

1 Notations

- The symbol `const` for `const`.
- The symbol $\hookrightarrow$ for *function returned value*.
- Template class parameters lead by outlined character. For example: `T`, `Key`, `Compare`. Interpreted in `template` definition context.
- Sometimes `class`, `typename` dropped.
- Template class parameters dropped, thus `C` sometimes used instead of `C(T)`.
- “See example” by ☞ , its output by ☞ .

2 Containers

2.1 Pair

```
#include <utility>
```

```
template<class T1, class T2>
struct pair {
    T1 first; T2 second;
    pair() {}
    pair(const T1& a, const T2& b):
        first(a), second(b) {} };
```

2.1.1 Types

```
pair::first_type
pair::second_type
```

2.1.2 Functions & Operators

See also 2.2.3.

```
pair(T1,T2)
make_pair(const T1&, const T2&);
```

2.2 Containers — Common

Here `X` is any of
`{vector, deque, list,`
`set, multiset, map, multimap}`

2.2.1 Types

```
X::value_type
X::reference
X::const_reference
X::iterator
X::const_iterator
X::reverse_iterator
X::const_reverse_iterator
X::difference_type
X::size_type
```

Iterators reference `value_type` (See 6).

2.2.2 Members & Operators

```
X::X();
X::X(const X&);
X::~X();
X& X::operator=(const X&);

X::iterator X::begin();
X::const_iterator X::begin() const;
X::iterator X::end();
X::const_iterator X::end() const;
X::reverse_iterator X::rbegin();
X::const_reverse_iterator X::rbegin() const;
X::reverse_iterator X::rend();
X::const_reverse_iterator X::rend() const;
```

```
X::size_type X::size() const;
X::size_type X::max_size() const;
bool X::empty() const;
void X::swap(X& x);
```

```
void X::clear();
```

2.2.3 Comparison Operators

Let, `X v, w`. `X` may also be `pair` (2.1).

```
v == w    v != w
v < w     v > w
v <= w    v >= w
```

All done lexicographically and $\hookrightarrow$ `bool`.

2.3 Sequence Containers

`S` is any of `{vector, deque, list}`

2.3.1 Constructors

```
S::S(S::size_type n,
    const S::value_type& t);
S::S(S::const_iterator first,
    S::const_iterator last); ☞ 7.2, 7.3
```

2.3.2 Members

```
S::iterator // inserted copy
S::insert(S::iterator before,
    const S::value_type& val);

S::iterator // inserted copy
S::insert(S::iterator before,
    S::size_type nVal,
    const S::value_type& val);

S::iterator // inserted copy
S::insert(S::iterator before,
    S::const_iterator first,
    S::const_iterator last);
```

```
S::iterator S::erase(S::iterator position);
```

```
S::iterator S::erase(S::const_iterator first,
    const S::const_iterator last);
void S::push_back(const S::value_type& x);
void S::pop_back();
S::reference S::front();
S::const_reference S::front() const;
S::reference S::back();
S::const_reference S::back() const;
```

2.4 Vector

```
#include <vector>
```

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

See also 2.2 and 2.3.

```
size_type vector::capacity() const;
void vector::reserve(size_type n);
vector::reference
vector::operator[](size_type i);
vector::const_reference
vector::operator[](size_type i) const;
☞ 7.1.
```

2.5 Deque

```
#include <deque>
```

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

Has all of `vector` functionality (see 2.4).

```
void deque::push_front(const T& x);
void deque::pop_front();
```

2.6 List

```
#include <list>
```

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

See also 2.2 and 2.3.

```
void list::pop_front();
void list::push_front(const T& x);
void // move all x (&x ≠ this) before pos
list::splice(iterator pos, list(T)& x); ☞ 7.2
void // move x's xElemPos before pos
list::splice(iterator pos,
    list(T)& x,
    iterator xElemPos); ☞ 7.2
```

```
void // move x's [xFirst,xLast) before pos
list::splice(iterator pos,
    list(T)& x,
    iterator xFirst,
    iterator xLast); ☞ 7.2

void list::remove(const T& value);
void list::remove_if(Predicate pred);
// after call: ∀ this iterator p, *p ≠ *(p+1)
void list::unique(); // remove repeats
void // as before but, ¬binPred(*p, *(p+1))
list::unique(BinaryPredicate binPred);
// Assuming both this and x sorted
void list::merge(list(T)& x);
// merge and assume sorted by cmp
void list::merge(list(T)& x, Compare cmp);
void list::reverse();
void list::sort();
void list::sort(Compare cmp);
```

2.7 Sorted Associative

Here `A` any of
`{set, multiset, map, multimap}`.

2.7.1 Types

For `A=[multi]set`, columns are the same

```
A::key_type    A::value_type
A::key_compare A::value_compare
```

2.7.2 Constructors

```
A::A(Compare c=Compare())
A::A(A::const_iterator first,
    A::const_iterator last,
    Compare c=Compare());
```

2.7.3 Members

```
A::key_compare    A::key_comp() const;
A::value_compare  A::value_comp() const;

A::iterator
A::insert(A::iterator hint,
    const A::value_type& val);

void A::insert(A::iterator first,
    A::iterator last);

A::size_type // # erased
A::erase(const A::key_type& k);
void A::erase(A::iterator p);
void A::erase(A::iterator first,
    A::iterator last);

A::size_type
A::count(const A::key_type& k) const;
A::iterator A::find(const A::key_type& k) const;
```

```
A::iterator
A::lower_bound(const A::key_type& k) const;
A::iterator
A::upper_bound(const A::key_type& k) const;
pair<A::iterator, A::iterator> // see 4.3.1
A::equal_range(const A::key_type& k) const;
```

2.8 Set

```
#include <set>
```

```
template<class Key,
         class Compare=less<Key>,
         class Alloc=allocator>
class set;
```

See also 2.2 and 2.7.

```
set::set(const Compare& cmp=Compare());
pair<set::iterator, bool> // bool = if new
set::insert(const set::value_type& x);
```

2.9 Multiset

```
#include <multiset.h>
```

```
template<class Key,
         class Compare=less<Key>,
         class Alloc=allocator>
class multiset;
```

See also 2.2 and 2.7.

```
multiset::multiset(
    const Compare& cmp=Compare());
multiset::multiset(
    InputIterator first,
    InputIterator last,
    const Compare& cmp=Compare());
multiset::iterator // inserted copy
multiset::insert(const multiset::value_type& x);
```

2.10 Map

```
#include <map>
```

```
template<class Key, class T,
         class Compare=less<Key>,
         class Alloc=allocator>
class map;
```

See also 2.2 and 2.7.

