

C++ Basics

Structs and Class

In vanilla C, structs are collections of variables, originally created for custom typing. In C++, structs and classes are the same and have the same function as any other object oriented language. The only difference between the two is that in structs, variables and methods are by default public and in classes they are by default private. This basically means that for the purpose of competitive programming we almost always want to use structs.

The following is an example of a struct used to keep track of a product on sale:

```

1 // this is a declaration of a struct
2 // it follows the general pattern of
3 // struct <struct_name> {
4 //     <member_type_1> <member_name_1>;
5 //     <member_type_2> <member_name_2>;
6 //     . . . . .
7 //     <method_type_1> <method_name_1>(<params>) {<implementation>;}
8 // };
9 struct product {
10     string name;
11     double price;
12     bool available;
13
14     // since structs and classes are the same, we can define constructors
15     product(string a_name, double a_price) {
16         name = a_name;
17         price = a_price;
18         available = true;
19     };
20
21     // we can also define our own comparison operators, default behavior
22     // is very glitchy so it is recommended if you want to sort an array
23     // of this type to define your own comparison
24     bool operator < (const product &B) const {
25         return price < B.price;
26     };
27 };
28
29 // to create an element of the type product you can use a constructor
30 product apple("apple", 6.5);
31 // or in c++11 you can initialize any struct with list initialization
32 // by default the order of arguments provided is the order of struct
33 // members in the definition, but you can also specify
34 // omitted values are given the default value of the type
35 product banana = {"banana", 3.33, true}; // <- for our purposes use this
36 product orange = {price = 3.33, .name = "orange", .available = true};

```

Lambda Expression

Lambda expressions are inline anonymous functions especially helpful when using certain functions in algorithms when doing special comparison. The following example is an im-

plementation of something similar to filter in cpp:

```

1 #define T 5
2
3 void filterAbove(vector<int> &v) {
4     // the syntax for a lambda expression is
5     // [<capture group>](<argument list>) -> <ret type> { <code> }
6     // the return type along with -> are often omitted for simple code
7     // because the compiler can guess the return type.
8     // the capture group is what the lambda function ‘captures’ from the
9     // surrounding namespace, for competitive programming purposes leave
10    // it empty and just use #define statements up top.
11    transform(v.begin(), v.end(), [](double d) { return d > T ? d : 0 });
12 }

```

Pointers

Don't use them on purpose... Just know that `*p` dereferences a pointer and `p+1` accesses the address at `p+` the size of the type of pointer that `p` is.

C++ Containers

vectors

Constructors		
<code>vector<T>v;</code>	Make an empty vector.	$O(1)$
<code>vector<T>v(n);</code>	Make a vector with N elements.	$O(n)$
<code>vector<T>v(n, value);</code>	Make a vector with N elements, initialized to value.	$O(n)$
<code>vector<T>v(begin, end);</code>	Make a vector and copy the elements from begin to end.	$O(n)$
Accessors		
<code>v[i];</code>	Return (or set) the I'th element.	$O(1)$
<code>v.at(i);</code>	Return (or set) the I'th element, with bounds checking.	$O(1)$
<code>v.size();</code>	Return current number of elements.	$O(1)$
<code>v.empty();</code>	Return true if vector is empty.	$O(1)$
<code>v.begin();</code>	Return random access iterator to start.	$O(1)$
<code>v.end();</code>	Return random access iterator to end.	$O(1)$
<code>v.front();</code>	Return the first element.	$O(1)$
<code>v.back();</code>	Return the last element.	$O(1)$
<code>v.capacity();</code>	Return maximum number of elements.	$O(1)$
Modifiers		
<code>v.push_back(value);</code>	Add value to end.	$O(1)^*$
<code>v.insert(iterator, value);</code>	Insert value at the position indexed by iterator.	$O(n)$
<code>v.pop_back();</code>	Remove value from end.	$O(1)$
<code>v.erase(iterator);</code>	Erase value indexed by iterator.	$O(n)$
<code>v.erase(begin, end);</code>	Erase the elements from begin to end.	$O(n)$

