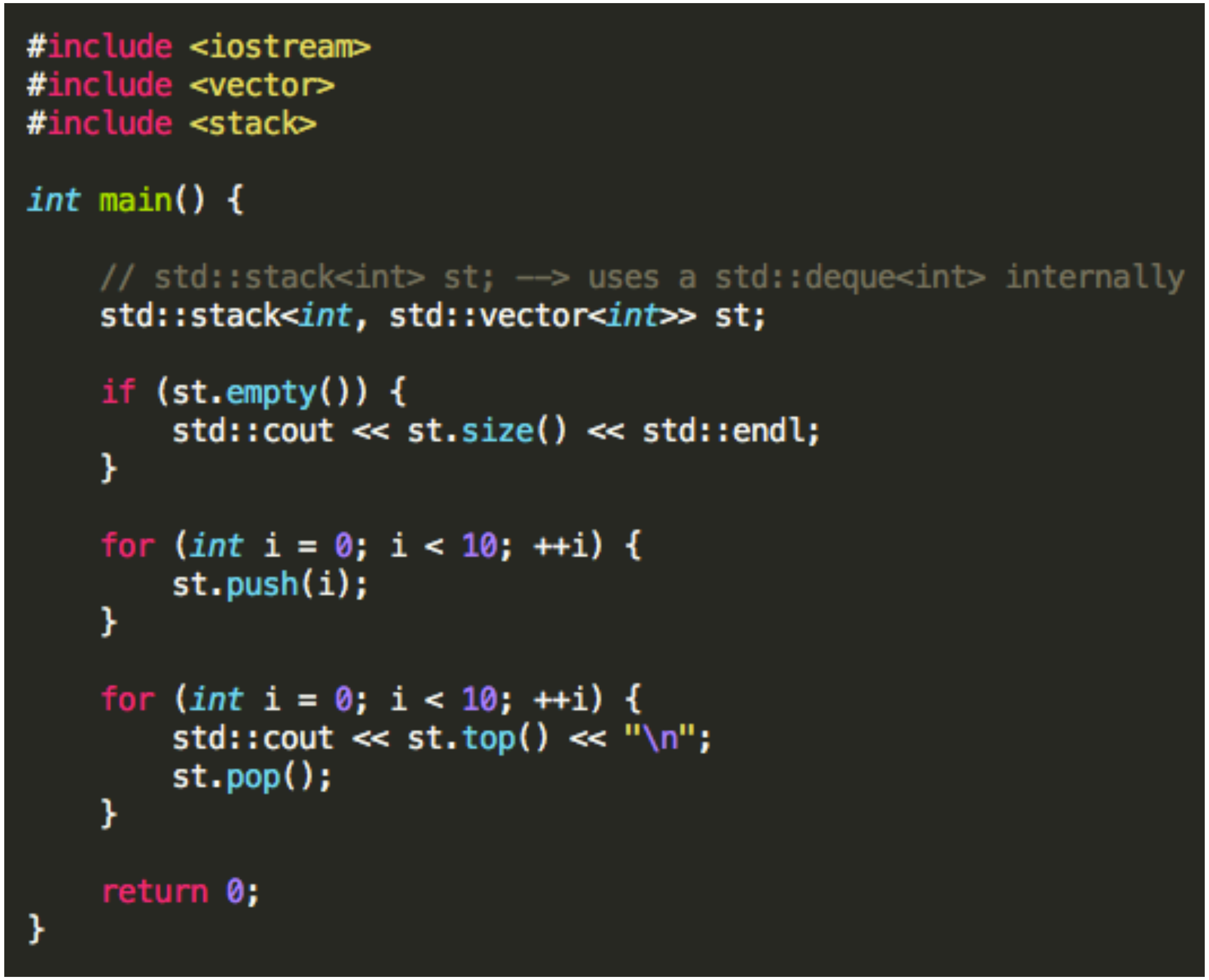
`vector`, `deque` and `list` can be used here

# Container adaptors

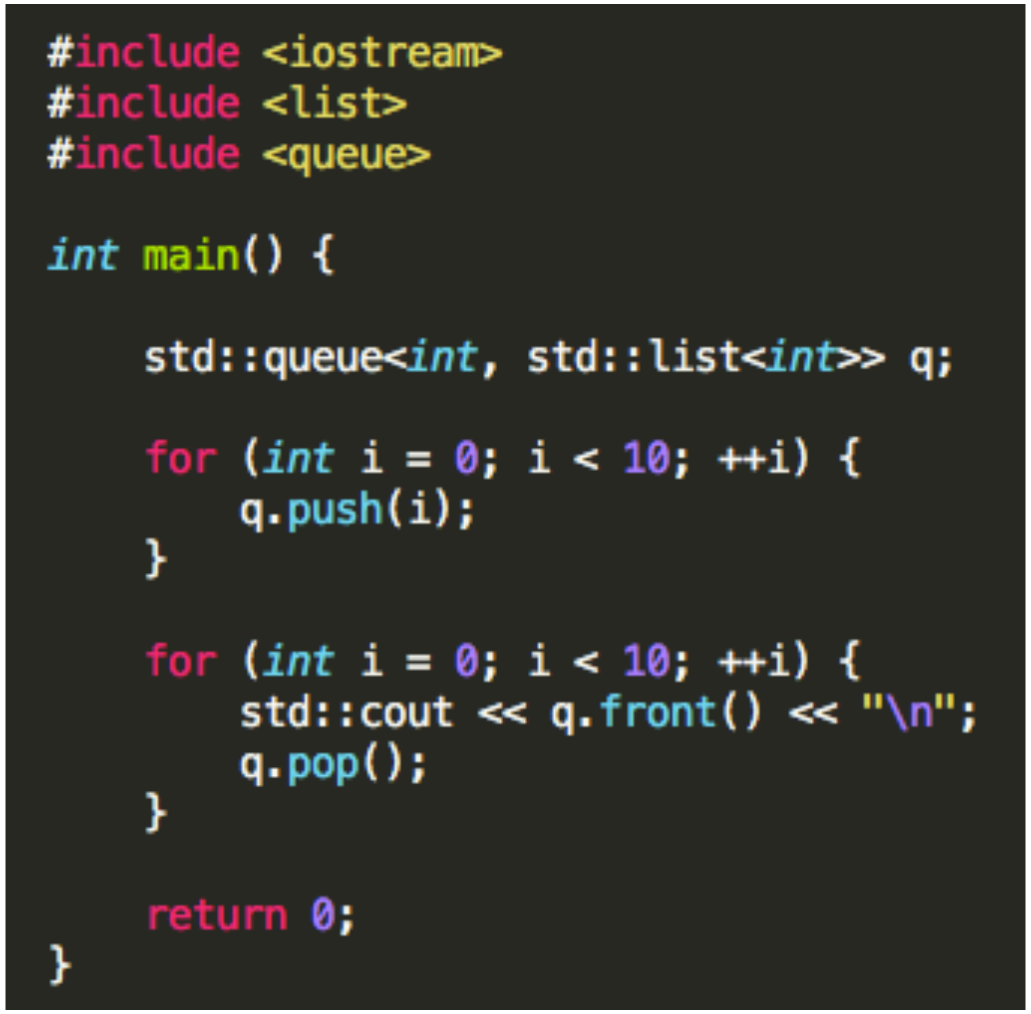


```
#include <iostream>
#include <vector>
#include <stack>

int main() {

    // std::stack<int> st; --> uses a std::deque<int> internally
    std::stack<int, std::vector<int>> st;

    if (st.empty()) {
        std::cout << st.size() << std::endl;
    }

    for (int i = 0; i < 10; ++i) {
        st.push(i);
    }

    for (int i = 0; i < 10; ++i) {
        std::cout << st.top() << "\n";
        st.pop();
    }

    return 0;
}
```

# Container adaptors

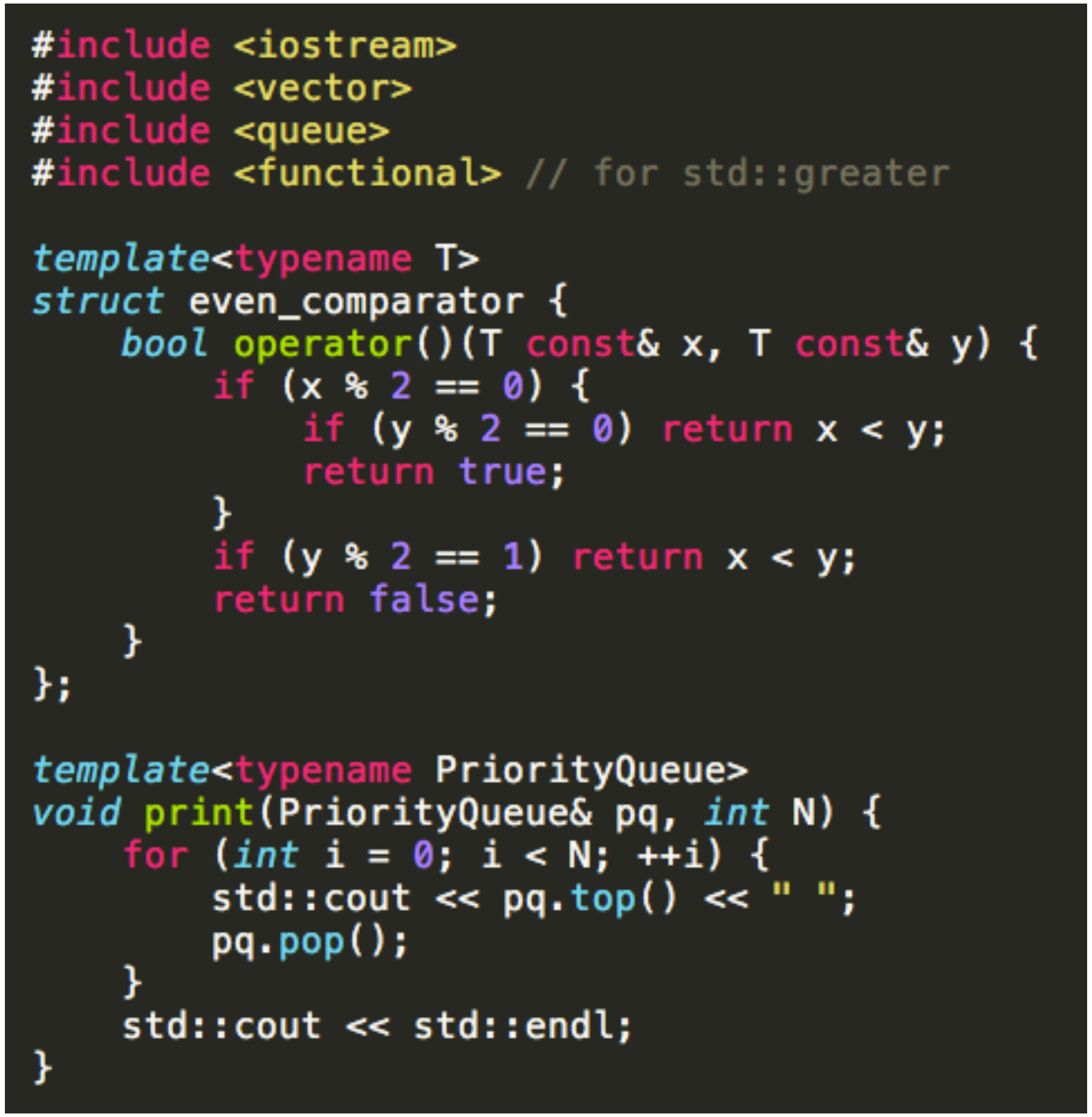


```cpp
#include <iostream>
#include <vector>
#include <stack>

int main() {

    // std::stack<int> st; --> uses a std::deque<int> internally
    std::stack<int, std::vector<int>> st;

    if (st.empty()) {
        std::cout << st.size() << std::endl;
    }

    for (int i = 0; i < 10; ++i) {
        st.push(i);
    }

    for (int i = 0; i < 10; ++i) {
        std::cout << st.top() << "\n";
        st.pop();
    }

    return 0;
}
```

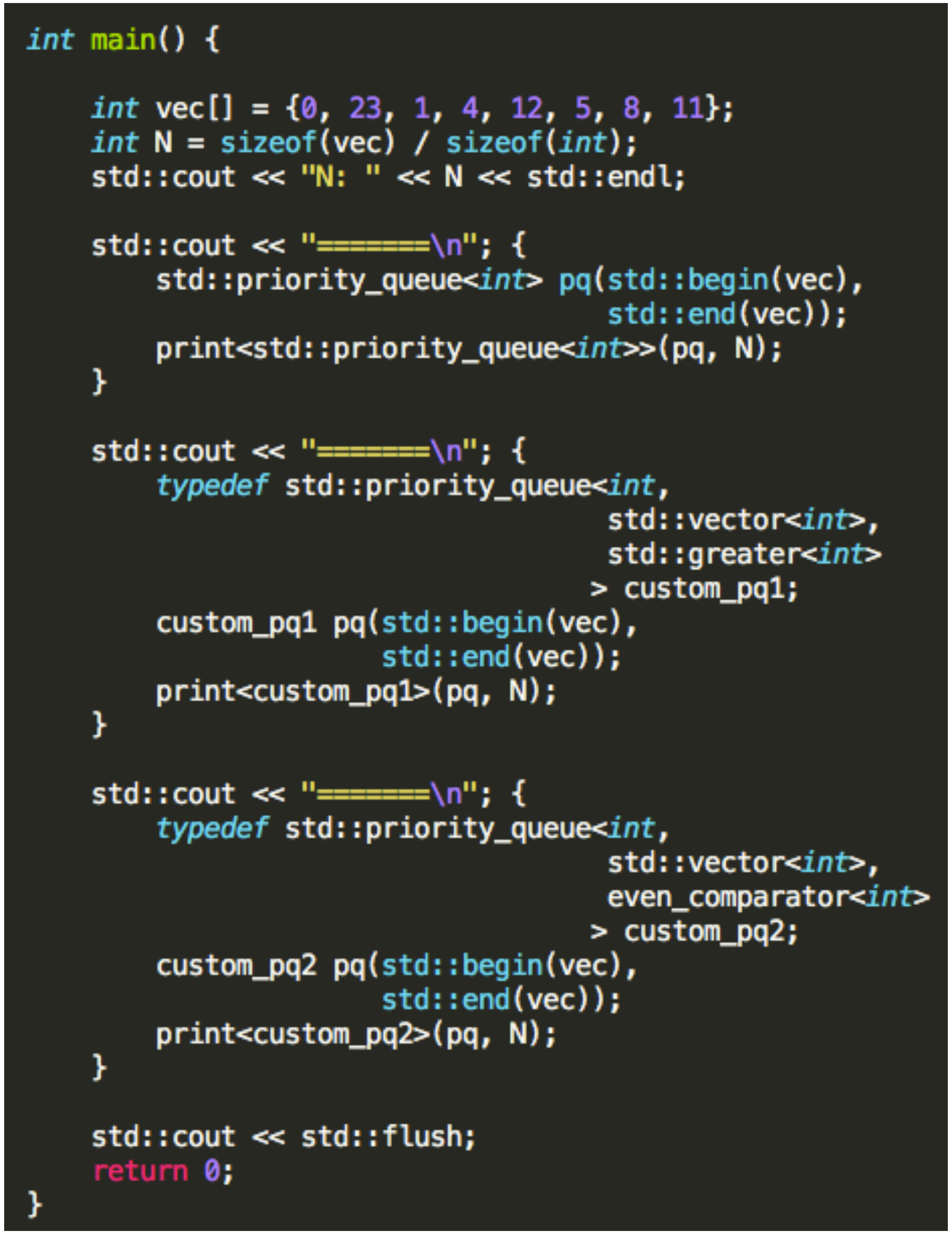


```cpp
#include <iostream>
#include <list>
#include <queue>

int main() {

    std::queue<int, std::list<int>> q;

    for (int i = 0; i < 10; ++i) {
        q.push(i);
    }

    for (int i = 0; i < 10; ++i) {
        std::cout << q.front() << "\n";
        q.pop();
    }

    return 0;
}
```

# Container adaptors

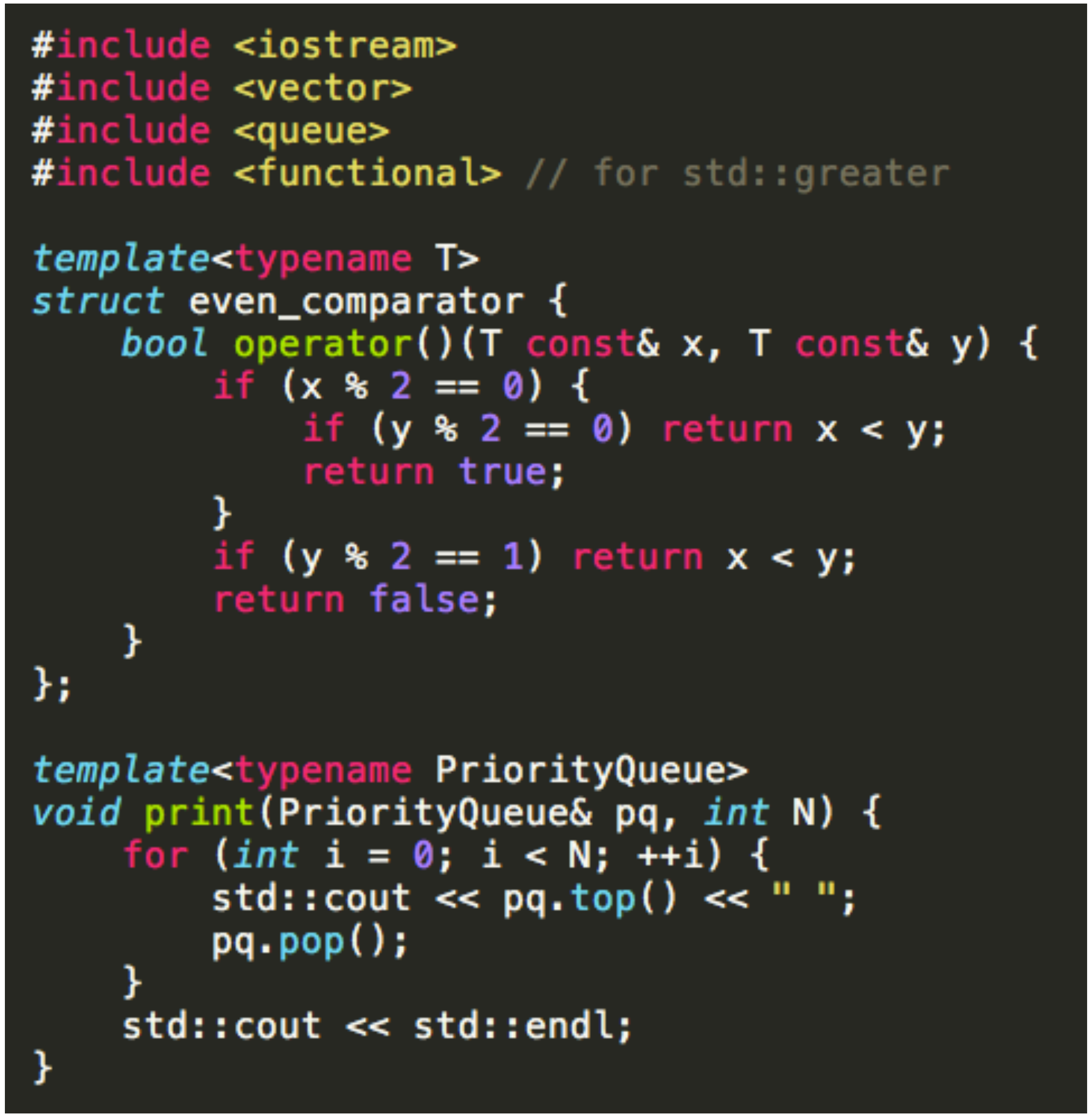


```cpp
#include <iostream>
#include <vector>
#include <queue>
#include <functional> // for std::greater

template<typename T>
struct even_comparator {
    bool operator()(T const& x, T const& y) {
        if (x % 2 == 0) {
            if (y % 2 == 0) return x < y;
            return true;
        }
        if (y % 2 == 1) return x < y;
        return false;
    }
};

template<typename PriorityQueue>
void print(PriorityQueue& pq, int N) {
    for (int i = 0; i < N; ++i) {
        std::cout << pq.top() << " ";
        pq.pop();
    }
    std::cout << std::endl;
}
```

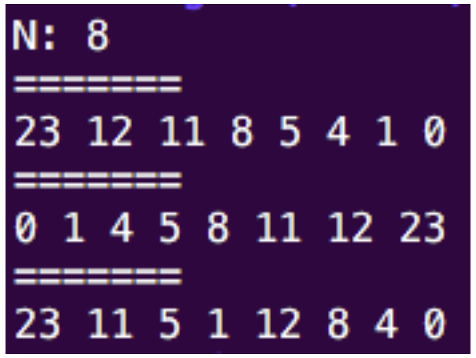


```cpp
int main() {

    int vec[] = {0, 23, 1, 4, 12, 5, 8, 11};
    int N = sizeof(vec) / sizeof(int);
    std::cout << "N: " << N << std::endl;

    std::cout << "=======\n"; {
        std::priority_queue<int> pq(std::begin(vec),
                                    std::end(vec));
        print<std::priority_queue<int>>(pq, N);
    }

    std::cout << "=======\n"; {
        typedef std::priority_queue<int,
                                    std::vector<int>,
                                    std::greater<int>
                                   > custom_pq1;
        custom_pq1 pq(std::begin(vec),
                      std::end(vec));
        print<custom_pq1>(pq, N);
    }

    std::cout << "=======\n"; {
        typedef std::priority_queue<int,
                                    std::vector<int>,
                                    even_comparator<int>
                                   > custom_pq2;
        custom_pq2 pq(std::begin(vec),
                      std::end(vec));
        print<custom_pq2>(pq, N);
    }

    std::cout << std::flush;
    return 0;
}
```

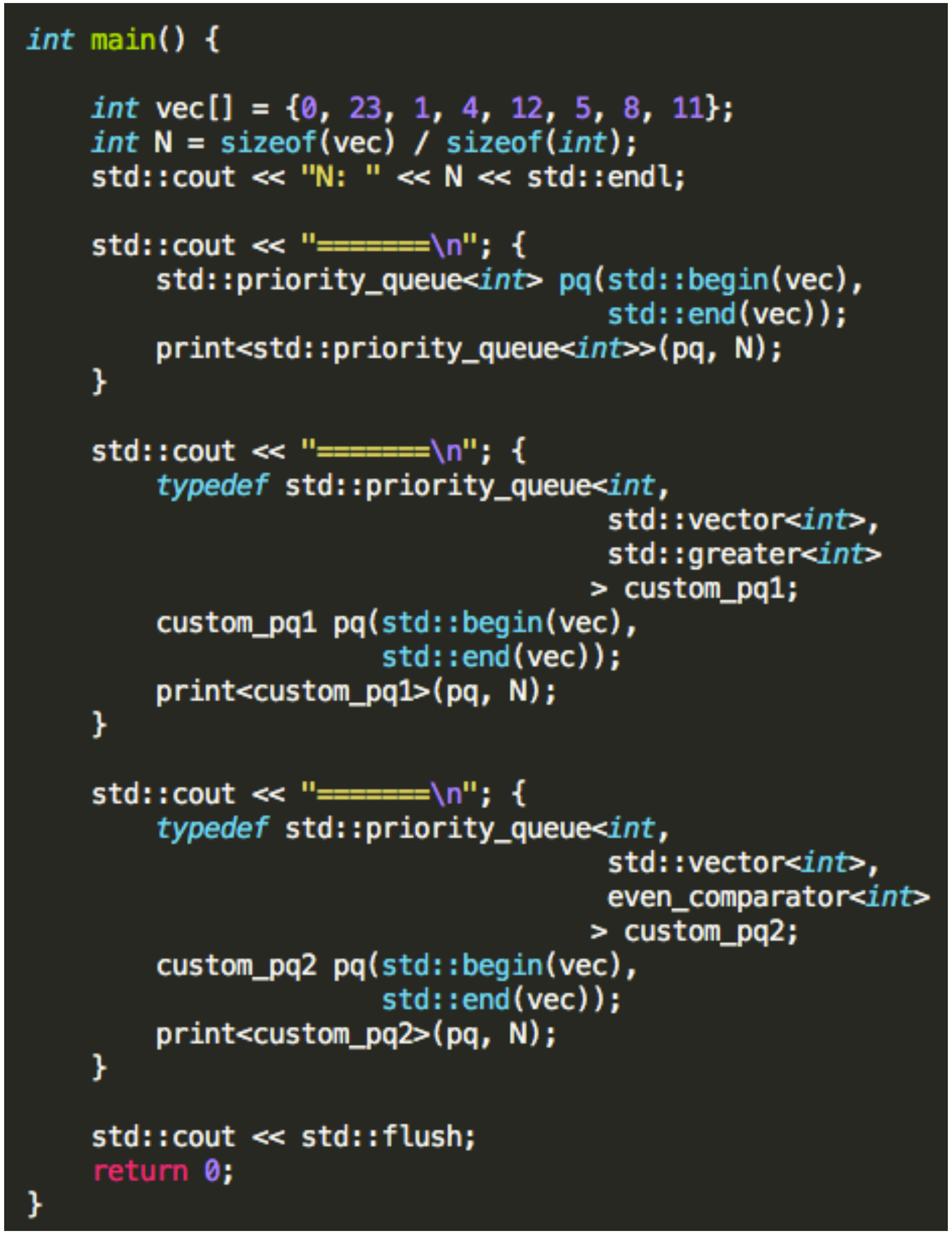
# Container adaptors



```cpp
#include <iostream>
#include <vector>
#include <queue>
#include <functional> // for std::greater

template<typename T>
struct even_comparator {
    bool operator()(T const& x, T const& y) {
        if (x % 2 == 0) {
            if (y % 2 == 0) return x < y;
            return true;
        }
        if (y % 2 == 1) return x < y;
        return false;
    }
};

template<typename PriorityQueue>
void print(PriorityQueue& pq, int N) {
    for (int i = 0; i < N; ++i) {
        std::cout << pq.top() << " ";
        pq.pop();
    }
    std::cout << std::endl;
}
```

