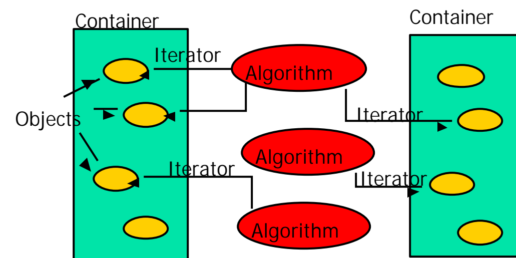
Standard Template Library

- The standard template library (STL) contains
  - Containers
  - Algorithms
  - Iterators
- A *container* is a way that stored data is organized in memory, for example an array of elements.
- *Algorithms* in the STL are procedures that are applied to containers to process their data, for example search for an element in an array, or sort an array.
- *Iterators* are a generalization of the concept of pointers, they point to elements in a container, for example you can increment an iterator to point to the next element in an array

Containers, Iterators, Algorithms

Algorithms use iterators to interact with objects stored in containers



Containers

- A container is a way to store data, either built-in data types like int and float, or class objects
- The STL provides several basic kinds of containers
  - <vector> : one-dimensional array
  - <list> : double linked list
  - <deque> : double-ended queue
  - <queue> : queue
  - <stack> : stack
  - <set> : set
  - <map> : associative array

Sequence Containers

- A sequence container stores a set of elements in sequence, in other words each element (except for the first and last one) is preceded by one specific element and followed by another, <vector>, <list> and <deque> are sequential containers
- In an ordinary C++ array the size is fixed and can not change during run-time, it is also tedious to insert or delete elements. Advantage: quick random access
- <vector> is an expandable array that can shrink or grow in size, but still has the disadvantage of inserting or deleting elements in the middle

Sequence Containers

- <list> is a double linked list (each element has points to its successor and predecessor), it is quick to insert or delete elements but has slow random access
- <deque> is a double-ended queue, that means one can insert and delete elements from both ends, it is a kind of combination between a stack (last in first out) and a queue (first in first out) and constitutes a compromise between a <vector> and a <list>

Associative Containers

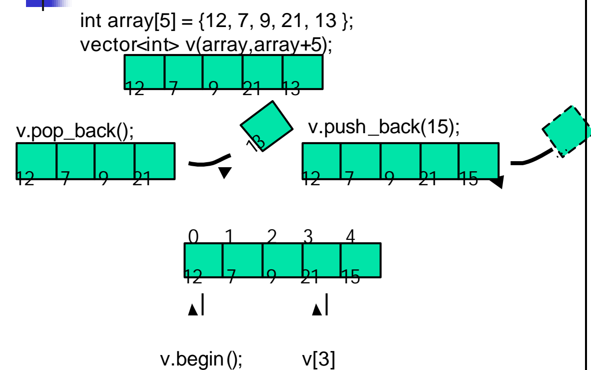
- An associative container is non-sequential but uses a *key* to access elements. The keys, typically a number or a string, are used by the container to arrange the stored elements in a specific order, for example in a dictionary the entries are ordered alphabetically.

Associative Containers

- A <set> stores a number of items which contain keys The keys are the attributes used to order the items, for example a set might store objects of the class Person which are ordered alphabetically using their name
- A <map> stores pairs of objects: a key object and an associated value object. A <map> is somehow similar to an array except instead of accessing its elements with index numbers, you access them with indices of an arbitrary type.
- <set> and <map> only allow one key of each value, whereas <multiset> and <multimap> allow multiple identical key values

Vector Container

```
int array[5] = {12, 7, 9, 21, 13 };
vector<int> v(array,array+5);
```



Vector Container

```
#include <vector>
#include <iostream>
vector<int> v(3);  // create a vector of ints of size 3
v[0]=23;
v[1]=12;
v[2]=9;    // vector full
v.push_back(17);   // put a new value at the end of array
for (int i=0; i<v.size(); i++)   // member function size() of vector
   cout << v[i] << " ";   // random access to i-th element
cout << endl;
```

Vector Container

```
#include <vector>
#include <iostream>
int arr[] = { 12, 3, 17, 8 };  // standard C array
vector<int> v(arr, arr+4);  // initialize vector with C array
while ( ! v.empty()) // until vector is empty
{
    cout << v.back() << " ";   // output last element of vector
    v.pop_back();               // delete the last element
}
cout << endl;
```

