The Standard Library

Wolfgang Schreiner
Wolfgang.Schreiner@risc.jku.at

Research Institute for Symbolic Computation (RISC)
Johannes Kepler University, Linz, Austria
http://www.risc.jku.at
1. General

2. Sequence Containers

3. Iterators

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5. Associative Containers

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The Standard Library

■ Set of headers with declarations.
  ```
  #include <name>
  ```
■ Headers need not be physical files (do not use `<name.h>`).
■ Almost all names are in namespace std.
  ```
  using namespace std;
  ```
■ Only exceptions are global operators `new` and `delete` (header `<new>`).
■ Provides lot of basic functionality.
  ■ Numerics.
  ■ Input/Output.
  ■ Containers, iterators, algorithms.
    ■ We will look at these in more detail.

For effective programming, it is important to know not only a programming language but also the associated basic libraries.
C Library Wrappers

For backward compatibility, the entire C standard library is included.

<table>
<thead>
<tr>
<th>C++ Header</th>
<th>C Header</th>
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<tbody>
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<td>&lt;cstdio&gt;</td>
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- **Use of C++ header** (places name in namespace std)
  ```cpp
  #include <cstdio>
  int main() { std::printf("Hello, world"); }
  ```

- **Use of C header** (places name in global namespace)
  ```c
  #include <stdio.h>
  int main() { printf("Hello, world"); }
  ```

The C++ library provides better alternatives for writing new applications.
Traits and Policies

The standard library makes heavy use of traits and policies.

- **Trait**: a class that provides information about a type.
  - By type definitions and/or static member data in the trait.
- **Policy**: a trait that also defines an operational interface for the type.
  - By static member functions in the policy.
- **Often implemented as specializations of dummy templates.**

```
template <type T> class Trait { }; // dummy trait template
template<> class Trait<int> { ... }; // trait for type "int"
```

- Thus the trait for a type can be deduced from the name of a type.
- **Mainly used as template arguments.**

```
template<class C, class T = Trait<C> >
class Lib { ... C ... T::member ... };
```

- Template thus receives required information about type parameter.
- Since trait holds information, atomic type can be template argument.

Many standard types are instantiations of templates with traits/policies.
Example: Class `string`

C++ strings are actually parameterized over the character type.

```cpp
// header <string>
template<typename charT> struct char_traits;
template<> struct char_traits<char> { ... }

template<class charT, class traits = char_traits<charT>, ... >
class basic_string { ... }
typedef basic_string<char> string;
```

- **Wide character type:** `wchar_t`
  - Narrow character type `char` is only one byte large.
  - `wchar_t` is typically 32 bit large and may hold any Unicode character.
    ```cpp
    wchar_t pi = '\u03c0'; // greek character "pi"
    ```
- **Wide strings:** another string type provided by the library.
  ```cpp
  template<> struct char_traits<wchar_t> { ... }
typedef basic_string<wchar_t> wstring;
  ```

The whole library (also I/O) works with any character type.
Example: Strings that Ignore Cases

template<typename T> struct ci_char_traits { }

template<> struct ci_char_traits<char> {
  typedef char char_type; typedef int int_type;
  typedef std::streamoff off_type; typedef std::streampos pos_type;
  typedef std::mbstate_t state_type;
  static void assign(char_type& dst, const char_type src) { dst = src; }
  static char_type* assign(char* dst, std::size_t n, char c) { return static_cast<char_type*>(std::memset(dst, n, c)); }
  static bool eq(const char_type& c1, const char_type& c2) { return lower(c1) == lower(c2); }
  static bool lt(const char_type& c1, const char_type& c2) { return lower(c1) < lower(c2); }
  static int compare(const char_type* s1, const char_type* s2, std::size_t n) {
    for (size_t i = 0; i < n; i++) {
      char_type lc1 = lower(s1[i]); char_type lc2 = lower(s2[i]);
      if (lc1 < lc2) return -1; if (lc1 > lc2) return +1;
    }
    return 0;
  }
  static int_type lower(char_type c) { return std::tolower(to_int_type(c)); }
};
Example (Contd)

typedef std::basic_string<char, ci_char_traits<char> > ci_string;

int main()
{
    ci_string s1 = "Hello, World";
    ci_string s2 = "hello, world";
    std::cout << (s1 == s2); // "true"
}

Ray Lischner “C++ in a Nutshell”.
Allocators

The standard library is also generic with respect to memory management.

- **Allocator**: a policy for managing dynamic memory.
- Use of `new` and `delete` is not hard-wired in the standard library.
- The library provides a standard allocator
  ```cpp
  // header <memory>
  template <class T> class allocator { ...
  }
  
  // header <string>
  template<class charT, class traits = char_traits<charT>,
    class Alloc = allocator<charT> >
  class basic_string { ... }
  
  // globally used
  template<> class allocator<int> {...} 
  
  // selectively used
  class MyCharAllocator {...} 
  typedef basic_string<char, char_traits<char>,
    MyCharAllocator> mystring;
  ```
template<typename T> class myallocator {
public:
    typedef std::size_t size_type; typedef std::ptrdiff_t difference_type;
    typedef T* pointer; typedef const T* const_pointer;
    typedef T& reference; typedef const T& const_reference;
    typedef T value_type;
    template <class U> struct rebind { typedef myallocator<U> other; };    
    myallocator() throw() {}    
    myallocator(const myallocator&) throw() {}    
    template <class U> myallocator(const myallocator<U>&) throw() {}    
    ~myallocator() throw() {}    
    pointer address(reference x) const {return &x;}    
    const_pointer address(const_reference x) const {return &x;}    
    pointer allocate(size_type n, void* hint = 0)    
    { return static_cast<T*>(::operator new (n * sizeof(T)) ); }    
    void deallocate(pointer p, size_type n)    
    { ::operator delete(static_cast<void*>(p)); }    
    size_type max_size() const throw()    
    { return std::numeric_limits<size_type>::max() / sizeof(T); }    
    void construct(pointer p, const T& val) { new(static_cast<void*>(p)) T(val); }    
    void destroy(pointer p) { p->~T(); }    
    
};

Wolfgang Schreiner http://www.risc.jku.at 10/99
template<> class myallocator<void> {
public:
  typedef void* pointer; typedef const void* const_pointer;
  typedef void value_type;
  template <class U> struct rebind { typedef myallocator<U> other; };
};

template<typename T>
bool operator==(const myallocator<T>&, const myallocator<T>&) { return true; }

template<typename T>
bool operator!=(const myallocator<T>&, const myallocator<T>&) { return false; }

int main() {
  std::list<int, myallocator<int> > data;
  data.push_back(10);
  data.push_back(20);
  return data.size();
}

Ray Lischner “C++ in a Nutshell”.
Standard Template Library (STL)

The core of SGI’s STL was integrated into the C++ standard.

- **Containers**: template classes that hold arbitrary kinds of items.
  - Vectors, double ended queues, lists, (multi)sets, (multi)maps, bitsets.
  - Sequence containers: preserve order in which items are added.
  - Associative containers: fast search by sorting items according to keys.
  - **Adaptors**: template classes that provide abstract container interfaces.
    - Stacks, queues, priority queues.

- **Iterators**: (abstractions of) container pointers/indices.
  - Identify (ranges of) elements in container.
  - Same code may be used for processing different kinds of containers.

