

## STL Components STL 1

Containers	classes for objects that contain
Iterators	“pointers” into containers
Generic algorithms	functions that work on different types of containers
Adaptors	classes that “adapt” other classes
Allocators	objects for allocating space

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Sequential Access Containers STL 2

These templates provide data structures supporting sequentially-organized storage. Sequential access is supported, and in some cases, random access as well.

`vector<T>` - random access, varying length, constant time insert/delete at end

`deque<T>` - random access, varying length, constant time insert/delete at either end

`list<T>` - linear time access, varying length, constant time insert/delete anywhere in list

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## STL Vector Container STL 3

The STL `vector` mimics the behavior of a dynamically allocated array and also supports automatic resizing at runtime.

**vector declarations:**

```
vector<int> iVector;
vector<int> jVector(100);
cin >> Size;
vector<int> kVector(Size);
```

**vector element access:**

```
jVector[23] = 71;
int temp = jVector[41];
cout << jVector.at(23) << endl;
int jFront = jVector.front();
int jBack = jVector.back();
```

**vector reporters:**

```
cout << jVector.size();
cout << jVector.capacity();
cout << jVector.max_capacity();
if ( jVector.empty() ) . . .
```

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Vector Constructors STL 4

The `vector` template provides several constructors:

```
vector<T> V; //empty vector
vector<T> V(n,value); //vector with n copies of value
vector<T> V(n); //vector with n copies of default for T
```

The `vector` template also provides a suitable deep copy constructor and assignment overload.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Vector Example STL 5

```
#include <iostream>
#include <iomanip>
#include <vector>           // for vector template definition
using namespace std;

void main() {
    int MaxCount = 100;
    vector<int> iVector(MaxCount);

    for (int Count = 0; Count < MaxCount; Count++) {
        iVector[Count] = Count;
    }
}
```

Specify initial vector size.

Can access like an array...

**Warning:** the capacity of this vector will NOT automatically increase as needed if access is performed using the `[]` operator. See the discussion of member functions `insert()` and `put_back()`.

Computer Science Dept/Va Tech/January 2000    OO Software Design and Construction    ©2000 McQuain WD

### STL Vector Indexing STL 6

In the simplest case, a vector object may be used as a simple dynamically allocated array:

```
int MaxCount = 100;
vector<int> iVector(MaxCount);

for (int Count = 0; Count < 2*MaxCount; Count++) {
    cout << iVector[Count];
}
```

However, the usage above provides neither runtime checking of the vector index bounds, or dynamic growth. If the loop counter exceeded the capacity of the vector object, an access violation would occur.

```
int MaxCount = 100;
vector<int> iVector(MaxCount);

for (int Count = 0; Count < 2*MaxCount; Count++) {
    cout << iVector.at(Count);
}
```

Use of the `at()` member function cause an exception in the same situation.

Computer Science Dept/Va Tech/January 2000    OO Software Design and Construction    ©2000 McQuain WD

### STL Iterators STL 7

**iterator** an object that keeps track of a location within an associated STL container object, providing support for traversal (increment/decrement), dereferencing, and container bounds detection. (See Stroustrup 3.8.1 – 3.8.4)

An iterator is declared with an association to a particular container type and its implementation is both dependent upon that type and of no particular importance to the user.

Iterators are fundamental to many of the STL algorithms and are a necessary tool for making good use of the STL container library.

Each STL container type includes member functions `begin()` and `end()` which effectively specify iterator values for the first element and the "first-past-last" element.

Computer Science Dept/Va Tech/January 2000    OO Software Design and Construction    ©2000 McQuain WD

### STL Vector Iterator Example STL 8

```
string DigitString = "45658228458720501289";
vector<int> BigInt;

for (int i = 0; i < DigitString.length(); i++) {
    BigInt.push_back(DigitString.at(i) - '0');
}

vector<int> Copy;
vector<int>::iterator It = BigInt.begin();

while ( It != BigInt.end() ) {
    Copy.push_back(*It);
    It++;
}
```

Inserting with the `push_back()` member, `BigInt` will grow to hold as many digits as necessary.

Obtain reference to target of iterator.

Advance iterator to next element.

This could also be written using a `for` loop, or by using the assignment operator.

