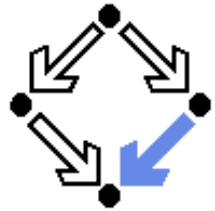
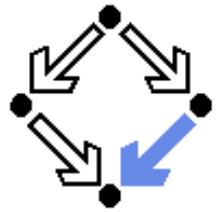
Containers, Iterators, Algorithms

Wolfgang Schreiner
Wolfgang.Schreiner@risc.uni-linz.ac.at

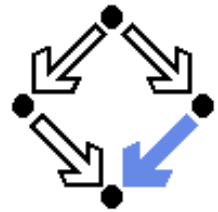
Research Institute for Symbolic Computation (RISC)
Johannes Kepler University, Linz, Austria
http://www.risc.uni-linz.ac.at





1. **The Standard Template Library (STL)**
2. Sequence Containers
3. Iterators
4. Adaptors
5. Associative Containers
6. Algorithms

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.

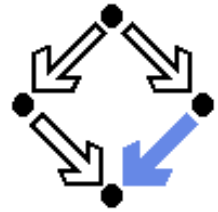
- Iterators: (abstractions of) container pointers/indices.
  - Identify (ranges of) elements in container.
  - Same code may be used for processing different kinds of containers.
- Algorithms: template functions that implement common algorithms.

  Processing, sorting, searching, merging, ...

  - Based on iterators, applicable to all kinds of containers.

The workhorse of generic programming in C++.

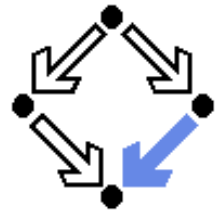
Containers (cplusplus.com)



			Sequence containers			Associative containers				
Headers			<vector>	<deque>	<list>	<set>		<map>		<bitset>
Members		complex	vector	deque	list	set	multiset	map	multimap	bitset
	constructor	*	constructor	constructor	constructor	constructor	constructor	constructor	constructor	constructor
	destructor	O(n)	destructor	destructor	destructor	destructor	destructor	destructor	destructor	
	operator=	O(n)	operator=	operator=	operator=	operator=	operator=	operator=	operator=	operators
iterators	begin	O(1)	begin	begin	begin	begin	begin	begin	begin	
	end	O(1)	end	end	end	end	end	end	end	
	rbegin	O(1)	rbegin	rbegin	rbegin	rbegin	rbegin	rbegin	rbegin	
	rend	O(1)	rend	rend	rend	rend	rend	rend	rend	
capacity	size	*	size	size	size	size	size	size	size	size
	max_size	*	max_size	max_size	max_size	max_size	max_size	max_size	max_size	
	empty	O(1)	empty	empty	empty	empty	empty	empty	empty	
	resize	O(n)	resize	resize	resize					
element access	front	O(1)	front	front	front					
	back	O(1)	back	back	back					
	operator[]	*	operator[]	operator[]				operator[]		operator[]
	at	O(1)	at	at						
modifiers	assign	O(n)	assign	assign	assign					
	insert	*	insert	insert	insert	insert	insert	insert	insert	
	erase	*	erase	erase	erase	erase	erase	erase	erase	
	swap	O(1)	swap	swap	swap	swap	swap	swap	swap	
	clear	O(n)	clear	clear	clear	clear	clear	clear	clear	
	push_front	O(1)		push_front	push_front					
	pop_front	O(1)		pop_front	pop_front					
	push_back	O(1)	push_back	push_back	push_back					
	pop_back	O(1)	pop_back	pop_back	pop_back					
observers	key_comp	O(1)				key_comp	key_comp	key_comp	key_comp	
	value_comp	O(1)				value_comp	value_comp	value_comp	value_comp	
operations	find	O(log n)				find	find	find	find	
	count	O(log n)				count	count	count	count	count
	lower_bound	O(log n)				lower_bound	lower_bound	lower_bound	lower_bound	
	upper_bound	O(log n)				upper_bound	upper_bound	upper_bound	upper_bound	
	equal_range	O(log n)				equal_range	equal_range	equal_range	equal_range	
unique members			capacity reserve		splice remove remove_if unique merge sort reverse					set reset flip to_ulong to_string test any none

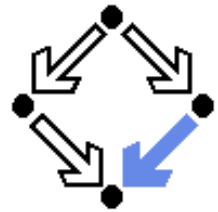
Amortized complexity shown. Legend: O(1) constant < O(log n) logarithmic < O(n) linear; *=depends on container

Example: A Vector Program

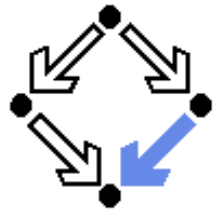


```
#include <iostream>
#include <vector>
#include <algorithm>
using namespace std;

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

  // iteratate 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;
}
```

Example: A List Program



```
#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

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

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

  return 0;
}
```



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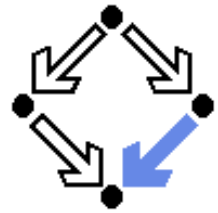
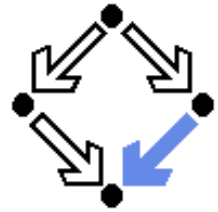
Sequence Containers



- 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.