lists

Constructors		
<code>list<T>l;</code>	Make an empty list.	$O(1)$
<code>list<T>l(begin, end);</code>	Make a list and copy the values from begin to end.	$O(n)$
Accessors		
<code>l.size();</code>	Return current number of elements.	$O(1)$
<code>l.empty();</code>	Return true if list is empty.	$O(1)$
<code>l.begin();</code>	Return bidirectional iterator to start.	$O(1)$
<code>l.end();</code>	Return bidirectional iterator to end.	$O(1)$
<code>l.front();</code>	Return the first element.	$O(1)$
<code>l.back();</code>	Return the last element.	$O(1)$
Modifiers		
<code>l.push_front(value);</code>	Add value to front.	$O(1)$
<code>l.push_back(value);</code>	Add value to end.	$O(1)$
<code>l.insert(iterator, value);</code>	Insert value after position indexed by iterator.	$O(1)$
<code>l.pop_front();</code>	Remove value from front.	$O(1)$
<code>l.pop_back();</code>	Remove value from end.	$O(1)$
<code>l.erase(iterator);</code>	Erase value indexed by iterator.	$O(1)$
<code>l.erase(begin, end);</code>	Erase the elements from begin to end.	$O(1)$
<code>l.remove(value);</code>	Remove all occurrences of value.	$O(n)$
<code>l.remove_if(test);</code>	Remove all element that satisfy test.	$O(n)$
<code>l.reverse();</code>	Reverse the list.	$O(n)$
<code>l.sort();</code>	Sort the list.	$O(n \log n)$
<code>l.sort(comparison);</code>	Sort with comparison function.	$O(n \log n)$
<code>l.merge(l2);</code>	Merge sorted lists.	$O(n)$

deques

Constructors		
<code>deque<T>d;</code>	Make an empty deque.	$O(1)$
<code>deque<T>d(n);</code>	Make a deque with N elements.	$O(n)$
<code>deque<T>d(n, value);</code>	Make a deque with N elements, initialized to value.	$O(n)$
<code>deque<T>d(begin, end);</code>	Make a deque and copy the values from begin to end.	$O(n)$
Accessors		
<code>d[i];</code>	Return (or set) the I'th element.	$O(1)$
<code>d.at(i);</code>	Return (or set) the I'th element, with bounds checking.	$O(1)$

stacks and queues

In C++ STL, stacks and queues are *container adaptors*, so they are created from another container (one of the ones listed above, default to vector).

<code>d.size();</code>	Return current number of elements.	$O(1)$
<code>d.empty();</code>	Return true if deque is empty.	$O(1)$
<code>d.begin();</code>	Return random access iterator to start.	$O(1)$
<code>d.end();</code>	Return random access iterator to end.	$O(1)$
<code>d.front();</code>	Return the first element.	$O(1)$
<code>d.back();</code>	Return the last element.	$O(1)$
Modifiers		
<code>d.push_front(value);</code>	Add value to front.	$O(1)^*$
<code>d.push_back(value);</code>	Add value to end.	$O(1)^*$
<code>d.insert(iterator, value);</code>	Insert value at the position indexed by iterator.	$O(n)$
<code>d.pop_front();</code>	Remove value from front.	$O(1)$
<code>d.pop_back();</code>	Remove value from end.	$O(1)$
<code>d.erase(iterator);</code>	Erase value indexed by iterator.	$O(n)$
<code>d.erase(begin, end);</code>	Erase the elements from begin to end.	$O(n)$

Constructors		
<code>stack< container<T> > s;</code>	Make an empty stack.	$O(1)$
<code>queue< container<T> > q;</code>	Make an empty queue.	$O(1)$
Accessors		
<code>s.top(); q.front(); q.back()</code>	Returns the top/front/back element.	$O(1)$
<code>s.size(); q.size();</code>	Returns current number of elements	$O(1)$
<code>s.empty(); q.empty();</code>	Returns true if empty	$O(1)$
Modifiers		
<code>s.push(v); q.push(v)</code>	Push value to top/end	varies
<code>s.pop(); q.pop()</code>	Removes value from the top/front	$O(1)$

Note that the complexity of `push` varies depending on the underlying container. But remember that it is always equal to the complexity of `push_back` for the underlying container.

priority queues

This is also a *container adaptor*. Except the element on top is irrelevant of order of insertion. Instead the “biggest” element is on top. Biggest is determined by the comparison predicate you give the priority queue constructor.