Computer Science Dept/Va Tech/January 2000    OO Software Design and Construction    ©2000 McQuain WD

## STL Iterator Operations

STL 9

Each STL iterator provides certain facilities via a standard interface:

```
string DigitString = "45658228458720501289";
vector<int> BigInt;

for (int i = 0; i < DigitString.length(); i++) {
    BigInt.push_back(DigitString.at(i) - '0');
}
```

```
vector<int>::iterator It; Create an iterator for vector<int> objects.
```

```
It = BigInt.begin(); Target the first element of BigInt and copy it.
int FirstElement = *It;
```

```
It++; Step to the second element of BigInt.
```

```
It = BigInt.end(); Now It targets a non-element of BigInt.
Dereference will yield a garbage value.
```

```
It--; Back It up to the last element of BigInt.
int LastElement = *It;
```

Computer Science Dept/Va Tech January 2000

OO Software Design and Construction

©2000 McQuain WD

## Insertion into Vector Objects

STL 10

Insertion at the end of the vector (using `push_back()`) is most efficient.

Inserting elsewhere requires shifting data.

A vector object is potentially like array that can increase size. The capacity of a vector (at least) doubles in size if insertion is performed when vector is "full".

Insertion invalidates any iterators that target elements following the insertion point.

Reallocation (enlargement) invalidates any iterators that are associated with the vector object.

You can set the minimum size of a vector object `V` with `V.reserve(n)`.

Computer Science Dept/Va Tech January 2000

OO Software Design and Construction

©2000 McQuain WD

## Insert() Member Function

STL 11

An element may be inserted at an arbitrary position in a vector by using an iterator and the `insert()` member function:

```
vector<int> Y;
for (int m = 0; m < 100; m++) {

    Y.insert(Y.begin(), m);

    cout << setw(3) << m
         << setw(5) << Y.capacity()
         << endl;
}
```

```
0 1
1 2
2 4
3 4
4 8
. . .
8 16
. . .
15 16
16 32
. . .
31 32
33 64
63 64
. . .
64 128
```

This is the worst case; insertion is always at the beginning of the sequence and that maximizes the amount of shifting.

There are overloads of `insert()` for inserting an arbitrary number of copies of a data value and for inserting a sequence from another vector object.

Computer Science Dept/Va Tech January 2000

OO Software Design and Construction

©2000 McQuain WD

## Deletion from Vector Objects

STL 12

As with insertion, deletion requires shifting (except for the special case of the last element).

Member for deletion of last element: `V.pop_back()`

Member for deletion of specific element, given an iterator `It`: `V.erase(It)`

Invalidates iterators that target elements following the point of deletion, so

```
j = V.begin();
while (j != V.end())
    V.erase(j++);
```

doesn't work.

Member for deletion of a range of values: `V.erase(Iter1, Iter2)`

Computer Science Dept/Va Tech January 2000

OO Software Design and Construction

©2000 McQuain WD

### Range Deletion Example STL 13

```

string DigitString = "00000028458720501289";
vector<char> BigChar;

for (int i = 0; i < DigitString.length(); i++) {
    BigChar.push_back( DigitString.at(i));
}

vector<char> Trimmed = BigChar;

vector<char>::iterator Stop = Trimmed.begin();
while (*Stop == '0') Stop++;

Trimmed.erase(Trimmed.begin(), Stop);

```

Note: be careful not to mix iterators for different objects; the results are usually not good...

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Const Iterators STL 14

Constant iterator must be used when object is const – typically for parameters.

Type is defined by container class: `vector<T>::const_iterator`

```

void ivecPrint(const vector<int> V, ostream& Out) {
    vector<int>::const_iterator It; // MUST be const

    for (It = V.begin(); It != V.end(); It++) {
        cout << *It;
    }
    cout << endl;
}

```

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Container Comparison STL 15

Two containers of the same type are equal if:

- they have same size
- elements in corresponding positions are equal

The element type in the container must have equality operator.

For other comparisons element type must have appropriate operator (<, >, ...).

All containers supply a deep assignment operator.

Also have `v.assign(fst, lst)` to assign a range to v.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Relational Comparison Example STL 16

```

void ivecPrint(const vector<int> V, ostream& Out);
void StringToVector(vector<int>& V, string Source);

void main() {
    string s1 = "413098", s2 = "413177";
    vector<int> V1, V2;
    StringToVector(V1, s1);
    StringToVector(V2, s2);
    ivecPrint(V1, cout);
    if (V1 < V2) {
        cout << " < ";
    }
    else if (V1 > V2) {
        cout << " > ";
    }
    else {
        cout << " = ";
    }
    ivecPrint(V2, cout);
    cout << endl;
}

```

```

void StringToVector(vector<int>& V,
                  string Source) {
    int i;
    for (i = 0; i < Source.length(); i++)
        V.push_back(Source.at(i) - '0');
}

```

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## STL Deque Container STL 17

deque: double-ended queue

Provides efficient insert/delete from either end.