Class Template `vector`



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.

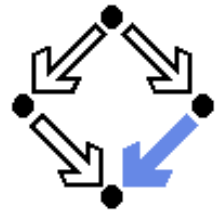
But unlike regular arrays, storage in vectors is handled automatically, allowing it to be expanded and contracted as needed.

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

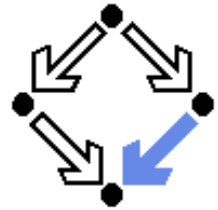


cplusplus.com: “C++ Reference”.

```
#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
```

Example

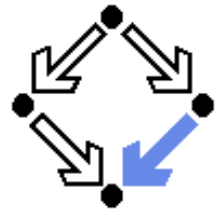


cplusplus.com: “C++ Reference”.

```
#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
```

Example

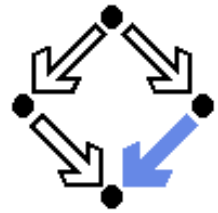


cplusplus.com: “C++ Reference”.

```
#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>



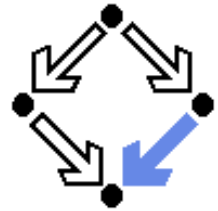
The vector class template has a special template specialization for the bool type. This specialization is provided to optimize for space allocation: In this template specialization, each element occupies only one bit (which is eight times less than the smallest type in C++: char).

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:

```
class vector<bool>::reference {
  friend class vector;
  reference();                                  // no public constructor
public:
  ~reference();
  operator bool () const;                       // convert to bool
  reference& operator= ( const bool x );        // assign from bool
  reference& operator= ( const reference& x );  // assign from bit
  void flip();                                  // flip bit value.
}
```

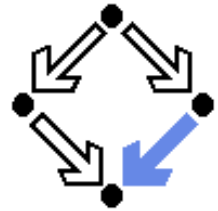
For a similar container class to contain bits, but with a fixed size, see bitset.

Class 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;
}
```

Class Template deque



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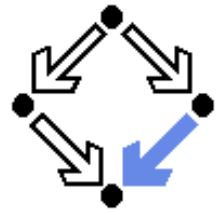
```
template < class T, class Allocator = allocator<T> > class deque;

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.
```

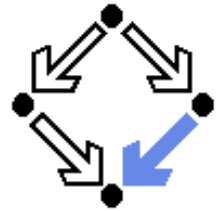
Example



cplusplus.com: “C++ Reference”.

```
#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



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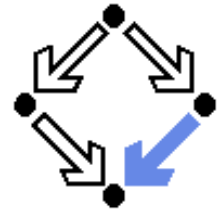
```
#include <iostream>
#include <deque>
using namespace std;

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 << "\nFinal size of mydeque is " << int(mydeque.size()) << endl;
  return 0;
}

100 200 300
Final size of mydeque is 0
```

Class Template `list`



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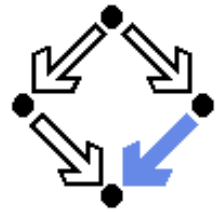
```
template < class T, class Allocator = allocator<T> > class list;

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 ...
```

Example



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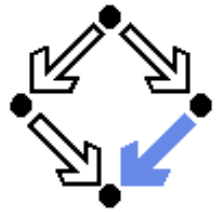
```
// reversing vector
#include <iostream>
#include <list>
using namespace std;

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
```



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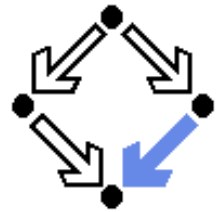
Iterators



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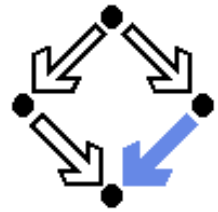
```
Header <iterator>

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”.

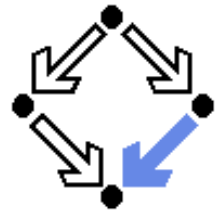
* Input and output iterators are the most limited types of iterators, specialized in performing only sequential input or ouput operations.