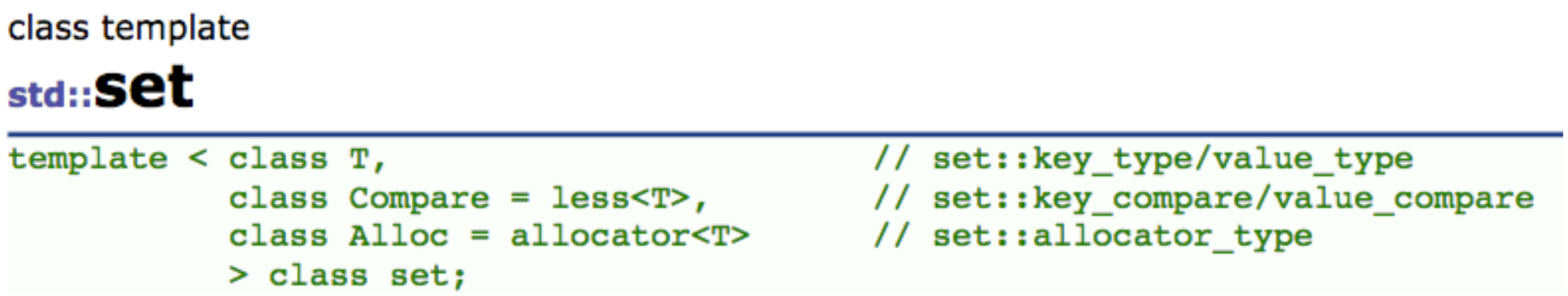


```
N: 8
=======
23 12 11 8 5 4 1 0
=======
0 1 4 5 8 11 12 23
=======
23 11 5 1 12 8 4 0
```



```cpp
int main() {

    int vec[] = {0, 23, 1, 4, 12, 5, 8, 11};
    int N = sizeof(vec) / sizeof(int);
    std::cout << "N: " << N << std::endl;

    std::cout << "=======\n"; {
        std::priority_queue<int> pq(std::begin(vec),
                                    std::end(vec));
        print<std::priority_queue<int>>(pq, N);
    }

    std::cout << "=======\n"; {
        typedef std::priority_queue<int,
                                    std::vector<int>,
                                    std::greater<int>
                                   > custom_pq1;
        custom_pq1 pq(std::begin(vec),
                      std::end(vec));
        print<custom_pq1>(pq, N);
    }

    std::cout << "=======\n"; {
        typedef std::priority_queue<int,
                                    std::vector<int>,
                                    even_comparator<int>
                                   > custom_pq2;
        custom_pq2 pq(std::begin(vec),
                      std::end(vec));
        print<custom_pq2>(pq, N);
    }

    std::cout << std::flush;
    return 0;
}
```

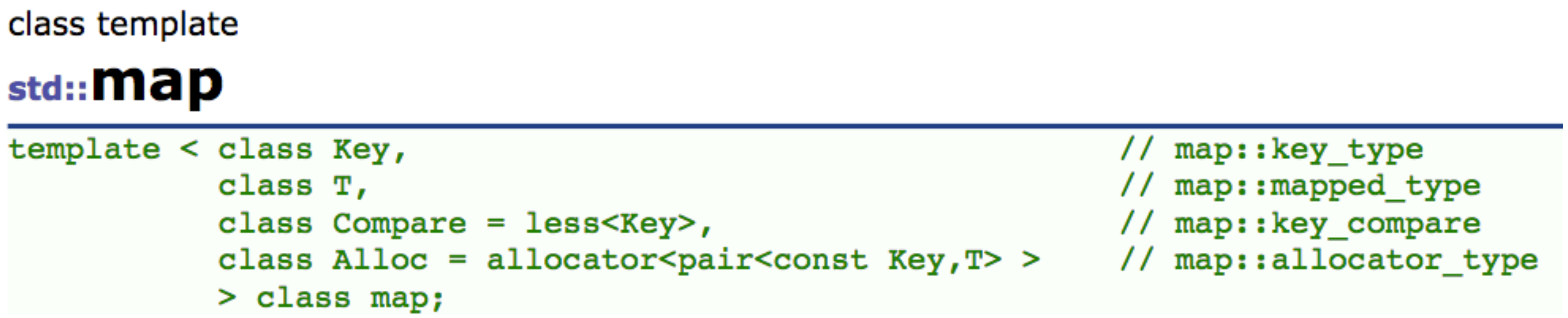
# Associative containers



class template

## std::set

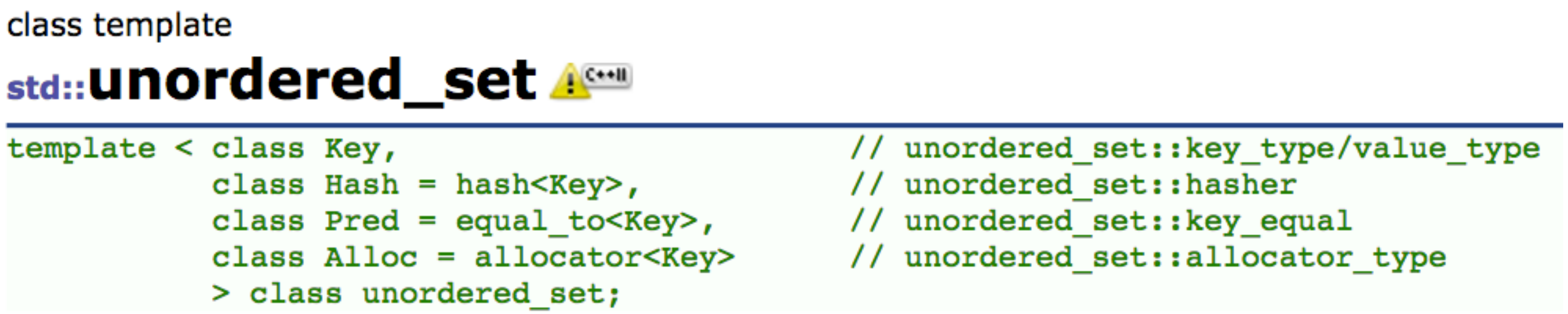
```
template < class T,                        // set::key_type/value_type
           class Compare = less<T>,        // set::key_compare/value_compare
           class Alloc = allocator<T>      // set::allocator_type
           > class set;
```



class template

## std::map

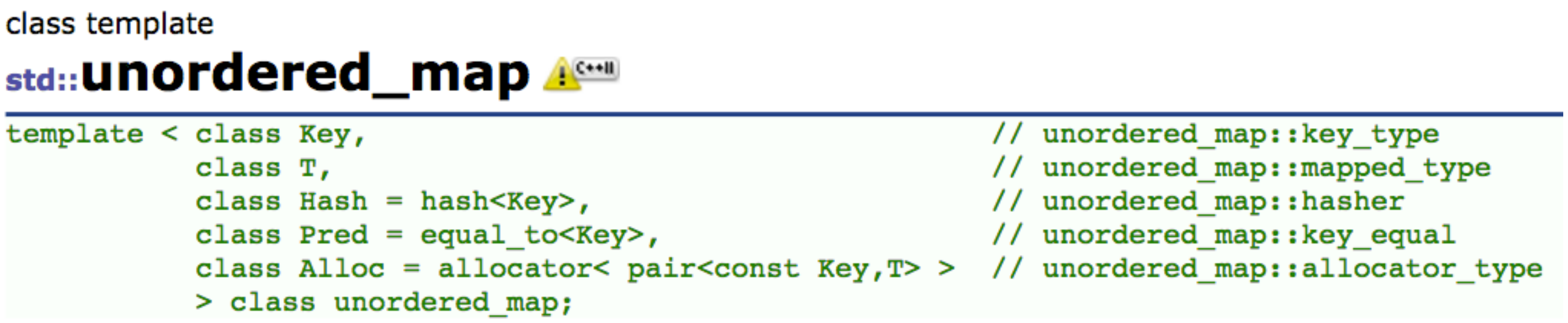
```
template < class Key,                                           // map::key_type
           class T,                                             // map::mapped_type
           class Compare = less<Key>,                           // map::key_compare
           class Alloc = allocator<pair<const Key,T> >          // map::allocator_type
           > class map;
```



class template

## std::unordered_set ⚠ C++11

```
template < class Key,                        // unordered_set::key_type/value_type
           class Hash = hash<Key>,           // unordered_set::hasher
           class Pred = equal_to<Key>,       // unordered_set::key_equal
           class Alloc = allocator<Key>      // unordered_set::allocator_type
           > class unordered_set;
```

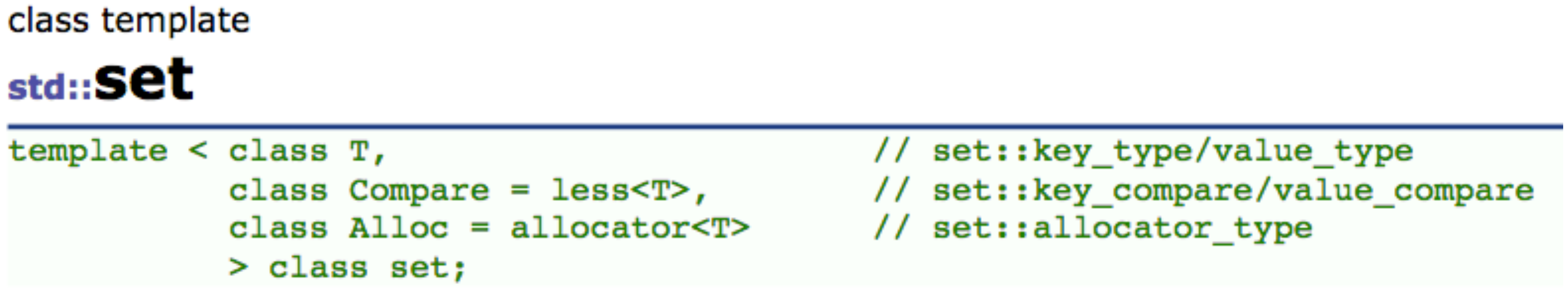


class template

## std::unordered_map ⚠ C++11

```
template < class Key,                                    // unordered_map::key_type
           class T,                                      // unordered_map::mapped_type
           class Hash = hash<Key>,                       // unordered_map::hasher
           class Pred = equal_to<Key>,                   // unordered_map::key_equal
           class Alloc = allocator< pair<const Key,T> >  // unordered_map::allocator_type
           > class unordered_map;
```

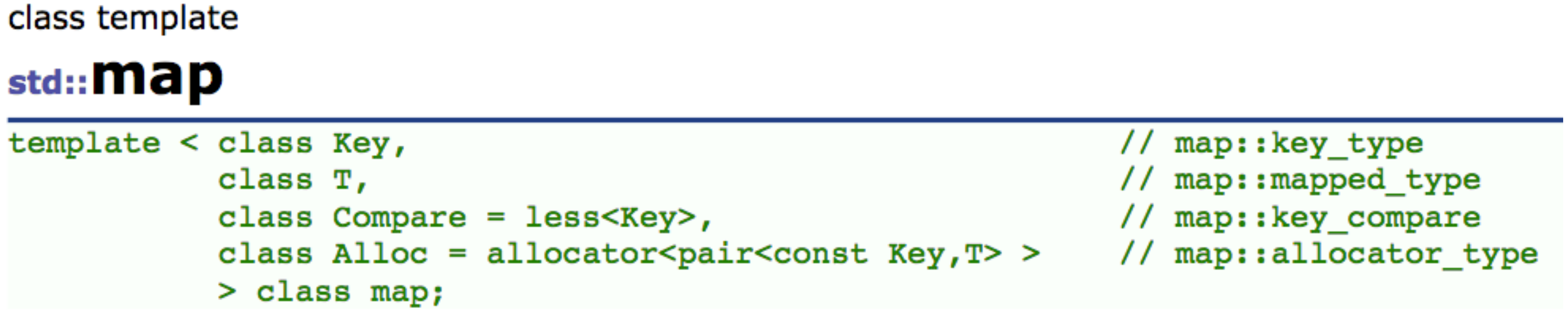
# Associative containers



class template

**std::set**

```
template < class T,                        // set::key_type/value_type
           class Compare = less<T>,        // set::key_compare/value_compare
           class Alloc = allocator<T>      // set::allocator_type
           > class set;
```



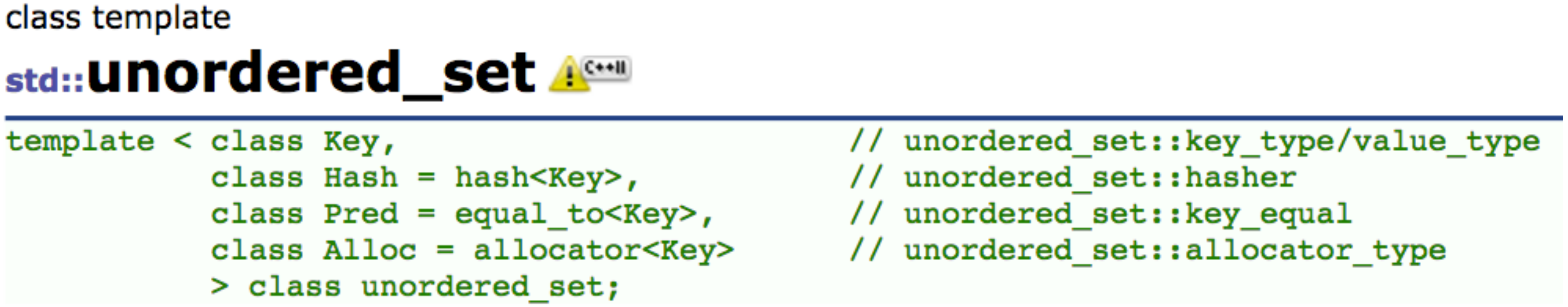
class template

**std::map**

```
template < class Key,                                     // map::key_type
           class T,                                       // map::mapped_type
           class Compare = less<Key>,                     // map::key_compare
           class Alloc = allocator<pair<const Key,T> >    // map::allocator_type
           > class map;
```

based on (balanced)
**binary search trees**

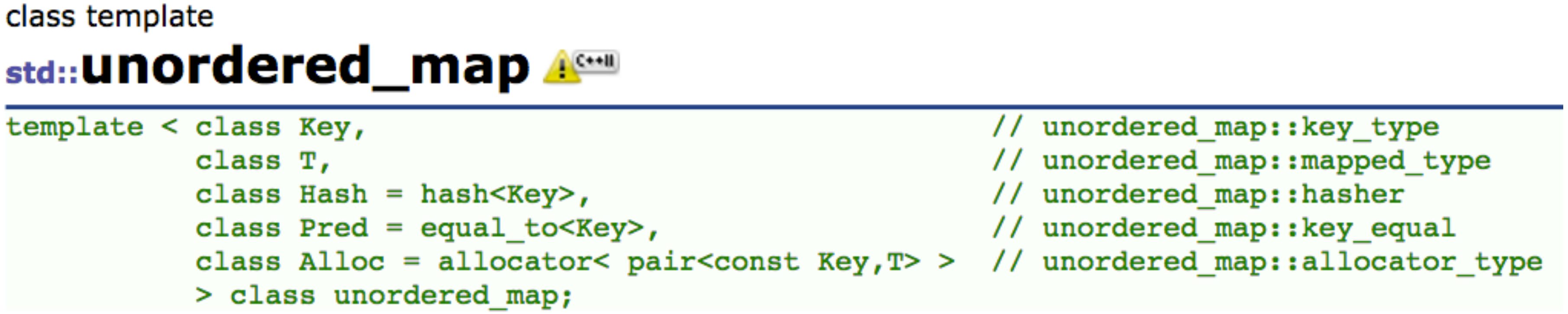
insert/delete:   O(log N)
range queries: O(|range|)



class template

**std::unordered_set** ⚠ C++11

```
template < class Key,                        // unordered_set::key_type/value_type
           class Hash = hash<Key>,           // unordered_set::hasher
           class Pred = equal_to<Key>,       // unordered_set::key_equal
           class Alloc = allocator<Key>      // unordered_set::allocator_type
           > class unordered_set;
```

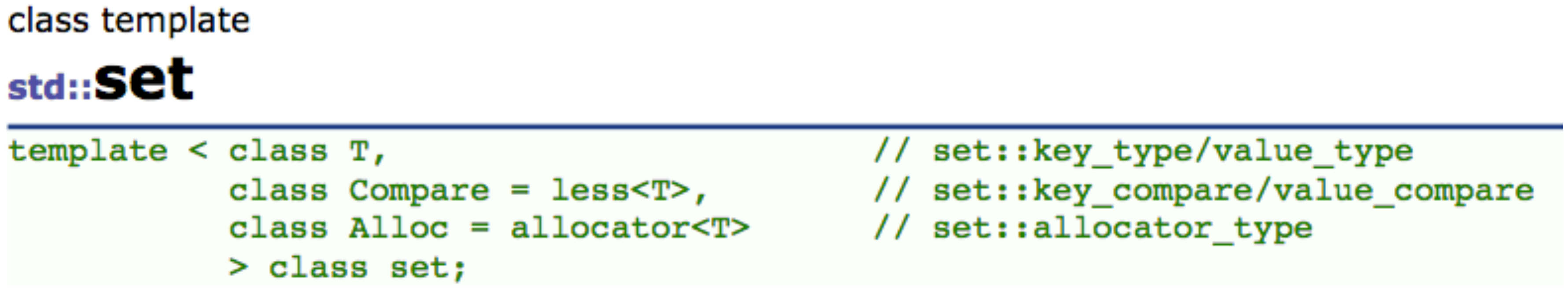


class template

**std::unordered_map** ⚠ C++11

```
template < class Key,                                    // unordered_map::key_type
           class T,                                      // unordered_map::mapped_type
           class Hash = hash<Key>,                       // unordered_map::hasher
           class Pred = equal_to<Key>,                   // unordered_map::key_equal
           class Alloc = allocator< pair<const Key,T> >  // unordered_map::allocator_type
           > class unordered_map;
```

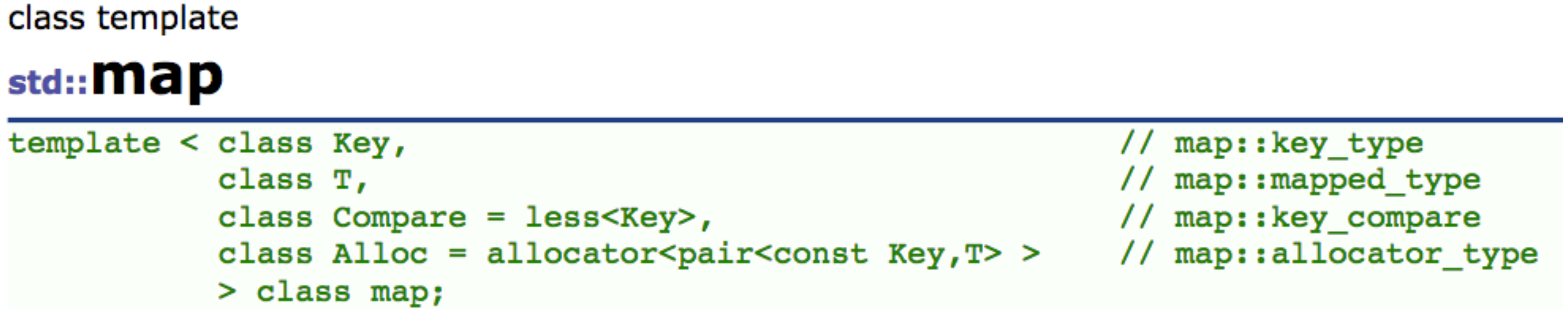
# Associative containers



class template

**std::set**

```
template < class T,                        // set::key_type/value_type
           class Compare = less<T>,        // set::key_compare/value_compare
           class Alloc = allocator<T>      // set::allocator_type
           > class set;
```



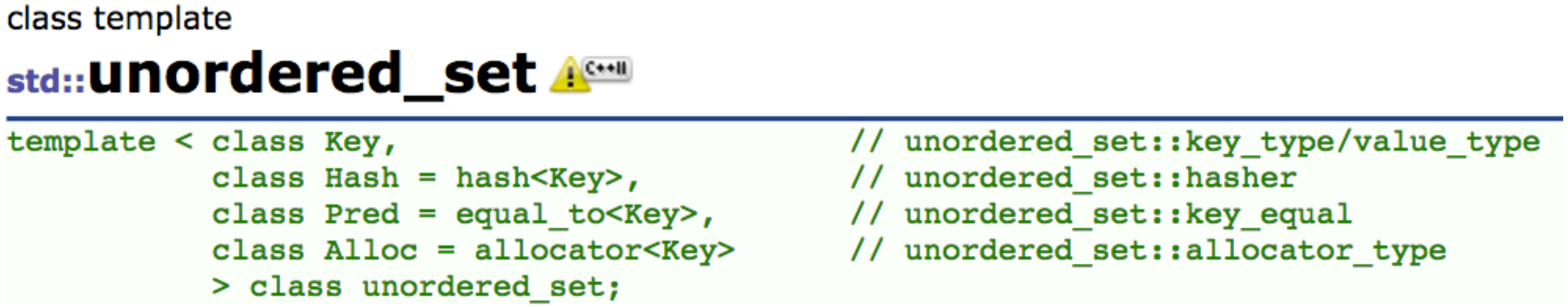
class template

**std::map**

```
template < class Key,                                      // map::key_type
           class T,                                        // map::mapped_type
           class Compare = less<Key>,                      // map::key_compare
           class Alloc = allocator<pair<const Key,T> >     // map::allocator_type
           > class map;
```

based on (balanced)
**binary search trees**

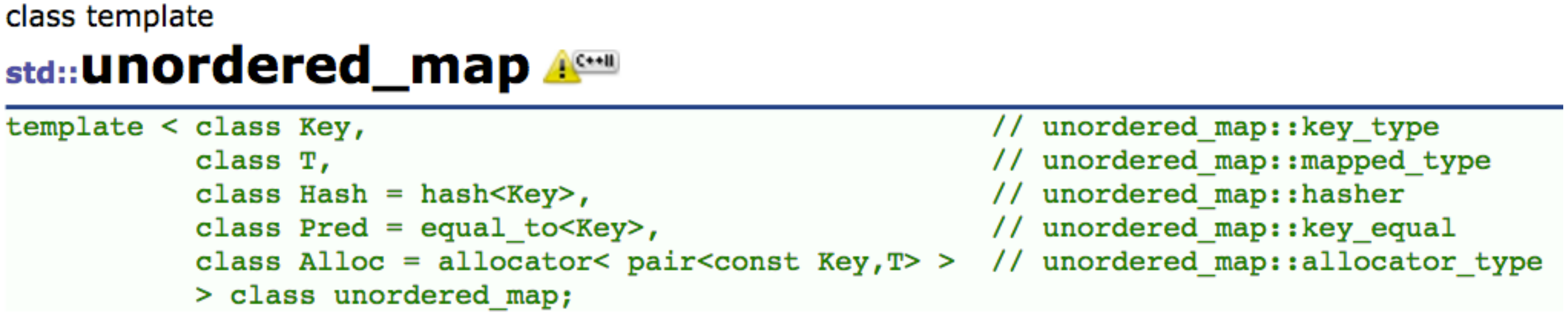
insert/delete: O(log N)
range queries: O(|range|)



class template

**std::unordered_set** C++11

```
template < class Key,                        // unordered_set::key_type/value_type
           class Hash = hash<Key>,           // unordered_set::hasher
           class Pred = equal_to<Key>,       // unordered_set::key_equal
           class Alloc = allocator<Key>      // unordered_set::allocator_type
           > class unordered_set;
```



class template

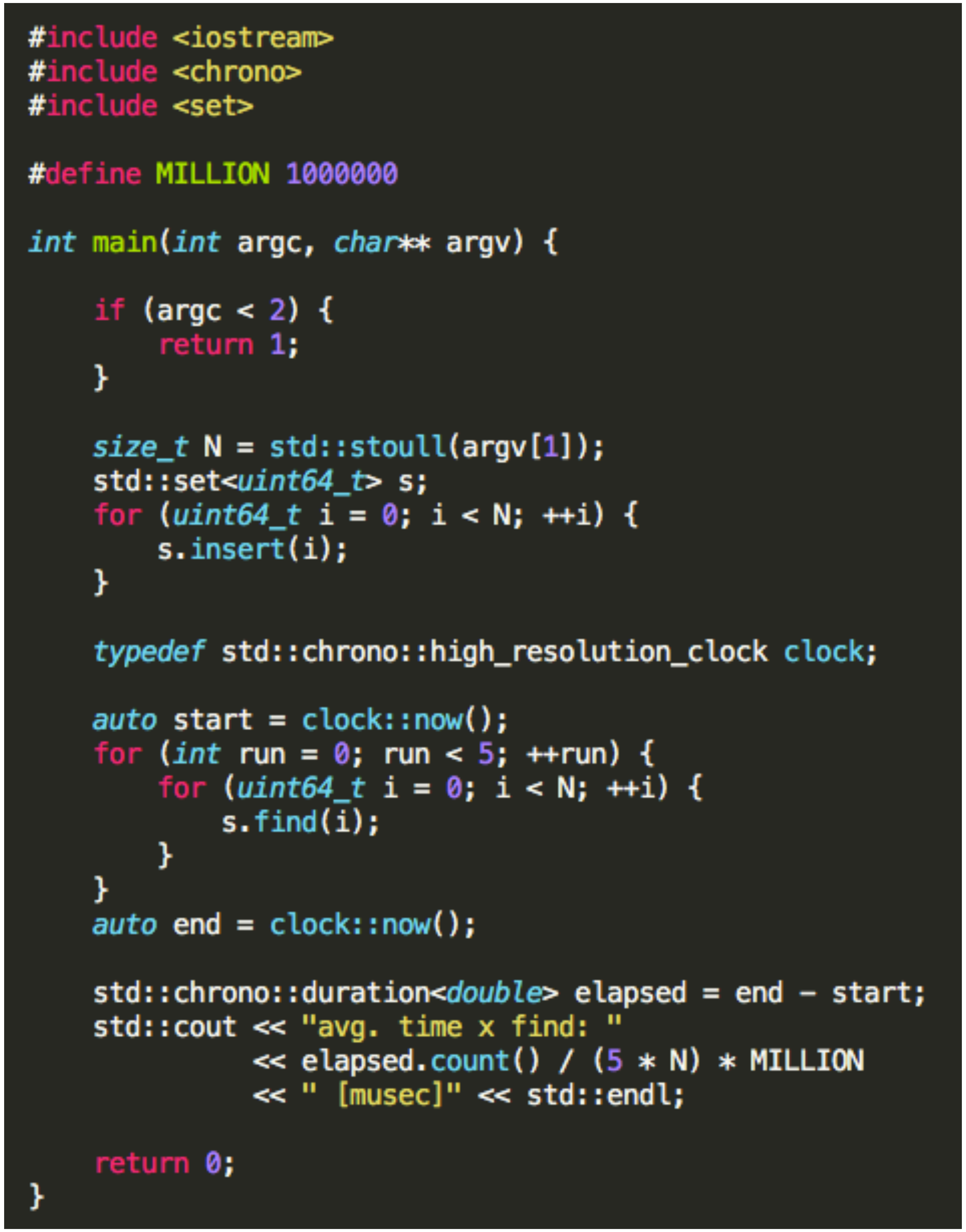
**std::unordered_map** C++11

```
template < class Key,                                    // unordered_map::key_type
           class T,                                      // unordered_map::mapped_type
           class Hash = hash<Key>,                       // unordered_map::hasher
           class Pred = equal_to<Key>,                   // unordered_map::key_equal
           class Alloc = allocator< pair<const Key,T> >  // unordered_map::allocator_type
           > class unordered_map;
```