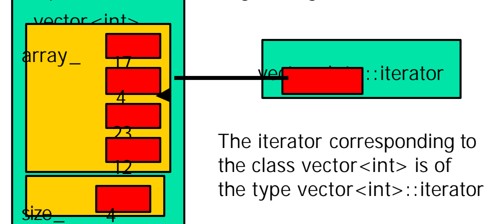
Constructors for Vector

- A vector can be initialized by specifying its size and a prototype element or by another vector

```
vector<Date> x(1000); // creates vector of size 1000,
                      // requires default constructor for Date
vector<Date> dates(10,Date(17,12,1999)); // initializes
                      // all elements with 17.12.1999
vector<Date> y(x); // initializes vector y with  vector x
```

Iterators

- Iterators are pointer-like entities that are used to access individual elements in a container.
- Often they are used to move sequentially from element to element, a process called *iterating* through a container.



The iterator corresponding to the class vector<int> is of the type vector<int>::iterator

Iterators

- The member functions begin() and end() return an iterator to the first and past the last element of a container

vector<int> v
array_
17
4
23
12
size_
4
v.begin()
v.end()

Iterators

- One can have multiple iterators pointing to different or identical elements in the container

vector<int> v
array_
17
4
23
12
size_
4
i1
i2
i3

Iterators

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

int arr[] = { 12, 3, 17, 8 };  // standard C array
vector<int> v(arr, arr+4);  // initialize vector with C array
vector<int>::iterator iter=v.begin();  // iterator for class vector
// define iterator for vector and point it to first element of v
cout << "first element of v=" << *iter; // de-reference iter
iter++;  // move iterator to next element
iter=v.end()-1;  // move iterator to last element
```

Iterators

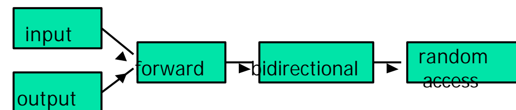
```
int max(vector<int>::iterator start, vector<int>::iterator end)
{
   int m=*start;
   while(start != stop)
     {
        if (*start > m)
          m=*start;
        ++start;
     }
     return m;
}
cout << "max of v = " << max(v.begin(),v.end());
```

Iterators

```
#include <vector>
#include <iostream>
int arr[] = { 12, 3, 17, 8 };  // standard C array
vector<int> v(arr, arr+4);  // initialize vector with C array
for (vector<int>::iterator i=v.begin(); i!=v.end(); i++)
// initialize i with pointer to first element of v
// i++ increment iterator, move iterator to next element
{
    cout << *i << " ";   // de-referencing iterator returns the
                         // value of the element the iterator points at
}
cout << endl;
```

Iterator Categories

- Not every iterator can be used with every container for example the list class provides no random access iterator
- Every algorithm requires an iterator with a certain level of capability for example to use the [] operator you need a random access iterator
- Iterators are divided into five categories in which a higher (more specific) category always subsumes a lower (more general) category, e.g. An algorithm that accepts a forward iterator will also work with a bidirectional iterator and a random access iterator



For_Each() Algorithm

```
#include <vector>
#include <algorithm>
#include <iostream>
void show(int n)
{
  cout << n << " ";
}

 int arr[] = { 12, 3, 17, 8 };  // standard C array
vector<int> v(arr, arr+4);  // initialize vector with C array
for_each (v.begin(), v.end(), show); // apply function show
                // to each element of vector v
```

Find() Algorithm

```
#include <vector>
#include <algorithm>
#include <iostream>
int key;
int arr[] = { 12, 3, 17, 8, 34, 56, 9 };  // standard C array
vector<int> v(arr, arr+7);  // initialize vector with C array
vector<int>::iterator iter;
cout << "enter value :";
cin >> key;
iter=find(v.begin(),v.end(),key); // finds integer key in v
if (iter != v.end()) // found the element
  cout << "Element " << key << " found" << endl;
else
  cout << "Element " << key << " not in vector v" << endl;
```

Find_If() Algorithm