* 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



category				characteristic	valid expressions
all categories				Can be copied and copy-constructed	`X b(a);` `b = a;`

				Can be incremented	`++a`
					`a++`
					`*a++`

Random Access	Bidirectional	Forward	Input	Accepts equality/inequality comparisons	`a == b` `a != b`
				Can be dereferenced as an *rvalue*	`*a` `a->m`
			Output	Can be dereferenced to be the left side of an assignment operation	`*a = t` `*a++ = t`
				Can be default-constructed	`X a;` `X()`

				Can be decremented	`--a`
					`a--`
					`*a--`

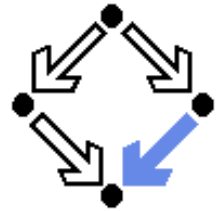
				Supports arithmetic operators + and -	`a + n`
					`n + a`
					`n - a`
					`a - b`

				Supports inequality comparisons (< and >) between iterators	`a < b` `a > b`

				Supports compound assignment operations +=, -=, <= and >=	`a += n`
					`a -= n`
					`a <= b`
					`a >= b`

				Supports offset dereference operator ([])	`a[n]`

Class <iterator>



cplusplus.com: "C++ Reference".

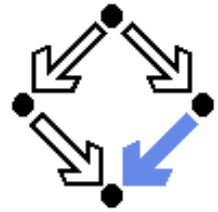
This is a base class template that can be used to derive iterator classes from it. It is not an iterator class and does not provide any of the functionality an iterator is expected to have.

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.

```
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;
  };
```

Category

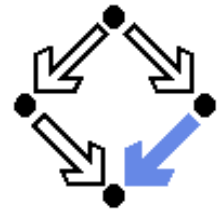
Example



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 << " ";
}
```

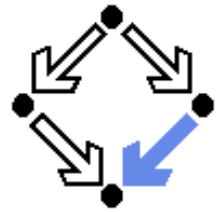
Containers and Iterators



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.
```

Example

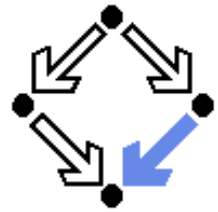


cplusplus.com: “C++ Reference”.

```
#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
```

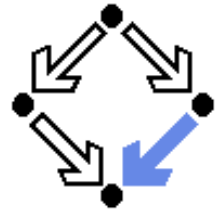
Advancing Iterators



cplusplus.com: “C++ Reference”.

```
template function                                          header <iterator>

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.
```

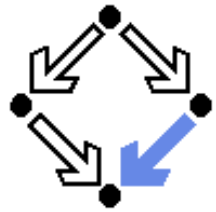
Example



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

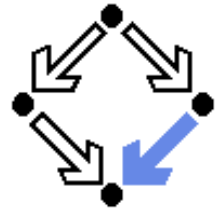


cplusplus.com: “C++ Reference”.

```
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.

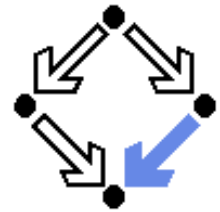
Example



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
```

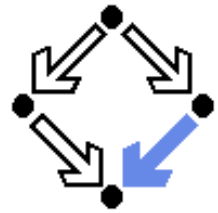
Reverse Iterators



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

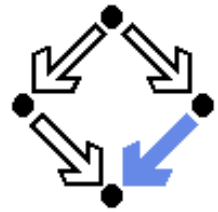


cplusplus.com: “C++ Reference”.

```
#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;
                                                  // ? 0 1 2 3 4 5 6 7 8 9 ?
  iter_int begin (myvector.begin());              //   ^
  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
```

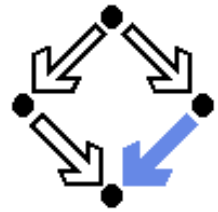
Containers and Reverse Iterators



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

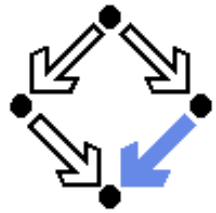


cplusplus.com: “C++ Reference”.

```
#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.

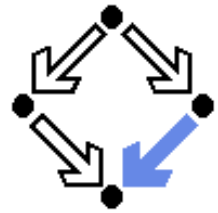
```
iterator insert (iterator p, const T& x );
void insert (iterator p, size_type n, const T& x);
template <class InputIterator>
void insert (iterator p, InputIterator f, InputIterator l);
```

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.

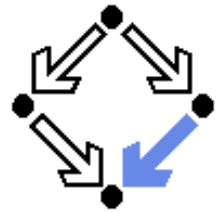
Example



cplusplus.com: “C++ Reference”.

```
#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;
}
```

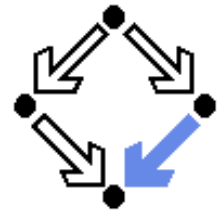
Example



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
```

Stream Iterators



cplusplus.com: “C++ Reference”.

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

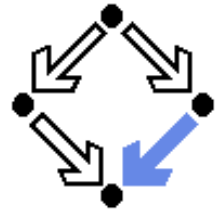
Istream iterators are a special input iterator class designed to read successive elements from an input stream ... whenever operator++ is used on the iterator, it extracts an element (with >>) from the stream.