2.10.1 Types

```
map::value_type // pair(const Key, T)
```

2.10.2 Members

```
map::map(
    const Compare& cmp=Compare());
pair<map::iterator, bool> // bool = if new
map::insert(const map::value_type& x);
T& map::operator[](const map::key_type&);
map::const_iterator
map::lower_bound(
    const map::key_type& k) const;
map::const_iterator
map::upper_bound(
    const map::key_type& k) const;
pair<map::const_iterator, map::const_iterator>
map::equal_range(
```

```
const map::key_type& k) const;
```

Example

```
typedef map<string, int> MSI;
MSI nam2num;
nam2num.insert(MSI::value_type("one", 1));
nam2num.insert(MSI::value_type("two", 2));
nam2num.insert(MSI::value_type("three", 3));
int n3 = nam2num["one"] + nam2num["two"];
cout << n3 << " called ";
for (MSI::const_iterator i = nam2num.begin();
     i != nam2num.end(); ++i)
    if ((*i).second == n3)
        {cout << (*i).first << endl;}
```

➤ 3 called three

2.11 Multimap

```
#include <multimap.h>
```

```
template<class Key, class T,
         class Compare=less<Key>,
         class Alloc=allocator>
class multimap;
```

See also 2.2 and 2.7.

2.11.1 Types

```
multimap::value_type // pair(const Key, T)
```

2.11.2 Members

```
multimap::multimap(
    const Compare& cmp=Compare());
multimap::multimap(
    InputIterator first,
    InputIterator last,
    const Compare& cmp=Compare());
```

```
multimap::const_iterator
multimap::lower_bound(
    const multimap::key_type& k) const;
multimap::const_iterator
multimap::upper_bound(
    const multimap::key_type& k) const;
pair<multimap::const_iterator,
     multimap::const_iterator>
multimap::equal_range(
    const multimap::key_type& k) const;
```

3 Container Adaptors

3.1 Stack Adaptor

```
#include <stack>
```

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

Default constructor. `Container` must have `back()`, `push_back()`, `pop_back()`. So `vector`, `list` and `deque` can be used.

```
bool stack::empty() const;
Container::size_type stack::size() const;
void
stack::push(const Container::value_type& x);
void stack::pop();
```

```
const Container::value_type&
stack::top() const;
void Container::value_type& stack::top();
```

Comparison Operators

```
bool operator==(const stack& s0,
                const stack& s1);
bool operator<(const stack& s0,
               const stack& s1);
```

3.2 Queue Adaptor

```
#include <queue>
```

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

Default constructor. `Container` must have `empty()`, `size()`, `back()`, `front()`, `push_back()` and `pop_front()`. So `list` and `deque` can be used.

```
bool queue::empty() const;
Container::size_type queue::size() const;
```

```
void
queue::push(const Container::value_type& x);
void queue::pop();
const Container::value_type&
queue::front() const;
Container::value_type& queue::front();
const Container::value_type&
queue::back() const;
Container::value_type& queue::back();
```

Comparison Operators

```
bool operator==(const queue& q0,
                const queue& q1);
bool operator<(const queue& q0,
               const queue& q1);
```

3.3 Priority Queue

```
#include <queue>
```

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

`Container` must provide random access iterator and have `empty()`, `size()`, `front()`, `push_back()` and `pop_back()`. So `vector` and `deque` can be used.

Mostly implemented as *heap*.

3.3.1 Constructors

```
explicit priority_queue::priority_queue(
    const Compare& comp=Compare());
priority_queue::priority_queue(
    InputIterator first,
    InputIterator last,
    const Compare& comp=Compare());
```

3.3.2 Members

```
bool priority_queue::empty() const;
Container::size_type
priority_queue::size() const;
const Container::value_type&
priority_queue::top() const;
Container::value_type& priority_queue::top();
void priority_queue::push(
    const Container::value_type& x);
void priority_queue::pop();
No comparison operators.
```

4 Algorithms

#include <algorithm>

STL algorithms use iterator type parameters. Their *names* suggest their category (See 6.1).

For abbreviation, the clause —

`template <class Foo, ...>` is dropped. The outlined leading character can suggest the template context.

Note: When looking at two sequences: $S_1 = [first_1, last_1)$ and $S_2 = [first_2, ?)$ or $S_2 = [?, last_2)$ — caller is responsible that function will not overflow S_2 .

4.1 Query Algorithms

Function // *f* not changing $[first, last)$

```
for_each(InputIterator first,
         InputIterator last,
         Function f); 7.4
```

InputIterator // *first* *i* so *i*==*last* or **i*==*val*

```
find(InputIterator first,
     InputIterator last,
     const T val); 7.2
```

InputIterator // *first* *i* so *i*==*last* or *pred*(*i*)

```
find_if(InputIterator first,
        InputIterator last,
        Predicate pred); 7.7
```

ForwardIterator // *first* duplicate

```
adjacent_find(ForwardIterator first,
              ForwardIterator last);
```

ForwardIterator // *first* binPred-duplicate

```
adjacent_find(ForwardIterator first,
              ForwardIterator last,
              BinaryPredicate binPred);
```

void // *n* = # equal val

```
count(ForwardIterator first,
     ForwardIterator last,
     const T val,
     Size& n);
```

void // *n* = # satisfying pred

```
count_if(ForwardIterator first,
         ForwardIterator last,
         Predicate pred,
         Size& n);
```