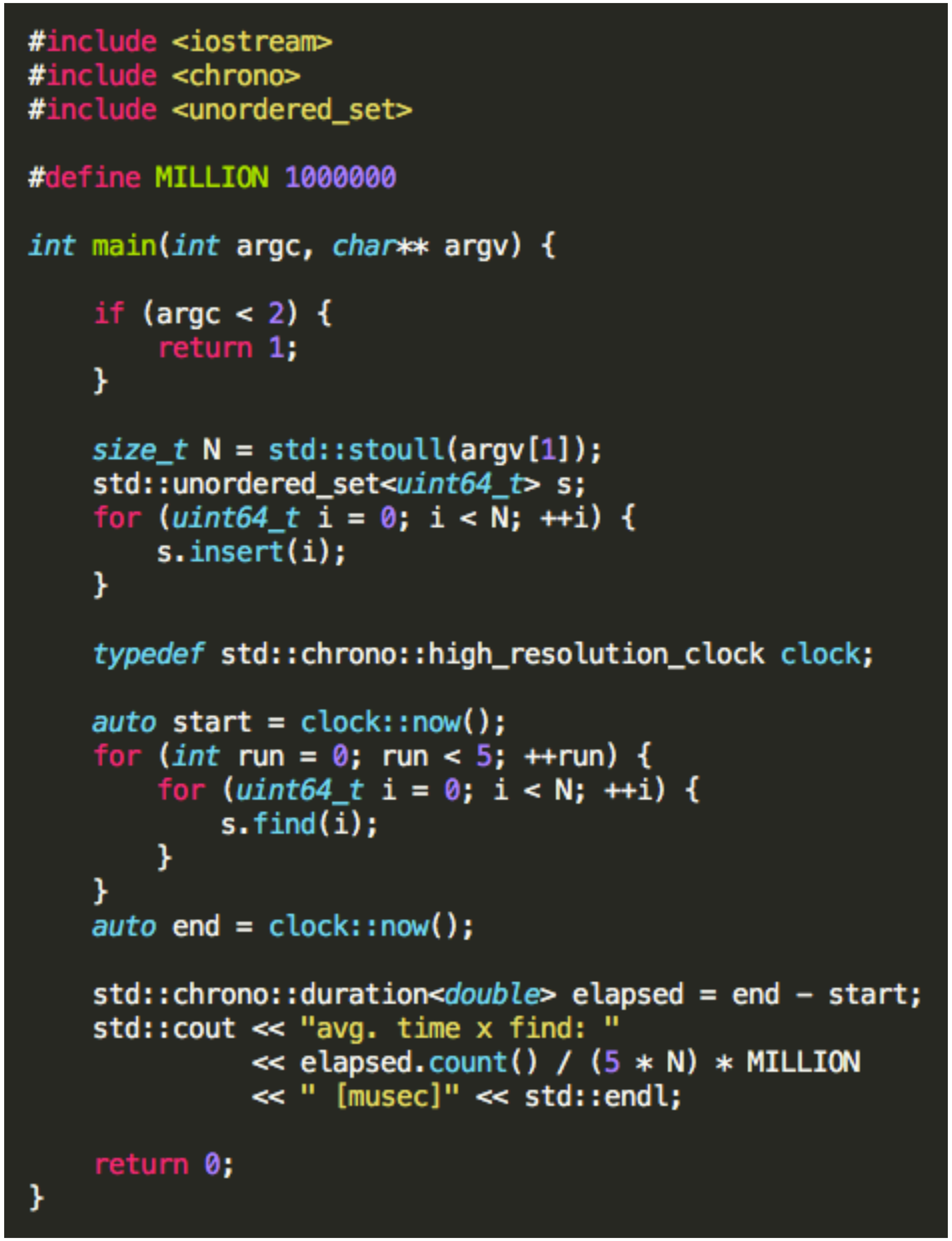
based on **hashing**

insert/delete: O(1) exp.
range queries: ——

# Associative containers

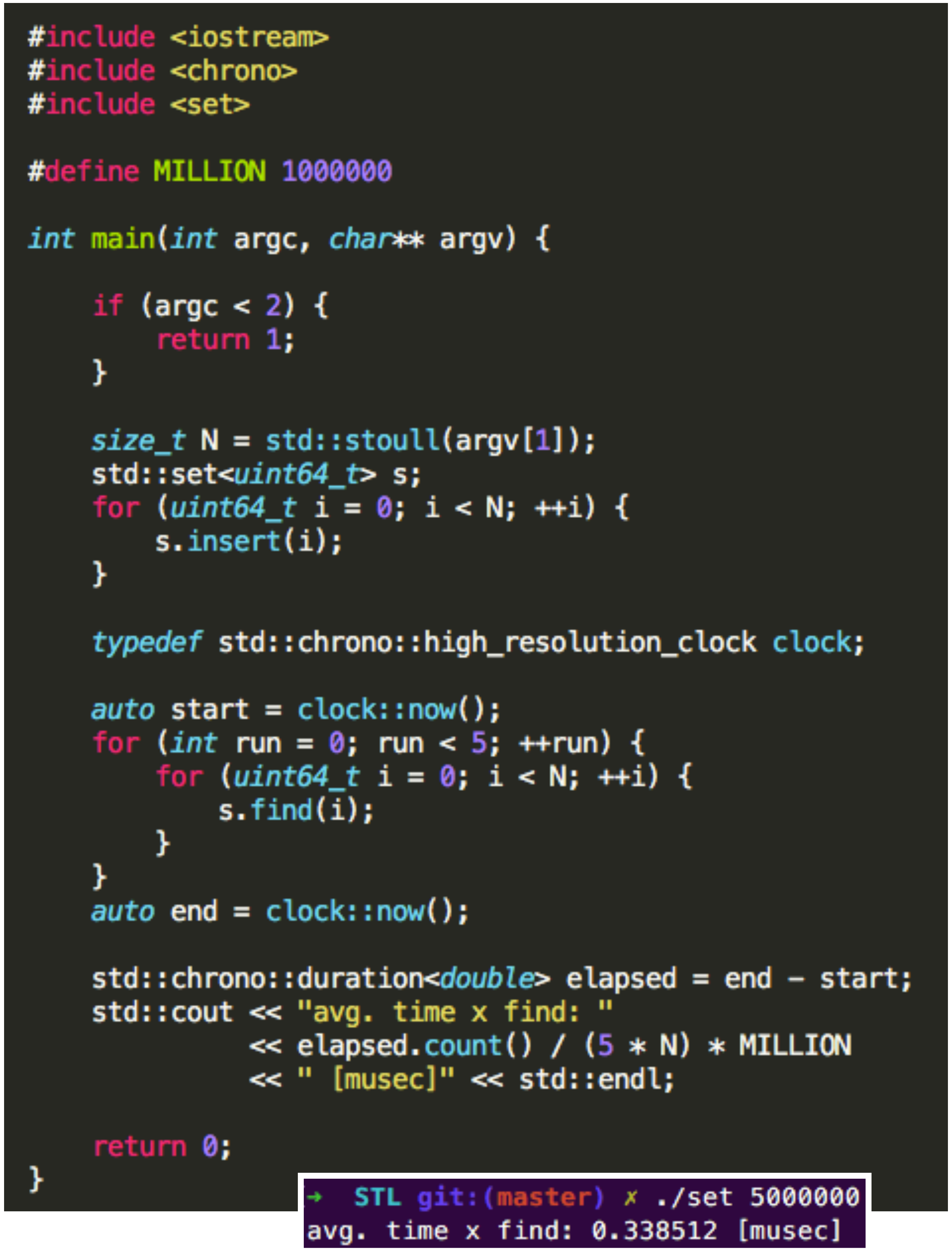


```
#include <iostream>
#include <chrono>
#include <set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```



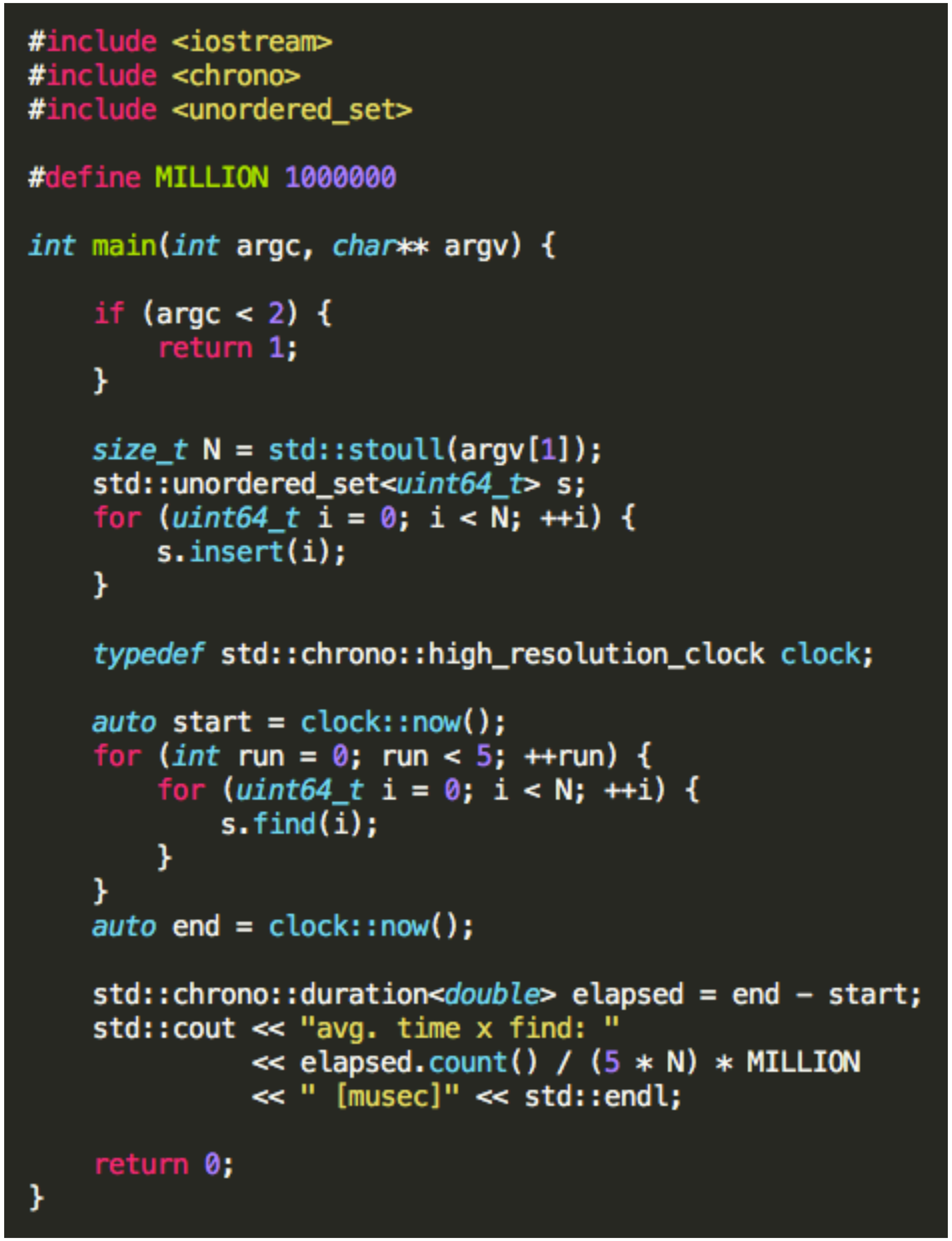
```
#include <iostream>
#include <chrono>
#include <unordered_set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::unordered_set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

# Associative containers



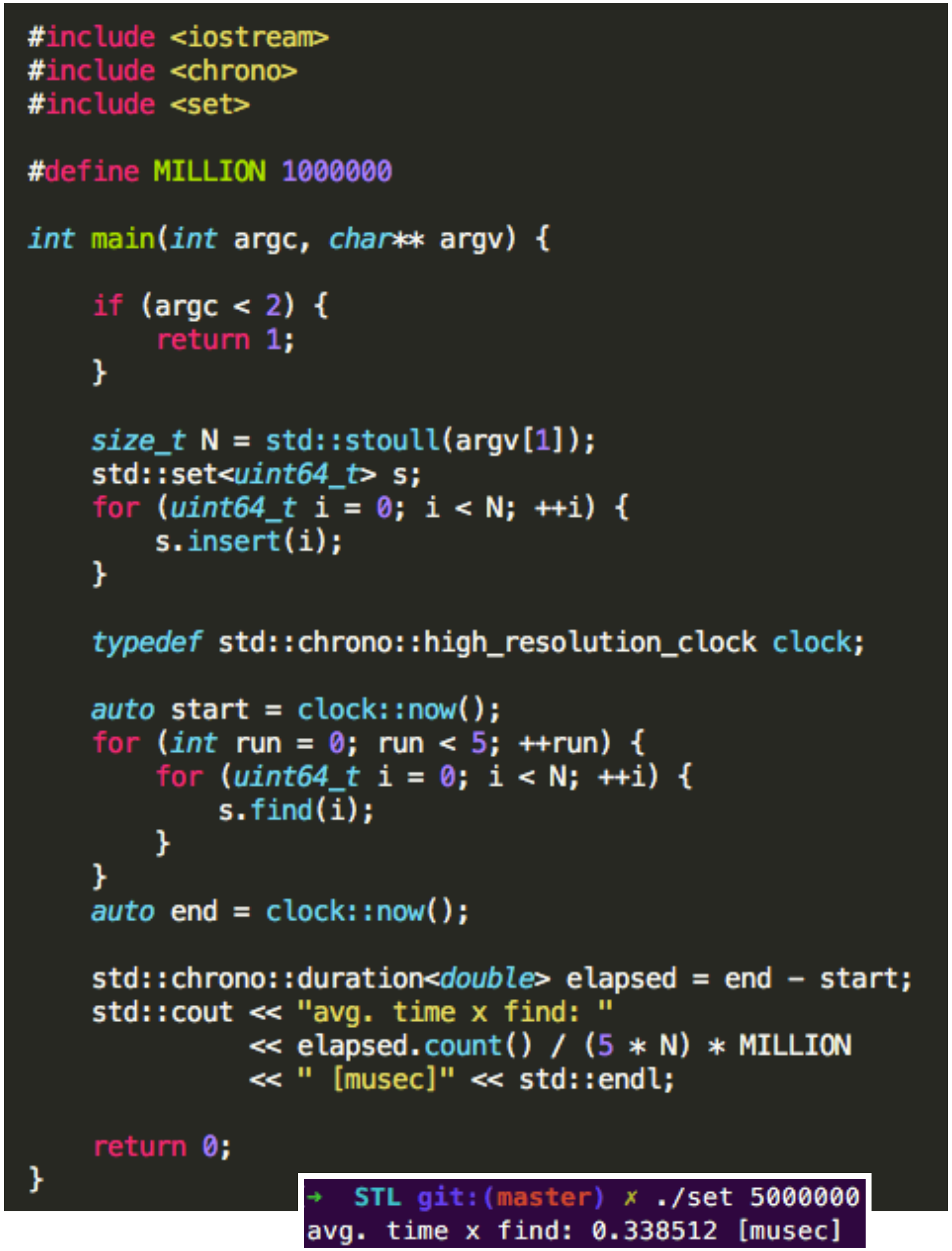
```cpp
#include <iostream>
#include <chrono>
#include <set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

```
➜  STL git:(master) ✗ ./set 5000000
avg. time x find: 0.338512 [musec]
```



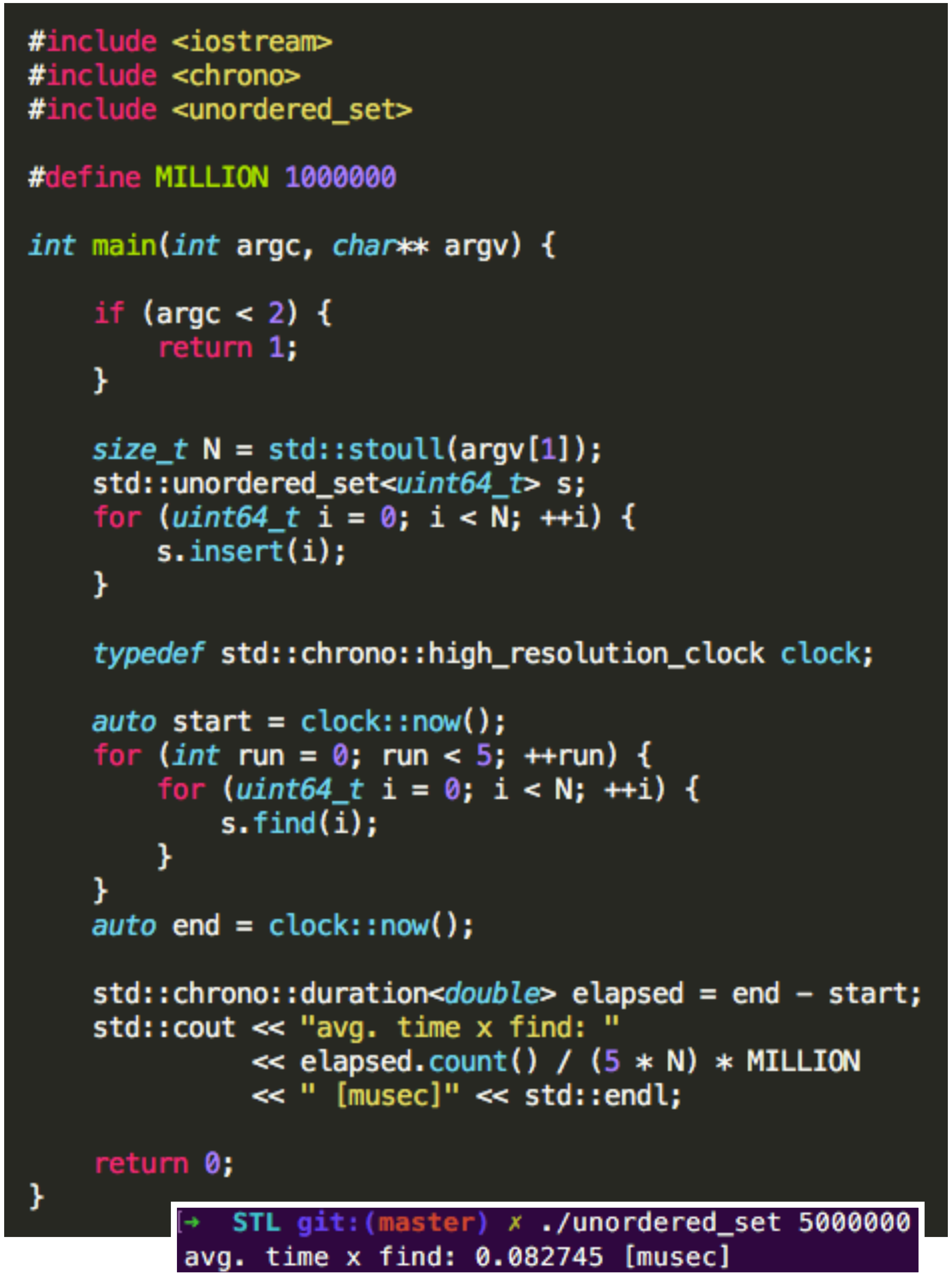
```cpp
#include <iostream>
#include <chrono>
#include <unordered_set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::unordered_set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

# Associative containers



```cpp
#include <iostream>
#include <chrono>
#include <set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

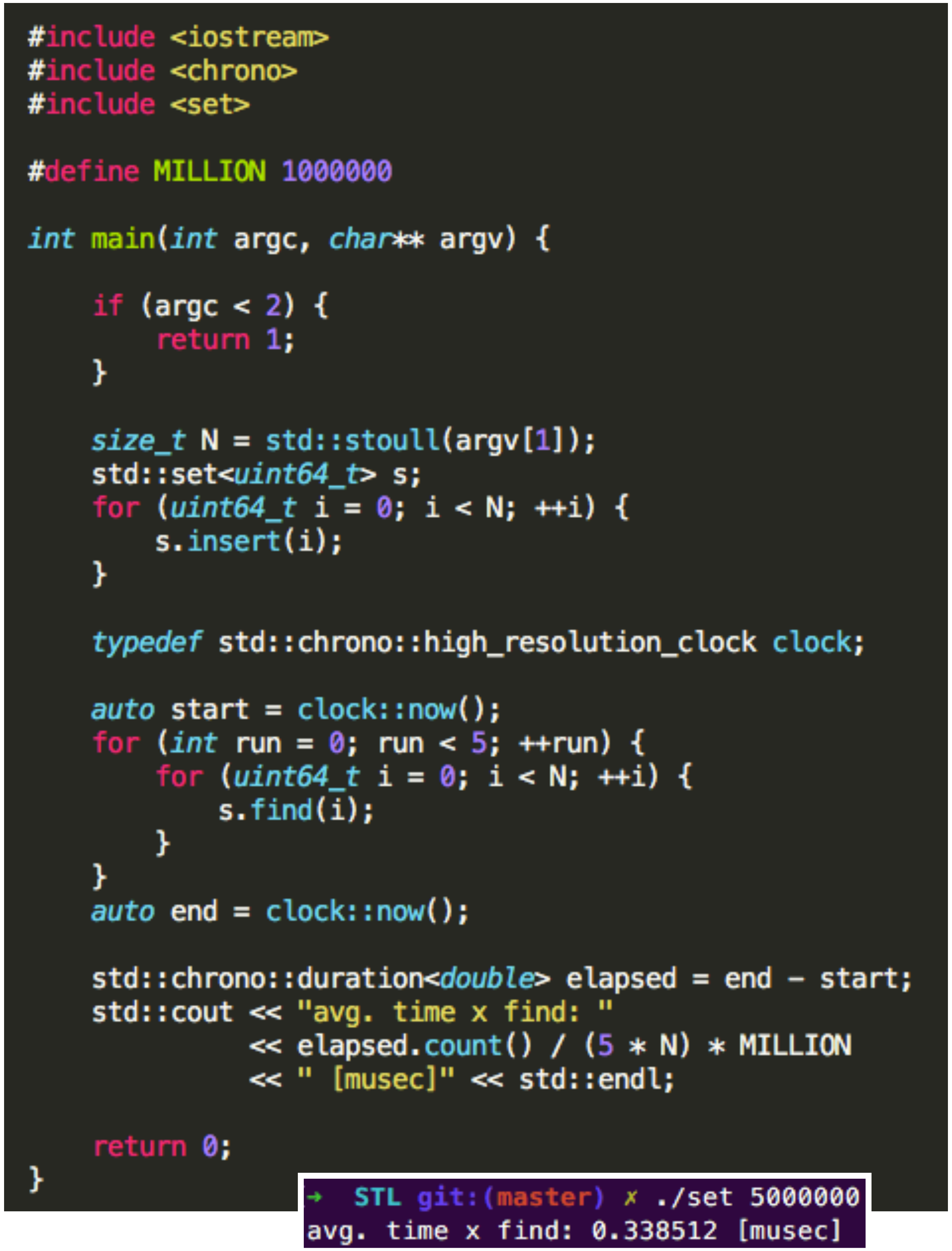
```
➜  STL git:(master) ✗ ./set 5000000
avg. time x find: 0.338512 [musec]
```



```cpp
#include <iostream>
#include <chrono>
#include <unordered_set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::unordered_set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

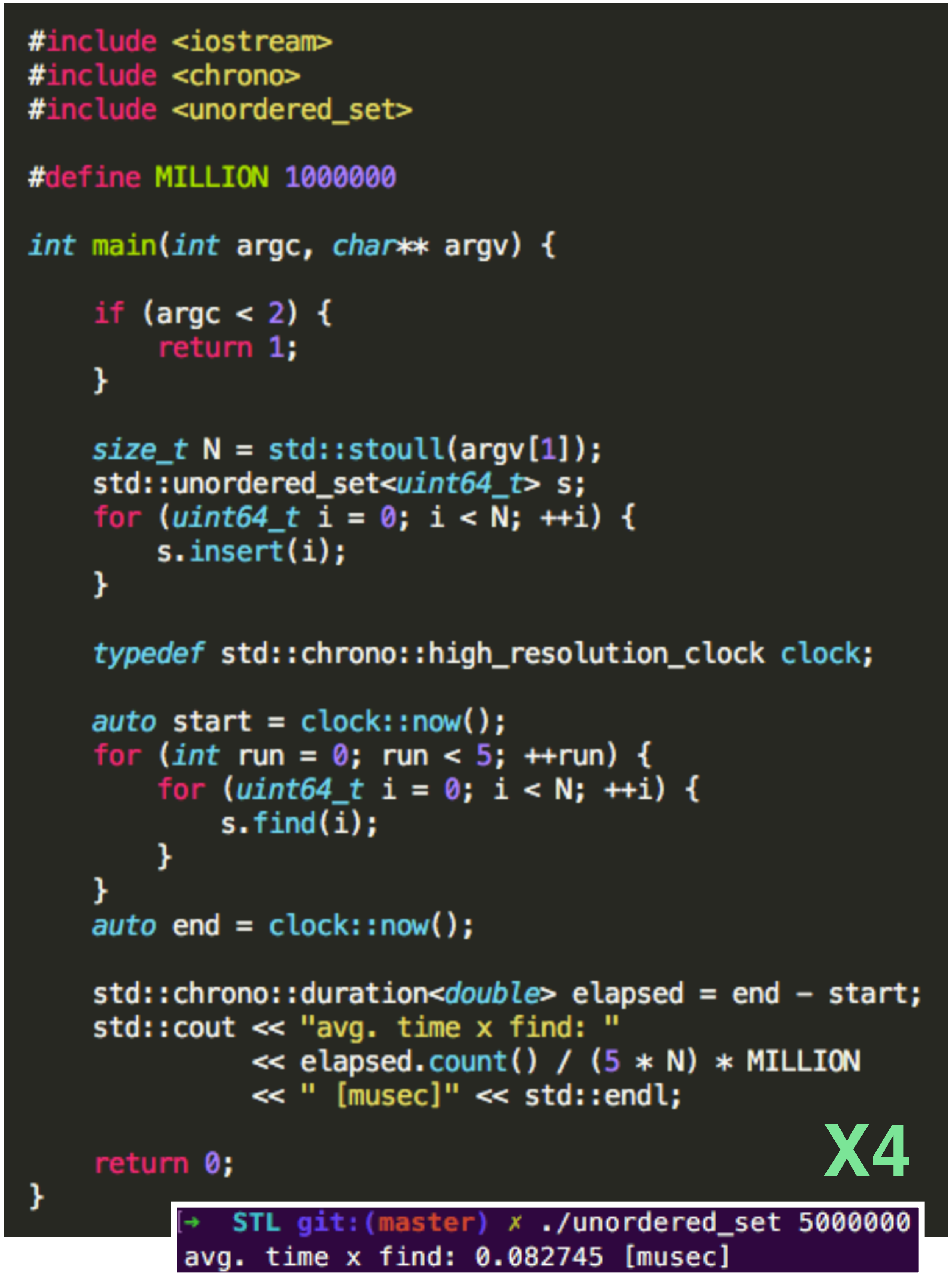
```
➜  STL git:(master) ✗ ./unordered_set 5000000
avg. time x find: 0.082745 [musec]
```