- **Algorithms**: template functions that implement common algorithms.
  - Processing, sorting, searching, merging, . . .
  - Based on iterators, applicable to all kinds of containers.

The workhorse of generic programming in C++. 

Wolfgang Schreiner

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## Sequence Containers

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### Associative containers

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</table>

### Buckets

- `hash_function`
- `bucket`
- `bucket_count`
- `bucket_size`
- `max_bucket_count`

### Hash policy

- `hash_policy`
- `load_factor`
- `max_load_factor`

Wolfgang Schreiner  
http://www.risc.jku.at
Example: A Vector Program

```cpp
#include <iostream>
#include <vector>
#include <algorithm>
using namespace std;

void print(int i) { cout << i << endl; }

int main ()
{
    int values[] = {75, 23, 65, 42, 14};
    vector<int> container(values, values+5); // pointers as iterators

    // iterate over container
    for (vector<int>::iterator it = container.begin(); it != container.end(); it++)
        cout << *it << endl;

    // use algorithm for iteration
    for_each(container.begin(), container.end(), print);

    return 0;
}
```
#include <iostream>
#include <list>
#include <algorithm>
using namespace std;

void print(int i) { cout << i << endl; }

int main ()
{
    int values[] = {75, 23, 65, 42, 14};
    list<int> container(values, values+5); // pointers as iterators

    // iterate over container
    for (list<int>::iterator it = container.begin(); it != container.end(); it++)
        cout << *it << " ";

    // use algorithm for iteration
    for_each(container.begin(), container.end(), print);

    return 0;
}
1. General

2. Sequence Containers

3. Iterators

4. Adaptors

5. Associative Containers

6. Algorithms
Sequence Containers

- **Strict linear sequences of elements**
  - `<vector>`: class template `vector`
    - Dynamic arrays.
  - `<deque>`: class template `deque` (“deck”)
    - Double-ended queues.
  - `<list>`: class template `list`
    - Doubly-linked lists.

- **Common operations**
  - Basic: constructor, destructor, `operator=`.
  - Iterators: `begin`, `end`, `rbegin`, `rend`.
  - Capacity: `size`, `max_size`, `empty`, `resize`.
  - Sequential access: `front`, `back`.
  - Random access (not `list`) `operator[]`, `at`.
  - Modifiers: `assign`, `insert`, `erase`, `swap`, `clear`.
  - Modify end: `push_back`, `pop_back`.
  - Modify begin (not `vector`): `push_front`, `pop_front`.

Similar interfaces, operations vary in performance.
cplusplus.com: “C++ Reference”.

template < class T, class Allocator = allocator<T> > class vector;

Vector containers are implemented as dynamic arrays; Just as regular arrays, vector containers have their elements stored in contiguous storage locations, which means that their elements can be accessed not only using iterators but also using offsets on regular pointers to elements.

But unlike regular arrays, storage in vectors is handled automatically, allowing it to be expanded and contracted as needed.

Vectors are good at:

* Accessing individual elements by their position index (constant time).
* Iterating over the elements in any order (linear time).
* Add and remove elements from its end (constant amortized time).

Compared to arrays, they provide almost the same performance for these tasks, plus they have the ability to be easily resized. Although, they usually consume more memory than arrays when their capacity is handled automatically (this is in order to accomodate for extra storage space for future growth).
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    vector<int> myvector (10);
    vector<int>::size_type sz = myvector.size();
    for (unsigned int i=0; i<sz; i++) myvector[i]=i;

    for (unsigned int i=0; i<sz/2; i++) { // reverse vector using operator[]
        int temp = myvector[sz-1-i];
        myvector[sz-1-i]=myvector[i];
        myvector[i]=temp;
    }

    for (unsigned int i=0; i<sz; i++) cout << " " << myvector[i];
    return 0;
}

9 8 7 6 5 4 3 2 1 0
```

Wolfgang Schreiner
http://www.risc.jku.at
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    vector<int> myvector;

    myvector.push_back(10);
    while (myvector.back() != 0)
    {
        myvector.push_back ( myvector.back() -1 );
    }

    for (unsigned i=0; i<myvector.size() ; i++)
    { 
        cout << " " << myvector[i];
    }
    return 0;
}
```

10 9 8 7 6 5 4 3 2 1 0
#include <iostream>
#include <vector>
using namespace std;

int main ()
{
    vector<int> myvector; // vector with 10 elements
    for (unsigned int i=1;i<10;i++) myvector.push_back(i);

    myvector.resize(5); // shrink to size 5
    myvector.resize(8,100); // extend to size 8, fill with 100
    myvector.resize(12); // extend to size 12, fill with 0

    for (unsigned int i=0;i<myvector.size();i++)
        cout << " " << myvector[i];
}

1 2 3 4 5 100 100 100 0 0 0 0
Class vector<bool>

The vector class template has a special template specialization for the bool type. This specialization is provided to optimize for space allocation: In this template specialization, each element occupies only one bit (which is eight times less than the smallest type in C++: char).

The references to elements of a bool vector returned by the vector members are not references to bool objects, but a special member type which is a reference to a single bit, defined inside the vector<bool> class specialization as:

```cpp
class vector<bool>::reference {
    friend class vector;
    reference(); // no public constructor

    public:
    ~reference(); // convert to bool
    operator bool () const; // assign from bool
    reference& operator= ( const bool x ); // assign from bit
    reference& operator= ( const reference& x ); // flip bit value.
    void flip();
}
```

For a similar container class to contain bits, but with a fixed size, see bitset.
#include <iostream>
#include <string>
#include <bitset>
using namespace std;

int main () {
    bitset<4> first (string("1001"));
    bitset<4> second (string("0011"));
    cout << (first^=second) << endl; // 1010 (XOR,assign)
    cout << (first&=second) << endl; // 0010 (AND,assign)
    cout << (first|=second) << endl; // 0011 (OR,assign)
    cout << (~second) << endl; // 1100 (NOT)
    cout << (second<<1) << endl; // 0110 (SHL)
    cout << (second>>1) << endl; // 0001 (SHR)
    cout << (first==second) << endl; // false (0110==0011)
    cout << (first!=second) << endl; // true (0110!=0011)
    cout << (first&second) << endl; // 0010
    cout << (first|second) << endl; // 0111
    cout << (first^second) << endl; // 0101
    return 0;
}
Deques may be implemented by specific libraries in different ways, but in all cases they allow for the individual elements to be accessed through random access iterators, with storage always handled automatically (expanding and contracting as needed).

Deque sequences have the following properties:

* Individual elements can be accessed by their position index.
* Iteration over the elements can be performed in any order.
* Elements can be efficiently added and removed from any of its ends (either the beginning or the end of the sequence).

Therefore they provide a similar functionality as the one provided by vectors, but with efficient insertion and deletion of elements also at the beginning of the sequence and not only at its end. On the drawback side, unlike vectors, deques are not guaranteed to have all its elements in contiguous storage locations, eliminating thus the possibility of safe access through pointer arithmetics.
Example

cplusplus.com: “C++ Reference”.