// $\curvearrowright$ bi-pointing to *first* !=

```
pair(InputIterator1, InputIterator2)
mismatch(InputIterator1 first1,
         InputIterator1 last1,
         InputIterator2 first2);
```

```
//  $\curvearrowright$  bi-pointing to first binPred-mismatch
pair(InputIterator1, InputIterator2)
mismatch(InputIterator1 first1,
         InputIterator1 last1,
         InputIterator2 first2,
         BinaryPredicate binPred);
```

bool

```
equal(InputIterator1 first1,
      InputIterator1 last1,
      InputIterator2 first2);
```

bool

```
equal(InputIterator1 first1,
      InputIterator1 last1,
      InputIterator2 first2,
      BinaryPredicate binPred);
```

// $[first_2, last_2) \subseteq [first_1, last_1)$

```
ForwardIterator1
search(ForwardIterator1 first1,
       ForwardIterator1 last1,
       ForwardIterator2 first2,
       ForwardIterator2 last2);
```

// $[first_2, last_2) \subseteq binPred [first_1, last_1)$

```
ForwardIterator1
search(ForwardIterator1 first1,
       ForwardIterator1 last1,
       ForwardIterator2 first2,
       ForwardIterator2 last2,
       BinaryPredicate binPred);
```

4.2 Mutating Algorithms

OutputIterator // $\curvearrowright$ *first*₂ + (*last*₁ − *first*₁)

```
copy(InputIterator first1,
     InputIterator last1,
     OutputIterator first2);
```

// $\curvearrowright$ *last*₂ − (*last*₁ − *first*₁)

```
BidirectionalIterator2
copy_backward(
    BidirectionalIterator1 first1,
    BidirectionalIterator1 last1,
    BidirectionalIterator2 last2);
```

void swap(T& x, T& y);

ForwardIterator2 // $\curvearrowright$ *first*₂ + # $[first_1, last_1)$

```
swap_ranges(ForwardIterator1 first1,
            ForwardIterator1 last1,
            ForwardIterator2 first2);
```

OutputIterator // $\curvearrowright$ *result* + (*last*₁ − *first*₁)

```
transform(InputIterator first,
          InputIterator last,
          OutputIterator result,
          UnaryOperation op); 7.6
```

OutputIterator // $\forall s_i^k \in S_k \ r_i = bop(s_i^1, s_i^2)$

```
transform(InputIterator1 first1,
          InputIterator1 last1,
          InputIterator2 first2,
          OutputIterator result,
          BinaryOperation bop);
```

void replace(ForwardIterator first,

```
ForwardIterator last,
const T& oldVal,
const T& newVal);
```

void

```
replace_if(ForwardIterator first,
           ForwardIterator last,
           Predicate& pred,
           const T& newVal);
```

OutputIterator // $\curvearrowright$ *result*₂ + # $[first, last)$

```
replace_copy(InputIterator first,
            InputIterator last,
            OutputIterator result,
            const T& oldVal,
            const T& newVal);
```

OutputIterator // *as above* but using pred

```
replace_copy_if(InputIterator first,
                InputIterator last,
                OutputIterator result,
                Predicate& pred,
                const T& newVal);
```

void fill(ForwardIterator first,

```
ForwardIterator last,
const T& value);
```

void fill_n(ForwardIterator first,

```
Size n,
const T& value);
```

void // *by calling* *gen*()

```
generate(ForwardIterator first,
         ForwardIterator last,
         Generator gen);
```

void // *n* calls to *gen*()

```
generate_n(ForwardIterator first,
           Size n,
           Generator gen);
```

All variants of **remove** and **unique** return iterator to *new end* or *past last copied*.

ForwardIterator // $[first, last)$ is all value

```
remove(ForwardIterator first,
      ForwardIterator last,
      const T& value);
```

ForwardIterator // *as above* but using pred

```
remove_if(ForwardIterator first,
          ForwardIterator last,
          Predicate pred);
```

OutputIterator // $\curvearrowright$ *past last copied*

```
remove_copy(InputIterator first,
            InputIterator last,
            OutputIterator result,
            const T& value);
```

OutputIterator // *as above* but using pred

```
remove_copy_if(InputIterator first,
               InputIterator last,
               OutputIterator result,
               Predicate pred);
```

All variants of **unique** template functions remove *consecutive* (*binPred*-) duplicates. Thus useful after sort (See 4.3).

ForwardIterator // $[first, last)$ gets repetitions

```
unique(ForwardIterator first,
      ForwardIterator last);
```

ForwardIterator // *as above* but using binPred

```
unique(ForwardIterator first,
      ForwardIterator last,
      BinaryPredicate binPred);
```

OutputIterator // $\curvearrowright$ *past last copied*

```
unique_copy(InputIterator first,
            InputIterator last,
            OutputIterator result,
            const T& result);
```

OutputIterator // *as above* but using binPred

```
unique_copy(InputIterator first,
            InputIterator last,
            OutputIterator result,
            BinaryPredicate binPred);
```

void

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

OutputIterator // $\curvearrowright$ *past last copied*

```
reverse_copy(BidirectionalIterator first,
             BidirectionalIterator last,
             OutputIterator result);
```

void // *with first moved to middle*

```
rotate(ForwardIterator first,
      ForwardIterator middle,
      ForwardIterator last);
```

OutputIterator // *first to middle* position

```
rotate_copy(ForwardIterator first,
            ForwardIterator middle,
            ForwardIterator last,
            OutputIterator result);
```

```

void
random_shuffle(
    RandomAccessIterator first,
    RandomAccessIterator last,
    RandomGenerator rand);

void // rand() returns double in [0, 1)
random_shuffle(
    RandomAccessIterator first,
    RandomAccessIterator last,
    RandomGenerator rand);

BidirectionalIterator // begin with true
partition(BidirectionalIterator first,
    BidirectionalIterator last,
    Predicate pred);

BidirectionalIterator // begin with true
stable_partition(
    BidirectionalIterator first,
    BidirectionalIterator last,
    Predicate pred);