# Associative containers



```
#include <iostream>
#include <chrono>
#include <set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

```
→  STL git:(master) ✗ ./set 5000000
avg. time x find: 0.338512 [musec]
```



```
#include <iostream>
#include <chrono>
#include <unordered_set>

#define MILLION 1000000

int main(int argc, char** argv) {

    if (argc < 2) {
        return 1;
    }

    size_t N = std::stoull(argv[1]);
    std::unordered_set<uint64_t> s;
    for (uint64_t i = 0; i < N; ++i) {
        s.insert(i);
    }

    typedef std::chrono::high_resolution_clock clock;

    auto start = clock::now();
    for (int run = 0; run < 5; ++run) {
        for (uint64_t i = 0; i < N; ++i) {
            s.find(i);
        }
    }
    auto end = clock::now();

    std::chrono::duration<double> elapsed = end - start;
    std::cout << "avg. time x find: "
              << elapsed.count() / (5 * N) * MILLION
              << " [musec]" << std::endl;

    return 0;
}
```

```
→  STL git:(master) ✗ ./unordered_set 5000000
avg. time x find: 0.082745 [musec]
```

X4

# Iterators

An iterator is any **object** that, pointing to some element in a range of elements (such as an array or a container), has the ability to **iterate** through the elements of that range using a set of operators, at least the increment (++) and dereference (*) operators.

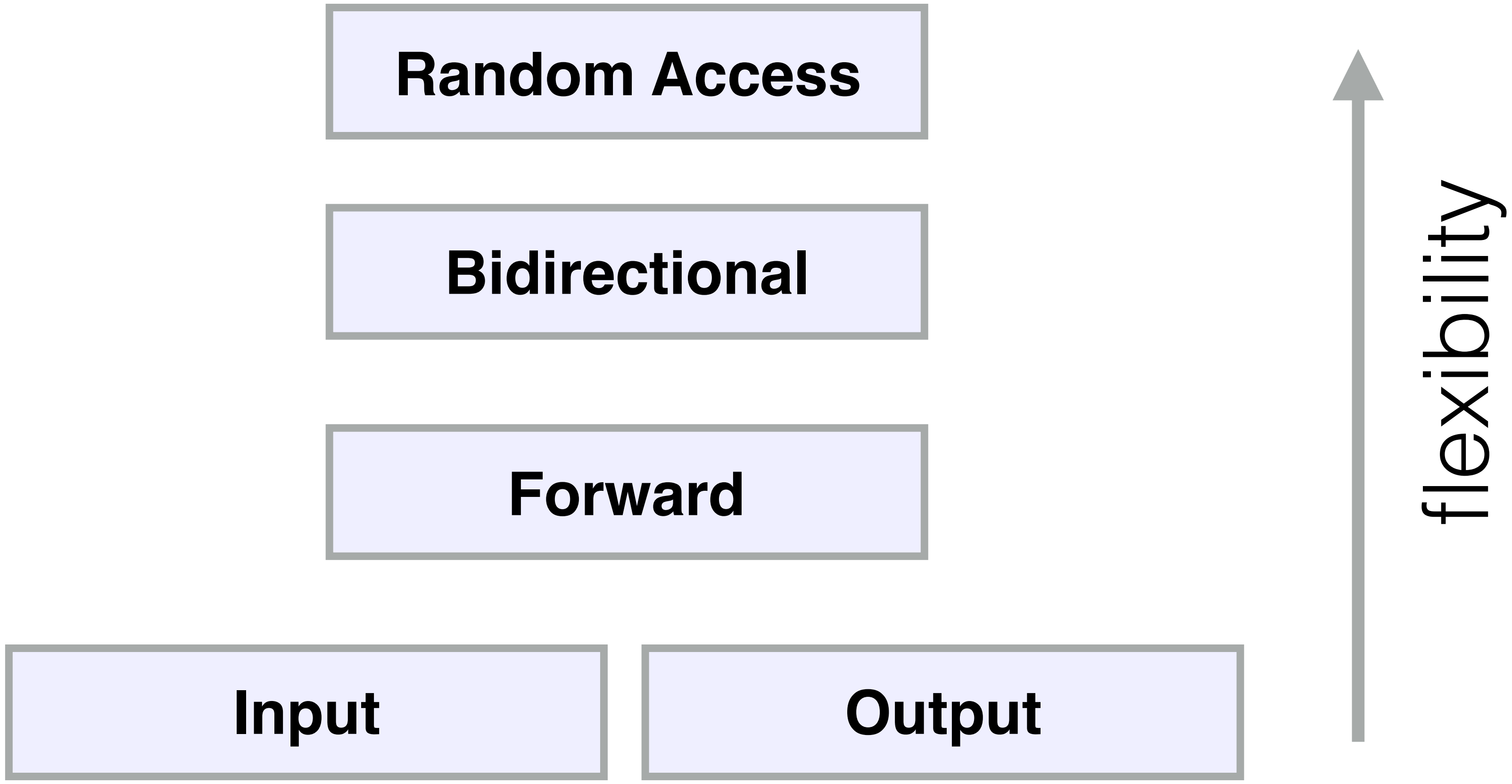
Operations:

```
advance
distance
begin
end
prev
next
```

# Iterators

An iterator is any **object** that, pointing to some element in a range of elements (such as an array or a container), has the ability to **iterate** through the elements of that range using a set of operators, at least the increment (++) and dereference (*) operators.

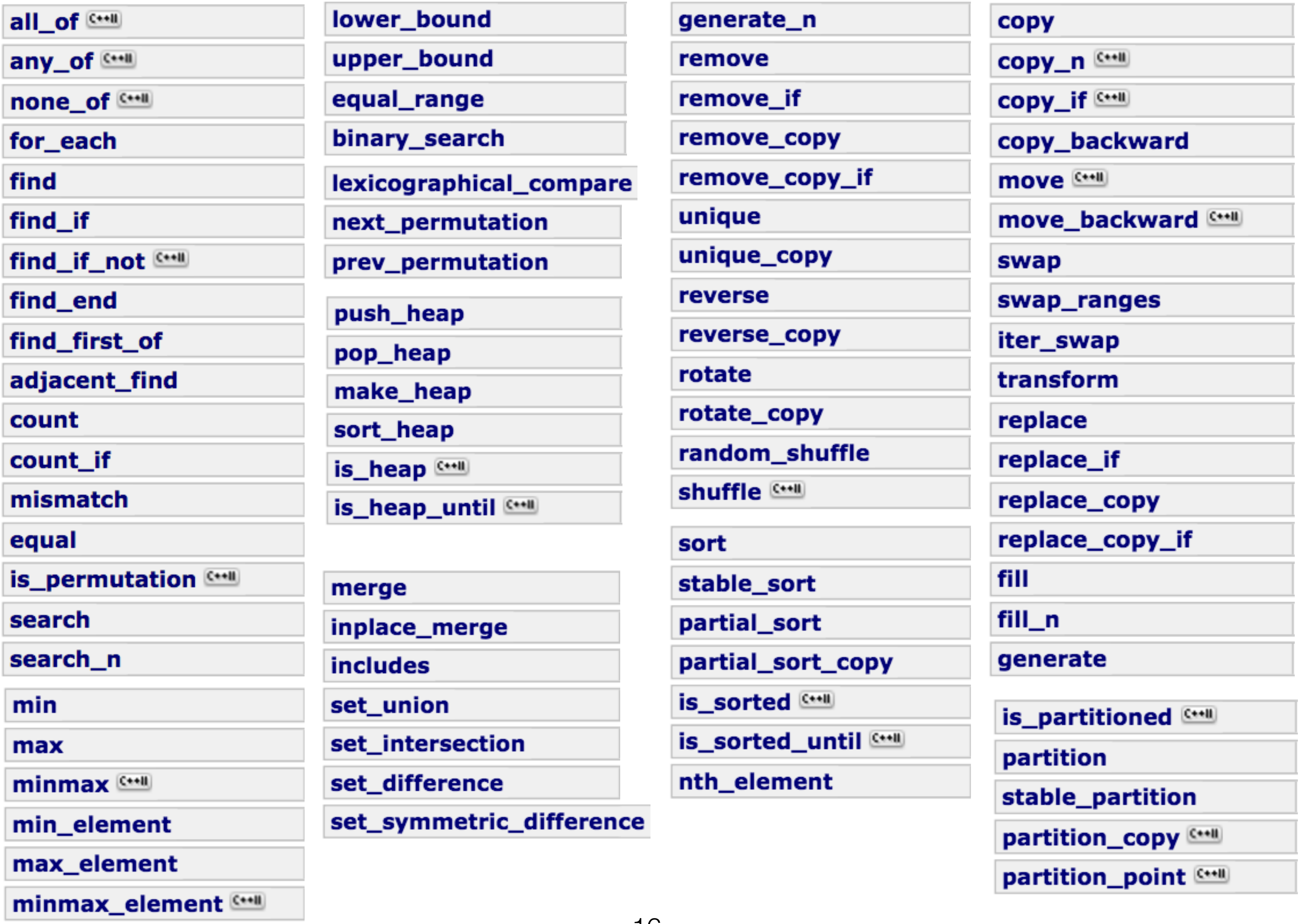
Operations:
`advance`
`distance`
`begin`
`end`
`prev`
`next`



`<algorithm>`

# Algorithms

+ 20 with `C++11`



- all_of C++11
- any_of C++11
- none_of C++11
- for_each
- find
- find_if
- find_if_not C++11
- find_end
- find_first_of
- adjacent_find
- count
- count_if
- mismatch
- equal
- is_permutation C++11
- search
- search_n

- min
- max
- minmax C++11
- min_element
- max_element
- minmax_element C++11

- lower_bound
- upper_bound
- equal_range
- binary_search

- lexicographical_compare
- next_permutation
- prev_permutation

- push_heap
- pop_heap
- make_heap
- sort_heap
- is_heap C++11
- is_heap_until C++11

- merge
- inplace_merge
- includes
- set_union
- set_intersection
- set_difference
- set_symmetric_difference

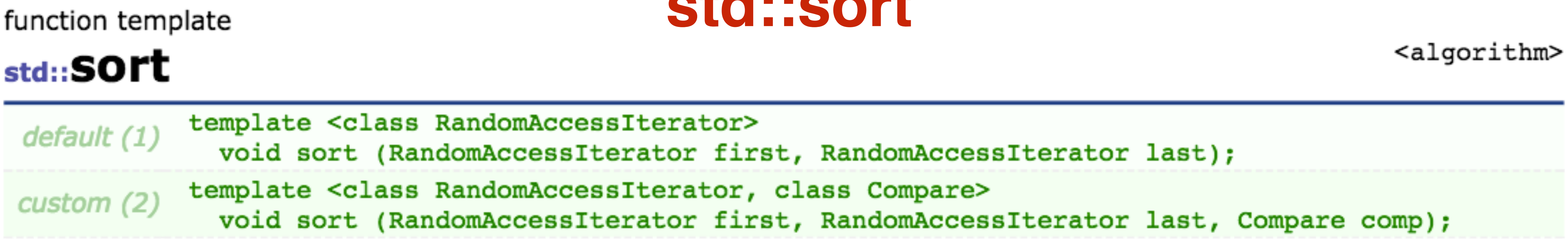
- generate_n
- remove
- remove_if
- remove_copy
- remove_copy_if
- unique
- unique_copy
- reverse
- reverse_copy
- rotate
- rotate_copy
- random_shuffle
- shuffle C++11

- sort
- stable_sort
- partial_sort
- partial_sort_copy
- is_sorted C++11
- is_sorted_until C++11
- nth_element

- copy
- copy_n C++11
- copy_if C++11
- copy_backward
- move C++11
- move_backward C++11
- swap
- swap_ranges
- iter_swap
- transform
- replace
- replace_if
- replace_copy
- replace_copy_if
- fill
- fill_n
- generate

- is_partitioned C++11
- partition
- stable_partition
- partition_copy C++11
- partition_point C++11

# std::sort

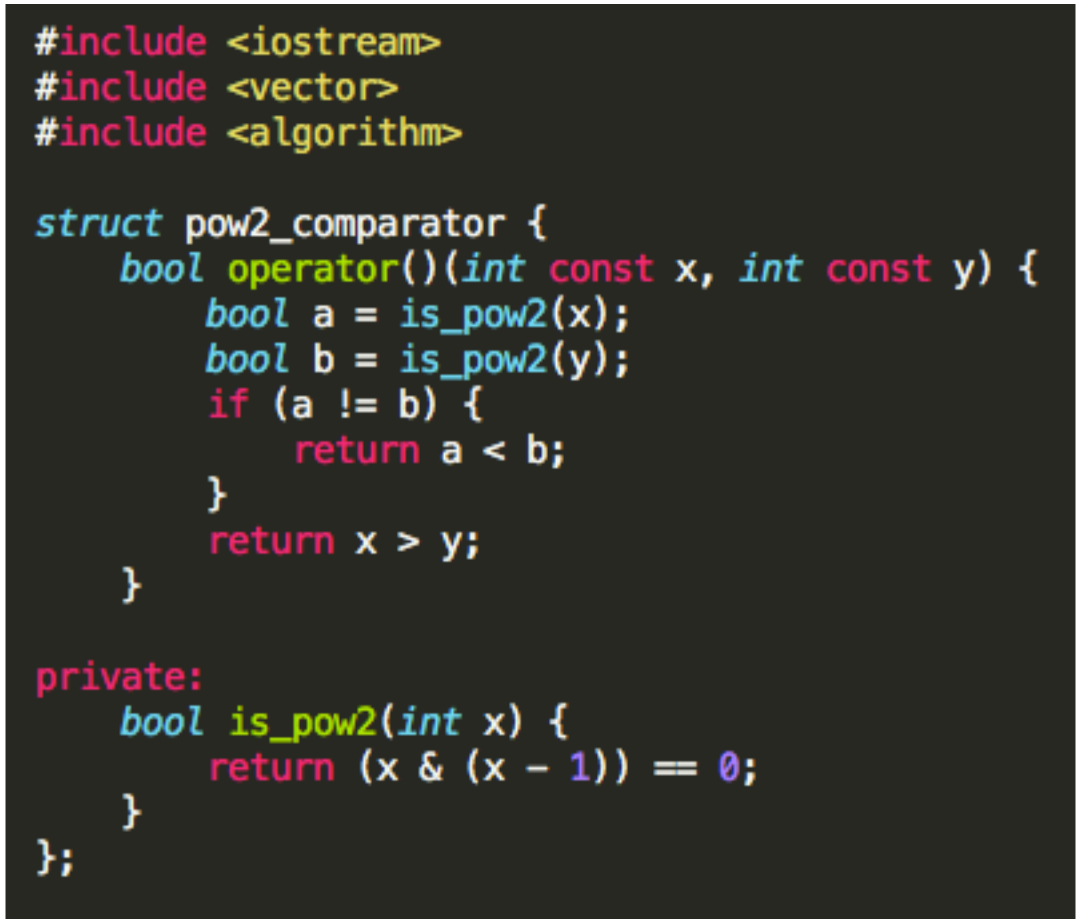


function template

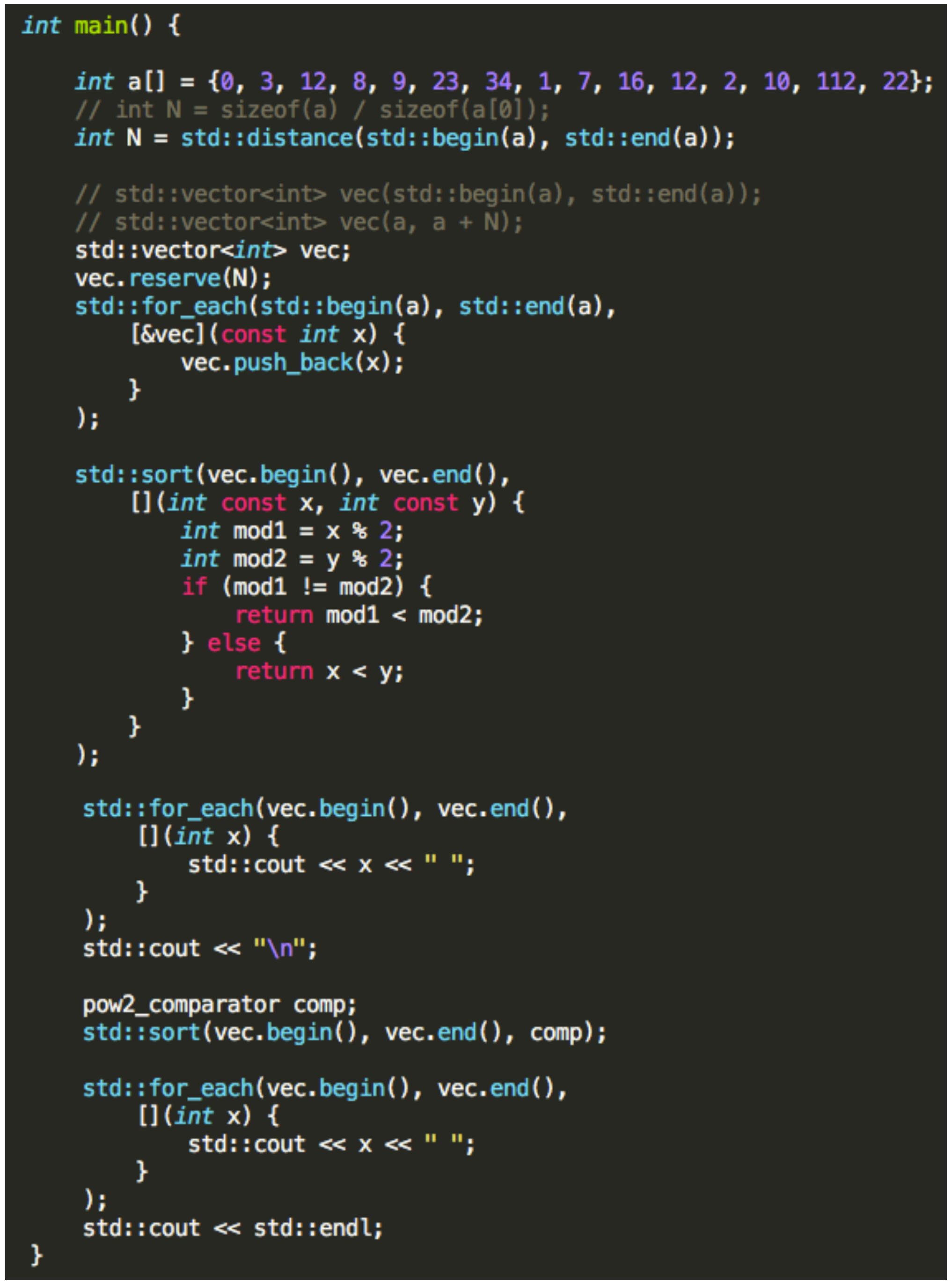
std::**sort**

<algorithm>

| | |
|---|---|
| *default (1)* | `template <class RandomAccessIterator>`<br>`  void sort (RandomAccessIterator first, RandomAccessIterator last);` |
| *custom (2)* | `template <class RandomAccessIterator, class Compare>`<br>`  void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);` |

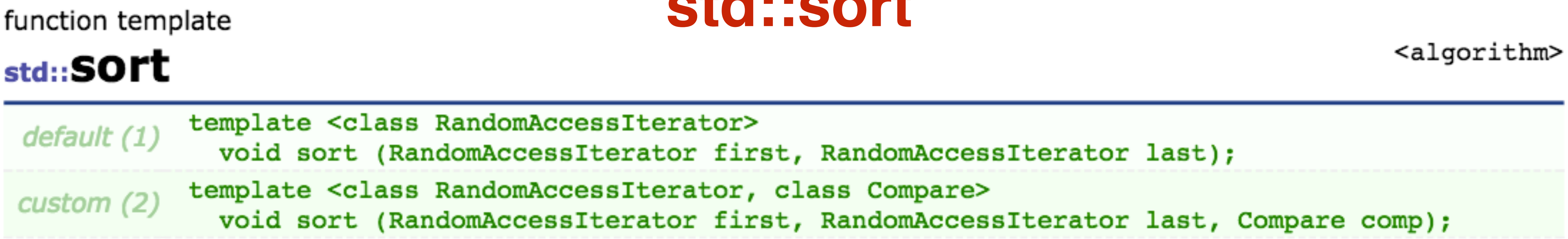


```cpp
#include <iostream>
#include <vector>
#include <algorithm>

struct pow2_comparator {
    bool operator()(int const x, int const y) {
        bool a = is_pow2(x);
        bool b = is_pow2(y);
        if (a != b) {
            return a < b;
        }
        return x > y;
    }

private:
    bool is_pow2(int x) {
        return (x & (x - 1)) == 0;
    }
};
```



```cpp
int main() {

    int a[] = {0, 3, 12, 8, 9, 23, 34, 1, 7, 16, 12, 2, 10, 112, 22};
    // int N = sizeof(a) / sizeof(a[0]);
    int N = std::distance(std::begin(a), std::end(a));

    // std::vector<int> vec(std::begin(a), std::end(a));
    // std::vector<int> vec(a, a + N);
    std::vector<int> vec;
    vec.reserve(N);
    std::for_each(std::begin(a), std::end(a),
        [&vec](const int x) {
            vec.push_back(x);
        }
    );

    std::sort(vec.begin(), vec.end(),
        [](int const x, int const y) {
            int mod1 = x % 2;
            int mod2 = y % 2;
            if (mod1 != mod2) {
                return mod1 < mod2;
            } else {
                return x < y;
            }
        }
    );

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }
    );
    std::cout << "\n";

    pow2_comparator comp;
    std::sort(vec.begin(), vec.end(), comp);