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

int main ()
{
    deque<int> mydeque (2,100);    // two ints with a value of 100
    mydeque.push_front (200);
    mydeque.push_front (300);

    for (unsigned i=0; i<mydeque.size(); ++i)
        cout << " " << mydeque[i];
    return 0;
}

300 200 100 100
```
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    deque<int> mydeque;
    mydeque.push_back (100);
    mydeque.push_back (200);
    mydeque.push_back (300);

    while (!mydeque.empty()) {
        cout << "  " << mydeque.front();
        mydeque.pop_front();
    }
    cout << endl;
    cout << "Final size of mydeque is " << int(mydeque.size()) << endl;
    return 0;
}
```

100 200 300
Final size of mydeque is 0
cplusplus.com: “C++ Reference”.

template < class T, class Allocator = allocator<T> > class list;

List containers are implemented as doubly-linked lists; doubly 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 element preceding it and a link to the element following it.

This provides the following advantages to list containers:

* Efficient insertion/removal of elements in the container (constant time).
* Efficient moving elements within the container (constant time).
* Iterating over the elements in forward or reverse order (linear time).

Compared to other base standard sequence containers (vectors and deques), lists perform generally better in inserting, extracting and moving elements in any position within the container, and therefore also in algorithms that make intensive use of these, like sorting algorithms.

The main drawback of lists compared to these other sequence containers is that they lack direct access to the elements by their position ...
// reversing vector
#include <iostream>
#include <list>
using namespace std;

int main ()
{
    list<int> mylist;
    for (int i=1; i<10; i++) mylist.push_back(i);

    mylist.reverse(); // additional member function of list

    for (list<int>::iterator it=mylist.begin(); it!=mylist.end(); ++it)
        cout << " " << *it;
    return 0;
}

9 8 7 6 5 4 3 2 1
1. General

2. Sequence Containers

3. Iterators

4. Adaptors

5. Associative Containers

6. Algorithms
Iterators

cplusplus.com: “C++ Reference”.

Header <iterator>

In C++, 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).

The most obvious form of iterator is a pointer: A pointer can point to elements in an array, and can iterate through them using the increment operator (++). But other forms of iterators exist. For example, each container type (such as a vector) has a specific iterator type designed to iterate through its elements in an efficient way.

Notice that while a pointer is a form of iterator, not all iterators have the same functionality a pointer has; to distinguish between the requirements an iterator shall have for a specific algorithm, five iterator categories exist:

RandomAccess -> Bidirectional -> Forward -> Input
-> Output
**Iterator Categories**

cplusplus.com: “C++ Reference”.

* Input and output iterators are the most limited types of iterators, specialized in performing only sequential input or output operations.

* Forward iterators have all the functionality of input and output iterators, although they are limited to one direction in which to iterate through a range.

* Bidirectional iterators can be iterated through in both directions. All standard containers support at least bidirectional iterators types.

* Random access iterators implement all the functionalities of bidirectional iterators, plus, they have the ability to access ranges non-sequentially: offsets can be directly applied to these iterators without iterating through all the elements in between. This provides these iterators with the same functionality as standard pointers (pointers are iterators of this category).
## Iterator Operations

<table>
<thead>
<tr>
<th>category</th>
<th>characteristic</th>
<th>valid expressions</th>
</tr>
</thead>
<tbody>
<tr>
<td>all categories</td>
<td>Can be copied and copy-constructed</td>
<td>X b(a); b = a;</td>
</tr>
<tr>
<td></td>
<td>Can be incremented</td>
<td>++a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a++</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*a++</td>
</tr>
<tr>
<td></td>
<td>Accepts equality/inequality comparisons</td>
<td>a == b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a != b</td>
</tr>
<tr>
<td></td>
<td>Can be dereferenced as an <code>rvalue</code></td>
<td>*a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a-&gt;m</td>
</tr>
<tr>
<td></td>
<td>Can be dereferenced to be the left side of an</td>
<td>*a = t</td>
</tr>
<tr>
<td></td>
<td>assignment operation</td>
<td>*a++ = t</td>
</tr>
<tr>
<td></td>
<td>Can be default-constructed</td>
<td>X a; X()</td>
</tr>
<tr>
<td></td>
<td>Can be decremented</td>
<td>- -a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a--</td>
</tr>
<tr>
<td></td>
<td></td>
<td>*a--</td>
</tr>
<tr>
<td></td>
<td>Supports arithmetic operators <code>+</code> and <code>-</code></td>
<td>a + n</td>
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<tr>
<td></td>
<td></td>
<td>n + a</td>
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<tr>
<td></td>
<td></td>
<td>n - a</td>
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<tr>
<td></td>
<td></td>
<td>a - b</td>
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<tr>
<td></td>
<td>Supports inequality comparisons (<code>&lt;</code> and <code>&gt;</code>) between</td>
<td>a &lt; b</td>
</tr>
<tr>
<td></td>
<td>iterators</td>
<td>a &gt; b</td>
</tr>
<tr>
<td></td>
<td>Supports compound assignment operations <code>+</code>=, <code>-</code>=,<code>&lt;</code>=</td>
<td>a += n</td>
</tr>
<tr>
<td></td>
<td>and <code>&gt;=</code></td>
<td>a -= n</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a &lt;= b</td>
</tr>
<tr>
<td></td>
<td></td>
<td>a &gt;= b</td>
</tr>
<tr>
<td></td>
<td>Supports offset dereference operator (<code>[]</code>)</td>
<td>a[n]</td>
</tr>
<tr>
<td>Bidirectional</td>
<td>Input</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forward</td>
<td></td>
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<tr>
<td>Random Access</td>
<td>Output</td>
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</tbody>
</table>
This is a base class template that can be used to derive iterator classes from it. It is not an iterator class and does not provide any of the functionality an iterator is expected to have.

This base class only provides some member types, which in fact are not required to be present in any iterator type (iterator types have no specific member requirements), but they might be useful, since they define the members needed for the default iterator_traits class template to generate the appropriate iterator_traits class automatically.

```cpp
template <class Category, class T, class Distance = ptrdiff_t, class Pointer = T*, class Reference = T&>
struct iterator {
    typedef T value_type;
    typedef Distance difference_type;
    typedef Pointer pointer;
    typedef Reference reference;
    typedef Category iterator_category;
};
```
Example

cplusplus.com: “C++ Reference”.

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

class myiterator : public iterator<input_iterator_tag, int> {
    int* p;

public:
    myiterator(int* x) : p(x) {}
    myiterator(const myiterator& mit) : p(mit.p) {}
    myiterator& operator++() {++p;return *this;}
    myiterator& operator++(int) {p++;return *this;}
    bool operator==(const myiterator& rhs) {return p==rhs.p;}
    bool operator!=(const myiterator& rhs) {return p!=rhs.p;}
    int& operator*() {return *p;}
};

int main () {
    int numbers[]={10,20,30,40,50};
    myiterator beginning(numbers); myiterator end(numbers+5);
    for (myiterator it=beginning; it!=end; it++) cout << *it << " ";
}
```
Containers and Iterators

cplusplus.com: “C++ Reference”.

{vector,deque,list}::{begin,end} public member function

    iterator begin ();
const_iterator begin () const;

Returns an iterator referring to the first element in the container.

    iterator end ();
const_iterator end () const;

Returns an iterator referring to the past-the-end element in the vector container.

Both iterator and const_iterator are member types.

* In the vector and dequeue class template, these are random access iterators.
* In the list class template, these are bidirectional iterators.
#include <iostream>
#include <vector>
using namespace std;

int main ()
{
    vector<int> myvector;
    for (int i=1; i<=5; i++) myvector.push_back(i);
    for ( vector<int>::iterator it=myvector.begin() ; it < myvector.end(); it++ )
        cout << " " << *it;
    return 0;
}

1 2 3 4 5
Advancing Iterators

cplusplus.com: “C++ Reference”.