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.

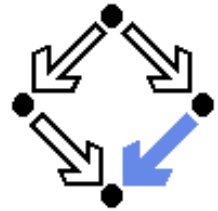
Example



cplusplus.com: “C++ Reference”.

```
#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;
    it++;
  }
  cout << "Your name is " << mystring << ".\n";
  return 0;
}

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

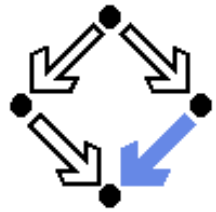
Example



cplusplus.com: “C++ Reference”.

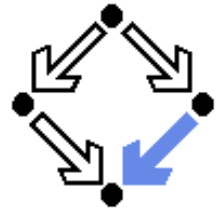
```
#include <iostream>
#include <iterator>
#include <vector>
using namespace std;

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,
```



1. The Standard Template Library (STL)
2. Sequence Containers
3. Iterators
4. **Adaptors**
5. Associative Containers
6. Algorithms

Adaptors

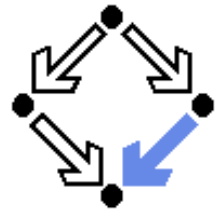


cplusplus.com: “C++ Reference”.

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.

			Container Adaptors		
Headers			<stack>	<queue>	
Members			stack	queue	priority_queue
	constructor	*	constructor	constructor	constructor
capacity	size	O(1)	size	size	size
	empty	O(1)	empty	empty	empty
element access	front	O(1)		front	
	back	O(1)		back	
	top	O(1)	top		top
modifiers	push	O(1)	push	push	push
	pop	O(1)	pop	pop	pop

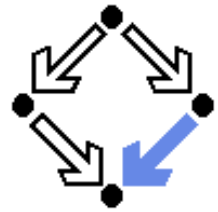
Class Template `stack`



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.
```

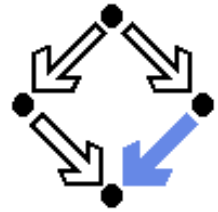
Example



cplusplus.com: “C++ Reference”.

```
#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
```

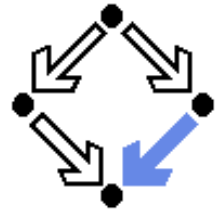
Class Template queue



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.
```

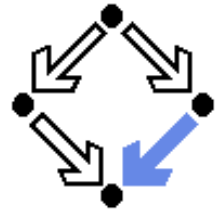
Example



cplusplus.com: “C++ Reference”.

```
#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”.

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

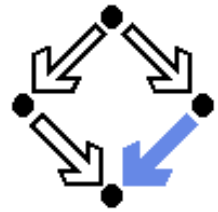
Priority queues are a type of container adaptors, specifically designed such that its first element is always the greatest of the elements it contains, according to some strict weak ordering condition. This context is similar to a heap where only the max heap element can be retrieved and elements can 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:

* 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`



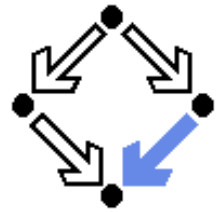
cplusplus.com: “C++ Reference”.

```
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.

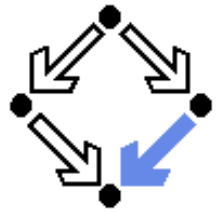
Example



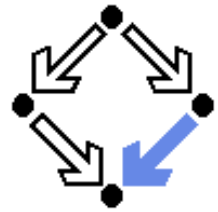
cplusplus.com: “C++ Reference”.

```
#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
```



Associative Containers

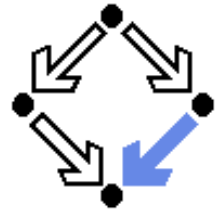


- Elements organized for fast access by keys
  - <set>: class templates `set` and `multiset`.
    - (Multi)sets of elements (elements themselves are the keys).
  - <map>: class templates `map` and `multimap`.
    - Mappings of keys to (sets of) values.
- Common operations
  - Most operations of sequence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

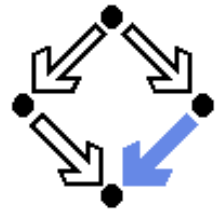
* Unique element values: no two elements in the set can compare equal to each other. For a similar associative container allowing for multiple equivalent elements, see multiset.

* 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.

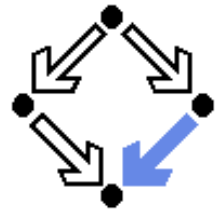
Example



cplusplus.com: “C++ Reference”.