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }
    );
    std::cout << std::endl;
}
```

# std::sort

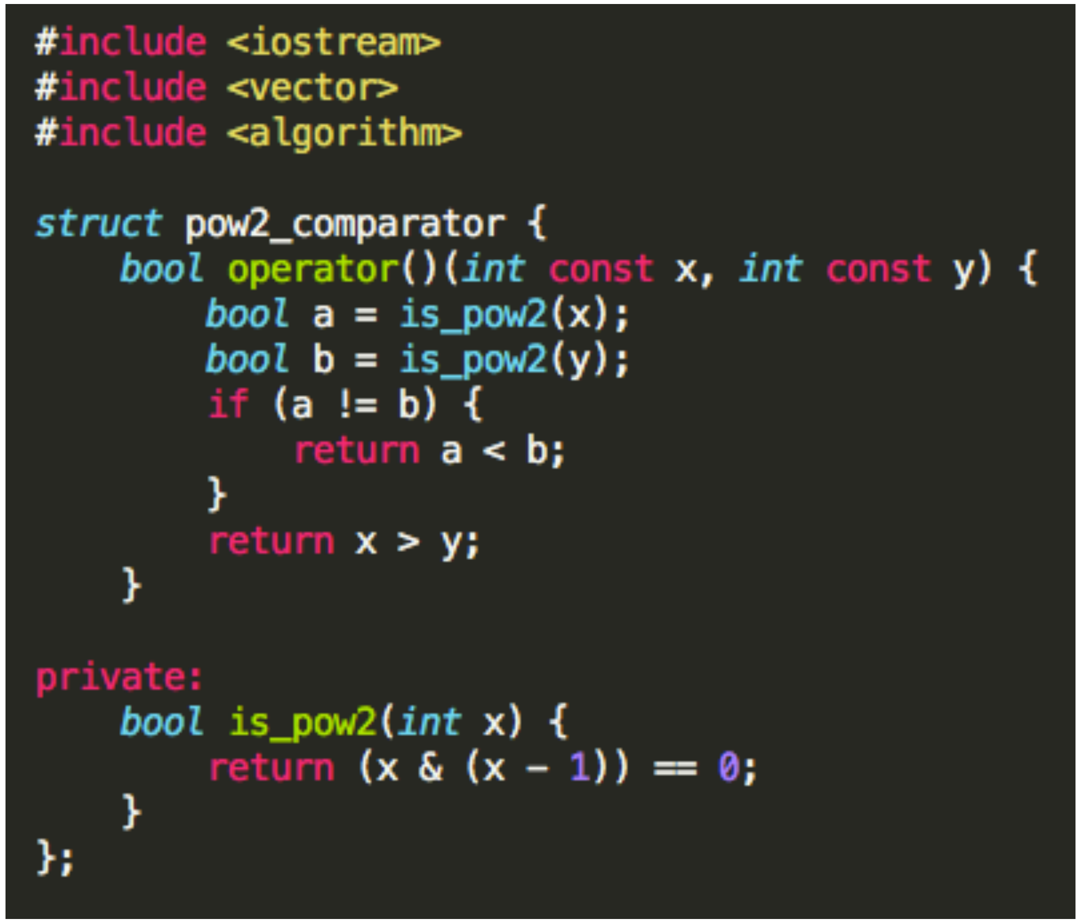


function template

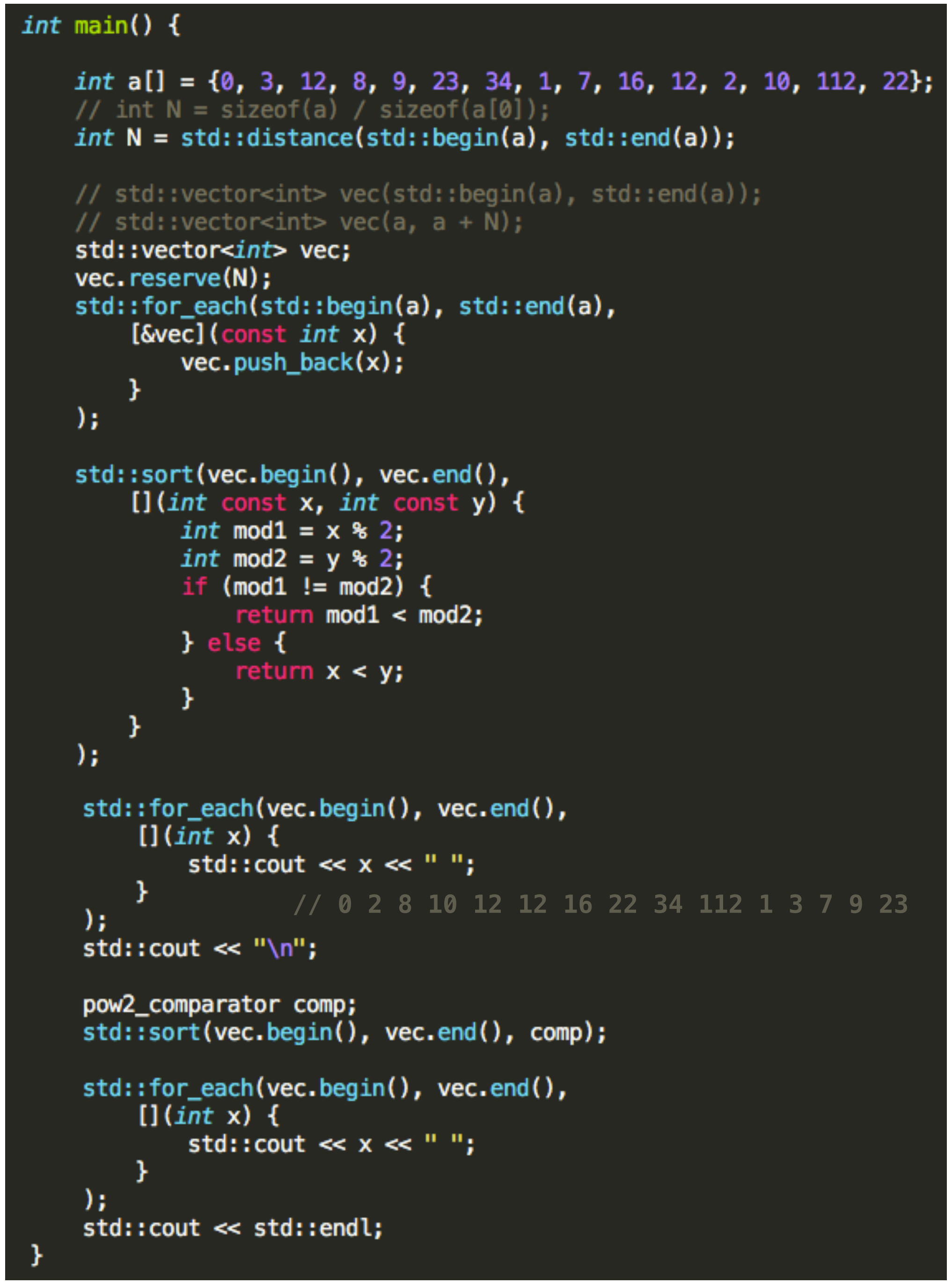
**std::sort**

<algorithm>

| | |
|---|---|
| *default (1)* | `template <class RandomAccessIterator>`<br>`  void sort (RandomAccessIterator first, RandomAccessIterator last);` |
| *custom (2)* | `template <class RandomAccessIterator, class Compare>`<br>`  void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);` |

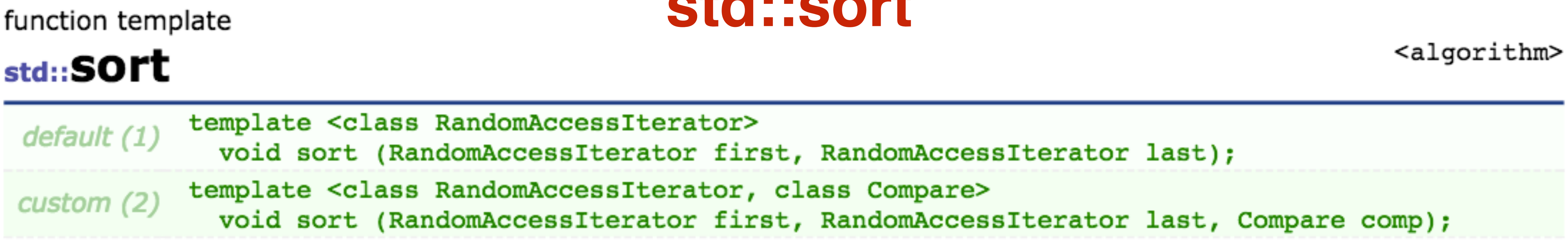


```
#include <iostream>
#include <vector>
#include <algorithm>

struct pow2_comparator {
    bool operator()(int const x, int const y) {
        bool a = is_pow2(x);
        bool b = is_pow2(y);
        if (a != b) {
            return a < b;
        }
        return x > y;
    }

private:
    bool is_pow2(int x) {
        return (x & (x - 1)) == 0;
    }
};
```



```
int main() {

    int a[] = {0, 3, 12, 8, 9, 23, 34, 1, 7, 16, 12, 2, 10, 112, 22};
    // int N = sizeof(a) / sizeof(a[0]);
    int N = std::distance(std::begin(a), std::end(a));

    // std::vector<int> vec(std::begin(a), std::end(a));
    // std::vector<int> vec(a, a + N);
    std::vector<int> vec;
    vec.reserve(N);
    std::for_each(std::begin(a), std::end(a),
        [&vec](const int x) {
            vec.push_back(x);
        }
    );

    std::sort(vec.begin(), vec.end(),
        [](int const x, int const y) {
            int mod1 = x % 2;
            int mod2 = y % 2;
            if (mod1 != mod2) {
                return mod1 < mod2;
            } else {
                return x < y;
            }
        }
    );

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }               // 0 2 8 10 12 12 16 22 34 112 1 3 7 9 23
    );
    std::cout << "\n";

    pow2_comparator comp;
    std::sort(vec.begin(), vec.end(), comp);

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }
    );
    std::cout << std::endl;
}
```

# std::sort



function template

**std::sort**

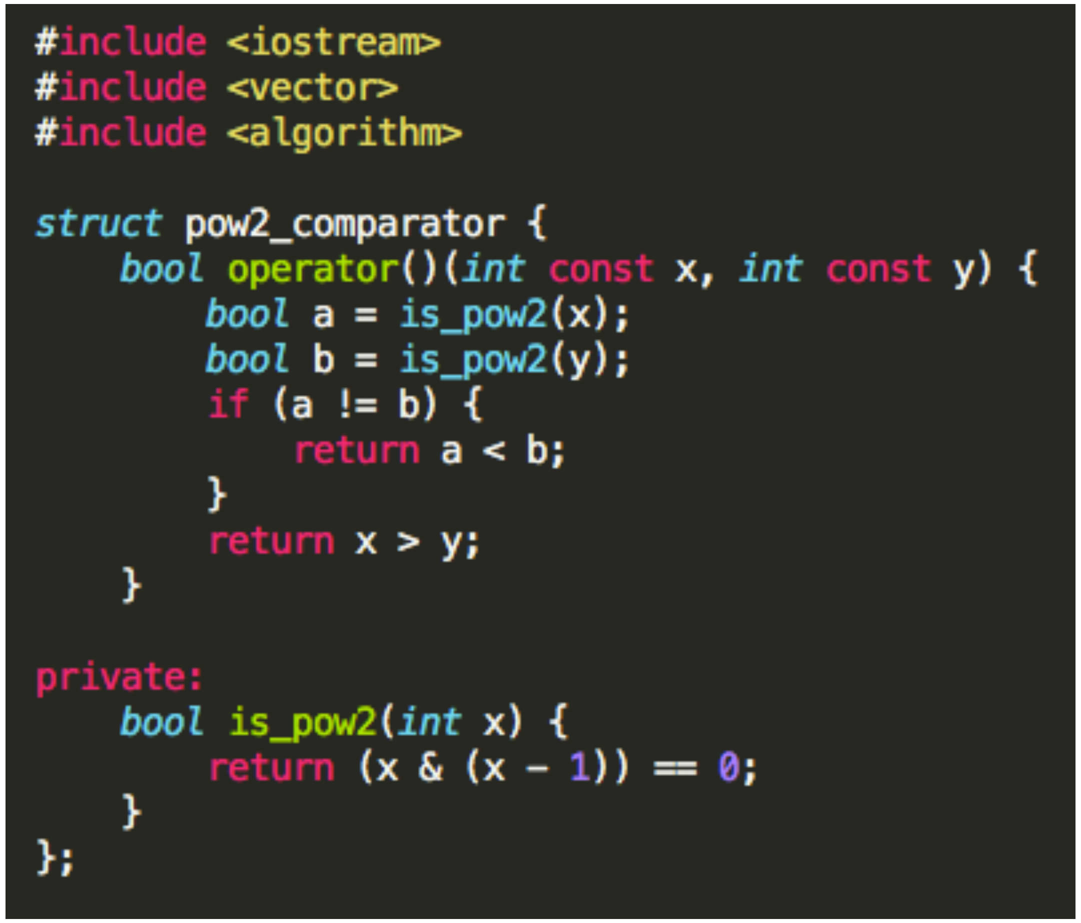
<algorithm>

default (1)

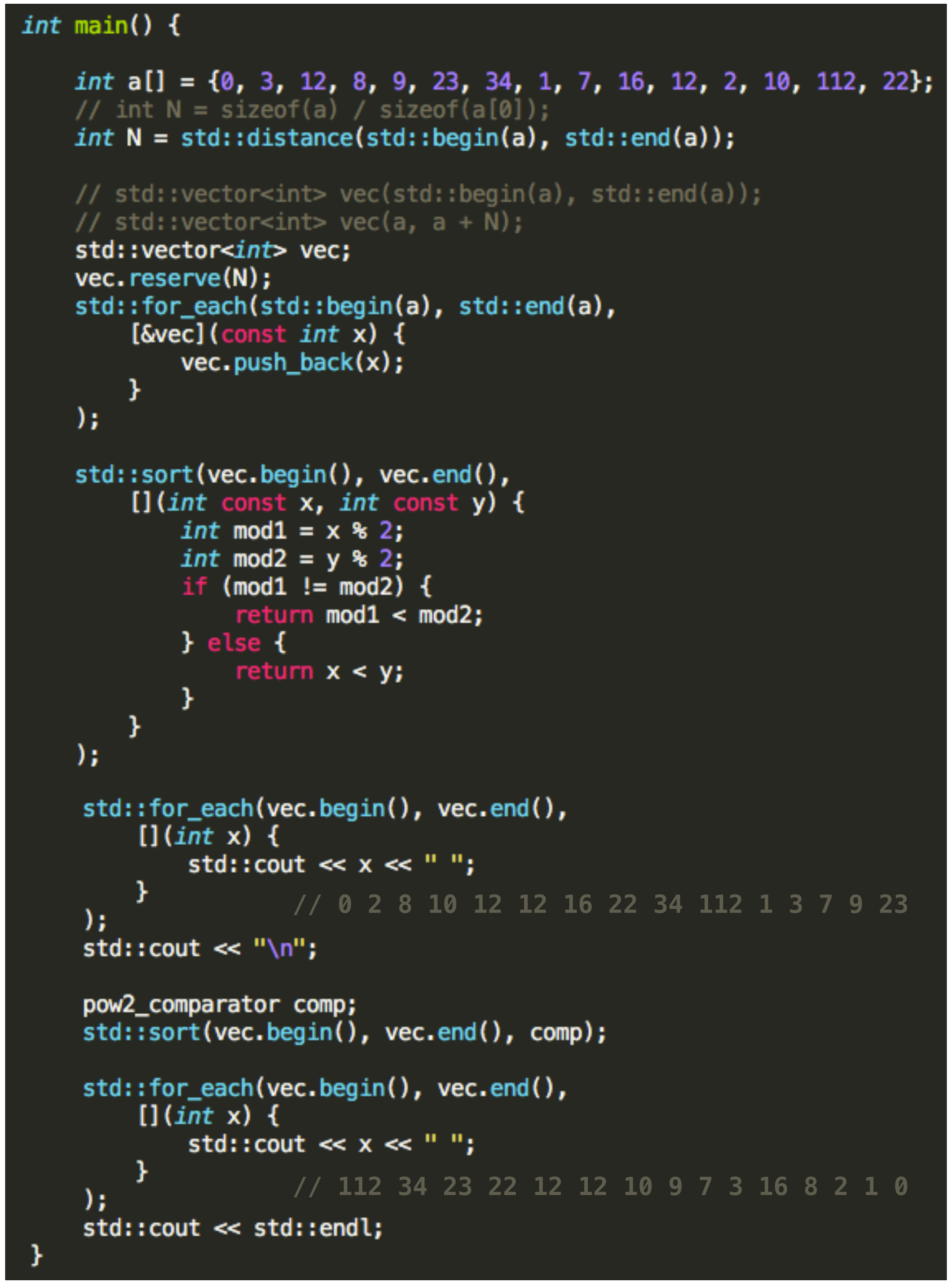
```
template <class RandomAccessIterator>
  void sort (RandomAccessIterator first, RandomAccessIterator last);
```

custom (2)

```
template <class RandomAccessIterator, class Compare>
  void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```

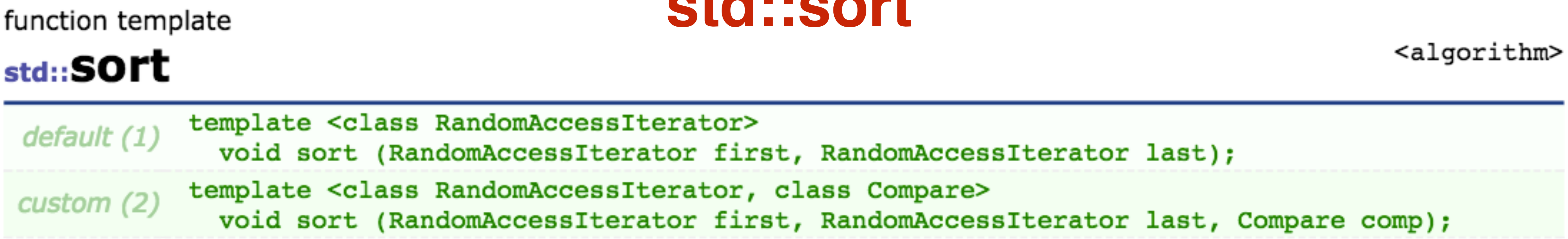


```
#include <iostream>
#include <vector>
#include <algorithm>

struct pow2_comparator {
    bool operator()(int const x, int const y) {
        bool a = is_pow2(x);
        bool b = is_pow2(y);
        if (a != b) {
            return a < b;
        }
        return x > y;
    }

private:
    bool is_pow2(int x) {
        return (x & (x - 1)) == 0;
    }
};
```



```
int main() {

    int a[] = {0, 3, 12, 8, 9, 23, 34, 1, 7, 16, 12, 2, 10, 112, 22};
    // int N = sizeof(a) / sizeof(a[0]);
    int N = std::distance(std::begin(a), std::end(a));

    // std::vector<int> vec(std::begin(a), std::end(a));
    // std::vector<int> vec(a, a + N);
    std::vector<int> vec;
    vec.reserve(N);
    std::for_each(std::begin(a), std::end(a),
        [&vec](const int x) {
            vec.push_back(x);
        }
    );

    std::sort(vec.begin(), vec.end(),
        [](int const x, int const y) {
            int mod1 = x % 2;
            int mod2 = y % 2;
            if (mod1 != mod2) {
                return mod1 < mod2;
            } else {
                return x < y;
            }
        }
    );

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }              // 0 2 8 10 12 12 16 22 34 112 1 3 7 9 23
    );
    std::cout << "\n";

    pow2_comparator comp;
    std::sort(vec.begin(), vec.end(), comp);

    std::for_each(vec.begin(), vec.end(),
        [](int x) {
            std::cout << x << " ";
        }              // 112 34 23 22 12 12 10 9 7 3 16 8 2 1 0
    );
    std::cout << std::endl;
}
```

# std::sort

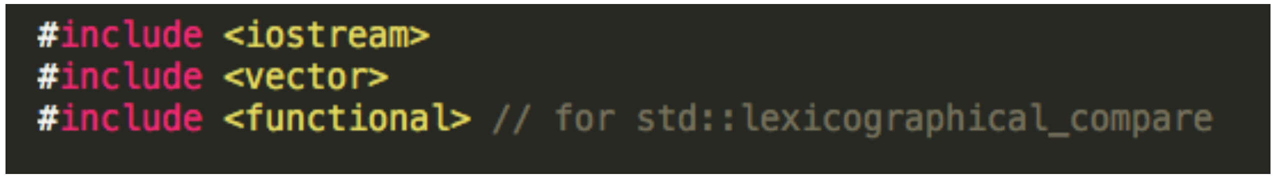


function template

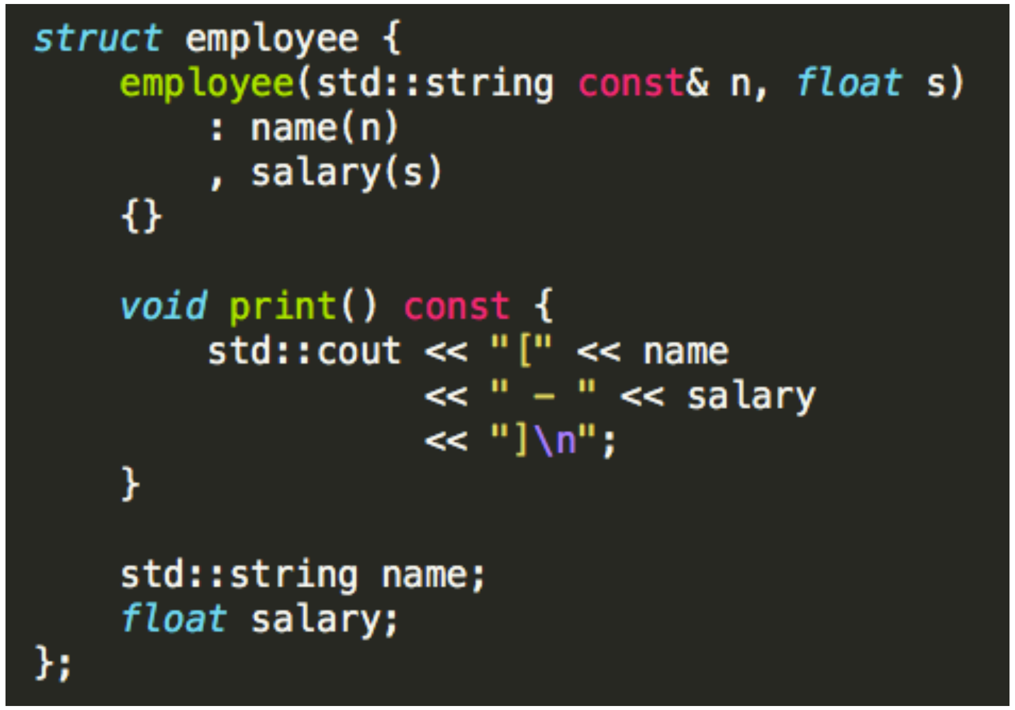
**std::sort**

`<algorithm>`

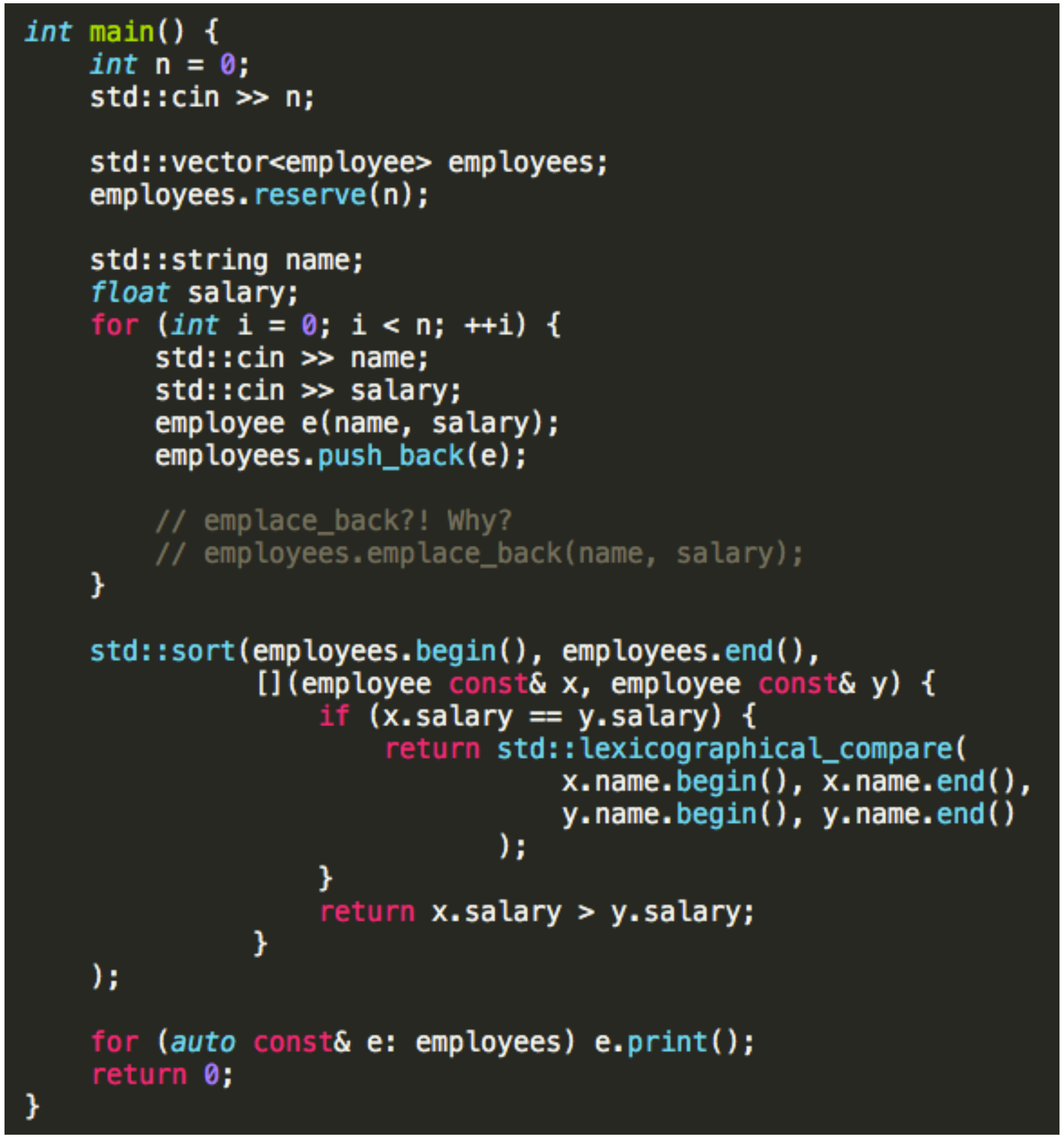
```
default (1)   template <class RandomAccessIterator>
                void sort (RandomAccessIterator first, RandomAccessIterator last);
custom (2)    template <class RandomAccessIterator, class Compare>
                void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);
```



```cpp
#include <iostream>
#include <vector>
#include <functional> // for std::lexicographical_compare
```

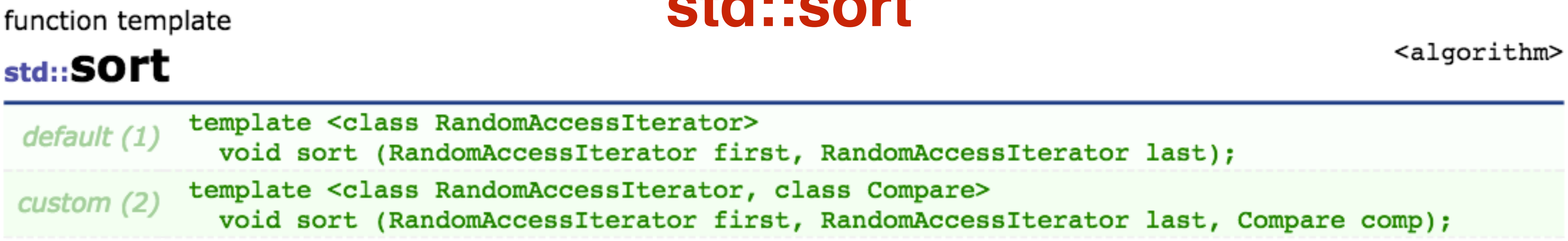


```cpp
struct employee {
    employee(std::string const& n, float s)
        : name(n)
        , salary(s)
    {}

    void print() const {
        std::cout << "[" << name
                  << " - " << salary
                  << "]\n";
    }

    std::string name;
    float salary;
};
```



```cpp
int main() {
    int n = 0;
    std::cin >> n;

    std::vector<employee> employees;
    employees.reserve(n);

    std::string name;
    float salary;
    for (int i = 0; i < n; ++i) {
        std::cin >> name;
        std::cin >> salary;
        employee e(name, salary);
        employees.push_back(e);

        // emplace_back?! Why?
        // employees.emplace_back(name, salary);
    }

    std::sort(employees.begin(), employees.end(),
              [](employee const& x, employee const& y) {
                  if (x.salary == y.salary) {
                      return std::lexicographical_compare(
                                 x.name.begin(), x.name.end(),
                                 y.name.begin(), y.name.end()
                             );
                  }
                  return x.salary > y.salary;
              }
    );

    for (auto const& e: employees) e.print();
    return 0;
}
```