```
template function

template <class InputIterator, class Distance>
void advance (InputIterator& i, Distance n);
```

Advances the iterator `i` by `n` elements.

If `i` is a Random Access Iterator, the function uses once operator+ or operator-, otherwise, the function uses repeatedly the increase or decrease operator (operator++ or operator--) until `n` elements have been advanced.

Complexity

* Constant for random access iterators.
* Linear on `n` for other categories of iterators.
Example

cplusplus.com: “C++ Reference”.

#include <iostream>
#include <iterator>
#include <list>
using namespace std;

int main () {
    list<int> mylist;
    for (int i=0; i<10; i++) mylist.push_back (i*10);

    list<int>::iterator it = mylist.begin();

    advance (it,5);

    cout << "The sixth element in mylist is: " << *it << endl;
    return 0;
}

The sixth element in mylist is: 50
Container Construction with Iterators

cplusplus.com: “C++ Reference”.

template <class InputIterator> vector
  ( InputIterator first, InputIterator last, const Allocator& = Allocator() );
template <class InputIterator> deque
  ( InputIterator first, InputIterator last, const Allocator& = Allocator() );
template < class InputIterator > list
  ( InputIterator first, InputIterator last, const Allocator& = Allocator() );

Iteration constructor: Iterates between first and last, setting a copy of each of the sequence of elements as the content of the container.

With input iterators, we can initialize a container by a range of elements from another container.
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    list<int> first; // empty list of ints
    list<int> second (4,100); // four ints with value 100
    list<int> third (second.begin(),second.end()); // iterating through second
    list<int> fourth (third); // a copy of third

    // the iterator constructor can also be used to construct from arrays:
    int myints[] = {16,2,77,29};
    list<int> fifth (myints, myints + sizeof(myints) / sizeof(int) );

    for (list<int>::iterator it = fifth.begin(); it != fifth.end(); it++)
        cout << *it << " ";
}

16 2 77 29
Reverse Iterators

cplusplus.com: “C++ Reference”.

template <class Iterator> class reverse_iterator;  
header <iterator>

This class reverses the direction a bidirectional or random access iterator iterates through a range.

A copy of the original iterator (the base iterator) is kept internally and used to reflect all operations performed on the reverse_iterator: whenever the reverse_iterator is incremented, its base iterator is decreased, and vice versa. The base iterator can be obtained at any moment by calling member base.

Notice however that when an iterator is reversed, the reversed version does not point to the same element in the range, but to the one preceding it. This is so, in order to arrange for the past-the-end element of a range: An iterator pointing to a past-the-end element in a range, when reversed, is changed to point to the last element (not past it) of the range (this would be the first element of the range if reversed). And if an iterator to the first element in a range is reversed, the reversed iterator points to the element before the first element (this would be the past-the-end element of the range if reversed).
Example

cplusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <iterator>
#include <vector>
using namespace std;

int main () {
    vector<int> myvector;
    for (int i=0; i<10; i++) myvector.push_back(i);
    typedef vector<int>::iterator iter_int;

    iter_int begin (myvector.begin()); // ? 0 1 2 3 4 5 6 7 8 9 ?
    iter_int end (myvector.end()); // ^
    reverse_iterator<iter_int> rev_end (begin); // ^
    reverse_iterator<iter_int> rev_iterator (end); // ^

    for ( ; rev_iterator < rev_end ; ++rev_iterator) cout << *rev_iterator << " ";
    return 0;
}
```

9 8 7 6 5 4 3 2 1 0
Containers and Reverse Iterators

cplusplus.com: “C++ Reference”.

```
{vector,deque,list}::{rbegin,rend} public member function

    reverse_iterator rbegin ();
const_reverse_iterator rbegin () const;

Returns a reverse iterator referring to the last element in the container.

    reverse_iterator rend ();
const_reverse_iterator rend () const;
```

Both reverse_iterator and const_reverse_iterator are member types defined as
reverse_iterator<iterator> and reverse_iterator<const_iterator> respectively.

* In the vector and dequeue class template, these are reverse random access iterators.
* In the list class template, these are reverse bidirectional iterators.
Example

cplusplus.com: “C++ Reference”.

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

int main ()
{
    vector<int> myvector;
    for (int i=1; i<=5; i++) myvector.push_back(i);

    vector<int>::reverse_iterator rit;
    for (rit=myvector.rbegin() ; rit < myvector.rend(); ++rit)
        cout << " " << *rit;
    return 0;
}

5 4 3 2 1
```
Container Operations with Iterators

{vector,deque,list}::*

public member functions

template <class InputIterator> void assign (InputIterator f, InputIterator l);
void assign (size_type n, const T& u);

Assigns new content to the container, dropping all the elements contained in
the container object and replacing them by those specified by the parameters.

iterator insert (iterator p, const T& x);
void insert (iterator p, size_type n, const T& x);
template <class InputIterator>
void insert (iterator p, InputIterator f, InputIterator l);

The container is extended by inserting new elements before position p. This
effectively increases the container size by the amount of elements inserted.

iterator erase ( iterator position );
iterator erase ( iterator first, iterator last );

Removes from the list container either a single element (position) or a
range of elements ([first,last)). This effectively reduces the list size by
the number of elements removed, calling each element’s destructor before.
Example

cplusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <list>
#include <vector>
using namespace std;

int main () {
    list<int> mylist;
    for (int i=1; i<=5; i++) mylist.push_back(i); // 1 2 3 4 5
    list<int>::iterator it = mylist.begin();
    ++it; // it points now to number 2
    mylist.insert (it,10); // 1 10 2 3 4 5
    // "it" still points to number 2
    mylist.insert (it,2,20); // 1 10 20 20 2 3 4 5
    --it; // it points now to the second 20
    vector<int> myvector (2,30);
    mylist.insert (it,myvector.begin(),myvector.end());
    // 1 10 20 30 30 20 2 3 4 5
    //
    for (it=mylist.begin(); it!=mylist.end(); it++) cout << " " << *it;
    return 0;
}
```

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Example

cplusplus.com: “C++ Reference”.

...  
int main () {
    list<unsigned int> mylist;
    list<unsigned int>::iterator it1,it2;
    for (unsigned int i=1; i<10; i++) mylist.push_back(i*10);
        // 10 20 30 40 50 60 70 80 90
    it1 = it2 = mylist.begin(); // ^^  
    advance (it2,6); // ^ ^  
    ++it1; // ^ ^  
    it1 = mylist.erase (it1); // 10 30 40 50 60 70 80 90
        // ^ ^
    it2 = mylist.erase (it2); // 10 30 40 50 60 80 90
        // ^ ^  
    ++it1; // ^ ^  
    --it2; // ^ ^  
    mylist.erase (it1,it2); // 10 30 60 80 90
        // ^
        for (it1=mylist.begin(); it1!=mylist.end(); ++it1) cout << " " << *it1;
}  
10 30 60 80 90

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Stream Iterators

cplusplus.com: “C++ Reference”.

template <class T, class charT=char, class traits=char_traits<charT>,
    class Distance = ptrdiff_t> class istream_iterator;

Istream iterators are a special input iterator class designed to read
successive elements from an input stream ... whenever operator++ is used on
the iterator, it extracts an element (with >>) from the stream.