```
#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

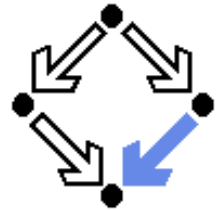


cplusplus.com: “C++ Reference”.

```
#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 map and multimap



```
template < class Key, class T, class Compare = less<Key>,
           class Allocator = allocator<pair<const Key,T> > > class (multi)map;
```

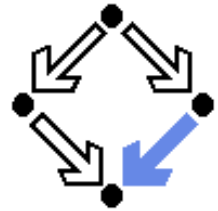
Maps are a kind of associative containers that stores elements formed by the combination of a key value and a mapped value. In a map, the key value is generally used to uniquely identify the element, while the mapped value is some sort of value associated to this key. Types of key and mapped value may 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

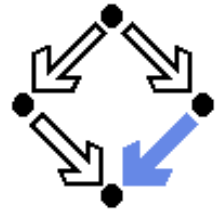


cplusplus.com: “C++ Reference”.

```
#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

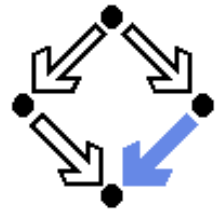


cplusplus.com: “C++ Reference”.

```
#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
```

Member Functions key/value_comp



cplusplus.com: “C++ Reference”.

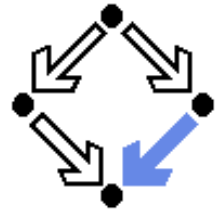
```
key_compare key_comp ( ) const;
value_compare value_comp ( ) const;
```

Returns the comparison object associated with the container, which can be used to compare two elements of the container.

This comparison object is set on object construction, and may either be a pointer to a function or an object of a class with a function call operator. In both cases it takes two arguments of the same type as the container elements, and returns true if the first argument is considered to go before the second in the strict weak ordering the object defines, and false otherwise.

In set containers, the element values are the keys themselves, therefore key_comp and its sibling member function value_comp both return the same.

Example

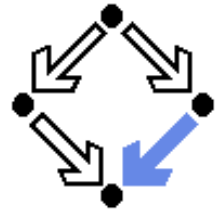


cplusplus.com: “C++ Reference”.

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

int main () {
  set<int> myset;
  set<int>::key_compare mycomp = myset.key_comp();
  for (int i=0; i<=5; i++) myset.insert(i);

  int highest=*myset.rbegin();
  set<int>::iterator it=myset.begin();
  while (true) {
    cout << " " << *it;
    if (!mycomp(*it,highest)) break;
    it++;
  }
  return 0;
}
```

```
0 1 2 3 4 5
```

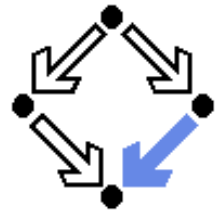
Example



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

int main () {
  map<char,int> mymap;
  map<char,int>::key_compare mycomp = mymap.key_comp();
  mymap['a']=100;
  mymap['b']=200;
  mymap['c']=300;

  char highest=mymap.rbegin()->first;     // key value of last element
  map<char,int>::iterator it=mymap.begin();
  while (true) {
    cout << (*it).first << " => " << (*it).second << " ";
    if (!mycomp((*it).first, highest)) break;
    it++;
  }
  return 0;
}
```

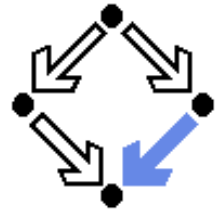
```
a => 100 b => 200 c => 300
```

Member Function `find`



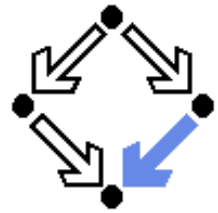
```
iterator find ( const key_type& x ) const;

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 <set>
using namespace std;

int main () {
  set<int> myset;
  for (int i=1; i<=5; i++) myset.insert(i*10);    // set: 10 20 30 40 50
  myset.erase (myset.find(20));                   // set: 10 30 40 50
  myset.erase (myset.find(40));                   // set: 10 30 50
  for (set<int>::iterator it=myset.begin(); it!=myset.end(); it++)
    cout << " " << *it;
  return 0;
}

10 30 50
```

Member Function count



```
size_type count ( cont 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.

#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

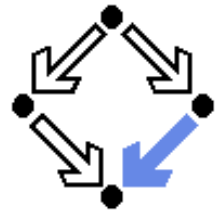


```
iterator lower/upper_bound ( const key_type& x );

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.
```

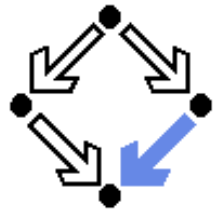
```
#include <iostream>
#include <map>
using namespace std;
int main () {
  map<char,int> mymap;
  mymap['a']=20; mymap['b']=40; mymap['c']=60; mymap['d']=80; mymap['e']=100;
  map<char,int>::iterator itlow=mymap.lower_bound ('b'); // itlow points to b
  map<char,int>::iterator itup=mymap.upper_bound ('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