- If that predicate is a “less than” type predicate, then biggest means largest.
- If it is a “greater than” type predicate, then biggest means smallest.

Again, the default container is a vector, the constructor is

```
priority_queue<T, container<T>, comparison<T> > q;
```

and the complexity for push and pop are both $O(n \log n)$

sets and multisets

Constructors		
<code>set<T, compare> s;</code>	Make an empty set. <code>compare</code> should be a binary predicate for ordering the set. It's optional and will default to a function that uses <code>operator<</code> .	$O(1)$
<code>set<T, compare> s(begin, end);</code>	Make a set and copy the values from <code>begin</code> to <code>end</code> .	$O(n \log n)$
Accessors		
<code>s.find(key)</code>	Return an iterator pointing to an occurrence of <code>key</code> in <code>s</code> , or <code>s.end()</code> if <code>key</code> is not in <code>s</code> .	$O(\log n)$
<code>s.lower_bound(key)</code>	Return an iterator pointing to the first occurrence of an item in <code>s</code> not less than <code>key</code> , or <code>s.end()</code> if no such item is found.	$O(\log n)$
<code>s.upper_bound(key)</code>	Return an iterator pointing to the first occurrence of an item greater than <code>key</code> in <code>s</code> , or <code>s.end()</code> if no such item is found.	$O(\log n)$
<code>s.equal_range(key)</code>	Returns <code>pair_bound(key), upper_bound(key)></code> .	$O(\log n)$
<code>s.count(key)</code>	Returns the number of items equal to <code>key</code> in <code>s</code> .	$O(\log n)$
<code>s.size();</code>	Return current number of elements.	$O(1)$
<code>s.empty();</code>	Return true if set is empty.	$O(1)$
<code>s.begin()</code>	Return an iterator pointing to the first element.	$O(1)$
<code>s.end()</code>	Return an iterator pointing one past the last element.	$O(1)$
Modifiers		
<code>s.insert(iterator, key)</code>	Inserts <code>key</code> into <code>s</code> . <code>iterator</code> is taken as a "hint" but <code>key</code> will go in the correct position no matter what. Returns an iterator pointing to where <code>key</code> went.	$O(\log n)$
<code>s.insert(key)</code>	Inserts <code>key</code> into <code>s</code> and returns a <code>pair<iterator, bool></code> , where <code>iterator</code> is where <code>key</code> went and <code>bool</code> is true if <code>key</code> was actually inserted, i.e., was not already in the set.	$O(\log n)$

maps and multimaps

Adapted from <http://www.cs.northwestern.edu/~riesbeck/programming/c++/stl-summary.html>

Using Lambda Functions as Comparisons

Usually comparisons call for a class, but that's annoying, below is an example of how to use lambda function to get around it.

```

1 using namespace std;
2
3 auto comparison = [](int a, int b) {return a > b;};
4 typedef set<int, decltype(comparison)> sint;
5
6 int main(int argc, char *argv[]) {
7     sint A(comparison);