A special value for this iterator exists: the end-of-stream; When an iterator
is set to this value has either reached the end of the stream (operator void*
applied to the stream returns false) or has been constructed using its default
constructor (without associating it with any basic_istream object).

template <class T, class charT=char, class traits=char_traits<charT>,
    class Distance = ptrdiff_t> class ostream_iterator;

Ostream iterators are a special output iterator class designed to write into
successive elements of an output stream ... whenever an assignment operator
is used on the ostream_iterator (even when dereferenced) it inserts a new
element into the stream. Optionally, a delimiter can be specified on
construction which is written to the stream after each element is inserted.
Example

cplusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <iterator>
#include <string>
using namespace std;

int main () {
    istream_iterator<char> eos;       // end-of-range iterator
    istream_iterator<char> iit (cin); // stdin iterator
    string mystring;
    cout << "Please, enter your name: ";
    while (iit!=eos && *iit!='\n') {
        mystring += *iit;
        iit++;
    }
    cout << "Your name is " << mystring << ".\n";
    return 0;
}
```

Please, enter your name: HAL 9000
Your name is HAL 9000.
Example

cplusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <iterator>
#include <vector>
using namespace std;

int main () {
    vector<int> myvector;
    for (int i=1; i<10; ++i) myvector.push_back(i*10);

    ostream_iterator<int> out_it (cout,", ");
    for (vector<int>::iterator it = myvector.begin(); it != myvector.end(); it++)
    {
        *out_it = *it;
        out_it++;
    }
    return 0;
}

10, 20, 30, 40, 50, 60, 70, 80, 90,
```

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1. General

2. Sequence Containers

3. Iterators

4. Adaptors

5. Associative Containers

6. Algorithms
Adaptors

cplusplus.com: "C++ Reference".

stack, queue and priority_queue are implemented as container adaptors. Container adaptors are not full container classes, but classes that provide a specific interface relying on an object of one of the container classes (such as deque or list) to handle the elements. The underlying container is encapsulated in such a way that its elements are accessed by the members of the container class independently of the underlying container class used.

<table>
<thead>
<tr>
<th>Headers</th>
<th>&lt;stack&gt;</th>
<th>&lt;queue&gt;</th>
<th>priority_queue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Members</td>
<td>stack</td>
<td>queue</td>
<td>priority_queue</td>
</tr>
<tr>
<td>constructor*</td>
<td>constructor</td>
<td>constructor</td>
<td>constructor</td>
</tr>
<tr>
<td>capacity</td>
<td>size</td>
<td>size</td>
<td>size</td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>size</td>
<td>size</td>
</tr>
<tr>
<td></td>
<td>empty</td>
<td>empty</td>
<td>empty</td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>empty</td>
<td>empty</td>
</tr>
<tr>
<td>element access</td>
<td>front</td>
<td>front</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>front</td>
<td></td>
</tr>
<tr>
<td></td>
<td>back</td>
<td>back</td>
<td></td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>back</td>
<td></td>
</tr>
<tr>
<td></td>
<td>top</td>
<td>top</td>
<td>top</td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>top</td>
<td>top</td>
</tr>
<tr>
<td>modifiers</td>
<td>push</td>
<td>push</td>
<td>push</td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>push</td>
<td>push</td>
</tr>
<tr>
<td></td>
<td>pop</td>
<td>pop</td>
<td>pop</td>
</tr>
<tr>
<td></td>
<td>O(1)</td>
<td>pop</td>
<td>pop</td>
</tr>
</tbody>
</table>
Class Template stack

cplusplus.com: “C++ Reference”.

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

Stacks are a type of container adaptors, specifically designed to operate in a LIFO context (last-in first-out), where elements are inserted and extracted only from the end of the container. ... Elements are pushed/popped from the "back" of the specific container, which is known as the top of the stack.

The underlying container may be any of the standard container class templates or some other specifically designed container class. The only requirement is that it supports the following operations:

   * back()
   * push_back()
   * pop_back()

Therefore, the standard container class templates vector, deque and list can be used. By default, if no container class is specified for a particular stack class, the standard container class template deque is used.
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    stack<int> mystack;
    for (int i=0; i<5; ++i) mystack.push(i);

    while (!mystack.empty()) {
        cout << " " << mystack.top();
        mystack.pop();
    }
    return 0;
}
```

4 3 2 1 0
class Template queue

cplusplus.com: “C++ Reference”.

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

queues are a type of container adaptors, specifically designed to operate in a FIFO context (first-in first-out), where elements are inserted into one end of the container and extracted from the other. ... Elements are pushed into the "back" of the specific container and popped from its "front".

The underlying container may be one of the standard container class template or some other specifically designed container class. The only requirement is that it supports the following operations:

* front()
* back()
* push_back()
* pop_front()

Therefore, the standard container class templates deque and list can be used. By default, if no container class is specified for a particular queue class, the standard container class template deque is used.
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    queue<int> myqueue;
    int myint;

    do { // enter integers (0 to end)
        cin >> myint;
        myqueue.push (myint);
    } while (myint);

    while (!myqueue.empty()) { // print integers (in the same order
        cout << " " << myqueue.front(); // in which they were entered)
        myqueue.pop();
    }
    return 0;
}
```
class Template priority_queue

cplusplus.com: “C++ Reference”.

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

Priority queues are a type of container adaptors, specifically designed such that its first element is always the greatest of the elements it contains, according to some strict weak ordering condition. This context is similar to a heap where only the max heap element can be retrieved and elements can be inserted indefinitely. ... Elements are popped from the "back" of the specific container, which is known as the top of the priority queue.

The underlying container may be any ... container class. The only requirement is that it must be accessible through random access iterators and it must support the following operations:

```cpp
* front()
* push_back()
* pop_back()
```

Therefore, the standard container class templates vector and deque can be used. By default ... the standard container class template vector is used.
Class Template priority_queue

cplusplus.com: “C++ Reference”.

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

template <class T> struct less : binary_function <T,T,bool> {
    bool operator() (const T& x, const T& y) const {return x<y;}
};

Compare is a class such that the expression comp(a,b), where comp is an object
of this class and a and b are elements of the container, returns true if a is
to be placed earlier than b in a strict weak ordering operation. This can
either be a class implementing a function call operator or a pointer to a
function. This defaults to less<T>, which returns the same as applying the
less-than operator (a<b).

The priority_queue object uses this expression when an element is inserted or
removed from it (using push or pop, respectively) to grant that the element
popped is always the greater in the priority queue.
#include <iostream>
#include <queue>
using namespace std;

int main () {
  priority_queue<int> mypq;
  mypq.push(30);
  mypq.push(100);
  mypq.push(25);
  mypq.push(40);
  
  while (!mypq.empty()) {
    cout << " " << mypq.top();
    mypq.pop();
  }
  return 0;
}

100 40 30 25
1. General

2. Sequence Containers

3. Iterators

4. Adaptors

5. Associative Containers

6. Algorithms
Associative Containers

- Elements organized for fast access by keys
  - `<set>`: class templates `set` and `multiset`.
    - (Multi)sets of elements (elements themselves are the keys).
  - `<map>`: class templates `map` and `multimap`.
    - Mappings of keys to (sets of) values.

