Teaching with the STL

Joseph Bergin

Michael Berman

Part 1

Introduction to STL Concepts

Templates are not Classes

- These are not cookies
- You can’t eat them
- They can be used to make cookies

Templates are not Classes

- These are cookies
- They are made with a cookie cutter
- You can eat them

Templates are not Cookies

- Templates are used to create classes
- You can’t compile them
- You can instantiate them
  - This gives you a class
- The instantiations are compiled
- The instantiations are strongly typed like other classes

Templates are not Classes

```
template <class E>
class stack
{         ...
          void push(E e){...}
}
```

<- A class template

```
stack <int> S;

S.push(55);
```

<- a template class

Templates are not Functions

```
template <class E>                    <- a function template
E& min(E& a, E& b)
{       if(a < b) return a;
        return b;
}


abox = min(box1, box2);               <- a template function
```

The Standard Template Library

- Containers
  - array, vector, deque, list, set, map, multiset, multimap
- Algorithms
  - sort, search, and nearly everything else
- Iterators
  - generalize pointers and pointer arithmetic
- Adaptors
  - change the behavior of other components
- Allocators
  - memory management

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The Major Dimensions

Independent Development of:

- Containers
  - » contain values
- Algorithms
  - » operate on containers
- Iterators
  - » interface between containers and algorithms

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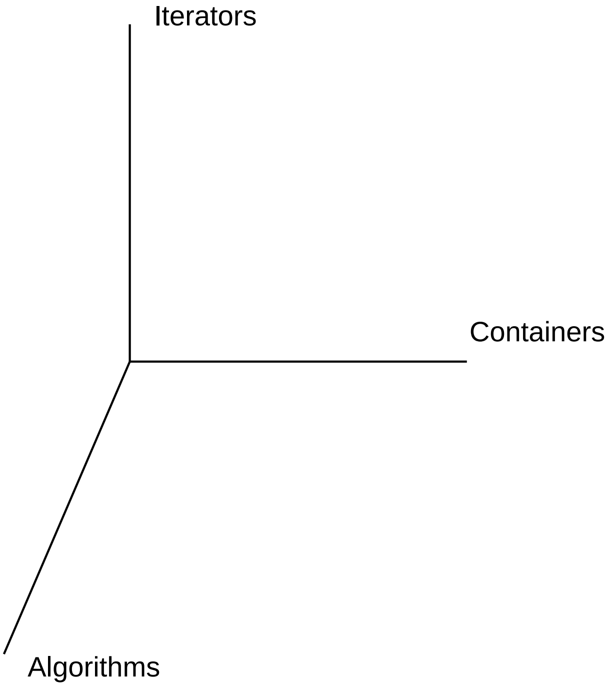

STL Example

```
vector<int> v;
v.push_back(3);
v.push_back(4);
v.push_back(5);
v.push_back(6);

vector<int>::iterator i;

for(i = v.begin(); i != v.end(); ++i) cout << *i << endl;

sort(v.begin(); v.end());

for(i = v.begin(); i != v.end(); ++i) cout << *i << endl;
```

Iterator Flavors

- Forward Iterators (operator++)
  - Input Iterators
  - Output Iterators
- Bidirectional Iterators (operator --)
- Random Access Iterators (operator +=)

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All Iterators have operator*
All Containers produce iterators begin() and end()
begin references first. end is “after” last

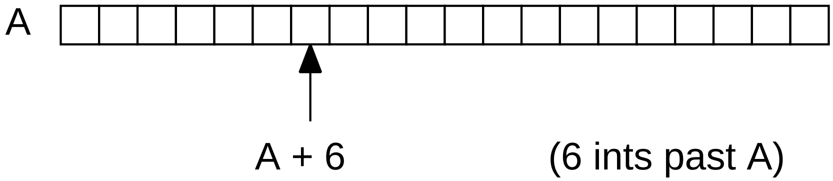
Slouching Toward Iterators

```
template < class T >
void selectionSort(T elements[ ], int length)
{       for(int i = 0; i < length - 1; ++i)
        {       int s = i;
                T small = elements[s];
                for(unsigned j = i + 1; j < length; ++j)
                        if(elements[j] < small)
                        {       s = j;
                                small = elements[s];
                        }
                elements[s] = elements[i];
                elements[i] = small;
        }
}
```

Pt. 1: Dependent on Arrays

Pointer Duality Law

```
int * A = new int [20];
-------------------------------------
A[i]  is equivalent to *(A + i)
```



Slouching Towards Iterators

~~int elements [20] = ...~~
~~selectionSort(elements, 20)~~

```
int * start = elements;
int * end = elements + 20; // or &elements[20]

selectionSort(start, end);
```

Pt. 2: The Goal

The Replacements

```
template < class T >
void selectionSort(T elements[ ], int length)
{       for(int i = 0; i < length - 1; ++i)
        {       int s = i;
                T small = elements[s];
                for(unsigned j = i + 1; j < length; ++j)
                        if(elements[j] < small)
                        {       s = j;
                                small = elements[s];
                        }
                elements[s] = elements[i];
                elements[i] = small;
        }
}
```

start = elements
end = elements + length
loc = & elements[s]
where = & elements[i]
inner = & elements[j]