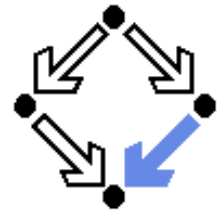


```
pair<iterator,iterator> equal_range ( const key_type& x ) const;

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.

#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. The Standard Template Library (STL)
2. Sequence Containers
3. Iterators
4. Adaptors
5. Associative Containers
6. **Algorithms**

Header <algorithm>



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

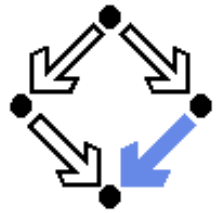
- Algorithm: a template function operating on a range of elements.
  - A range is a sequence of objects accessible by iterators/pointers.
    - Iterator type is argument of function template.
    - Iterators of this type are arguments to function.

```
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.

Header <functional>



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
```

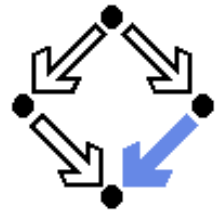
- <functional> provides a collection of function object templates.
  - Unary function objects inherit from unary_function.

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

  - Binary function objects inherit from binary_function.

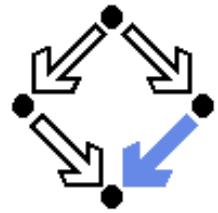
```
template <class Arg1, class Arg2, class Result>
  struct binary_function {
    typedef Arg1 first_argument_type;
    typedef Arg2 second_argument_type;
    typedef Result result_type;
  };
```

Example



```
#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;
}
```

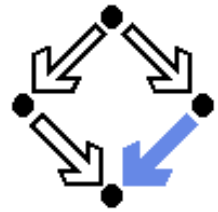
Function Objects



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
`...`	

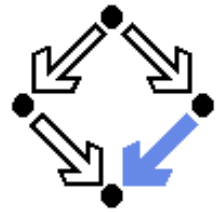
Example



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

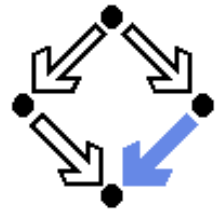


cplusplus.com: “C++ Reference”.

`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.

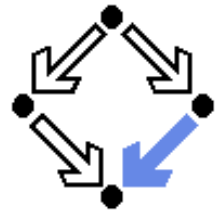
Algorithm `for_each`



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;
  }
```

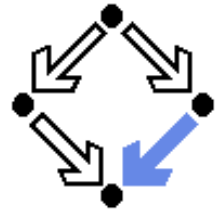
Example



clusplus.com: “C++ Reference”.

```
#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
```

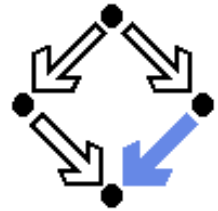
Algorithm `find`



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



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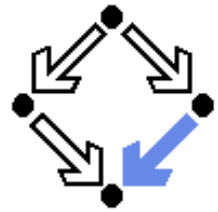
```
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

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
```

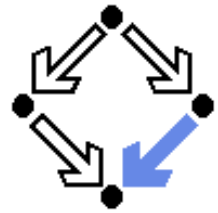
Algorithm `find_if`



clusplus.com: “C++ Reference”.

```
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:

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

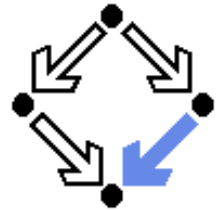
Example



clusplus.com: “C++ Reference”.

```
#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
```

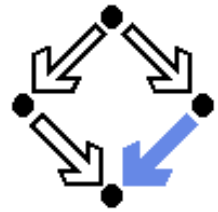
Modifying Sequence Operations



`copy`	Copy range of elements
`copy_backward`	Copy range of elements backwards
`swap`	Exchange values of two objects
`swap_ranges`	Exchange values of two ranges
`iter_swap`	Exchange values of objects pointed by two iterators
`transform`	Apply function to range
`replace Replace`	value in range
`replace_if`	Replace values in range
`replace_copy`	Copy range replacing value
`replace_copy_if`	Copy range replacing value
`fill`	Fill range with value
`fill_n`	Fill sequence with value
`generate`	Generate values for range with function
`generate_n`	Generate values for sequence with function
`remove`	Remove value from range
`remove_if`	Remove elements from range
`remove_copy`	Copy range removing value
`remove_copy_if`	Copy range removing values
`unique`	Remove consecutive duplicates in range
`unique_copy`	Copy range removing duplicates
`reverse`	Reverse range
`reverse_copy`	Copy range reversed
`rotate`	Rotate elements in range
`rotate_copy`	Copy rotated range
`random_shuffle`	Rearrange elements in range randomly
`partition`	Partition range in two
`stable_partition`	Parition range in two - stable ordering

These operations modify the contents of the sequence.

Algorithm copy



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

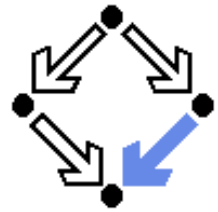
Copies the elements in the range [first,last) into a range beginning at result.
Returns an iterator to the last element in the destination range.

The behavior of this function template is equivalent to:

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

If both ranges overlap in such a way that result points to an element in the range [first,last), the function copy_backward should be used instead.

Example



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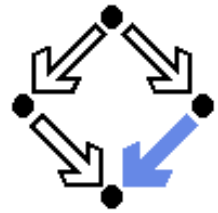
```
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