# std::sort

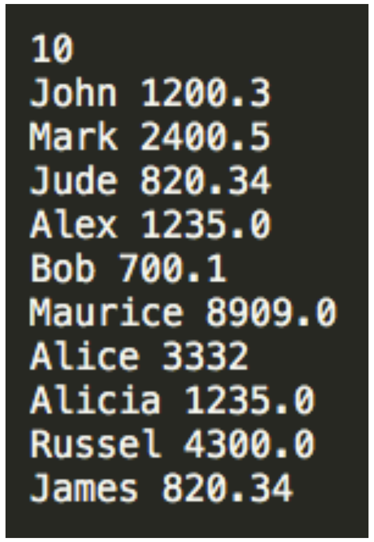


function template

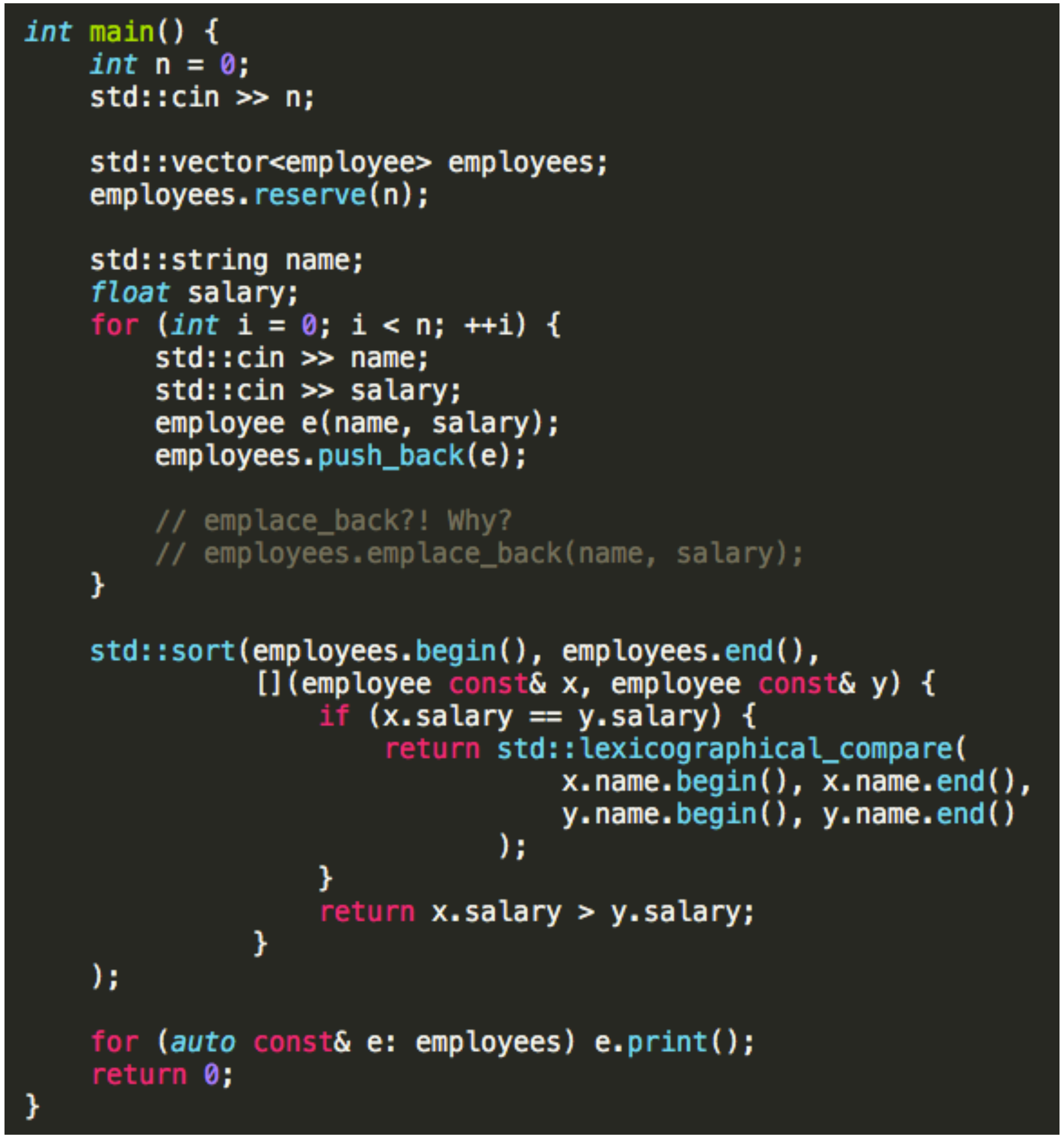
**std::sort**

<algorithm>

| | |
|---|---|
| *default (1)* | `template <class RandomAccessIterator>`<br>`void sort (RandomAccessIterator first, RandomAccessIterator last);` |
| *custom (2)* | `template <class RandomAccessIterator, class Compare>`<br>`void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);` |

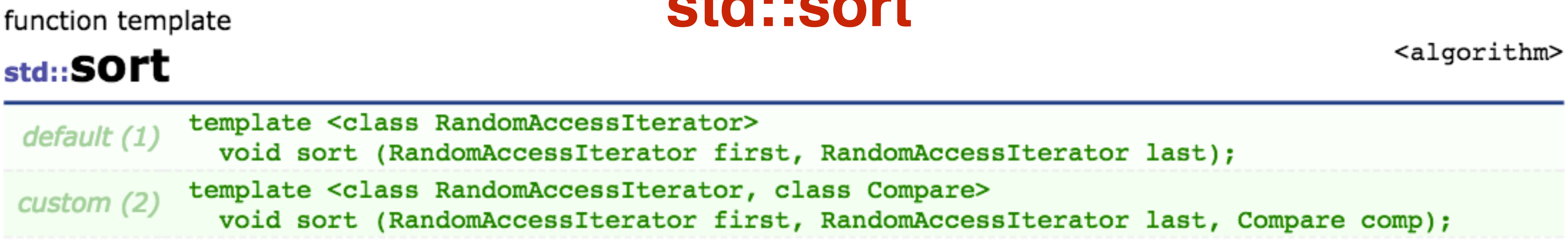


```
10
John 1200.3
Mark 2400.5
Jude 820.34
Alex 1235.0
Bob 700.1
Maurice 8909.0
Alice 3332
Alicia 1235.0
Russel 4300.0
James 820.34
```



```
int main() {
    int n = 0;
    std::cin >> n;

    std::vector<employee> employees;
    employees.reserve(n);

    std::string name;
    float salary;
    for (int i = 0; i < n; ++i) {
        std::cin >> name;
        std::cin >> salary;
        employee e(name, salary);
        employees.push_back(e);

        // emplace_back?! Why?
        // employees.emplace_back(name, salary);
    }

    std::sort(employees.begin(), employees.end(),
              [](employee const& x, employee const& y) {
                  if (x.salary == y.salary) {
                      return std::lexicographical_compare(
                                 x.name.begin(), x.name.end(),
                                 y.name.begin(), y.name.end()
                             );
                  }
                  return x.salary > y.salary;
              }
    );

    for (auto const& e: employees) e.print();
    return 0;
}
```

# std::sort

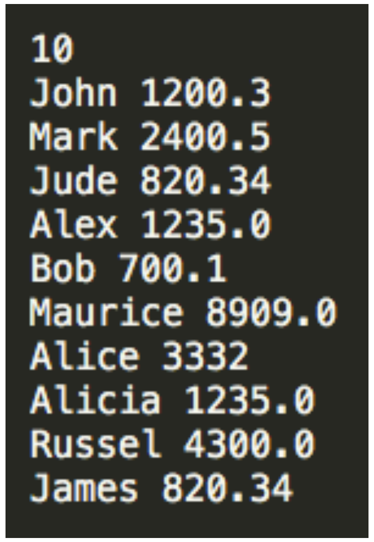


function template

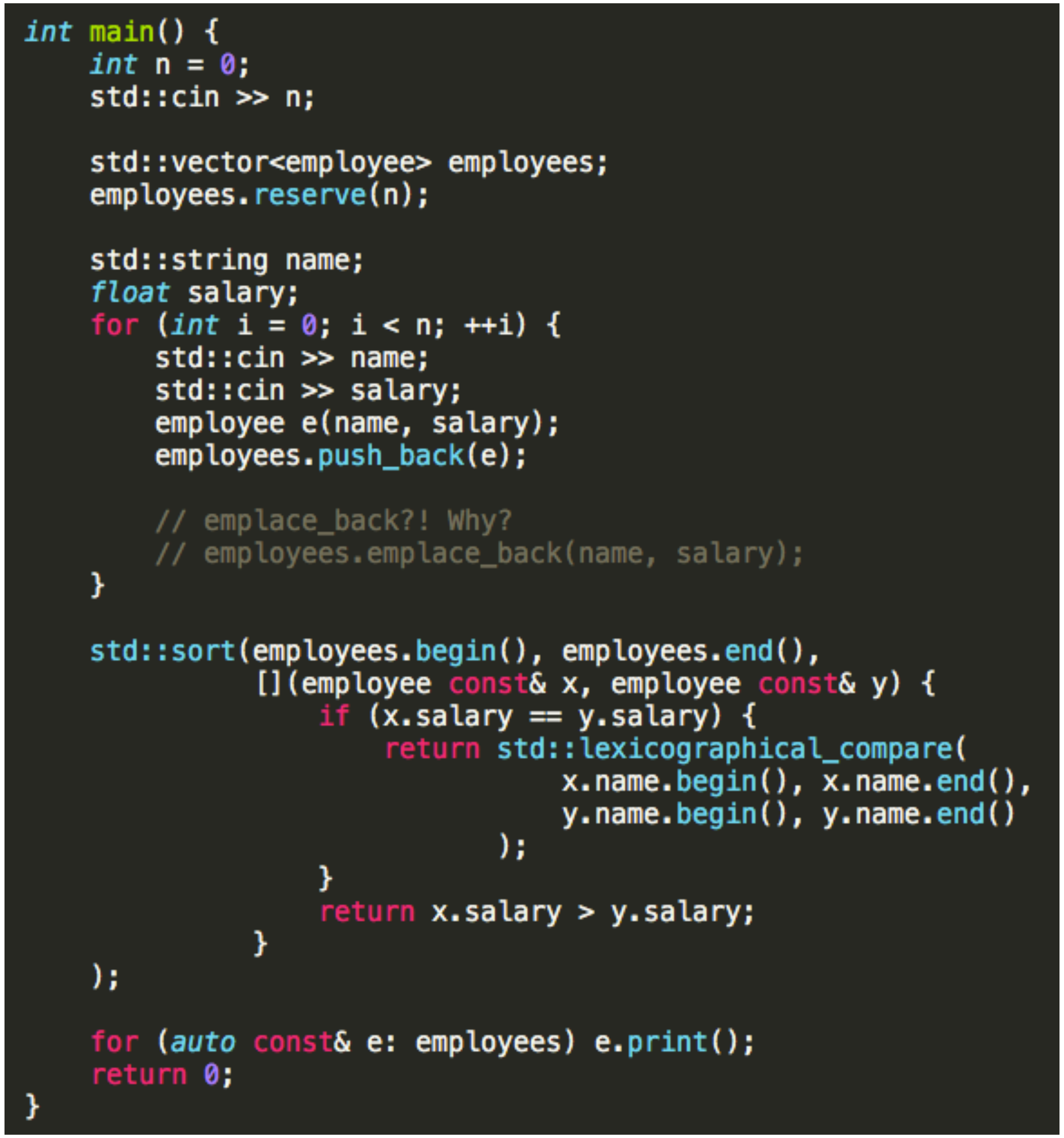
**std::sort**

<algorithm>

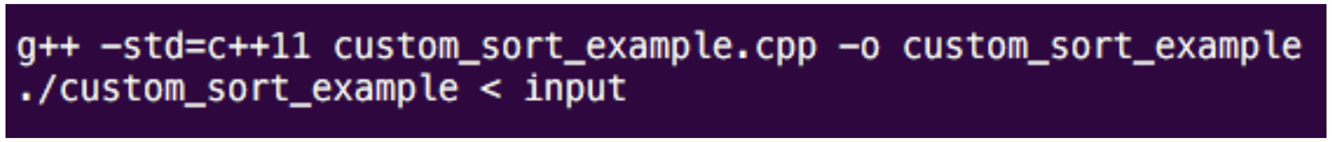
| | |
|---|---|
| *default (1)* | `template <class RandomAccessIterator>`<br>`void sort (RandomAccessIterator first, RandomAccessIterator last);` |
| *custom (2)* | `template <class RandomAccessIterator, class Compare>`<br>`void sort (RandomAccessIterator first, RandomAccessIterator last, Compare comp);` |



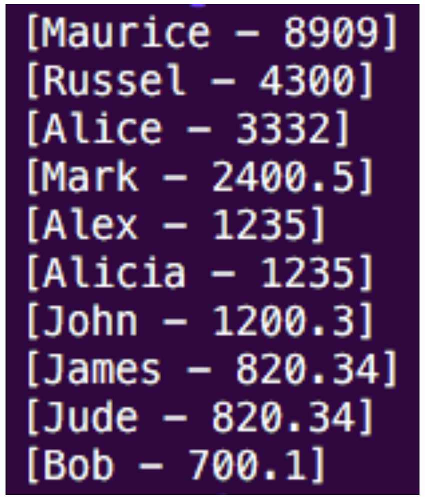
```
10
John 1200.3
Mark 2400.5
Jude 820.34
Alex 1235.0
Bob 700.1
Maurice 8909.0
Alice 3332
Alicia 1235.0
Russel 4300.0
James 820.34
```



```cpp
int main() {
    int n = 0;
    std::cin >> n;

    std::vector<employee> employees;
    employees.reserve(n);

    std::string name;
    float salary;
    for (int i = 0; i < n; ++i) {
        std::cin >> name;
        std::cin >> salary;
        employee e(name, salary);
        employees.push_back(e);

        // emplace_back?! Why?
        // employees.emplace_back(name, salary);
    }

    std::sort(employees.begin(), employees.end(),
              [](employee const& x, employee const& y) {
                  if (x.salary == y.salary) {
                      return std::lexicographical_compare(
                                 x.name.begin(), x.name.end(),
                                 y.name.begin(), y.name.end()
                             );
                  }
                  return x.salary > y.salary;
              }
    );

    for (auto const& e: employees) e.print();
    return 0;
}
```

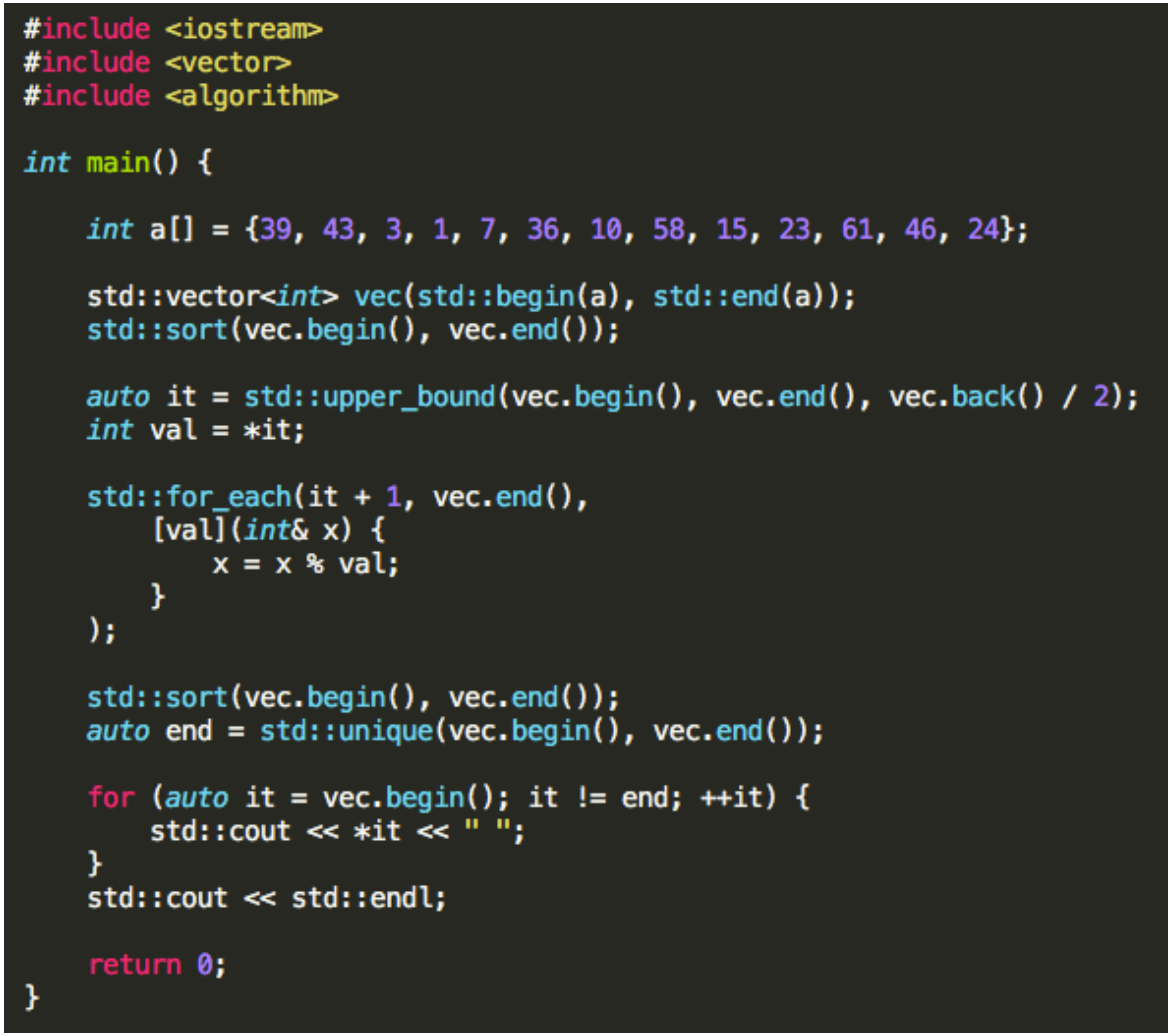


```
g++ -std=c++11 custom_sort_example.cpp -o custom_sort_example
./custom_sort_example < input
```



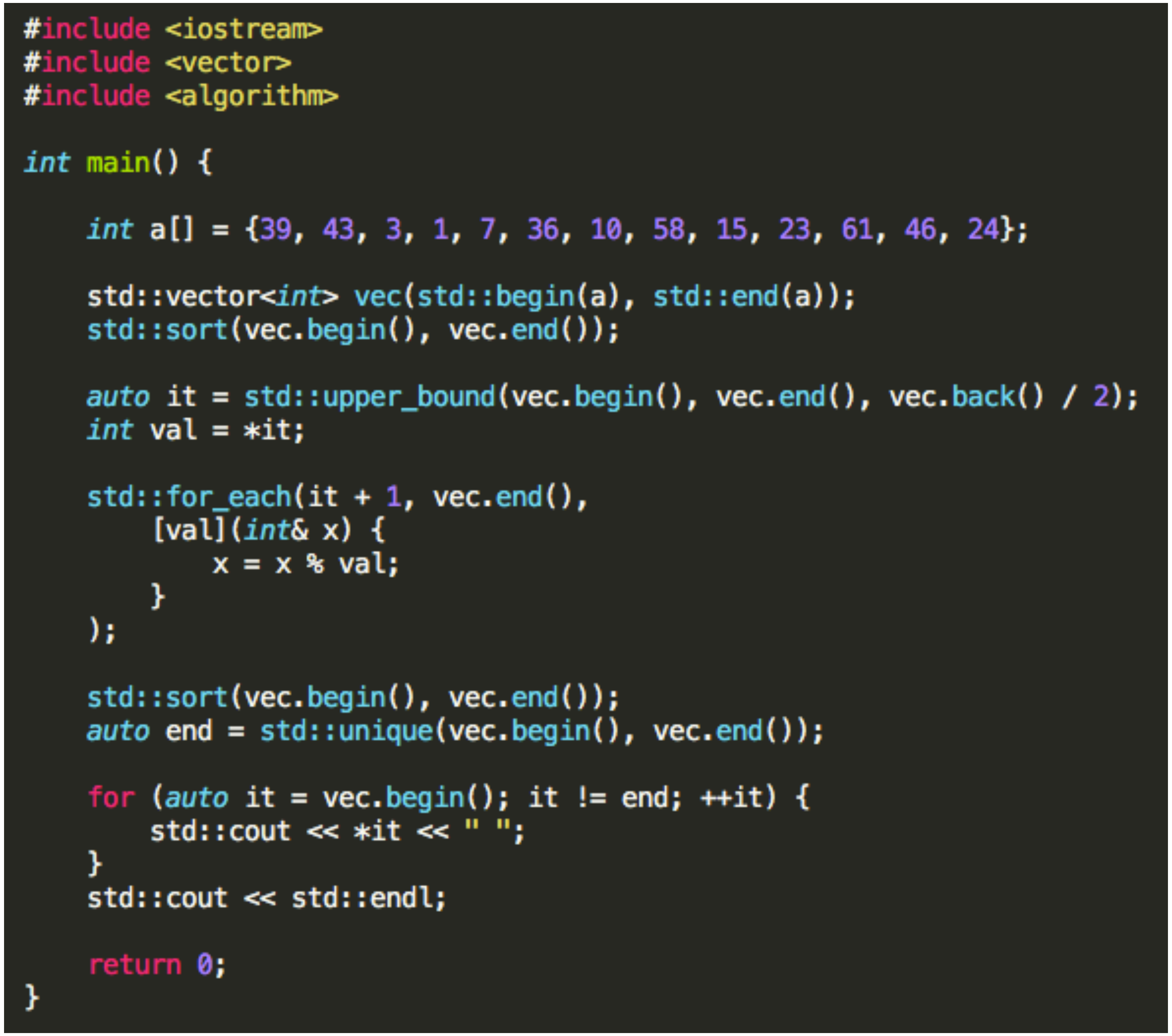
```
[Maurice - 8909]
[Russel - 4300]
[Alice - 3332]
[Mark - 2400.5]
[Alex - 1235]
[Alicia - 1235]
[John - 1200.3]
[James - 820.34]
[Jude - 820.34]
[Bob - 700.1]
```

# Another example

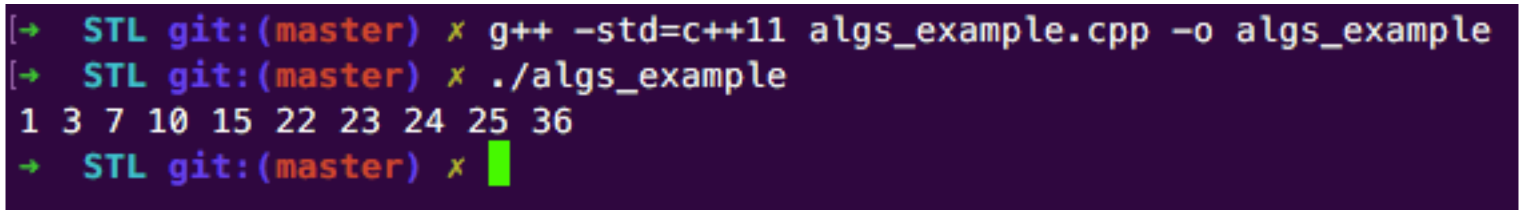


```
#include <iostream>
#include <vector>
#include <algorithm>

int main() {

    int a[] = {39, 43, 3, 1, 7, 36, 10, 58, 15, 23, 61, 46, 24};

    std::vector<int> vec(std::begin(a), std::end(a));
    std::sort(vec.begin(), vec.end());

    auto it = std::upper_bound(vec.begin(), vec.end(), vec.back() / 2);
    int val = *it;

    std::for_each(it + 1, vec.end(),
        [val](int& x) {
            x = x % val;
        }
    );

    std::sort(vec.begin(), vec.end());
    auto end = std::unique(vec.begin(), vec.end());

    for (auto it = vec.begin(); it != end; ++it) {
        std::cout << *it << " ";
    }
    std::cout << std::endl;

    return 0;
}
```

# Another example



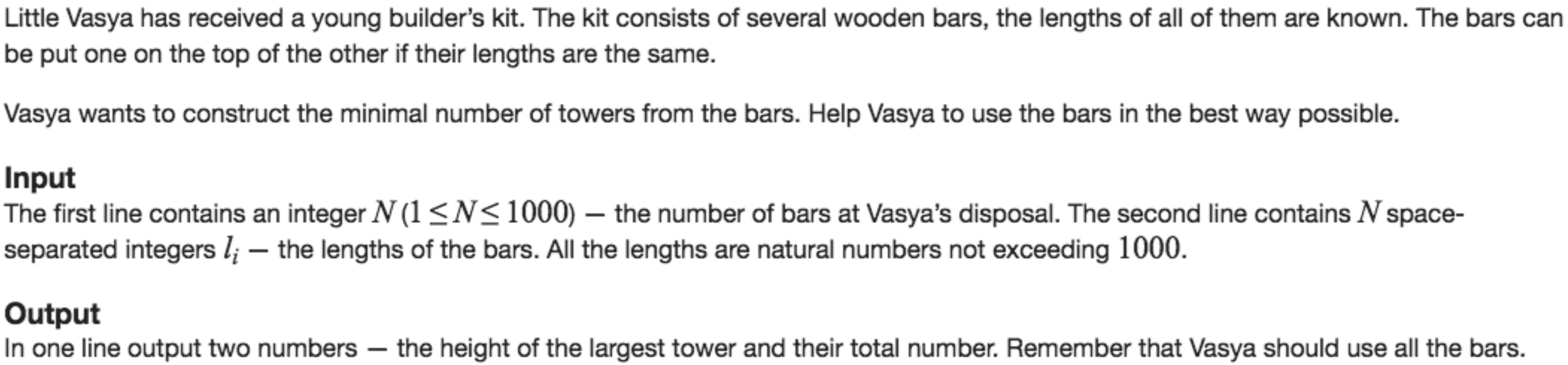
```cpp
#include <iostream>
#include <vector>
#include <algorithm>

int main() {

    int a[] = {39, 43, 3, 1, 7, 36, 10, 58, 15, 23, 61, 46, 24};

    std::vector<int> vec(std::begin(a), std::end(a));
    std::sort(vec.begin(), vec.end());

    auto it = std::upper_bound(vec.begin(), vec.end(), vec.back() / 2);
    int val = *it;

    std::for_each(it + 1, vec.end(),
        [val](int& x) {
            x = x % val;
        }
    );

    std::sort(vec.begin(), vec.end());
    auto end = std::unique(vec.begin(), vec.end());

    for (auto it = vec.begin(); it != end; ++it) {
        std::cout << *it << " ";
    }
    std::cout << std::endl;

    return 0;
}
```



```
[→  STL git:(master) ✗ g++ -std=c++11 algs_example.cpp -o algs_example
[→  STL git:(master) ✗ ./algs_example
1 3 7 10 15 22 23 24 25 36
→  STL git:(master) ✗ █
```

# Exercises

1. Towers http://codeforces.com/problemset/problem/37/A?locale=en



Little Vasya has received a young builder's kit. The kit consists of several wooden bars, the lengths of all of them are known. The bars can be put one on the top of the other if their lengths are the same.