```

Constructors		
<code>map<key_type, value_type, key_compare> m;</code>	Make an empty map. <code>key_compare</code> should be a binary predicate for ordering the keys. It's optional and will default to a function that uses operator<.	$O(1)$
<code>map<key_type, value_type, key_compare> m(begin, end);</code>	Make a map and copy the values from <code>begin</code> to <code>end</code> .	$O(n \log n)$
Accessors		
<code>m[key]</code>	Return the value stored for <code>key</code> . This adds a default value if <code>key</code> not in map.	$O(\log n)$
<code>m.find(key)</code>	Return an iterator pointing to a key-value pair, or <code>m.end()</code> if <code>key</code> is not in map.	$O(\log n)$
<code>m.lower_bound(key)</code>	Return an iterator pointing to the first pair containing <code>key</code> , or <code>m.end()</code> if <code>key</code> is not in map.	$O(\log n)$
<code>m.upper_bound(key)</code>	Return an iterator pointing one past the last pair containing <code>key</code> , or <code>m.end()</code> if <code>key</code> is not in map.	$O(\log n)$
<code>m.equal_range(key)</code>	Return a pair containing the lower and upper bounds for <code>key</code> . This may be more efficient than calling those functions separately.	$O(\log n)$
<code>m.size();</code>	Return current number of elements.	$O(1)$
<code>m.empty();</code>	Return true if map is empty.	$O(1)$
<code>m.begin();</code>	Return an iterator pointing to the first pair.	$O(1)$
<code>m.end();</code>	Return an iterator pointing one past the last pair.	$O(1)$
Modifiers		
<code>m[key] = value;</code>	Store value under <code>key</code> in map.	$O(\log n)$
<code>m.insert(pair)</code>	Inserts the <code><key, value></code> pair into the map. Equivalent to the above operation.	$O(\log n)$

```

8     int N = 1;
9     while (N) {
10         cin >> N;
11         auto print_bool = [](int b) {return b == 0 ? "False" : "True";};
12         cout << print_bool(A.insert(N).second) << '\n';
13     }
14     return 0;
15 }