```

4.3 Sort and Application

```

void sort(RandomAccessIterator first,
    RandomAccessIterator last);

void sort(RandomAccessIterator first,
    RandomAccessIterator last,
    Compare comp);

void
stable_sort(RandomAccessIterator first,
    RandomAccessIterator last);

void
stable_sort(RandomAccessIterator first,
    RandomAccessIterator last,
    Compare comp);

void // [first,middle) sorted,
partial_sort( // [middle,last) eq-greater
    RandomAccessIterator first,
    RandomAccessIterator middle,
    RandomAccessIterator last);

void // as above but using comp(ei, ej)
partial_sort(
    RandomAccessIterator first,
    RandomAccessIterator middle,
    RandomAccessIterator last,
    Compare comp);

RandomAccessIterator // post last sorted
partial_sort_copy(
    InputIterator first,
    InputIterator last,
    RandomAccessIterator resultFirst,
    RandomAccessIterator resultLast);

```

```

RandomAccessIterator
partial_sort_copy(
    InputIterator first,
    InputIterator last,
    RandomAccessIterator resultFirst,
    RandomAccessIterator resultLast,
    Compare comp);

Let  $n = \text{position} - \text{first}$ , nth_element
partitions  $[\text{first}, \text{last})$  into:  $L = [\text{first}, \text{position})$ ,
 $e_n$ ,  $R = [\text{position} + 1, \text{last})$  such that
 $\forall l \in L, \forall r \in R \quad l \not\geq e_n \leq r$ .

void
nth_element(
    RandomAccessIterator first,
    RandomAccessIterator position,
    RandomAccessIterator last);

void // as above but using comp(ei, ej)
nth_element(
    RandomAccessIterator first,
    RandomAccessIterator position,
    RandomAccessIterator last,
    Compare comp);

```

4.3.1 Binary Search

```

bool
binary_search(ForwardIterator first,
    ForwardIterator last,
    const T& value);

bool
binary_search(ForwardIterator first,
    ForwardIterator last,
    const T& value,
    Compare comp);

ForwardIterator
lower_bound(ForwardIterator first,
    ForwardIterator last,
    const T& value);

ForwardIterator
lower_bound(ForwardIterator first,
    ForwardIterator last,
    const T& value,
    Compare comp);

ForwardIterator
upper_bound(ForwardIterator first,
    ForwardIterator last,
    const T& value);

ForwardIterator
upper_bound(ForwardIterator first,
    ForwardIterator last,
    const T& value,
    Compare comp);

```

equal_range returns iterators pair that lower_bound and upper_bound return.

```

pair(ForwardIterator, ForwardIterator)
equal_range(ForwardIterator first,
    ForwardIterator last,
    const T& value);

pair(ForwardIterator, ForwardIterator)
equal_range(ForwardIterator first,
    ForwardIterator last,
    const T& value,
    Compare comp);

```

7.5

4.3.2 Merge

Assuming $S_1 = [\text{first}_1, \text{last}_1)$ and $S_2 = [\text{first}_2, \text{last}_2)$ are sorted, stably merge them into $[\text{result}, \text{result} + N)$ where $N = |S_1| + |S_2|$.

```

OutputIterator
merge(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result);

```

```

OutputIterator
merge(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result,
    Compare comp);

```

```

void // ranges [first,middle) [middle,last)
inplace_merge( // into [first,last)
    BidirectionalIterator first,
    BidirectionalIterator middle,
    BidirectionalIterator last);

```

```

void // as above but using comp
inplace_merge(
    BidirectionalIterator first,
    BidirectionalIterator middle,
    BidirectionalIterator last,
    Compare comp);

```

4.3.3 Functions on Sets

Can work on sorted associative containers (see 2.7). For **multiset** the interpretation of — *union*, *intersection* and *difference* is by: *maximum*, *minimum* and *subtraction* of occurrences respectively.

Let $S_i = [\text{first}_i, \text{last}_i)$ for $i = 1, 2$.

```

bool //  $S_1 \supseteq S_2$ 
includes(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2);

```

```

bool // as above but using comp
includes(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    Compare comp);

```

```

OutputIterator //  $S_1 \cup S_2$ , past end
set_union(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result);

```

```

OutputIterator // as above but using comp
set_union(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result,
    Compare comp);

```

```

OutputIterator //  $S_1 \cap S_2$ , past end
set_intersection(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result);

```

```

OutputIterator // as above but using comp
set_intersection(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result,
    Compare comp);

```

```

OutputIterator //  $S_1 \setminus S_2$ , past end
set_difference(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result);

```

```

OutputIterator // as above but using comp
set_difference(InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result,
    Compare comp);

```

```
OutputIterator //  $S_1 \Delta S_2$ ,  $\curvearrowright$  past end
set_symmetric_difference(
    InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result);
```

```
OutputIterator // as above but using comp
set_symmetric_difference(
    InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    OutputIterator result,
    Compare comp);
```

4.3.4 Heap

```
void // (last - 1) is pushed
push_heap(RandomAccessIterator first,
           RandomAccessIterator last);
```

```
void // as above but using comp
push_heap(RandomAccessIterator first,
           RandomAccessIterator last,
           Compare comp);
```

```
void // first is popped
pop_heap(RandomAccessIterator first,
          RandomAccessIterator last);
```

```
void // as above but using comp
pop_heap(RandomAccessIterator first,
          RandomAccessIterator last,
          Compare comp);
```

```
void // [first,last) arbitrary ordered
make_heap(RandomAccessIterator first,
           RandomAccessIterator last);
```

```
void // as above but using comp
make_heap(RandomAccessIterator first,
           RandomAccessIterator last,
           Compare comp);
```

```
void // sort the [first,last) heap
sort_heap(RandomAccessIterator first,
           RandomAccessIterator last);
```

```
void // as above but using comp
sort_heap(RandomAccessIterator first,
           RandomAccessIterator last,
           Compare comp);
```