Also allows insert/delete at other locations via iterators.

Adds `push_front()` and `pop_front()` methods to those provided for `vector`.

Otherwise, most methods and constructors the same as for `vector`.

Requires header file `<deque>`.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## STL List Container STL 18

Essentially a doubly linked list.

Not random access, but constant time insert and delete at current iterator position.

Some differences in methods from `vector` and `deque` (e.g., no `operator[]`)

Insertions and deletions do not invalidate iterators.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Other STL Containers STL 19

The STL also provides two standard variants of the linear list:

```
stack<T>
```

```
queue<T>
```

Generally these conform to the usual expectations for stack and queue implementations, although the standard operation names are not used.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Associative Containers STL 20

A standard array is indexed by values of a numeric type:

- `A[0], ..., A[Size]`
- dense indexing

An associative array would be indexed by any type:

- `A["alfred"], A["judy"]`
- sparse indexing

Associative data structures support direct lookup ("indexing") via complex key values.

The STL provides templates for a number of associative structures.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Sorted Associative Containers STL 21

The values (objects) stored in the container are maintained in sorted order with respect to a key type (e.g., a Name field in an Employee object)

The STL provides:

<code>set&lt;Key&gt;</code>	collection of <u>unique</u> Key values
<code>multiset&lt;Key&gt;</code>	possibly duplicate Keys
<code>map&lt;Key, T&gt;</code>	collection of T values indexed by <u>unique</u> Key values
<code>multimap&lt;Key, T&gt;</code>	possibly duplicate Keys

But of course the objects cannot be maintained this way unless there is some well-defined sense of ordering for such objects...

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Strict Orderings STL 22

STL makes assumptions about orders in sort functions and sorted associative containers.

Logically we have a set  $S$  of potential key values.

Ideally, we want a strict total ordering on  $S$ :

- For every  $x$  in  $S$ ,  $x = x$ .
- For every  $x, y, z$  in  $S$ , if  $x < y$  and  $y < z$  then  $x < z$
- For every  $x$  and  $y$  in  $S$ , then precisely one of  $x < y$ ,  $y < x$ , and  $x = y$  is true.

Actually, can get by with a weaker notion of order:

Given a relation  $R$  on  $S$ , define relation  $E$  on  $S$  by:

$$x E y \text{ iff both } x R y \text{ and } y R x \text{ are false}$$

Then a relation  $R$  is a strict weak ordering on  $S$  if  $R$  is transitive and asymmetric, and  $E$  is an equivalence relation on  $S$ .

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Example Order STL 23

```
class Name {
public:
    string LName;
    string FName;
};

class LastNameLess {
public:
    bool operator()(const Name& N1, const Name& N2) {
        return (N1.LName < N2.LName);
    }
};
```

Using `LastNameLess`,

Zephram Alonzo < Alfred Zimbalist  
Alonzo Church is equivalent to Bob Church

Notice that equivalence defined this way is not the same as `operator==`.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Special Function Objects STL 24

If there is an operator< for a class T then you can use the special template `less<T>` (implicitly) to build order function objects. `<functional>`

When an ordering is required, the default STL implementation is built around the `less<T>` functional, so you don't have to do anything special...

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Sets and Multisets STL 25

Both `set` and `multiset` templates store key values, which must have a defined ordering.

`set` only allows distinct objects (by order) whereas `multiset` allows duplicate objects.

```
set<int> iSet; // fine, built-in type has < operator
set<Employee> Payroll; // class Employee did not
                        // implement a < operator
```

However, a suitable operator can be provided:

```
bool Employee::operator<(const Employee& Other) const {
    return (ID < Other.ID);
}
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Sets and Multisets STL 26

Both `set` and `multiset` templates store key values, which must have a defined ordering.

`set` only allows distinct objects (by order) whereas `multiset` allows duplicate objects.