- Common operations
  - Most operations of sequence containers.
    - Except sequential access, random access, modification of begin and end of container.
  - Observers: `key_comp`, `value_comp`.
  - Miscellaneous operations: `find`, `count`, `lower_bound`, `upper_bound`, `equal_range`.

Chosen according to required mathematical functionality.
Class Templates set and multiset

template < class Key, class Compare = less<Key>,
          class Allocator = allocator<Key> > class (multi)set;

Sets are a kind of associative containers that stores unique elements, and in which the elements themselves are the keys. Internally, the elements in a set are always sorted from lower to higher following a specific strict weak ordering criterion set on container construction. Sets are typically implemented as binary search trees. Therefore, the main characteristics of set as an associative container are:

* Unique element values: no two elements in the set can compare equal to each other. For a similar associative container allowing for multiple equivalent elements, see multiset.

* The element value is the key itself. For a similar associative container where elements are accessed using a key, but map to a value different than this key, see map.

* Elements follow a strict weak ordering at all times. Unordered associative arrays, like unordered_set, are available in implementations following TR1.

Multisets ... allow for multiple keys with equal values.
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    int myints[] = {75,23,65,23,42,13}; // 23 occurs twice
    set<int> myset (myints,myints+6);
    myset.insert(23); // once more 23 is inserted

    for ( set<int>::iterator it=myset.begin() ; it != myset.end(); it++ )
        cout << " " << *it;
    return 0;
}
```

13 23 42 65 75
Example

cplusplus.com: “C++ Reference”.

```c++
#include <iostream>
#include <set>
using namespace std;

int main () {
    int myints[] = {75,23,65,23,42,13}; // 23 occurs twice
    multiset<int> myset (myints,myints+6);
    myset.insert(23); // once more 23 is inserted

    for ( multiset<int>::iterator it=myset.begin() ; it != myset.end(); it++ )
        cout << " " << *it;
    return 0;
}
```

13 23 23 23 42 65 75
Class Templates \texttt{map} and \texttt{multimap}

template < class Key, class T, class Compare = \texttt{less<Key>},
    class Allocator = \texttt{allocator<pair<const Key,T> >} > > class (multi)map;

Maps are a kind of associative containers that stores elements formed by the combination of a key value and a mapped value. In a map, the key value is generally used to uniquely identify the element, while the mapped value is some sort of value associated to this key. Types of key and mapped value may differ. Internally, the elements in the map are sorted from lower to higher key value following a specific strict weak ordering criterion set on construction. Therefore, the main characteristics of a map as an associative container are:

* Unique key values: no two elements in the map have keys that compare equal to each other. For a similar associative container allowing for multiple elements with equivalent keys, see multimap.
* Each element is composed of a key and a mapped value. For a simpler associative container where the element value itself is its key, see set.
* Elements follow a strict weak ordering at all times.

Maps ... implement the direct access operator (operator[]) which allows for direct access of the mapped value.

Multimaps ... allow different elements to have the same key value.
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    map<char,int> mymap;
    map<char,int>::iterator it;

    mymap[’b’] = 100;
    mymap[’a’] = 200;
    mymap[’c’] = 300;

    for ( it=mymap.begin() ; it != mymap.end(); it++ )
        cout << (*it).first << " => " << (*it).second << endl;
    return 0;
}
```

a => 200
b => 100
c => 300
Example

cplusplus.com: “C++ Reference”.

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

int main () {
    multimap<char,int> mymultimap;
    multimap<char,int>::iterator it;

    mymultimap.insert (pair<char,int>('a',10));
    mymultimap.insert (pair<char,int>('b',20));
    mymultimap.insert (pair<char,int>('b',150));

    for ( it=mymultimap.begin() ; it != mymultimap.end(); it++ )
        cout << (*it).first << " => " << (*it).second << endl;
    return 0;
}

a => 10
b => 20
b => 150
```

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Member Function find

iterator find ( const key_type& x ) const;

Searches the container for an element with a value of x and returns an iterator to it if found, otherwise it returns an iterator to the element past the end of the container.

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

int main ()
{
    map<char,int> mymap;
    map<char,int>::iterator it;

    mymap[’a’]=50; mymap[’b’]=100;

    it = mymap.find(’b’);
    if (it != mymap.end()) mymap.erase (it);
    cout << "a => " << mymap.find(’a’)->second << ‘\n’;
    return 0;
}
Member Function **count**

```cpp
size_type count ( const key_type& x ) const;
```

Searches the container for an element with a key of `x` and returns the number of times the element appears in the container.

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

int main () {
    set<int> myset;
    for (int i=1; i<5; i++) myset.insert(i*3); // set: 3 6 9 12
    for (int i=0;i<10; i++) {
        cout << i;
        if (myset.count(i)>0)
            cout << " is an element of myset.\n";
        else cout << " is not an element of myset.\n";
    }
    return 0;
}
```

0 is not an element of myset. ...
**Member Functions** lower/upper_bound

**iterator lower/upper_bound ( const key_type& x );**

lower_bound returns an iterator pointing to the first element in the container whose key does not compare less than x (using the container’s comparison object), i.e. it is either equal or greater. upper_bound returns an iterator pointing to the first element in the container whose key compares greater than x.

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

int main () {
    map<char,int> mymap;
    mymap['a']=20; mymap['b']=40; mymap['c']=60; mymap['d']=80; mymap['e']=100;
    map<char,int>::iterator itlow=mymap.lower_bound ('b'); // itlow points to b
    map<char,int>::iterator itup=mymap.upper_bound ('d'); // itup points to e
    mymap.erase(itlow,itup); // erases [itlow,itup)
    for (map<char,int>::iterator it=mymap.begin() ; it != mymap.end(); it++ )
        cout << (*it).first << " => " << (*it).second << " ";
    return 0;
}
```

```
a => 20 e => 100
```
### Member Function `equal_range`

```
pair<iterator,iterator> equal_range ( const key_type& x ) const;
```

Returns the bounds of a range that includes all the elements in the container with a key that compares equal to `x`. If `x` does not match any key in the container, the range has a length of zero, with both iterators pointing to the nearest value greater than `x`, if any, or to the element past the end of the container if `x` is greater than all the elements in the container.

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

int main () {
    int myints[] = {77,30,16,2,30,30};
    multiset<int> mymultiset (myints, myints+6); // 2 16 30 30 30 77
    pair<multiset<int>::iterator,multiset<int>::iterator> ret = mymultiset.equal_range(30); // ^ ^
    for (multiset<int>::iterator it=ret.first; it!=ret.second; ++it)
        cout << " " << *it;
    return 0;
}
```