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

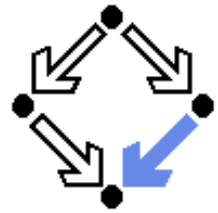


```
template < class InIter, class OutIter, class UnaryOp >
OutIter transform ( InIter first1, InIter last1, OutIter result, UnaryOp op );

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



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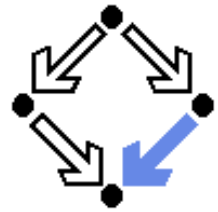
```
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

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



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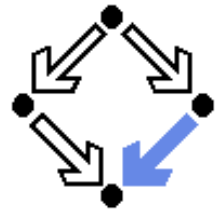
```
template <class ForwardIterator, class Generator>
void generate ( ForwardIterator first, ForwardIterator last, Generator gen );

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();
}
```

Example



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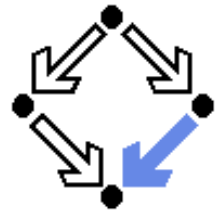
```
#include <iostream>
#include <algorithm>
#include <vector>
#include <cstdlib>
using namespace std;

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



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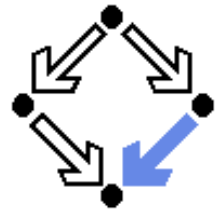
`sort`	Sort elements in range
`stable_sort`	Sort elements preserving order of equivalents
`partial_sort`	Partially Sort elements in range
`partial_sort_copy`	Copy and partially sort range
`nth_element`	Sort element in range
`lower_bound`	Return iterator to lower bound
`upper_bound`	Return iterator to upper bound
`equal_range`	Get subrange of equal elements
`binary_search`	Test if value exists in sorted array
`merge`	Merge sorted ranges
`inplace_merge`	Merge consecutive sorted ranges
`includes`	Test whether sorted range includes another one
`set_union`	Union of two sorted ranges
`set_intersection`	Intersection of two sorted ranges
`set_difference`	Difference of two sorted ranges
`set_symmetric_difference`	Symmetric difference of two sorted ranges

Algorithm `sort`



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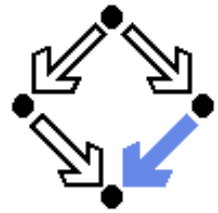
```
template <class RandomAccessIterator>
void sort (RandomAccessIterator first, RandomAccessIterator last);

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*logN comparisons on average (where N is last-first).

In the worst case, up to N2, depending on specific sorting algorithm used by
library implementation.
```

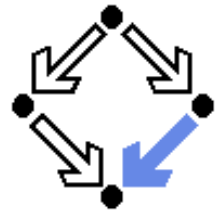
Example



clusplus.com: “C++ Reference”.

```
#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 `binary_search`



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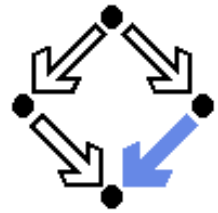
```
template <class ForwIter, class T>
bool binary_search ( ForwIter first, ForwIter last, const T& value );

template <class ForwIter, class T, class Compare>
bool binary_search ( ForwIter first, ForwIter last, const T& value, Compare comp );

Returns true if an element in the range [first,last) is equivalent to value,
and false otherwise. The comparison is performed using either operator< for
the first version, or comp for the second: A value, a, is considered
equivalent to another, b, when (!(a<b) && !(b<a)) or (!comp(a,b) && !comp(b,a))
For the function to yield the expected result, the elements in the range shall
already be ordered according to the same criterion (operator< or comp).

The behavior of this function template is equivalent to:

template <class ForwIter, class T>
bool binary_search ( ForwIter first, ForwIter last, const T& value ) {
  first = lower_bound(first,last,value);
  return (first!=last && !(value<*first));
}
```

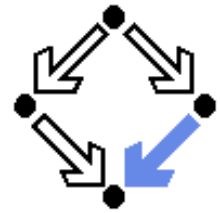
Example



clusplus.com: “C++ Reference”.