Vasya wants to construct the minimal number of towers from the bars. Help Vasya to use the bars in the best way possible.

**Input**

The first line contains an integer $N$ $(1 \le N \le 1000)$ — the number of bars at Vasya's disposal. The second line contains $N$ space-separated integers $l_i$ — the lengths of the bars. All the lengths are natural numbers not exceeding $1000$.

**Output**

In one line output two numbers — the height of the largest tower and their total number. Remember that Vasya should use all the bars.

# Exercises

1. Towers http://codeforces.com/problemset/problem/37/A?locale=en

Little Vasya has received a young builder's kit. The kit consists of several wooden bars, the lengths of all of them are known. The bars can be put one on the top of the other if their lengths are the same.

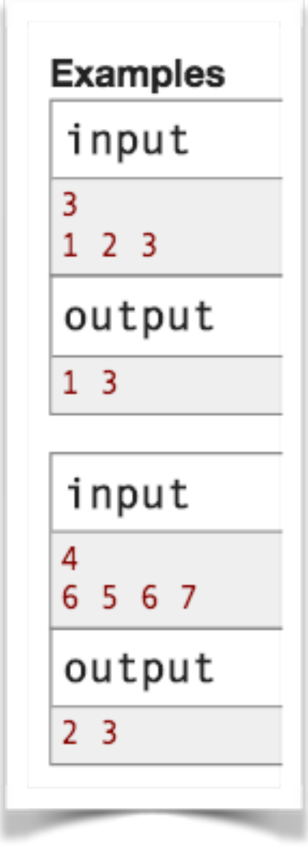
Vasya wants to construct the minimal number of towers from the bars. Help Vasya to use the bars in the best way possible.

**Input**

The first line contains an integer $N$ $(1 \leq N \leq 1000)$ — the number of bars at Vasya's disposal. The second line contains $N$ space-separated integers $l_i$ — the lengths of the bars. All the lengths are natural numbers not exceeding $1000$.

**Output**

In one line output two numbers — the height of the largest tower and their total number. Remember that Vasya should use all the bars.



**Examples**

input

```
3
1 2 3
```

output

```
1 3
```

input

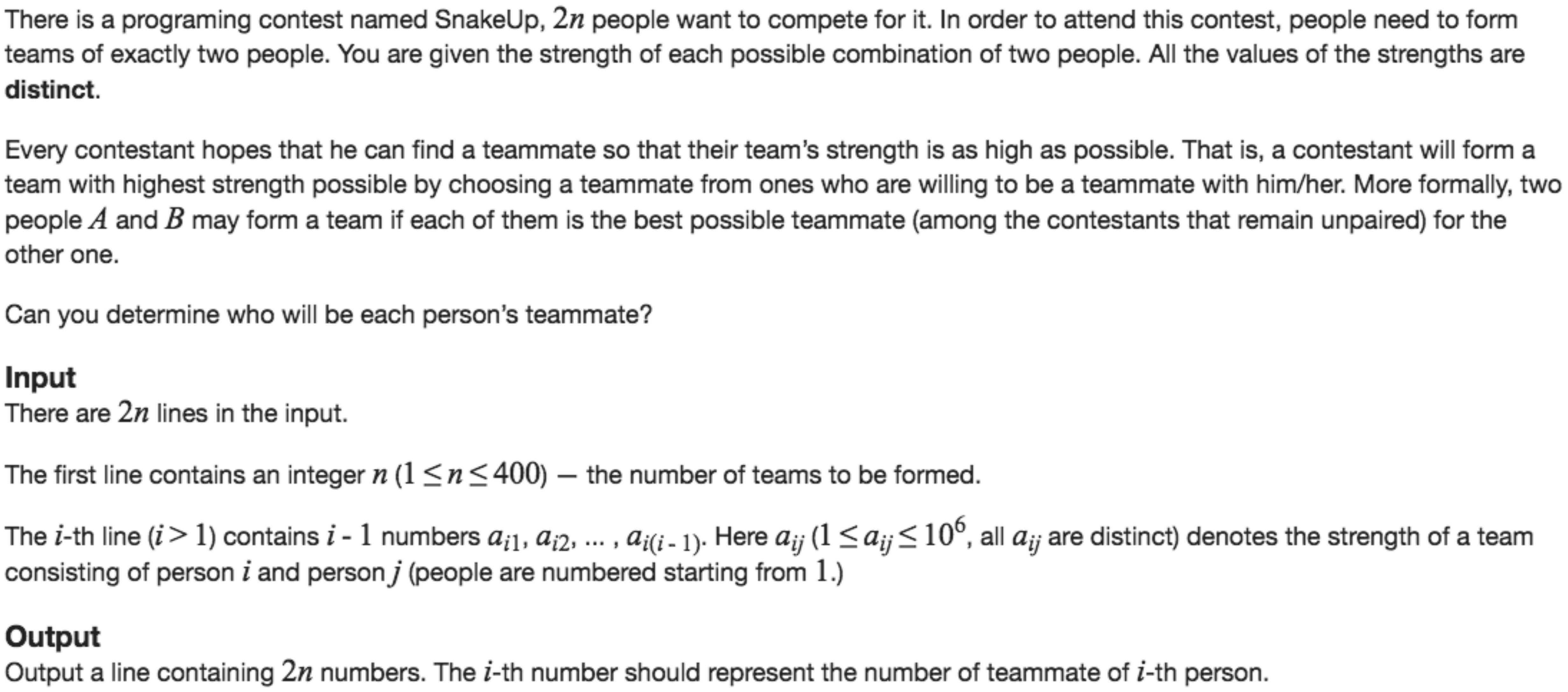
```
4
6 5 6 7
```

output

```
2 3
```

# Exercises

2. Finding Team Member http://codeforces.com/problemset/problem/579/B?locale=en



There is a programing contest named SnakeUp, $2n$ people want to compete for it. In order to attend this contest, people need to form teams of exactly two people. You are given the strength of each possible combination of two people. All the values of the strengths are **distinct**.

Every contestant hopes that he can find a teammate so that their team's strength is as high as possible. That is, a contestant will form a team with highest strength possible by choosing a teammate from ones who are willing to be a teammate with him/her. More formally, two people $A$ and $B$ may form a team if each of them is the best possible teammate (among the contestants that remain unpaired) for the other one.

Can you determine who will be each person's teammate?

**Input**

There are $2n$ lines in the input.

The first line contains an integer $n$ ($1 \le n \le 400$) — the number of teams to be formed.

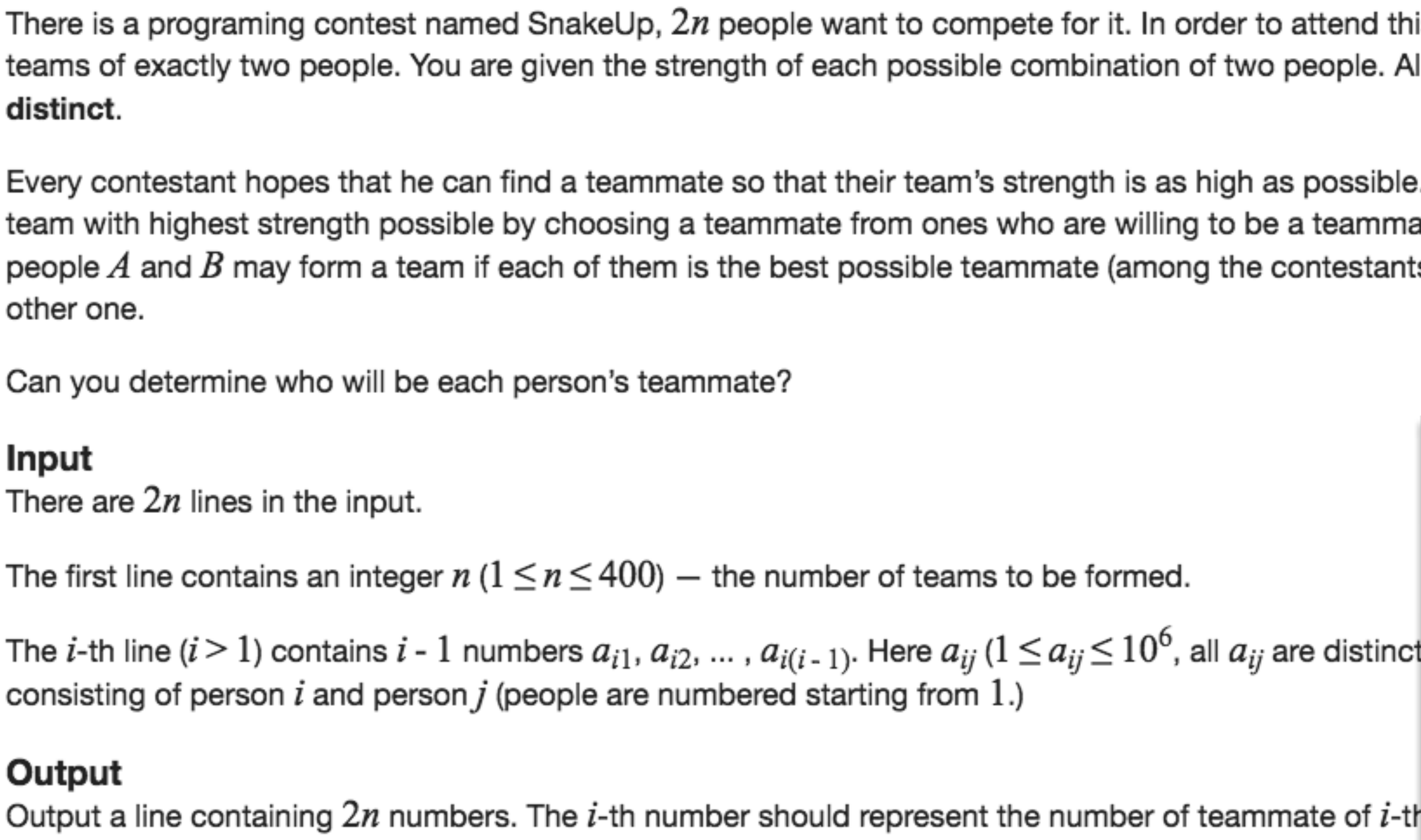
The $i$-th line ($i > 1$) contains $i$ - 1 numbers $a_{i1}$, $a_{i2}$, ... , $a_{i(i-1)}$. Here $a_{ij}$ ($1 \le a_{ij} \le 10^6$, all $a_{ij}$ are distinct) denotes the strength of a team consisting of person $i$ and person $j$ (people are numbered starting from $1$.)

**Output**

Output a line containing $2n$ numbers. The $i$-th number should represent the number of teammate of $i$-th person.

# Exercises

2. Finding Team Member http://codeforces.com/problemset/problem/579/B?locale=en



There is a programing contest named SnakeUp, $2n$ people want to compete for it. In order to attend this contest, people need to form teams of exactly two people. You are given the strength of each possible combination of two people. All the values of the strengths are **distinct**.

Every contestant hopes that he can find a teammate so that their team's strength is as high as possible. That is, a contestant will form a team with highest strength possible by choosing a teammate from ones who are willing to be a teammate with him/her. More formally, two people $A$ and $B$ may form a team if each of them is the best possible teammate (among the contestants that remain unpaired) for the other one.

Can you determine who will be each person's teammate?

### Input

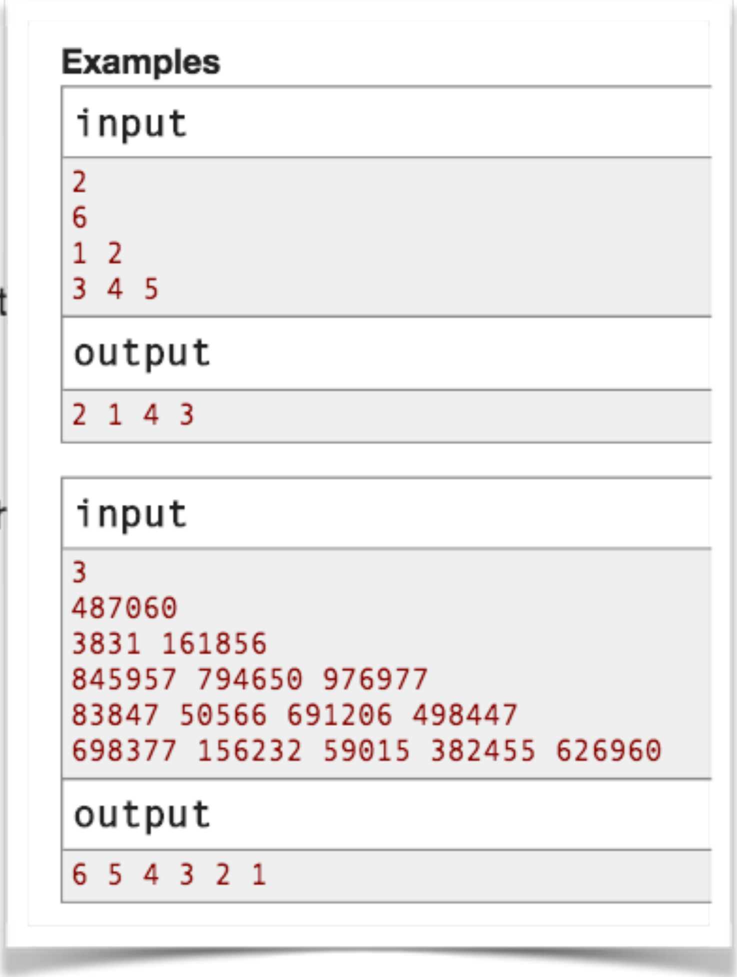
There are $2n$ lines in the input.

The first line contains an integer $n$ $(1 \le n \le 400)$ — the number of teams to be formed.

The $i$-th line $(i > 1)$ contains $i - 1$ numbers $a_{i1}$, $a_{i2}$, ... , $a_{i(i-1)}$. Here $a_{ij}$ $(1 \le a_{ij} \le 10^6$, all $a_{ij}$ are distinct consisting of person $i$ and person $j$ (people are numbered starting from $1$.)

### Output

Output a line containing $2n$ numbers. The $i$-th number should represent the number of teammate of $i$-t



**Examples**

input

```
2
6
1 2
3 4 5
```

output

```
2 1 4 3
```

input

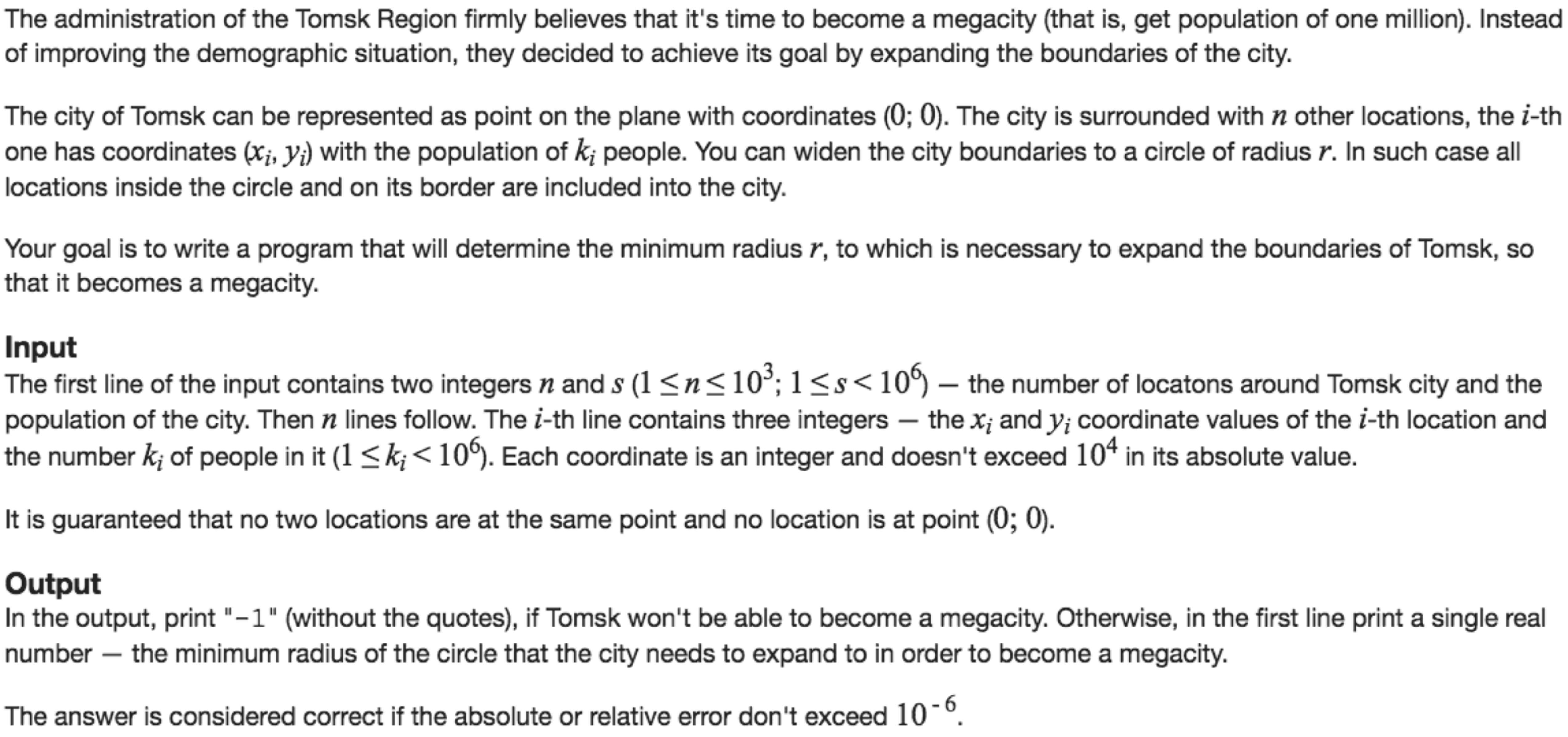
```
3
487060
3831 161856
845957 794650 976977
83847 50566 691206 498447
698377 156232 59015 382455 626960
```

output

```
6 5 4 3 2 1
```

# Exercises

3. Megacity http://codeforces.com/problemset/problem/424/B?locale=en



The administration of the Tomsk Region firmly believes that it's time to become a megacity (that is, get population of one million). Instead of improving the demographic situation, they decided to achieve its goal by expanding the boundaries of the city.

The city of Tomsk can be represented as point on the plane with coordinates $(0; 0)$. The city is surrounded with $n$ other locations, the $i$-th one has coordinates $(x_i, y_i)$ with the population of $k_i$ people. You can widen the city boundaries to a circle of radius $r$. In such case all locations inside the circle and on its border are included into the city.

Your goal is to write a program that will determine the minimum radius $r$, to which is necessary to expand the boundaries of Tomsk, so that it becomes a megacity.

**Input**

The first line of the input contains two integers $n$ and $s$ $(1 \le n \le 10^3; 1 \le s < 10^6)$ — the number of locatons around Tomsk city and the population of the city. Then $n$ lines follow. The $i$-th line contains three integers — the $x_i$ and $y_i$ coordinate values of the $i$-th location and the number $k_i$ of people in it $(1 \le k_i < 10^6)$. Each coordinate is an integer and doesn't exceed $10^4$ in its absolute value.

It is guaranteed that no two locations are at the same point and no location is at point $(0; 0)$.

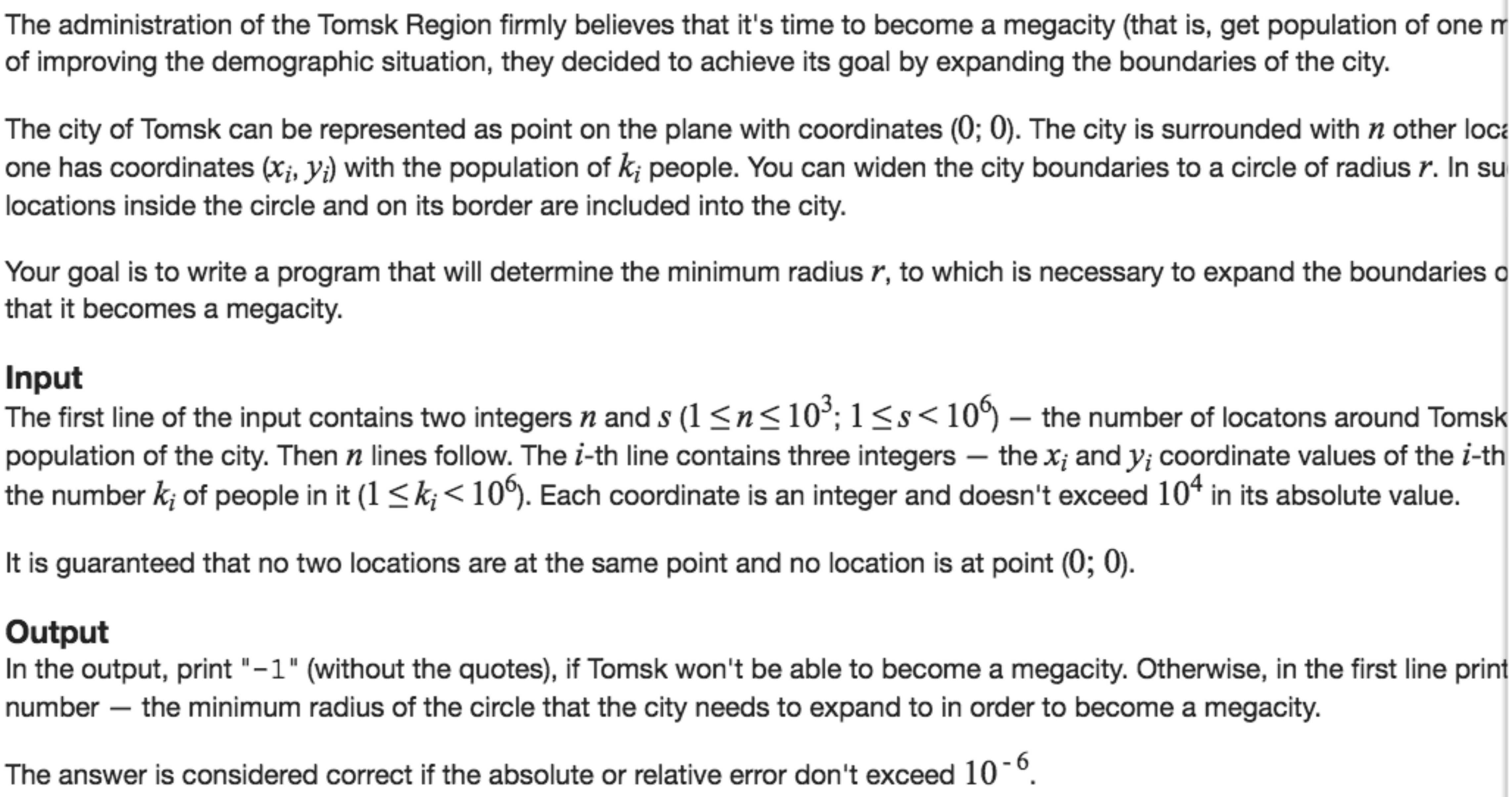
**Output**

In the output, print "-1" (without the quotes), if Tomsk won't be able to become a megacity. Otherwise, in the first line print a single real number — the minimum radius of the circle that the city needs to expand to in order to become a megacity.

The answer is considered correct if the absolute or relative error don't exceed $10^{-6}$.

# Exercises

3. Megacity http://codeforces.com/problemset/problem/424/B?locale=en



The administration of the Tomsk Region firmly believes that it's time to become a megacity (that is, get population of one m of improving the demographic situation, they decided to achieve its goal by expanding the boundaries of the city.

The city of Tomsk can be represented as point on the plane with coordinates $(0; 0)$. The city is surrounded with $n$ other loca one has coordinates $(x_i, y_i)$ with the population of $k_i$ people. You can widen the city boundaries to a circle of radius $r$. In su locations inside the circle and on its border are included into the city.

Your goal is to write a program that will determine the minimum radius $r$, to which is necessary to expand the boundaries o that it becomes a megacity.

### Input

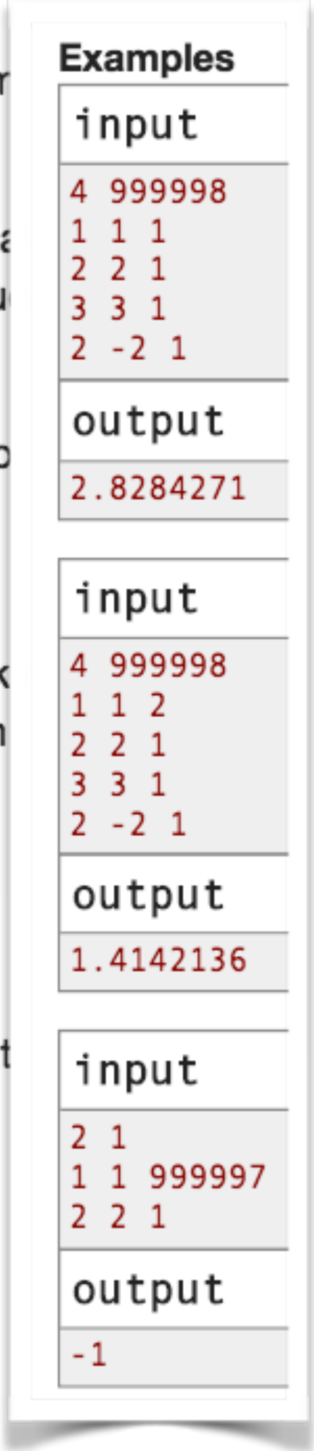
The first line of the input contains two integers $n$ and $s$ $(1 \leq n \leq 10^3; 1 \leq s < 10^6)$ — the number of locatons around Tomsk population of the city. Then $n$ lines follow. The $i$-th line contains three integers — the $x_i$ and $y_i$ coordinate values of the $i$-th the number $k_i$ of people in it $(1 \leq k_i < 10^6)$. Each coordinate is an integer and doesn't exceed $10^4$ in its absolute value.