30 30 30
1. General

2. Sequence Containers

3. Iterators

4. Adaptors

5. Associative Containers

6. Algorithms
The standard library comes with a rich set of (so-called) algorithms.

- **Algorithm**: a template function operating on a range of elements.
  - A range is a sequence of objects accessible by iterators/pointers.
    - Iterator type is argument of function template.
    - Iterators of this type are arguments to function.
      ```cpp
template<class InIter, class T>
  InIter find(InIter first, InIter last, const T& value);
```
  - Works on any object that provides suitable iterators/pointers.
    - Containers, plain arrays, streams.
  - **Algorithms and containers are mostly orthogonal.**
    - New algorithms can be written without modifying containers.
      - Algorithms will be automatically applicable on containers.
    - New containers can be developed without modifying algorithms.
      - Containers can be immediately processed by algorithms.

When processing containers, remember the already available algorithms.
Many algorithms operate on function objects.

- **Function object**: any object that provides function application.
  - Any function and any object that provides `operator()`.
    ```
    struct F { int operator()(int a) {return a;} 
    }; 
    F f; int x = f(0); // function-like syntax with object f
    ```

- **<functional>** provides a collection of function object templates.

  - **Unary function objects inherit from `unary_function`**.
    ```
    template <class Arg, class Result>
    struct unary_function {
      typedef Arg argument_type;
      typedef Result result_type;
    };
    ```

  - **Binary function objects inherit from `binary_function`**.
    ```
    template <class Arg1, class Arg2, class Result>
    struct binary_function {
      typedef Arg1 first_argument_type;
      typedef Arg2 second_argument_type;
      typedef Result result_type;
    };
    ```
Example

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

struct Compare : public binary_function<int, int, bool> {
    bool operator() (int a, int b) {return (a==b);}
};

int main () {
    Compare::first_argument_type input1;
    Compare::second_argument_type input2;
    cout << "Please enter first number: "; cin >> input1;
    cout << "Please enter second number: "; cin >> input2;
    cout << "Numbers " << input1 << " and " << input2;
    Compare Compare_object;
    Compare::result_type result = Compare_object (input1, input2);
    if (result)
        cout << " are equal.\n";
    else
        cout << " are not equal.\n";
    return 0;
}
```
Function Objects

cplusplus.com: “C++ Reference”.

- **plus**       Addition function object class
- **minus**      Subtraction function object class
- **multiplies** Multiplication function object class
- **divides**   Division function object class
- **modulus**   Modulus function object class
- **negate**    Negative function object class
- **equal_to**  Function object class for equality comparison
- **not_equal_to** Function object class for non-equality comparison
- **greater**   Function object class for greater-than inequality comparison
- **less**      Function object class for less-than inequality comparison
- **greater_equal** Function object class for greater-than-or-equal-to comparison
- **less_equal** Function object class for less-than-or-equal-to comparison
- **logical_and** Logical AND function object class
- **logical_or** Logical OR function object class
- **logical_not** Logical NOT function object class

...
Example

cplusplus.com: “C++ Reference”.

template <class T> struct less : binary_function <T,T,bool> {
  bool operator() (const T& x, const T& y) const
  {return x<y;}
};

Objects of this class can be used with some standard algorithms such as sort, merge or lower_bound.

#include <iostream>
#include <functional>
#include <algorithm>
using namespace std;

int main () {
  int foo[]={10,20,5,15,25};
  sort (foo, foo+5, less<int>() ); // 5 10 15 20 25
  return 0;
}
Non-Modifying Sequence Operations

cplusplus.com: “C++ Reference”.

- `for_each`: Apply function to range
- `find`: Find value in range
- `find_if`: Find element in range
- `find_end`: Find last subsequence in range
- `find_first_of`: Find element from set in range
- `adjacent_find`: Find equal adjacent elements in range
- `count`: Count appearances of value in range
- `count_if`: Return number of elements in range satisfying condition
- `mismatch`: Return first position where two ranges differ
- `equal`: Test whether the elements in two ranges are equal
- `search`: Find subsequence in range
- `search_n`: Find succession of equal values in range

These operations do not modify the contents of the sequence.
Algorithm for_each

clusplus.com: “C++ Reference”.

template <class InputIterator, class Function>
Function for_each (InputIterator first, InputIterator last, Function f);

Applies function f to each of the elements in the range [first,last).

The behavior of this template function is equivalent to:

template<class InputIterator, class Function>
Function for_each(InputIterator first, InputIterator last, Function f)
{
    while ( first!=last ) f(*first++);
    return f;
}
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

void myfunction (int i) { cout << " " << i; }
struct myclass { void operator() (int i) {cout << " " << i;} };

int main () {
    vector<int> myvector;
    myvector.push_back(10); myvector.push_back(20); myvector.push_back(30);
    
    for_each (myvector.begin(), myvector.end(), myfunction);
    myclass myobject;
    for_each (myvector.begin(), myvector.end(), myobject);
    return 0;
}
```

10 20 30 10 20 30
Algorithm find

clusplus.com: “C++ Reference”.

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

Returns an iterator to the first element in the range [first,last) that compares equal to value, or last if not found.

The behavior of this function template is equivalent to:

template<class InputIterator, class T>
InputIterator find ( InputIterator first, InputIterator last, const T& value )
{
    for ( ;first!=last; first++) if ( *first==value ) break;
    return first;
}

Complexity

At most, performs as many comparisons as the number of elements in the range [first,last).
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

int main () {
    int myints[] = {10, 20, 30, 40};
    int *p = find(myints,myints+4,30);
    ++p;
    cout << "The element following 30 is " << *p << endl;

    vector<int> myvector (myints,myints+4);
    vector<int>::iterator it = find (myvector.begin(), myvector.end(), 30);
    ++it;
    cout << "The element following 30 is " << *it << endl;
    return 0;
}
```

The element following 30 is 40
The element following 30 is 40
Algorithm **find_if**

clusplus.com: “C++ Reference”.

```cpp
template <class InputIterator, class Predicate>
InputIterator find_if(InputIterator first, InputIterator last, Predicate pred);
```

Returns an iterator to the first element in the range [first,last) for which applying pred to it, is true.

The behavior of this function template is equivalent to:

```cpp
template<class InputIterator, class Predicate>
InputIterator find_if(InputIterator first, InputIterator last, Predicate pred)
{
    for ( ; first!=last ; first++ ) if ( pred(*first) ) break;
    return first;
}
```
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