4.3.5 Min and Max

```
const T& min(const T& x0, const T& x1);
```

```
const T& min(const T& x0,
             const T& x1,
             Compare comp);
```

```
const T& max(const T& x0, const T& x1);
```

```
const T& max(const T& x0,
             const T& x1,
             Compare comp);
```

```
ForwardIterator
min_element(ForwardIterator first,
            ForwardIterator last);
```

```
ForwardIterator
min_element(ForwardIterator first,
            ForwardIterator last,
            Compare comp);
```

```
ForwardIterator
max_element(ForwardIterator first,
            ForwardIterator last);
```

```
ForwardIterator
max_element(ForwardIterator first,
            ForwardIterator last,
            Compare comp);
```

4.3.6 Permutations

To get all permutations, start with ascending sequence end with descending.

```
bool //  $\curvearrowright$  iff available
next_permutation(
    BidirectionalIterator first,
    BidirectionalIterator last);
```

```
bool // as above but using comp
next_permutation(
    BidirectionalIterator first,
    BidirectionalIterator last,
    Compare comp);
```

```
bool //  $\curvearrowright$  iff available
prev_permutation(
    BidirectionalIterator first,
    BidirectionalIterator last);
```

```
bool // as above but using comp
prev_permutation(
    BidirectionalIterator first,
    BidirectionalIterator last,
    Compare comp);
```

4.3.7 Lexicographic Order

```
bool lexicographical_compare(
    InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2);
```

```
bool lexicographical_compare(
    InputIterator1 first1,
    InputIterator1 last1,
    InputIterator2 first2,
    InputIterator2 last2,
    Compare comp);
```

4.4 Computational

```
#include <numeric>
```

```
T //  $\sum_{[first,last)}$   $\approx$  7.6
accumulate(InputIterator first,
            InputIterator last,
            T initVal);
```

```
T // as above but using binop
accumulate(InputIterator first,
            InputIterator last,
            T initVal,
            BinaryOperation binop);
```

```
T //  $\sum_i e_i^1 \times e_i^2$  for  $e_i^k \in S_k, (k = 1, 2)$ 
inner_product(InputIterator1 first1,
              InputIterator1 last1,
              InputIterator2 first2,
              T initVal);
```

```
T // Similar, using  $\sum^{(sum)}$  and  $\times^{mult}$ 
inner_product(InputIterator1 first1,
              InputIterator1 last1,
              InputIterator2 first2,
              T initVal,
              BinaryOperation sum,
              BinaryOperation mult);
```

```
OutputIterator //  $r_k = \sum_{i=first}^{first+k} e_i$ 
partial_sum(InputIterator first,
            InputIterator last,
            OutputIterator result);
```

```
OutputIterator // as above but using binop
partial_sum(
    InputIterator first,
    InputIterator last,
    OutputIterator result,
    BinaryOperation binop);
```

```
OutputIterator //  $r_k = s_k - s_{k-1}$  for  $k > 0$ 
adjacent_difference( //  $r_0 = s_0$ 
    InputIterator first,
    InputIterator last,
    OutputIterator result);
```

```
OutputIterator // as above but using binop
adjacent_difference(
    InputIterator first,
    InputIterator last,
    OutputIterator result,
    BinaryOperation binop);
```

5 Function Objects

```
#include <functional>
```

```
template<class Arg, class Result>
struct unary_function {
    typedef Arg argument_type;
    typedef Result result_type;};
```

Derived unary objects:

```
struct negate<T>;
struct logical_not<T>;
 $\approx$  7.6
```

```
template<class Arg1, class Arg2,
         class Result>
struct binary_function {
    typedef Arg1 first_argument_type;
    typedef Arg2 second_argument_type;
    typedef Result result_type;};
```

Following derived template objects accept two operands. Result obvious by the name.

```
struct plus<T>;
struct minus<T>;
struct multiplies<T>;
struct divides<T>;
struct modulus<T>;
struct equal_to<T>;
struct not_equal_to<T>;
struct greater<T>;
struct less<T>;
struct greater_equal<T>;
struct less_equal<T>;
struct logical_and<T>;
struct logical_or<T>;
```

5.1 Function Adaptors

5.1.1 Negators

```
template<class Predicate>
class unary_negate : public
    unary_function<Predicate::argument_type,
                   bool>;
```

```
unary_negate::unary_negate(
    Predicate pred);

bool // negate pred
unary_negate::operator()(
    Predicate::argument_type x);

unary_negate(Predicate)
not1(const Predicate pred);
```

```
template<class Predicate>
class binary_negate : public
    binary_function<
        Predicate::first_argument_type,
        Predicate::second_argument_type>;
bool>;
```

```
binary_negate::binary_negate(
    Predicate pred);

bool // negate pred
binary_negate::operator()(
    Predicate::first_argument_type x
    Predicate::second_argument_type y);

binary_negate(Predicate)
not2(const Predicate pred);
```

5.1.2 Binders

```
template<class Operation>
class binder1st: public
    unary_function<
        Operation::second_argument_type,
        Operation::result_type>;
```

```
binder1st::binder1st(
    const Operation& op,
    const Operation::first_argument_type y);

// argument_type from unary_function
Operation::result_type
binder1st::operator()(
    const binder1st::argument_type x);

binder1st(Operation)
bind1st(const Operation& op, const T& x);
```

```
template<class Operation>
class binder2nd: public
    unary_function<
        Operation::first_argument_type,
        Operation::result_type>;
```

```
binder2nd::binder2nd(
    const Operation& op,
    const Operation::second_argument_type y);

// argument_type from unary_function
Operation::result_type
binder2nd::operator()(
    const binder2nd::argument_type x);

binder2nd(Operation)
bind2nd(const Operation& op, const T& x);
§ 7.7.
```

5.1.3 Pointers to Functions

```
template<class Arg, class Result>
class pointer_to_unary_function :
    public unary_function<Arg, Result>;
```

```
pointer_to_unary_function<Arg, Result>
ptr_fun(Result(*x)(Arg));
```

```
template<class Arg1, class Arg2,
         class Result>
class pointer_to_binary_function :
    public binary_function<Arg1, Arg2,
                           Result>;
```

```
pointer_to_binary_function<Arg1, Arg2,
                           Result>
ptr_fun(Result(*x)(Arg1, Arg2));
```

6 Iterators

```
#include <iterator>
```

6.1 Iterators Categories

Here, we will use:

X iterator type.
a, b iterator values.
r iterator reference (X& r).
t a value type T.