```
#include <vector>
#include <algorithm>
#include <iostream>
Bool mytest(int n) { return (n>21) && (n <36); };
int arr[] = { 12, 3, 17, 8, 34, 56, 9 };  // standard C array
vector<int> v(arr, arr+7);  // initialize vector with C array
vector<int>::iterator iter;
iter=find_if(v.begin(),v.end(),mytest);
  // finds element in v  for which mytest is true
if (iter != v.end()) // found the element
   cout << ”found ” << *iter << endl;
else
  cout << ”not found” << endl;
```

Count_If() Algorithm

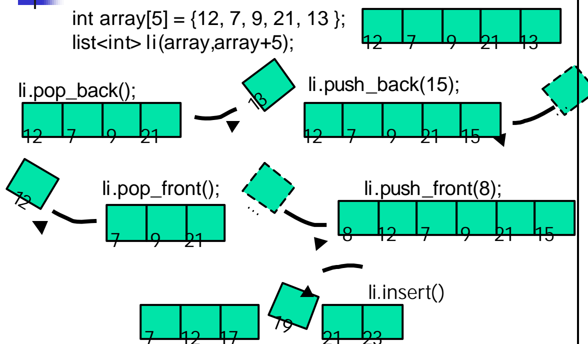
```
#include <vector>
#include <algorithm>
#include <iostream>
Bool mytest(int n) { return (n>14) && (n <36); };
int arr[] = { 12, 3, 17, 8, 34, 56, 9 };  // standard C array
vector<int> v(arr, arr+7);  // initialize vector with C array
int n=count_if(v.begin(),v.end(),mytest);
  // counts element in v  for which mytest is true
cout << ”found ” << n << ” elements” << endl;
```

List Container

- An STL list container is a double linked list, in which each element contains a pointer to its successor and predecessor.
- It is possible to add and remove elements from both ends of the list
- Lists do not allow random access but are efficient to insert new elements and to sort and merge lists

List Container

```
int array[5] = {12, 7, 9, 21, 13 };
list<int> li(array,array+5);
```



Insert Iterators

- If you normally copy elements using the copy algorithm you overwrite the existing contents

```
#include <list>
int arr1[]= { 1, 3, 5, 7, 9 };
int arr2[]= { 2, 4, 6, 8, 10 };
list<int> l1(arr1, arr1+5); // initialize l1 with arr1
list<int> l2(arr2, arr2+5); // initialize l2 with arr2
copy(l1.begin(), l1.end(), l2.begin());
   // copy contents of l1 to l2 overwriting the elements in l2
   // l2 = { 1, 3, 5, 7, 9 }
```

Insert Iterators

- With insert operators you can modify the behavior of the copy algorithm
  - back_inserter : inserts new elements at the end
  - front_inserter : inserts new elements at the beginning
  - inserter : inserts new elements at a specified location

```
#include <list>
int arr1[]= { 1, 3, 5, 7, 9 };
int arr2[]= { 2, 4, 6, 8, 10 };
list<int> l1(arr1, arr1+5); // initialize l1 with arr1
list<int> l2(arr2, arr2+5); // initialize l2 with arr2
copy(l1.begin(), l1.end(), back_inserter(l2)); // use back_inserter
  // adds contents of l1 to the end of l2 = { 2, 4, 6, 8, 10, 1, 3, 5, 7, 9 }
copy(l1.begin(), l1.end(), front_inserter(l2)); // use front_inserter
  // adds contents of l1 to the front of l2 = { 9, 7, 5, 3, 1, 2, 4, 6, 8, 10 }
copy(l1.begin(), l1.end, inserter(l2,l2.begin());
 // adds contents of l1 at the "old" beginning of l2 = { 1, 3, 5, 7, 9, 2, 4, 6, 8, 10 }
```

Sort & Merge

- Sort and merge allow you to sort and merge elements in a container

```
#include <list>
int arr1[]= { 6, 4, 9, 1, 7 };
int arr2[]= { 4, 2, 1, 3, 8 };
list<int> l1(arr1, arr1+5); // initialize l1 with arr1
list<int> l2(arr2, arr2+5); // initialize l2 with arr2
l1.sort(); // l1 = {1, 4, 6, 7, 9}
l2.sort(); // l2= {1, 2, 3, 4, 8 }
l1.merge(l2); // merges l2 into l1
// l1 = { 1, 1, 2, 3, 4, 4, 6, 7, 8, 9}, l2= {}
```

Functions Objects

- Some algorithms like sort, merge, accumulate can take a function object as argument.
- A function object is an object of a template class that has a single member function : the overloaded operator ()
- It is also possible to use user-written functions in place of pre-defined function objects

```
#include <list>
#include <functional>
int arr1[]= { 6, 4, 9, 1, 7 };
list<int> l1(arr1, arr1+5); // initialize l1 with arr1
l1.sort(greater<int>()); // uses function object greater<int>
// for sorting in reverse order l1 = { 9, 7, 6, 4, 1 }
```

Function Objects

- The accumulate algorithm accumulates data over the elements of the containing, for example computing the sum of elements