```

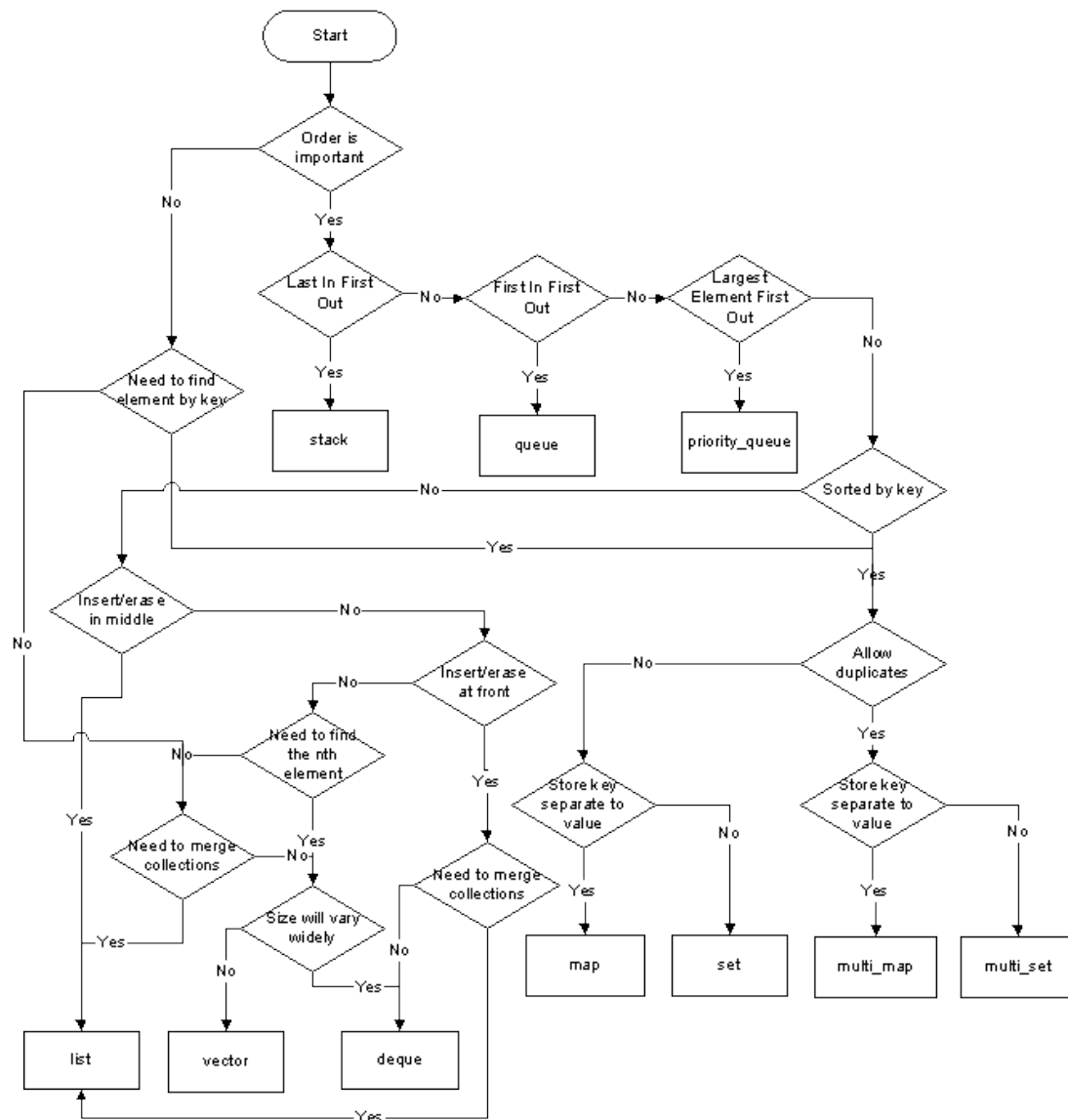
Choosing the Right Container

Algorithms

```

1 #include <algorithm>
2 // almost all of these modify on containers with c.begin(), c.end()
3 // let us first create a vector!
4 vector<int> v(10);

```



```

5 // fill - fills the vector, O(n)
6 // this fills the vector with the value 10
7 fill(v.begin(), v.end(), 10);
8 // this fills the length - 2 with the value 5
9 fill(v.begin(), v.end() - 2, 5);
10
11 // find - returns the iterator to the first object with value v
12 // returns .end() if none found
13 auto it = find(v.begin(), v.end(), 5);
14 // find_if - returns the iterator to the first object satisfying
15 // condition
16 // the following returns the iterator to the first even number
17 auto it = find(v.begin(), v.end(), [](int i) {return i % 2 == 0;});
18
19 // count - returns the number of objects w/ value
20 int N = count(v.begin(), v.end(), 5);

```

```
21 // count_if - returns the number of objects satisfying a condition
22 int N = count_if(v.begin(), v.end(), [](int i) {return i % 2 == 0;});
23
24 // search - searches a subsequence within a bigger sequence
25 // returns an iterator to the beginning of the subsequence
26 // O(mn) where m and n are the lengths of the target and source
27 int target[] = {5,5,5};
28 auto it = search(v.begin(), v.end(), target.begin(), target.end());
29
30 // sort - sorts the range according to comparison function
31 // if less than sorts lowest -> highest
32 // if more than sorts highest -> lowest
33 // the following sorts lowest -> highest
34 // O(N log N)
35 sort(v.begin(), v.end(), [](int a, int b) {return a < b;});
36
37 // partition - moves the content around such that elements satisfying
38 // the precondition comes before elements that don't
39 // O(N)
40 // the following puts the 10's in front of the 5's
41 partition(v.begin(), v.end(), [](int a) {return a > 10;});
42
43 // following are based on binary searches on a *sorted* container
44 // lower_bound - returns iterator to the lower bound of the value
45 // upper_bound - returns iterator to the upper bound of the value
46 // equal_range - return <lower_bound, upper_bound>
47 // binary_search - returns true if the value is found
48 // all of these are O(log N)
49 auto it_l = lower_bound(v.begin(), v.end(), 7);
50 auto it_u = upper_bound(v.begin(), v.end(), 7);
51 auto range = equal_range(v.begin(), v.end(), 7);
52 bool contains7 = binary_search(v.begin(), v.end(), 7, less<int>);
```