Imposed by empty struct tags.

6.1.1 Input, Output, Forward

```
struct input_iterator_tag {} § 7.8
struct output_iterator_tag {}
struct forward_iterator_tag {}
```

In table follows requirements check list for Input, Output and Forward iterators.

Expression; Requirements	I	O	F
X()			•
X u			•
X(a)	⇒ X(a) == a	•	•
	*a=t ⇔ *X(a)=t		•
X u(a)	⇒ u == a	•	•
X u=a	u copy of a	•	•
a==b	equivalence relation	•	•
a!=b	⇔ !(a==b)	•	•
r = a	⇒ r == a		•
*a	convertible to T. a==b ⇔ *a==*b	•	•
*a=t	(for forward, if X mutable)	•	•
++r	result is dereferenceable or past-the-end. &r == &++r convertible to const X& convertible to X& r==s ⇔ ++r==++s	•	•
r++	convertible to X& ⇔ {X x=r; ++r; return x;}	•	•
***r	convertible to T	•	•
*r++		•	•

§ 7.7.

6.1.2 Bidirectional Iterators

```
struct bidirectional_iterator_tag {}
```

The forward requirements and:

```
--r Convertible to const X&. If ∃ r=++s then
--r refers same as s. &r==&--r.
--(++r)==r. (--r == --s ⇒ r==s.

r-- ⇔ {X x=r; --r; return x;}.
```

6.1.3 Random Access Iterator

```
struct random_access_iterator_tag {}
```

The bidirectional requirements and (m,n iterator's distance (integral) value):

```
r+=n ⇔ {for (m=n; m-->0; ++r);
        for (m=n; m++<0; --r);
        return r;} //but time = O(1).

a+n ⇔ n+a ⇔ {X x=a; return a+=n;}
r-=n ⇔ r += -n.
a-n ⇔ a+(-n).
b-a Returns iterator's distance value n, such
that a+n == b.

a[n] ⇔ *(a+n).
a<b Convertible to bool, < total ordering.
a<b Convertible to bool, > opposite to <.
a<=b ⇔ !(a>b).
a>=b ⇔ !(a<b).
```

6.2 Stream Iterators

```
template<class T,
         class Distance=ptrdiff_t>
class istream_iterator :
    public iterator(input_iterator_tag, T, Distance);
```

```
// end of stream § 7.4
istream_iterator::istream_iterator();
```

```
istream_iterator::istream_iterator(
    istream& s); § 7.4
```

```
istream_iterator::istream_iterator(
    const istream_iterator(T, Distance)&);
```

```
istream_iterator::~istream_iterator();
```

```
const T& istream_iterator::operator*() const;
```

```
istream_iterator& // Read and store T value
istream_iterator::operator++() const;
```

```
bool // all end-of-streams are equal
operator==(const istream_iterator,
            const istream_iterator);
```

```
template<class T>
class ostream_iterator :
    public iterator(output_iterator_tag, void, ...);
```

```
// If delim ≠ 0 add after each write
ostream_iterator::ostream_iterator(
    ostream& s,
    const char* delim=0);
```

```
ostream_iterator::ostream_iterator(
    const ostream_iterator s);
```

```
ostream_iterator& // Assign & write (*o=t)
ostream_iterator::operator*() const;
```

```
ostream_iterator&
ostream_iterator::operator=(
    const ostream_iterator s);
```

```
ostream_iterator& // No-op
ostream_iterator::operator++();
```

```
ostream_iterator& // No-op
ostream_iterator::operator++(int);
```

§ 7.4.

6.3 Typedefs & Adaptors

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

6.3.1 Traits

```
template<I>
class iterator_traits {
    I::iterator_category    iterator_category;
    I::value_type           value_type;
    I::difference_type      difference_type;
    I::pointer              pointer;
    I::reference             reference;};
```

Pointer specilaizations: § 7.8

```
template<T>
class iterator_traits<T*> {
    random_access_iterator_tag
        iterator_category ;
    T           value_type;
    ptrdiff_t   difference_type;
    T*          pointer;
    T&          reference;};
```

```
template<T>
class iterator_traits<const T*> {
    random_access_iterator_tag
        iterator_category ;
    T           value_type;
    ptrdiff_t   difference_type;
    const T*    pointer;
    const T&    reference;};
```

6.3.2 Reverse Iterator

Transform $[i \nearrow j] \mapsto [j - 1 \searrow i - 1]$.

```
template<Iter>
class reverse_iterator : public iterator<
    iterator_traits<Iter>::iterator_category,
    iterator_traits<Iter>::value_type,
    iterator_traits<Iter>::difference_type,
    iterator_traits<Iter>::pointer,
    iterator_traits<Iter>::reference>;
```

Denote
 $RI = \text{reverse_iterator}$
 $AI = \text{RandomAccessIterator}$.