```
#include <list>
#include <functional>
#include <numeric>
int arr1[]= { 6, 4, 9, 1, 7 };
list<int> l1(arr1, arr1+5); // initialize l1 with arr1
int sum = accumulate(l1.begin(), l1.end() , 0, plus<int>());
int sum = accumulate(l1.begin(), l1.end(),0); // equivalent
int fac = accumulate(l1.begin(), l1.end() , 0, times<int>());
```

User Defined Function Objects

```
class squared _sum // user-defined function object
{
  public:
    int operator()(int n1, int n2) { return n1+n2*n2; }
};
int sq = accumulate(l1.begin(), l1.end() , 0, squared_sum() );
// computes the sum of squares
```

User Defined Function Objects

```
template <class T>
class squared _sum // user-defined function object
{
  public:
    T operator()(T n1, T n2) { return n1+n2*n2; }
};
vector<complex> vc;
complex sum_vc;
vc.push_back(complex(2,3));
vc.push_back(complex(1,5));
vc.push_back(complex(-2,4));
sum_vc = accumulate( vc.begin(), vc.end() ,
           complex(0,0) , squared_sum<complex>() );
// computes the sum of squares of a vector of complex numbers
```

Associative Containers

- In an associative container the items are not arranged in sequence, but usually as a tree structure or a hash table.
- The main advantage of associative containers is the speed of searching (binary search like in a dictionary)
- Searching is done using a *key* which is usually a single value like a number or string
- The *value* is an attribute of the objects in the container
- The STL contains two basic associative containers
  - sets and multisets
  - maps and multimaps

Sets and Multisets

```
#include <set>
string names[] = {"Ole", "Hedvig", "Juan", "Lars", "Guido"};
set<string, less<string> > nameSet(names,names+5);
// create a set of names in which elements are alphabetically
// ordered string is the key and the object itself
nameSet.insert("Patric"); // inserts more names
nameSet.insert("Maria");
nameSet.erase("Juan"); // removes an element
set<string, less<string> >::iterator iter; // set iterator
string searchname;
cin >> searchname;
iter=nameSet.find(searchname);  // find matching name in set
if (iter == nameSet.end())   // check if iterator points to end of set
  cout << searchname << " not in set!" <<endl;
else
  cout << searchname << " is in set!" <<endl;
```

Set and Multisets

```
string names[] = {"Ole", "Hedvig", "Juan", "Lars",
   "Guido", "Patric", "Maria", "Ann"};
set<string, less< string> > nameSet(names,names+7);
set<string, less< string> >::iterator iter; // set iterator
iter=nameSet.lower_bound("K");
// set iterator to lower start value "K"
while (iter != nameSet.upper_bound("Q"))
  cout << *iter++ << endl;

// displays Lars, Maria, Ole, Patric
```

Maps and Multimaps

- A map stores pairs <key, value> of a key object and associated value object.
- The key object contains a key that will be searched for and the value object contains additional data
- The key could be a string, for example the name of a person and the value could be a number, for example the telephone number of a person

Maps and Multimaps

```
#include <map>
string names[]= {"Ole", "Hedvig", "Juan", "Lars", "Guido", "Patric",
   "Maria", "Ann"};
int numbers[]= {75643, 83268, 97353, 87353, 19988, 76455,
   77443,12221};
map<string, int, less< string> > phonebook;
map<string, int, less< string> >::iterator iter;
for (int j=0; j<8; j++)
   phonebook[names[j]]=numbers[j];  // initialize map phonebook
for (iter = phonebook.begin(); iter !=phonebook.end(); iter++)
   cout << (*iter).first << " : " << (*iter).second << endl;
cout << "Lars phone number is " << phonebook["Lars"] << endl;
```

Person Class

```
class person
{
   private:
     string lastName;
     string firstName;
     long phoneNumber;
   public:
      person(string lana, string fina, long pho) :
   lastName(lana), firstName(fina), phonenumber(pho) {}
   bool operator<(const person& p);
   bool operator==(const person& p);
}
```

Maps & Multimaps

```
person p1(”Neuville”, ”Oliver”, 5103452348);
person p2(”Kirsten”, ”Ulf”, 5102782837);
person p3(”Larssen”, ”Henrik”, 8904892921);
multiset<person, less<person>> persSet;
multiset<person, less<person>>::iterator iter;
persSet.insert(p1);
persSet.insert(p2);
persSet.insert(p3);
```