It is guaranteed that no two locations are at the same point and no location is at point $(0; 0)$.

### Output

In the output, print "-1" (without the quotes), if Tomsk won't be able to become a megacity. Otherwise, in the first line print number — the minimum radius of the circle that the city needs to expand to in order to become a megacity.

The answer is considered correct if the absolute or relative error don't exceed $10^{-6}$.



**Examples**

input

```
4 999998
1 1 1
2 2 1
3 3 1
2 -2 1
```

output

```
2.8284271
```

input

```
4 999998
1 1 2
2 2 1
3 3 1
2 -2 1
```

output

```
1.4142136
```

input

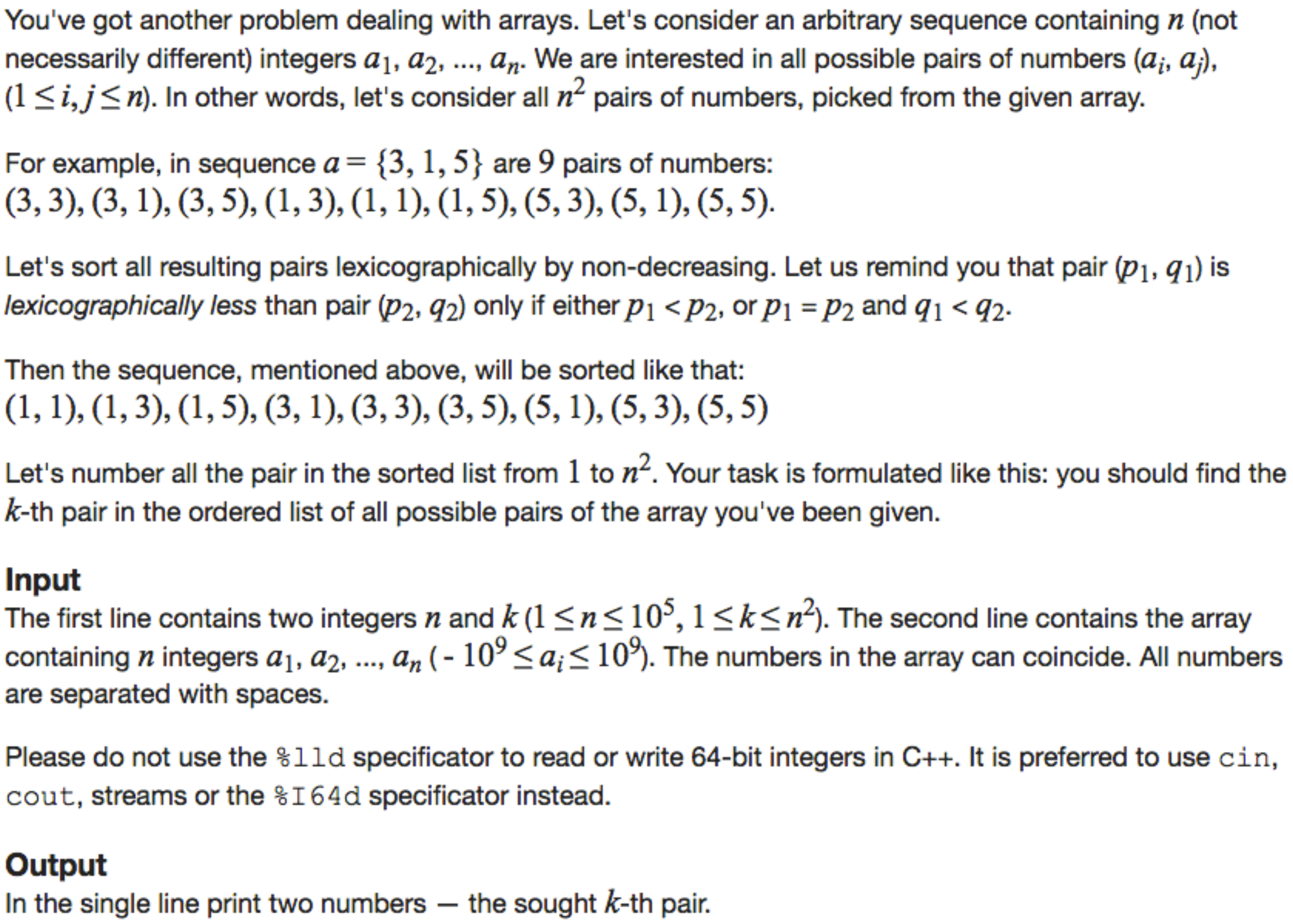
```
2 1
1 1 999997
2 2 1
```

output

```
-1
```

# Exercises

4. Find Pair http://codeforces.com/problemset/problem/160/C?locale=en



You've got another problem dealing with arrays. Let's consider an arbitrary sequence containing $n$ (not necessarily different) integers $a_1, a_2, ..., a_n$. We are interested in all possible pairs of numbers $(a_i, a_j)$, $(1 \le i, j \le n)$. In other words, let's consider all $n^2$ pairs of numbers, picked from the given array.

For example, in sequence $a = \{3, 1, 5\}$ are $9$ pairs of numbers: $(3, 3), (3, 1), (3, 5), (1, 3), (1, 1), (1, 5), (5, 3), (5, 1), (5, 5)$.

Let's sort all resulting pairs lexicographically by non-decreasing. Let us remind you that pair $(p_1, q_1)$ is *lexicographically less* than pair $(p_2, q_2)$ only if either $p_1 < p_2$, or $p_1 = p_2$ and $q_1 < q_2$.

Then the sequence, mentioned above, will be sorted like that: $(1, 1), (1, 3), (1, 5), (3, 1), (3, 3), (3, 5), (5, 1), (5, 3), (5, 5)$

Let's number all the pair in the sorted list from $1$ to $n^2$. Your task is formulated like this: you should find the $k$-th pair in the ordered list of all possible pairs of the array you've been given.

**Input**

The first line contains two integers $n$ and $k$ $(1 \le n \le 10^5, 1 \le k \le n^2)$. The second line contains the array containing $n$ integers $a_1, a_2, ..., a_n$ $(-10^9 \le a_i \le 10^9)$. The numbers in the array can coincide. All numbers are separated with spaces.

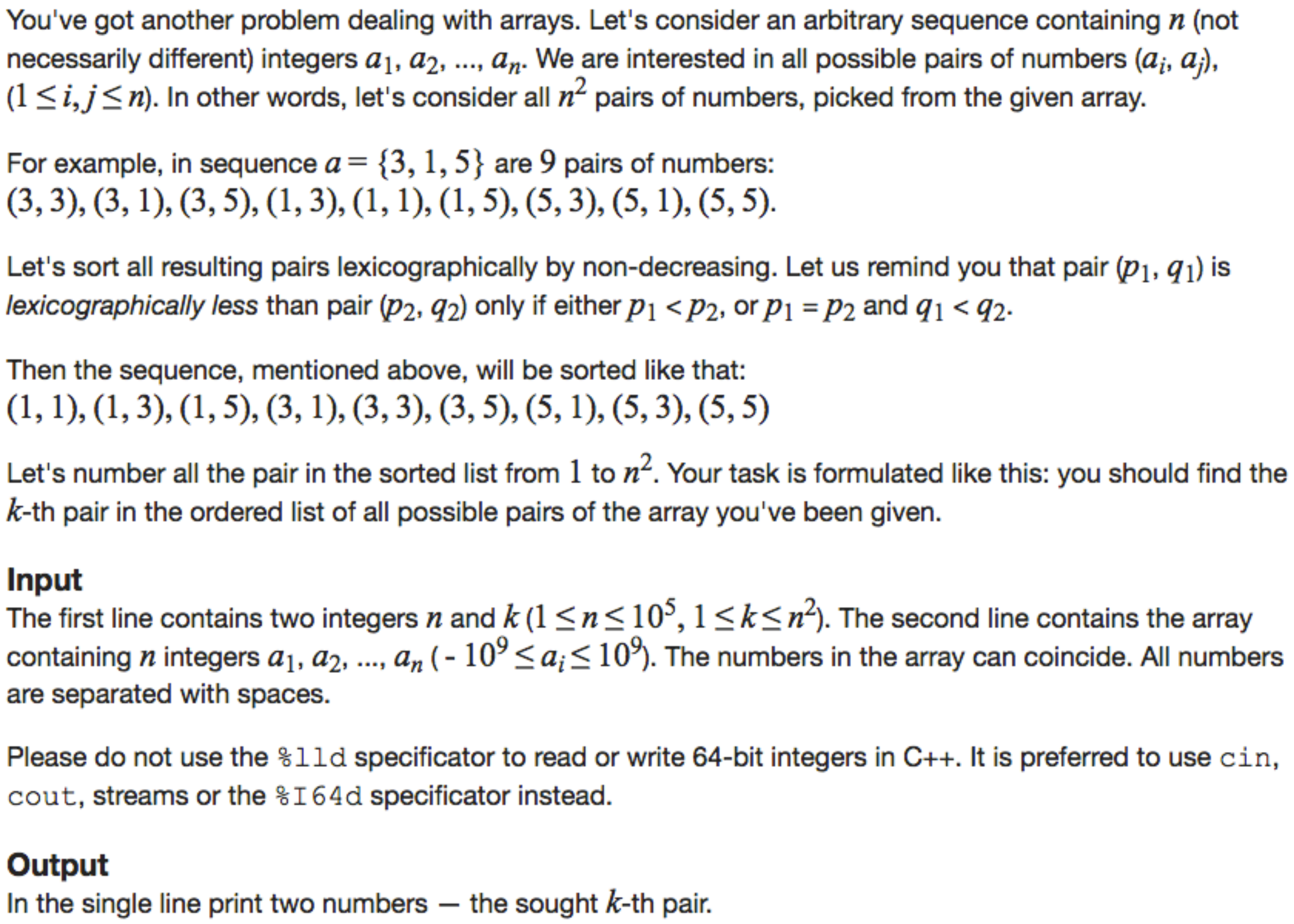
Please do not use the `%lld` specificator to read or write 64-bit integers in C++. It is preferred to use `cin`, `cout`, streams or the `%I64d` specificator instead.

**Output**

In the single line print two numbers — the sought $k$-th pair.

# Exercises

4. Find Pair http://codeforces.com/problemset/problem/160/C?locale=en



You've got another problem dealing with arrays. Let's consider an arbitrary sequence containing $n$ (not necessarily different) integers $a_1, a_2, ..., a_n$. We are interested in all possible pairs of numbers $(a_i, a_j)$, $(1 \leq i, j \leq n)$. In other words, let's consider all $n^2$ pairs of numbers, picked from the given array.

For example, in sequence $a = \{3, 1, 5\}$ are $9$ pairs of numbers: $(3, 3), (3, 1), (3, 5), (1, 3), (1, 1), (1, 5), (5, 3), (5, 1), (5, 5)$.

Let's sort all resulting pairs lexicographically by non-decreasing. Let us remind you that pair $(p_1, q_1)$ is *lexicographically less* than pair $(p_2, q_2)$ only if either $p_1 < p_2$, or $p_1 = p_2$ and $q_1 < q_2$.

Then the sequence, mentioned above, will be sorted like that: $(1, 1), (1, 3), (1, 5), (3, 1), (3, 3), (3, 5), (5, 1), (5, 3), (5, 5)$

Let's number all the pair in the sorted list from $1$ to $n^2$. Your task is formulated like this: you should find the $k$-th pair in the ordered list of all possible pairs of the array you've been given.

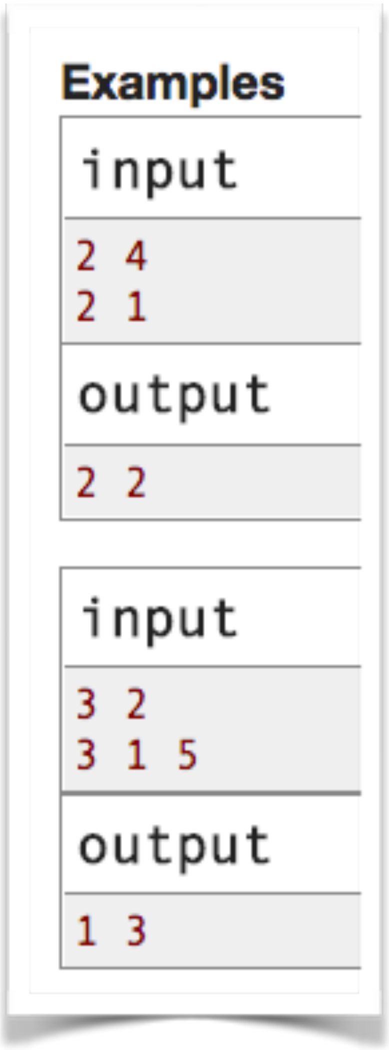
**Input**

The first line contains two integers $n$ and $k$ $(1 \leq n \leq 10^5, 1 \leq k \leq n^2)$. The second line contains the array containing $n$ integers $a_1, a_2, ..., a_n$ $(-10^9 \leq a_i \leq 10^9)$. The numbers in the array can coincide. All numbers are separated with spaces.

Please do not use the `%lld` specificator to read or write 64-bit integers in C++. It is preferred to use `cin`, `cout`, streams or the `%I64d` specificator instead.

**Output**

In the single line print two numbers — the sought $k$-th pair.



**Examples**

input

```
2 4
2 1
```

output

```
2 2
```

input

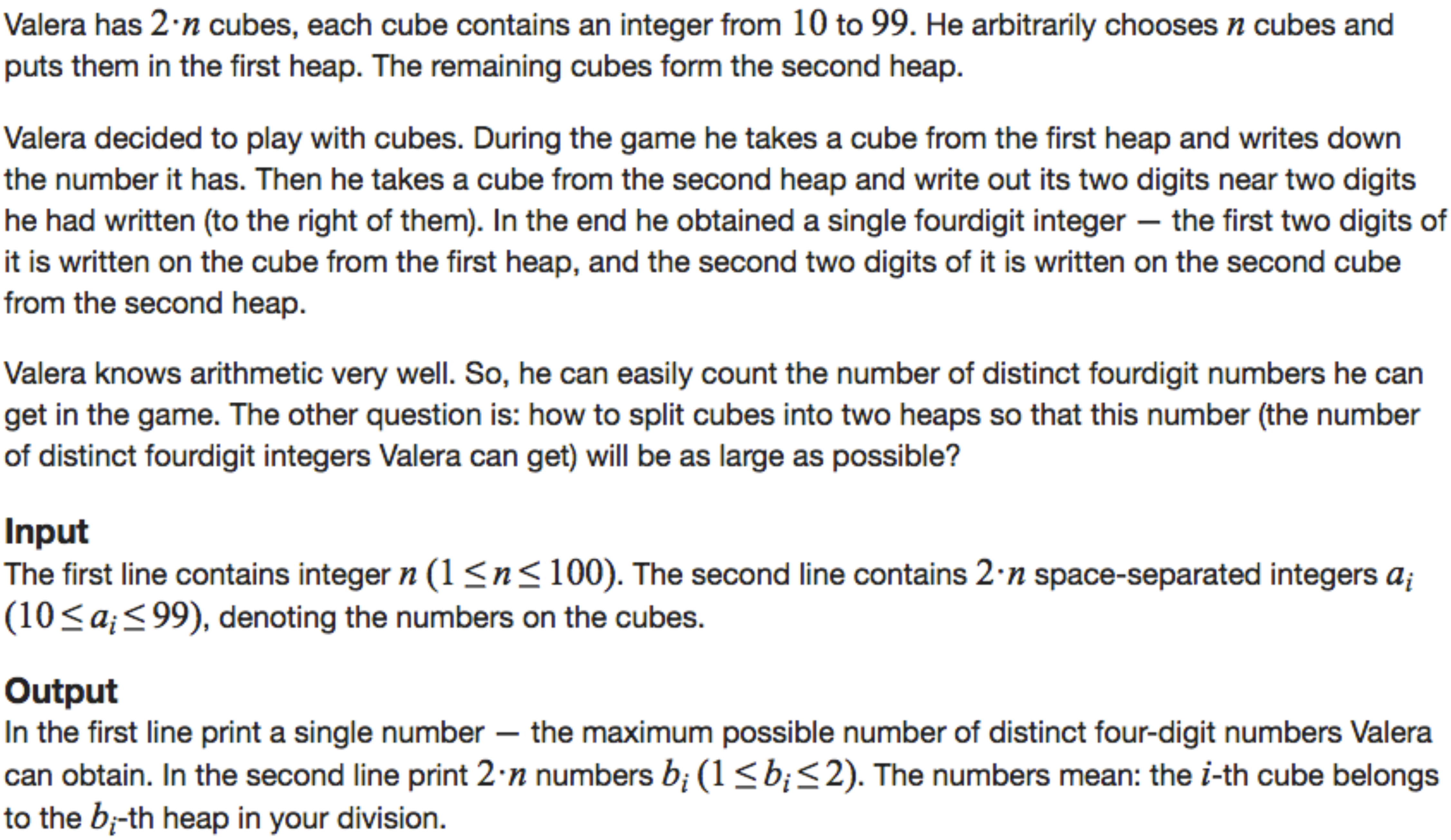
```
3 2
3 1 5
```

output

```
1 3
```

# Exercises

5. Two Heaps http://codeforces.com/problemset/problem/353/B?locale=en



Valera has $2 \cdot n$ cubes, each cube contains an integer from $10$ to $99$. He arbitrarily chooses $n$ cubes and puts them in the first heap. The remaining cubes form the second heap.

Valera decided to play with cubes. During the game he takes a cube from the first heap and writes down the number it has. Then he takes a cube from the second heap and write out its two digits near two digits he had written (to the right of them). In the end he obtained a single fourdigit integer — the first two digits of it is written on the cube from the first heap, and the second two digits of it is written on the second cube from the second heap.

Valera knows arithmetic very well. So, he can easily count the number of distinct fourdigit numbers he can get in the game. The other question is: how to split cubes into two heaps so that this number (the number of distinct fourdigit integers Valera can get) will be as large as possible?

### Input

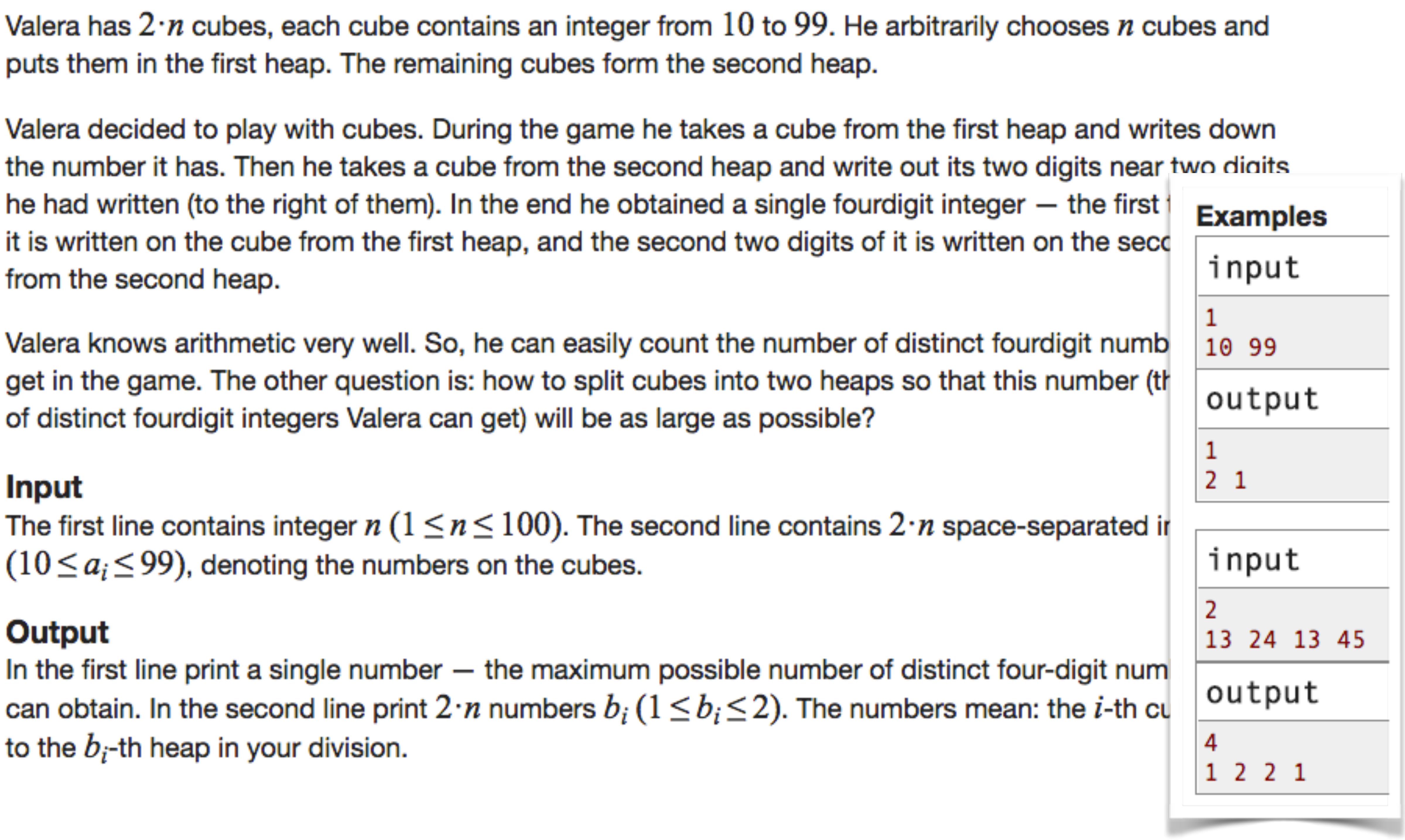
The first line contains integer $n$ $(1 \le n \le 100)$. The second line contains $2 \cdot n$ space-separated integers $a_i$ $(10 \le a_i \le 99)$, denoting the numbers on the cubes.

### Output

In the first line print a single number — the maximum possible number of distinct four-digit numbers Valera can obtain. In the second line print $2 \cdot n$ numbers $b_i$ $(1 \le b_i \le 2)$. The numbers mean: the $i$-th cube belongs to the $b_i$-th heap in your division.

# Exercises

5. Two Heaps http://codeforces.com/problemset/problem/353/B?locale=en



Valera has $2 \cdot n$ cubes, each cube contains an integer from $10$ to $99$. He arbitrarily chooses $n$ cubes and puts them in the first heap. The remaining cubes form the second heap.

Valera decided to play with cubes. During the game he takes a cube from the first heap and writes down the number it has. Then he takes a cube from the second heap and write out its two digits near two digits he had written (to the right of them). In the end he obtained a single fourdigit integer — the first it is written on the cube from the first heap, and the second two digits of it is written on the secc from the second heap.

Valera knows arithmetic very well. So, he can easily count the number of distinct fourdigit numb get in the game. The other question is: how to split cubes into two heaps so that this number (th of distinct fourdigit integers Valera can get) will be as large as possible?

**Input**

The first line contains integer $n$ $(1 \le n \le 100)$. The second line contains $2 \cdot n$ space-separated ir $(10 \le a_i \le 99)$, denoting the numbers on the cubes.

**Output**

In the first line print a single number — the maximum possible number of distinct four-digit num can obtain. In the second line print $2 \cdot n$ numbers $b_i$ $(1 \le b_i \le 2)$. The numbers mean: the $i$-th cu to the $b_i$-th heap in your division.

**Examples**

input

```
1
10 99
```

output

```
1
2 1
```

input

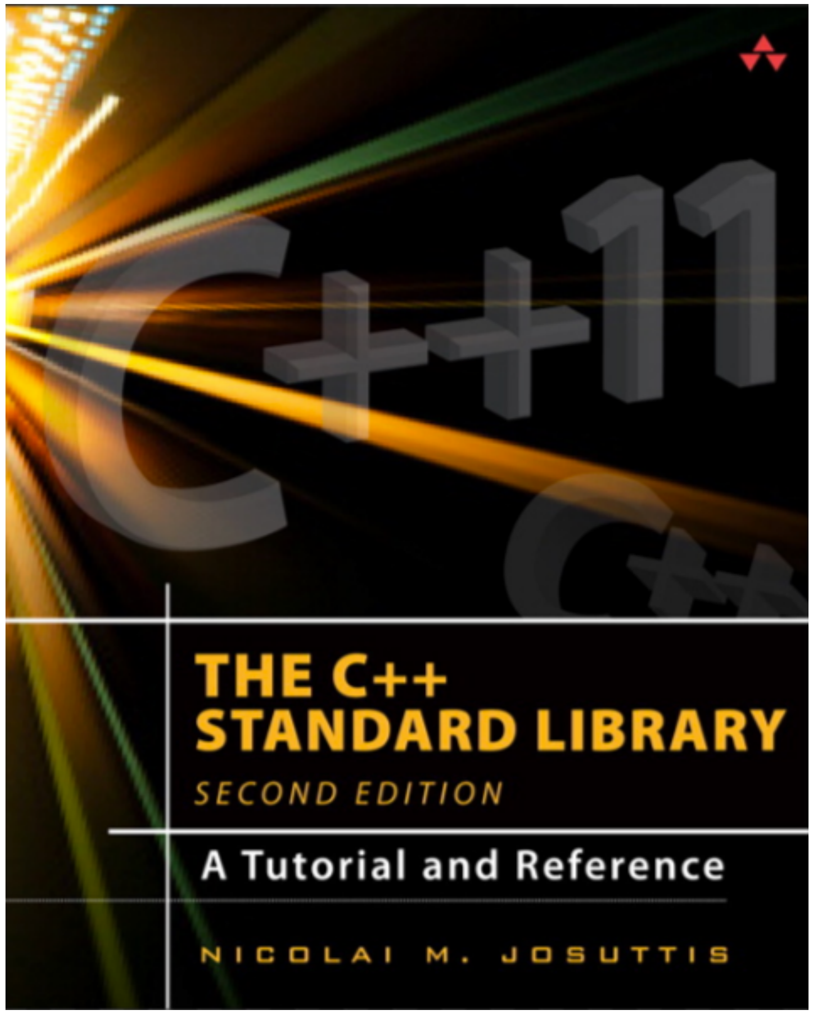
```
2
13 24 13 45
```

output

```
4
1 2 2 1
```

# References

http://www.cplusplus.com/


C++11
THE C++
STANDARD LIBRARY
SECOND EDITION
A Tutorial and Reference
NICOLAI M. JOSUTTIS