Abbreviate:
`typedef RI<AI, T, Reference, Distance> self;`

`// Default constructor  $\Rightarrow$  singular value`
`self::RI();`

`explicit // Adaptor Constructor`
`self::RI(AI i);`

`AI self::base(); // adaptee's position`

`// so that:  $\&*(RI(i)) == \&(i-1)$  Reference`
`self::operator*();`

`self // position to & return base()-1`
`RI::operator++();`

`self& // return old position and move`
`RI::operator++(int); // to base()-1`

`self // position to & return base()+1`
`RI::operator--();`

`self& // return old position and move`
`RI::operator--(int); // to base()+1`

`bool //  $\Leftrightarrow s0.base() == s1.base()$`
`operator==(const self& s0, const self& s1);`

reverse_iterator Specific

`self // returned value positioned at base()-n`
`reverse_iterator::operator+(`
`Distance n) const;`

`self& // change & return position to base()-n`
`reverse_iterator::operator+=(Distance n);`

`self // returned value positioned at base()+n`
`reverse_iterator::operator-(`
`Distance n) const;`

`self& // change & return position to base()+n`
`reverse_iterator::operator-=(Distance n);`

`Reference //  $*(this + n)$`
`reverse_iterator::operator[](Distance n);`

`Distance //  $r0.base() - r1.base()$`
`operator-(const self& r0, const self& r1);`

`self //  $n + r.base()$`
`operator-(Distance n, const self& r);`

`bool //  $r0.base() < r1.base()$`
`operator<(const self& r0, const self& r1);`

6.3.3 Insert Iterators

```
template<class Container>
class back_insert_iterator :
    public output_iterator;
```

```
template<class Container>
class front_insert_iterator :
    public output_iterator;
```

```
template<class Container>
class insert_iterator :
    public output_iterator;
```

Here T will denote the `Container::value_type`.

Constructors

`explicit //  $\exists$  Container::push_back(const T&)`
`back_insert_iterator::back_insert_iterator(`
`Container& x);`

`explicit //  $\exists$  Container::push_front(const T&)`
`front_insert_iterator::front_insert_iterator(`
`Container& x);`

`//  $\exists$  Container::insert(const T&)`
`insert_iterator::insert_iterator(`
`Container x,`
`Container::iterator i);`

Denote

`InsIter = back_insert_iterator`
`insFunc = push_back`
`iterMaker = back_inserter § 7.4`

or

`InsIter = front_insert_iterator`
`insFunc = push_front`
`iterMaker = front_inserter`

or

`InsIter = insert_iterator`
`insFunc = insert`

Member Functions & Operators

`InsIter& // calls x.insFunc(val)`
`InsIter::operator=(const T& val);`
`InsIter& // return *this`
`InsIter::operator*();`
`InsIter& // no-op, just return *this`
`InsIter::operator++();`
`InsIter& // no-op, just return *this`
`InsIter::operator++(int);`

Template Function

`InsIter // return InsIter(Container)(x)`
`iterMaker(Container& x);`
`// return insert_iterator(Container)(x, i)`
`insert_iterator(Container)`
`inserter(Container& x, Iterator i);`

7 Examples

7.1 Vector

```
// safe get
int vi(const vector<unsigned>& v, int i)
{ return(i < (int)v.size() ? (int)v[i] : -1);}
```

```
// safe set
void vin(vector<int>& v, unsigned i, int n) {
    int nAdd = i - v.size() + 1;
    if (nAdd>0) v.insert(v.end(), nAdd, n);
    else v[i] = n;
}
```

7.2 List Splice

```
void lShow(ostream& os, const list<int>& l) {
    ostream_iterator<int> osi(os, " ");
    copy(l.begin(), l.end(), osi); os<<endl;}
```

```
void lmShow(ostream& os, const char* msg,
            const list<int>& l,
            const list<int>& m) {
    os << msg << (m.size() ? ":\n" : ": ");
    lShow(os, l);
    if (m.size()) lShow(os, m); } // lmShow
```

```
list<int>::iterator p(list<int>& l, int val)
{ return find(l.begin(), l.end(), val);}
```

```
static int prim[] = {2, 3, 5, 7};
static int perf[] = {6, 28, 496};
const list<int> lPrimes(prim+0, prim+4);
const list<int> lPerfects(perf+0, perf+3);
list<int> l(lPrimes), m(lPerfects);
lmShow(cout, "primes & perfects", l, m);
l.splice(l.begin(), m);
lmShow(cout, "splice(l.beg, m)", l, m);
l = lPrimes; m = lPerfects;
l.splice(l.begin(), m, p(m, 28));
lmShow(cout, "splice(l.beg, m, ^28)", l, m);
m.erase(m.begin(), m.end()); // <=>m.clear()
l = lPrimes;
l.splice(p(l, 3), l, p(l, 5));
lmShow(cout, "5 before 3", l, m);
l = lPrimes;
l.splice(l.begin(), l, p(l, 7), l.end());
lmShow(cout, "tail to head", l, m);
l = lPrimes;
l.splice(l.end(), l, l.begin(), p(l, 3));
lmShow(cout, "head to tail", l, m);
```

☞

```
primes & perfects:
2 3 5 7
6 28 496
splice(l.beg, m): 6 28 496 2 3 5 7
splice(l.beg, m, ^28):
28 2 3 5 7
6 496
5 before 3: 2 5 3 7
tail to head: 7 2 3 5
head to tail: 3 5 7 2
```

7.3 Compare Object Sort

```
class ModN {
public:
    ModN(unsigned m): _m(m) {}
    bool operator()(const unsigned& u0,
                    const unsigned& u1)
    {return ((u0 % _m) < (u1 % _m));}
private: unsigned _m;
}; // ModN

ostream_iterator<unsigned> oi(cout, " ");
unsigned q[6];
for (int n=6, i=n-1; i>=0; n=i--)
    q[i] = n*n*n*n;
cout<<"four-powers: ";
copy(q + 0, q + 6, oi);
for (unsigned b=10; b<=1000; b *= 10) {
    vector<unsigned> sq(q + 0, q + 6);
    sort(sq.begin(), sq.end(), ModN(b));
    cout<<endl<<"sort mod "<<setw(4)<<b<<" ";
    copy(sq.begin(), sq.end(), oi);
} cout << endl;
```



```
four-powers:  1 16 81 256 625 1296
sort mod  10: 1 81 625 16 256 1296
sort mod 100: 1 16 625 256 81 1296
sort mod 1000: 1 16 81 256 1296 625
```