```
set<int> iSet; // fine, built-in type has < operator
set<Employee> Payroll; // class Employee did not
                        // implement a < operator
```

However, a suitable operator can be provided:

```
bool Employee::operator<(const Employee& Other) const {
    return (ID < Other.ID);
}
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Set Example STL 27

```
#include <functional>
#include <set>
using namespace std;
#include "Employee.h"

void EmpsetPrint(const set<Employee> S, ostream& Out);
void PrintEmployee(Employee toPrint, ostream& Out);

void main() {
    Employee Ben("Ben", "Keller", "000-00-0000");
    Employee Bill("Bill", "McQuain", "111-11-1111");
    Employee Dwight("Dwight", "Barnette", "888-88-8888");

    set<Employee> S;
    S.insert(Bill);
    S.insert(Dwight);
    S.insert(Ben);

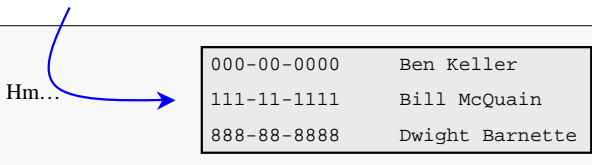
    EmpsetPrint(S, cout);
}
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Set Example STL 28

```
void EmpsetPrint(const set<Employee> S, ostream& Out) {
    int Count;
    set<Employee>::const_iterator It;

    for (It = S.begin(), Count = 0; It != S.end();
         It++, Count++)
        PrintEmployee(*It, cout);
}
```

Hm... 

000-00-0000	Ben Keller
111-11-1111	Bill McQuain
888-88-8888	Dwight Barnette

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Multiset Example

STL 29

```
void main() {
    list<char> L = lst("dogs love food");
    //copy list to multiset
    multiset<char> M;
    list<char>::iterator i = L.begin();
    while (i != L.end()) M.insert(*i++);
    // copy multiset to list
    list<char> L2;
    multiset<char>::iterator k = M.begin();
    while (k != M.end()) L2.push_back(*k++);
    cmultisetPrint(M, cout);
}
```

0:	
1:	
2:	d
3:	d
4:	e
5:	f
6:	g
7:	l
8:	o
9:	o
10:	o
11:	o
12:	s
13:	v

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Set/Multiset Member Functions

STL 30

**Insert and Erase**

by value:

```
S.erase(k); //k is a Key variable
M.erase(k); //erase all copies of value
```

at iterator:

```
S.erase(i); //i an iterator
M.erase(i); //erase only value *i
```

**Accessors**

`find(Key)` - returns iterator to an element with given value, equals `end()` if not found

`lower_bound(k)` - returns iterator to first position where `k` could be inserted and maintain sorted order

`upper_bound(k)` - iterator is to last such position

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Maps and Multimaps

STL 31

Associative "arrays" indexed on a given Key type.

`map` requires unique Keys (by def of order)  
`multimap` allows duplicate Keys

A `map` is somewhat like a `set` that holds key-value pairs, which are only ordered on the keys.

A `map` element can be addressed with the usual array syntax: `map1[k] = v`

However: the semantics are different!

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Values in Maps

STL 32

An elements of a map is a pair of items: `pair<const Key, T>`

Once a pair has been inserted, you can only change the T value.

The `pair` class has public member fields `first` and `second`.

To create a `pair` object to insert into a map use `pair` constructor:

```
HourlyEmployee Homer("Homer", "Simpson", "000-00-0001");

pair<const string, Employee>(Homer.getID(), Homer)
```

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Inserting in Maps and Multimaps STL 33

Insert value (can also insert using iterator):

```
map<string, Employee> Payroll;
Payroll.insert(pair<const string, Employee>
               Homer.getID(), Homer);
```

A multimap allows duplicate keys:

```
multimap<string, string> mpl;
mpl.insert(pair<const string, string>("blue", "Jenny"));
mpl.insert(pair<const string, string>("blue", "John"));
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Map Example STL 34

```
#include <iostream>
#include <fstream>
#include <iomanip>
#include <string>
#include <functional>
#include <map>
using namespace std;
#include "Employee.h"

void EmpmapPrint(const map<const string, Employee*> S,
                 ostream& Out);
void PrintEmployee(Employee toPrint, ostream& Out);

void main() {
    Employee Ben("Ben", "Keller", "000-00-0000");
    Employee Bill("Bill", "McQuain", "111-11-1111");
    Employee Dwight("Dwight", "Barnette", "888-88-8888");

    map<const string, Employee*> S;
    // . . . continues . . .
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Map Example STL 35

```
// . . . continued . . .
S.insert(pair<const string, Employee>
         (Bill.getID(), &Bill));
S.insert(pair<const string, Employee>
         (Dwight.getID(), &Dwight));
S.insert(pair<const string, Employee>
         (Ben.getID(), &Ben));

EmpmapPrint(S, cout);
// . . . continues . . .
```

000-00-0000	Ben Keller
111-11-1111	Bill McQuain
888-88-8888	Dwight Barnette

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Finding Data in Map STL 36

Use find(Key) function to find entry by key:

```
map<string, string> mp;
... //insert some values
map<string, string>::iterator m_i;
m_i = mp.find("222-22-2222");
if (m_i != mp.end()) //do something with entry
```

Can manipulate the data entry, but not the key value:

```
(*m_i).first //get key value, cannot be changed (const)
(*m_i).second //data value, may be changed
```

Computer Science Dept/Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Map Example STL 37

```
// . . . continued . . .
map<const string, Employee>::const_iterator It;
It = S.find("111-11-1111");
cout << (*It).second->getName() << endl;

// . . . continues . . .
```

Bill McQuain

Of course, the value of the iterator is not checked before dereferencing, so if the specified key value isn't found (so the iterator equals `S.end()`), the subsequent dereference will blow up...

Computer Science Dept Va Tech January 2000 OO Software Design and Construction ©2000 McQuain WD

### Finding Data in a Multimap STL 38

The `find()` method is only guaranteed to find a value with the specified key.

`lower_bound()` method finds first pair with the specified key  
`upper_bound()` method finds last pair with the specified key

Use an iterator to look at each of duplicate values.

Computer Science Dept Va Tech January 2000 OO Software Design and Construction ©2000 McQuain WD

### Subscripting in Maps STL 39

The `map` template allows use of a subscript: `mp[k] = t`  
 (even if the key value isn't integral).

If no pair exists in the map with the key `k`, then the pair `(k, t)` is inserted.

If pair `(k, t0)` exists, then `t0` is replaced in that pair with `t`.

If no pair with key `k` exists in `mp` the expression `mp[k]` will insert a pair `(k, T())`.

This ensures that `mp[k]` always defined.

Subscripting is not defined for multimaps.

Computer Science Dept Va Tech January 2000 OO Software Design and Construction ©2000 McQuain WD

### Map Example STL 40

```
// . . . continued . . .
Employee Fred("Fred", "Flintstone", "888-88-8888");
Employee Homer("Homer", "Simpson", "123-45-6789");

S[Fred.getID()] = &Fred;
S[Homer.getID()] = &Homer;
EmpmapPrint(S, cout);

// . . . continues . . .
```

000-00-0000	Ben Keller
111-11-1111	Bill McQuain
123-45-6789	Homer Simpson
888-88-8888	Fred Flintstone

Computer Science Dept Va Tech January 2000 OO Software Design and Construction ©2000 McQuain WD

### Map Example STL 41

```

It = S.find("000-00-0000");
if (It != S.end())
    cout << (*It).second->getName() << endl;

It = S.find("000-00-0001");
if (It != S.end())
    cout << (*It).second->getName() << endl;
}

```

Ben Keller

This prints nothing. No record in the map matches the specified key value, so `find()` has returned the end marker of the map.

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### More on Iterators STL 42

There are several kinds of iterators, which correspond to various assumptions made by generic algorithms.

The properties of an iterator correspond to properties of the “container” for which it is defined.

Input iterators:  
 Operations: equality, inequality, next (`++j`, `j++`), dereference (`*j`)  
 No guarantee you can assign to `*j`: `istream_iterator<char>`

Output iterators  
 Operations: dereference for assignment: `*j = t`, next (`++j`, `j++`)  
 May not have equality, inequality  
`ostream_iterator<int>`

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Other Iterators STL 43

**Forward Iterators**  
 Operations of both input and output iterator  
 Iterator value can be stored and used to traverse container

**Bidirectional Iterators**  
 Operations of forward iterators  
 Previous: `--j`, `j--`

**Random Access Iterators**  
 Bidirectional operators  
 Addition, subtraction by integers: `r + n`, `r - n`  
 Jump by integer `n`: `r += n`, `r -= n`  
 Iterator subtraction `r - s` yields integer

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

### Reverse Iterators STL 44

Adapted from iterators of container classes.

Containers define the types:  
`reverse_iterator`  
`const_reverse_iterator`

Containers provide supporting member functions:  
`rbegin()`  
`rend()`

Computer Science Dept Va Tech January 2000    OO Software Design and Construction    ©2000 McQuain WD

## Choosing a Container

STL 45

A `vector` may be used in place of a dynamically allocated array.

A `list` allows dynamically changing size for linear access.

A `set` may be used when there is a need to keep data sorted and random access is unimportant.

A `map` should be used when data needs to be indexed by a unique non-integral key.

Use `multiset` or `multimap` when a `set` or `map` would be appropriate except that key values are not unique.