Slouching Towards Iterators

```
template < class T >
void selectionSort(T* start, T* end)
{       for(T* where = start ; where < end - 1 ; ++where)
        {       T* loc = where;
                T small = *loc;
                for(T* inner = where + 1; inner < end; ++inner)
                        if(*inner < *loc)
                        {       loc = inner;
                                small = *loc;
                        }
                *loc = *where;
                *where = small;
        }
}
```

Pt 3: The Result (almost)

The Advantages

- This version will sort more than arrays.
  - All we need is a structure referenced by a datatype like a pointer that implements
    - operator *
    - operator++
    - operator+
    - operator-
    - operator=
    - operator<

With care we could reduce this list

Such datatypes are called iterators

The Lesson

- Implement containers separate from algorithms
- Use pointer like structures as an interfacing mechanism

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ToGain →

Advantages

- Generality
- A framework for thinking about containers and algorithms
- Smaller written code
- Smaller compiled code

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But... →

Disadvantages

- Students must become thoroughly familiar with all aspects of pointers including
  - The pointer duality law
  - Pointer arithmetic
  - Pointer “gotchas”

Part 2

STL Containers

STL Containers

- Ordinary Arrays
- Vectors -- expandable array
- Deques -- expandable at both ends
- Lists -- doubly linked circular with header
- Sets and Multisets -- red-black tree
- Maps and Multimaps -- dictionary like

Note: Implementation is not specified
but efficiency is specified.

All Containers Provide

- A Storage Service
  - insert and erase...
- An Associated Iterator type
  - The type of iterator determines what can be done with the container.
- begin() and end() iterators - - - [b, e)
- A collection of types: vector::value_type...
- constructors, assignment, cast, equality...

All Iterators Provide

- operator*
  - may be readonly or read/write
- copy constructor
- operator++ and operator++(int)
- operator== and operator!=
- Most provide operator=

Specialized Iterators

- Forward
  - provide operator=
- Bidirectional (extend forward)
  - provide operator-- and operator--(int)
- Random Access (extend bidirectional)
  - provide operator<..., operator+=..., operator-

Algorithms

- Defined in terms of a specific iterator type
  - e.g. sort requires random access iterators
- Work with all containers that provide that iterator type -- including user written.
- Combine good generality with good efficiency
- Do not appear within container classes
  - This is important to generality & efficiency

Function Objects 1

- Predicates
  - A function of one argument returning bool
- Comparisons
  - A function of two arguments returning bool
- Unary Operator, Binary Operator
  - A function of one or two arguments returning a value

Function Objects 2

- Can be functions or template functions
- Can be objects implementing an appropriate operator()
- Many are built in
  - » less..., plus..., and...,...
- Function adaptors too
  - » not1, not2, bind1st, bind2nd,...

Function Object Example

```
class stringLess
{         bool operator()(char* s1, char* s2)
          {         return strcmp(s1, s2) < 0;
          }
          . . .
} // Defines a function object.

vector< char* > stringVec;
. . .
sort (stringVec.begin(), stringVec.end(), stringLess());
// Note the constructor call in the last argument ^^^^
```

vector

- Expandable array -- operator[]
- push_back, pop_back
- Average O(1) insert at end.
- O(n) insert in middle
- Random Access Iterators
- Fastest (average) container for most purposes.

deque

- Expandable “array” at both ends
- push_front, pop_front
- Average O(1) insert at both ends
- Linear insert in middle
- Random Access Iterators
- Good choice for queues & such.

list

- Doubly linked list
- O(1) inserts everywhere, but slower on average than vector and deque
- Bidirectional iterators
- Some specialized algorithms (sort).

set and multiset

- Sorted set (multiset) of values
- O(lg n) inserts and deletions
  - Balanced binary search tree
- Sorted with respect to operator< or any user defined comparison operator
- Bidirectional iterators
- Good choice if elements must stay in order.

map and multimap

- Ordered set (multiset) of key-value pairs
- Kept in key order
- O(lg n) inserts and deletions
- Bidirectional iterators
- Good choice for dictionaries, property lists, & finite functions as long as keys have comparison operation

Extending the STL

- Not standardized but available
  - hash_set
  - hash_map
  - hash_multiset
  - hash_multimap
- Like set... but have a (self reorgainzing) hashed implementation
- Constant average time for insert/erase

STL in Java

- ObjectSpace has developed an equivalent library for Java
- (JGL) Java Generic Library
- Public domain, available on internet.
- Depends on run-time typing instead of compile time typing, but is otherwise equivalent.

Resources

- http://csis.pace.edu/~bergin
- http://www.objectspace.com
- http://www.cs.rpi.edu/~musser/stl.html
- http://weber.u.washington.edu/~bytewave/bytewave_stl.html
- ftp.cs.rpi.edu/pub/stl
- http://www.sgi.com/Technology/STL/
- http://www.cs.brown.edu/people/jak/programming/stl-tutorial/home.html

Books

- Data Structures Programming with the STL, Bergin, Springer-Verlag (to appear)
- STL Tutorial and Reference Guide, Musser and Saini, Addison-Wesley, 1996
- The STL <primer>, Glass and Schuchert, Prentice-Hall, 1996
- The Standard Template Library, Plauger, Stepanov, and Musser, Prentice-Hall, 1996