bool IsOdd (int i) { return ((i%2)==1); }

int main () {
    vector<int> myvector;
    myvector.push_back(10);
    myvector.push_back(25);
    myvector.push_back(40);
    myvector.push_back(55);
    vector<int>::iterator it = find_if (myvector.begin(), myvector.end(), IsOdd);
    cout << "The first odd value is " << *it << endl;
    return 0;
}
```

The first odd value is 25
Modifying Sequence Operations

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</table>

These operations modify the contents of the sequence.

Wolfgang Schreiner

http://www.risc.jku.at
Algorithm \texttt{copy}

\begin{verbatim}

template <class InIter, class OutIter>
OutIter copy ( InIter first, InIter last, OutIter result );

Copies the elements in the range \([\text{first},\text{last})\) into a range beginning at \text{result}. Returns an iterator to the last element in the destination range.

The behavior of this function template is equivalent to:

\begin{verbatim}

template<class InIter, class OutIter>
OutIter copy ( InIter first, InIter last, OutIter result )
{
    while (first!=last) *result++ = *first++;
    return result;
}
\end{verbatim}

If both ranges overlap in such a way that \text{result} points to an element in the range \([\text{first},\text{last}),\) the function \texttt{copy\_backward} should be used instead.
\end{verbatim}
\end{center}

Wolfgang Schreiner

http://www.risc.jku.at

Example

clusplus.com: “C++ Reference”.

#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

int main () {
    int myints[]={10,20,30,40,50,60,70};
    vector<int> myvector;

    myvector.resize(7);  // allocate space for 7 elements
    copy ( myints, myints+7, myvector.begin() );

    for (vector<int>::iterator it=myvector.begin(); it!=myvector.end(); ++it)
        cout << " " << *it;
    return 0;
}

10 20 30 40 50 60 70
Algorithm transform

template < class InIter, class OutIter, class UnaryOp >
OutIter transform ( InIter first1, InIter last1, OutIter result, UnaryOp op );

template < class InIter1, class InIter2, class OutIter, class BinaryOp >
OutIter transform ( InIter1 first1, InIter1 last1,
                 InIter2 first2, OutIter result, BinaryOp binary_op );

The first version applies op to all the elements in the input range ([first1,last1)) and stores each returned value in the range beginning at result. The second version uses as argument for each call to binary_op one element from the first input range ([first1,last1)) and one element from the second input range (beginning at first2). The behavior of this function template is equivalent to:

template < class InIter, class OutIter, class UnaryOperator >
OutIter transform ( InIter first1, InIter last1,
                 OutIter result, UnaryOperator op )
{
    while (first1 != last1)
        *result++ = op(*first1++);  // or: *result++=binary_op(*first1++,*first2++);
    return result;
}
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

int op_increase (int i) { return ++i; }
int op_sum (int i, int j) { return i+j; }

int main () {
  vector<int> first, second;
  for (int i=1; i<6; i++) first.push_back (i*10); // first: 10 20 30 40 50
  second.resize(first.size()); // allocate space
  transform (first.begin(), first.end(), second.begin(), op_increase);
  // second: 11 21 31 41 51
  transform (first.begin(), first.end(), second.begin(), first.begin(), op_sum);
  // first: 21 41 61 81 101
  return 0;
}
```
Algorithm generate

clusplus.com: “C++ Reference”.

template <class ForwardIterator, class Generator>
void generate ( ForwardIterator first, ForwardIterator last, Generator gen );

Sets the value of the elements in the range [first,last) to the value returned by successive calls to gen.

The behavior of this function template is equivalent to:

template <class ForwardIterator, class Generator>
void generate ( ForwardIterator first, ForwardIterator last, Generator gen )
{
    while (first != last) *first++ = gen();
}

Wolfgang Schreiner http://www.risc.jku.at 91/99
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
#include <cstdlib>
using namespace std;

int RandomNumber () { return (rand()%100); }
struct c_unique { int c; c_unique() {c=0;} int operator()() {return ++c;} };

int main () {
    vector<int> myvector (8); // e.g.: 57 87 76 66 85 54 17 15
    generate (myvector.begin(), myvector.end(), RandomNumber);

    c_unique UniqueNumber; // 1 2 3 4 5 6 7 8
    generate (myvector.begin(), myvector.end(), UniqueNumber);
    return 0;
}
```
# Sorting and Operations on Sorted Ranges

 cúlusplús.com: “C++ Reference”.

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</table>
**Algorithm** sort

clusplus.com: “C++ Reference”.

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

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

Sorts the elements in the range `[first,last)` into ascending order. The elements are compared using operator `<` for the first version, and `comp` for the second. Elements that would compare equal to each other are not guaranteed to keep their original relative order.

**Complexity**

Approximately \(N \times \log N\) comparisons on average (where \(N\) is \(last\)-\(first\)).

In the worst case, up to \(N^2\), depending on specific sorting algorithm used by library implementation.
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

bool myfunction (int i, int j) { return (i<j); }
struct myclass { bool operator() (int i, int j) { return (i<j);} };

int main () {
    int myints[] = {32,71,12,45,26,80,53,33};
    vector<int> myvector (myints, myints+8); // 32 71 12 45 26 80 53 33

    sort (myvector.begin(), myvector.begin()+4); // (12 32 45 71) 26 80 53 33
    // 12 32 45 71 (26 33 53 80)
    sort (myvector.begin()+4, myvector.end(), myfunction);

    myclass myobject; // (12 26 32 33 45 53 71 80)
    sort (myvector.begin(), myvector.end(), myobject);
    return 0;
}
```
Algorithm lower_bound

clusplus.com: “C++ Reference”.

template <class FwdIterator, class T> FwdIterator lower_bound
  (FwdIterator first, FwdIterator last, const T& val);
template <class FwdIterator, class T, class Compare> FwdIterator lower_bound
  (FwdIterator first, FwdIterator last, const T& val, Compare comp);

Returns an iterator pointing to the first element in the range [first,last) which does not compare less than val.

The elements are compared using operator< for the first version, and comp for the second. The elements in the range shall already be sorted according to this same criterion (operator< or comp), or at least partitioned with respect to val. The function optimizes the number of comparisons performed by comparing non-consecutive elements of the sorted range, which is specially efficient for random-access iterators.

Complexity
On average, logarithmic in the distance between first and last: Performs approximately log2(N)+1 element comparisons (where N is this distance). On non-random-access iterators, the iterator advances produce themselves an additional linear complexity in N on average.
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream> // std::cout
#include <algorithm> // std::lower_bound, std::upper_bound, std::sort
#include <vector> // std::vector
using namespace std;

int main () {
    int myints[] = {10,20,30,30,20,10,10,20};
    vector<int> v(myints,myints+8); // 10 20 30 30 20 10 10 20
    sort (v.begin(), v.end()); // 10 10 10 20 20 20 30 30

    vector<int>::iterator low,up;
    low=lower_bound (v.begin(), v.end(), 20); // ^
    up=upper_bound (v.begin(), v.end(), 20); // ^

    cout << "lower_bound at position " << (low- v.begin()) << ’\n’;
    cout << "upper_bound at position " << (up - v.begin()) << ’\n’;
    return 0;
}

lower_bound at position 3
upper_bound at position 6
```
Algorithm `merge`

clusplus.com: “C++ Reference”.

```cpp
template <class InIter1, class InIter2, class OutIter>
OutIter merge ( InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2,
    OutIter result [, Compare comp] );
```

Combines the elements in the sorted ranges `[first1,last1)` and `[first2,last2)`, into a new range beginning at `result` with its elements sorted. The comparison for sorting uses either `operator<` for the first version, or `comp` for the second. For the function to yield the expected result, the elements in the both ranges shall already be ordered according to the same strict weak ordering criterion (`operator<` or `comp`). The resulting range is also sorted according to it.

The behavior of this function template is equivalent to:

```cpp
template <class InIter1, class InIter2, class OutIter>
OutIter merge ( InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2,
    OutIter result ) {
    while (true) {
        *result++ = (*first2<*first1)? *first2++ : *first1++;
        if (first1==last1) return copy(first2,last2,result);
        if (first2==last2) return copy(first1,last1,result); } }
```
Example

clusplus.com: “C++ Reference”.

```cpp
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

int main () {
    int first[] = {5,10,15,20,25};
    int second[] = {50,40,30,20,10};
    vector<int> v(10);

    sort (first,first+5);
    sort (second,second+5);
    merge (first,first+5,second,second+5,v.begin());

    for (vector<int>::iterator it=v.begin(); it!=v.end(); ++it)
        cout << " " << *it;
    return 0;
}
```

5 10 10 15 20 20 25 30 40 50