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

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

int main () {
  int myints[] = {1,2,3,4,5,4,3,2,1};
  vector<int> v(myints,myints+9);                         // 1 2 3 4 5 4 3 2 1
  sort (v.begin(), v.end());
  if (binary_search (v.begin(), v.end(), 3))
    cout << "found! "; else cout << "not found. ";
  sort (v.begin(), v.end(), myfunction);
  if (binary_search (v.begin(), v.end(), 6, myfunction))
    cout << "found!\n"; else cout << "not found.\n";
  return 0;
}

found! not found.
```

Algorithm merge



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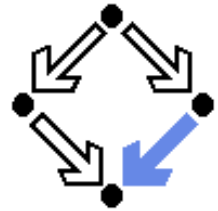
```
template <class InIter1, class InIter2, class OutIter>
OutIter merge ( InIter1 first1, InIter1 last1, InIter2 first2, InIter2 last2,
                OutIter result [, Compare comp] );
```

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:

```
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



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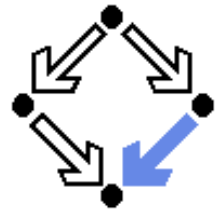
```
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

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
```

Heap and Min/Max



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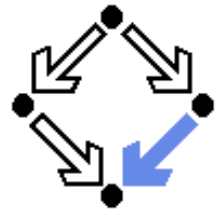
`push_heap`	Push element into heap range
`pop_heap`	Pop element from heap range
`make_heap`	Make heap from range
`sort_heap`	Sort elements of heap
`min`	Return the lesser of two arguments
`max`	Return the greater of two arguments
`min_element`	Return smallest element in range
`max_element`	Return largest element in range
`lexicographical_compare`	Lexicographical less-than comparison
`next_permutation`	Transform range to next permutation
`prev_permutation`	Transform range to previous permutation

Algorithm make_heap



clusplus.com: “C++ Reference”.

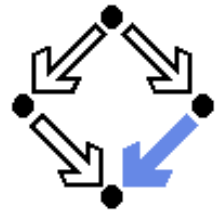
```
template <class RandomAccessIterator>
  void make_heap ( RandomAccessIterator first, RandomAccessIterator last
                   [, Compare comp] );
```

Rearranges the elements in the range [first,last) in such a way that they form a heap. In order to rearrange these elements, the function performs comparisons using operator< for the first version, and comp for the second.

Internally, a heap is a tree where each node links to values not greater than its own value. In heaps generated by make_heap, the specific position of an element in the tree rather than being determined by memory-consuming links is determined by its absolute position in the sequence, with *first being always the highest value in the heap.

Heaps allow to add or remove elements from it in logarithmic time by using functions push_heap and pop_heap, which preserve its heap properties.

Example



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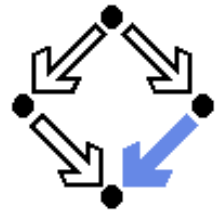
```
#include <iostream>
#include <algorithm>
#include <vector>
using namespace std;

int main () {
  int myints[] = {10,20,30,5,15};
  vector<int> v(myints,myints+5);
  vector<int>::iterator it;
  make_heap (v.begin(),v.end());
  cout << "initial max heap   : " << v.front() << endl;
  pop_heap (v.begin(),v.end()); v.pop_back();
  cout << "max heap after pop : " << v.front() << endl;
  v.push_back(99); push_heap (v.begin(),v.end());
  cout << "max heap after push: " << v.front() << endl;
  return 0;
}

initial max heap   : 30
max heap after pop : 20
max heap after push: 99
```

Algorithm `min_element`



clusplus.com: “C++ Reference”.

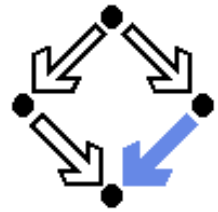
```
template <class ForwardIterator>
ForwardIterator min_element ( ForwardIterator first, ForwardIterator last
                              [, Compare comp] );

Returns an iterator pointing to the element with the smallest value in the
range [first,last). The comparisons are performed using either operator< for
the first version, or comp for the second; An element is the smallest if no
other element compares less than it (it may compare equal, though).

The behavior of this function template is equivalent to:

template <class ForwardIterator>
ForwardIterator min_element ( ForwardIterator first, ForwardIterator last )
{
  ForwardIterator lowest = first;
  if (first==last) return last;
  while (++first!=last)
    if (*first<*lowest)    // or: if (comp(*first,*lowest)) for the comp version
      lowest=first;
  return lowest;
}
```

Example



clusplus.com: “C++ Reference”.

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

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

int main () {
  int myints[] = {3,7,2,5,6,4,9};
  myclass myobj;
  cout << "Smallest: " << *min_element(myints,myints+7) << endl;
  cout << "Smallest: " << *min_element(myints,myints+7,myfn) << endl;
  cout << "Smallest: " << *min_element(myints,myints+7,myobj) << endl;
  return 0;
}
```

```
Smallest: 2
Smallest: 2
Smallest: 2
```