7.4 Stream Iterators

```
void unitRoots(int n) {
    cout << "unit " << n << "-roots:" << endl;
    vector<complex<float>> roots;
    float arg = 2.*M_PI/(float)n;
    complex<float> r, r1 = polar((float)1., arg);
    for (r = r1; --n; r *= r1)
        roots.push_back(r);
    copy(roots.begin(), roots.end(),
        ostream_iterator<complex<float>>(cout,
            "\n"));
} // unitRoots
```

```
{ofstream o("primes.txt"); o << "2 3 5";}
ifstream pream("primes.txt");
vector<int> p;
istream_iterator<int> priter(pream);
istream_iterator<int> eos;
copy(riter, eos, back_inserter(p));
for_each(p.begin(), p.end(), unitRoots);
```



```
unit 2-roots:
(-1.000,-0.000)
unit 3-roots:
(-0.500,0.866)
(-0.500,-0.866)
unit 5-roots:
(0.309,0.951)
(-0.809,0.588)
```

```
(-0.809,-0.588)
(0.309,-0.951)
```

7.5 Binary Search

```
// first 5 Fibonacci
static int fb5[] = {1, 1, 2, 3, 5};
for (int n = 0; n <= 6; ++n) {
    pair<int*,int*> p =
        equal_range(fb5, fb5+5, n);
    cout<< n <<":["<< p.first-fb5 <<','
        << p.second-fb5 <<"] ";
    if (n==3 || n==6) cout << endl;
}
```



```
0:[0,0] 1:[0,2] 2:[2,3] 3:[3,4]
4:[4,4] 5:[4,5] 6:[5,5]
```

7.6 Transform & Numeric

```
template <class T>
class AbsPwr : public unary_function<T, T> {
public:
    AbsPwr(T p): _p(p) {}
    T operator()(const T& x) const
    { return pow(fabs(x), _p); }
private: T _p;
}; // AbsPwr
```

```
template<typename InIter> float
normNP(InIter xb, InIter xe, float p) {
    vector<float> vf;
    transform(xb, xe, back_inserter(vf),
        AbsPwr<float>(p > 0. ? p : 1.));
    return( (p > 0.)
        ? pow(accumulate(vf.begin(), vf.end(), 0.),
            1./p)
        : *(max_element(vf.begin(), vf.end())));
} // normNP
```

```
float distNP(const float* x, const float* y,
            unsigned n, float p) {
    vector<float> diff;
    transform(x, x + n, y, back_inserter(diff),
        minus<float>());
    return normNP(diff.begin(), diff.end(), p);
} // distNP
```

```
float x3y4[] = {3., 4., 0.};
float z12[] = {0., 0., 12.};
float p[] = {1., 2., M_PI, 0.};
for (int i=0; i<4; ++i) {
    float d = distNP(x3y4, z12, 3, p[i]);
    cout << "d_{" << p[i] << "}=" << d << endl;
}
```



```
d_{1}=19
d_{2}=13
d_{3.14159}=12.1676
d_{0}=12
```

7.7 Iterator and Binder

```
// self-referring int
class Iterator : public
    iterator<input_iterator_tag, int, size_t> {
    int _n;
public:
    Iterator(int n=0) : _n(n) {}
    int operator*() const {return _n;}
    Iterator& operator++() {
        ++_n; return *this; }
    Iterator operator++(int) {
        Iterator t(*this);
        ++_n; return t;}
}; // Iterator
bool operator==(const Iterator& i0,
                const Iterator& i1)
{ return (*i0 == *i1); }
bool operator!=(const Iterator& i0,
                const Iterator& i1)
{ return !(i0 == i1); }
```

```
struct Fermat: public
    binary_function<int, int, bool> {
    Fermat(int p=2) : n(p) {}
    int n;
    int nPower(int t) const { // t^n
        int i=n, tn=1;
        while (i-->0) tn *= t;
        return tn; } // nPower
    int nRoot(int t) const {
        return (int)pow(t +.1, 1./n); }
    int xNyN(int x, int y) const {
        return(nPower(x)+nPower(y)); }
    bool operator()(int x, int y) const {
        int zn = xNyN(x, y), z = nRoot(zn);
        return(zn == nPower(z)); }
}; // Fermat
```

```
for (int n=2; n<=Mp; ++n) {
    Fermat f(n);
    for (int x=1; x<Mx; ++x) {
        binder1st<Fermat>
            fx = bind1st(f, x);
        Iterator iy(x), iyEnd(My);
        while ((iy = find_if(++iy, iyEnd, fx))
            != iyEnd) {
            int y = *iy,
                z = f.nRoot(f.xNyN(x, y));
            cout << x << '^' << n << " = "
                << y << '^' << n << " = "
                << z << '^' << n << endl;
            if (n>2)
                cout << "Fermat is wrong!" << endl;
        }
    }
}
```



```
3^2 + 4^2 = 5^2
5^2 + 12^2 = 13^2
6^2 + 8^2 = 10^2
7^2 + 24^2 = 25^2
```

7.8 Iterator Traits

```
template <class Itr>
typename iterator_traits<Itr>::value_type
mid(Itr b, Itr e, input_iterator_tag) {
    cout << "mid(general):\n";
    Itr bm(b); bool next = false;
    for (; b != e; ++b, next = !next) {
        if (next) { ++bm; }
    }
    return *bm;
} // mid<input>
```

```
template <class Itr>
typename iterator_traits<Itr>::value_type
mid(Itr b, Itr e,
    random_access_iterator_tag) {
    cout << "mid(random):\n";
    Itr bm = b + (e - b)/2;
    return *bm;
} // mid<random>
```

```
template <class Itr>
typename iterator_traits<Itr>::value_type
mid(Itr b, Itr e) {
    typename
        iterator_traits<Itr>::iterator_category t;
    return mid(b, e, t);
} // mid
```

```
template <class Ctr>
void fillmid(Ctr& ctr) {
    static int perfects[5] =
        {6, 14, 496, 8128, 33550336},
        *pb = &perfects[0];
    ctr.insert(ctr.end(), pb, pb + 5);
    int m = mid(ctr.begin(), ctr.end());
    cout << "mid=" << m << "\n";
} // fillmid
```

```
list<int> l; vector<int> v;
fillmid(l); fillmid(v);
```



```
mid(general):
mid=496
mid(random):
mid=496
```