Advanced Containers and Iterators

Bad Dad Joke of the Day:

- Dad: Hey son, take some of this jerky 😉*
- Son: Thanks dad 🙂
- Dad: It was nice meating you

*emojis replicated as given

Creds: Adam

Game Plan

- Map Iterators
- Further Iterator Usages
- Announcements
- Iterator Types

Brief Recap

Associative Containers

Useful abstraction for “associating” a key with a value.

```
std::map
   map<string, int> directory;   // name -> phone number

std::set
   set<string> dict;             // does it contain a word?
```

Iterators provide a guaranteed interface!

Four essential iterator operations:

- Create iterator
- Dereference iterator to read value currently pointed to
- Advance iterator
- Compare against another iterator (especially `.end()` iterator)

Iterators provide a guaranteed interface!

Four essential iterator operations:

Create iterator

```
std::set<int>::iterator iter = mySet.begin();
```

Dereference iterator to read value currently pointed to

Advance iterator

Compare against another iterator (especially `.end()` iterator)

Iterators provide a guaranteed interface!

Four essential iterator operations:

Create iterator

```
std::set<int>::iterator iter = mySet.begin();
```

Dereference iterator to read value currently pointed to

```
int val = *iter;
```

Advance iterator

Compare against another iterator (especially `.end()` iterator)

Iterators provide a guaranteed interface!

Four essential iterator operations:

Create iterator

```
std::set<int>::iterator iter = mySet.begin();
```

Dereference iterator to read value currently pointed to

```
int val = *iter;
```

Advance iterator

```
iter++; or ++iter;
```

Compare against another iterator (especially `.end()` iterator)

Iterators provide a guaranteed interface!

Four essential iterator operations:

Create iterator

```
std::set<int>::iterator iter = mySet.begin();
```

Dereference iterator to read value currently pointed to

```
int val = *iter;
```

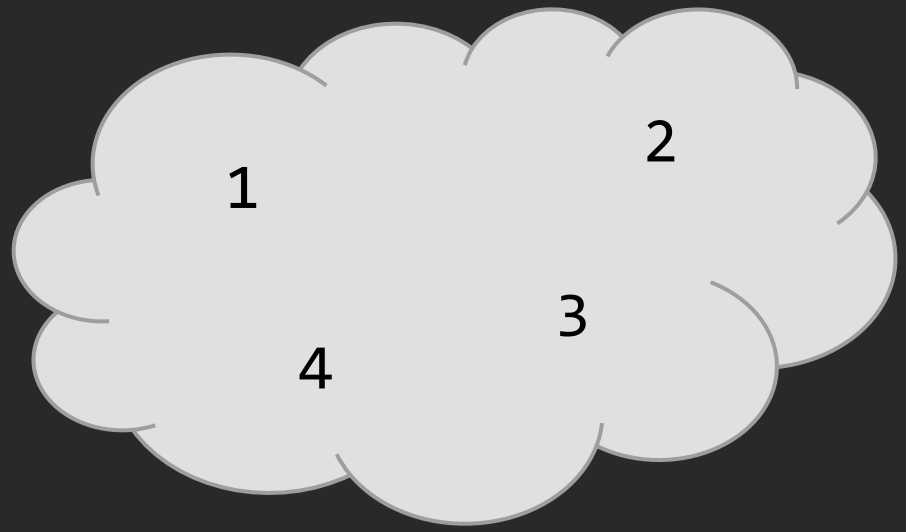
Advance iterator

```
iter++; or ++iter;
```

Compare against another iterator (especially `.end()` iterator)

```
if (iter == mySet.end()) return;
```

The Result

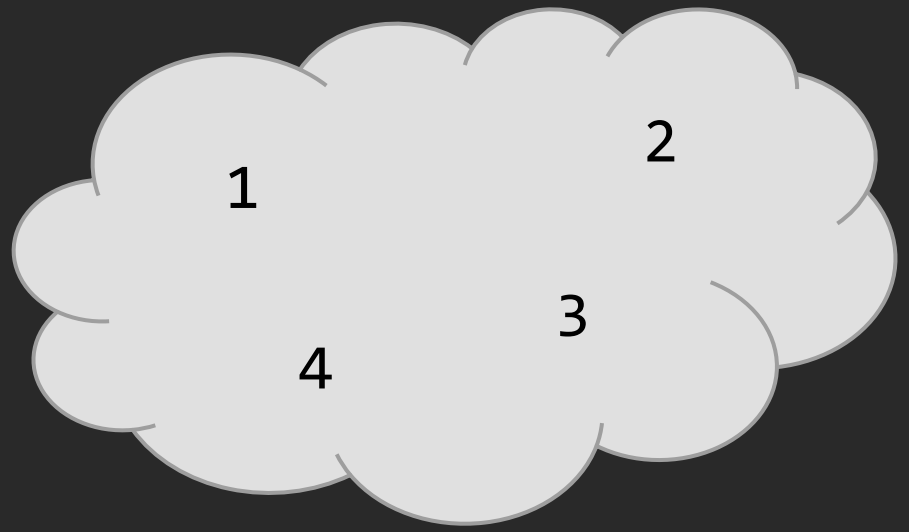


The Result

This could be a

`std::vector<Node> myVec`,

`std::set<int> mySet`, etc.

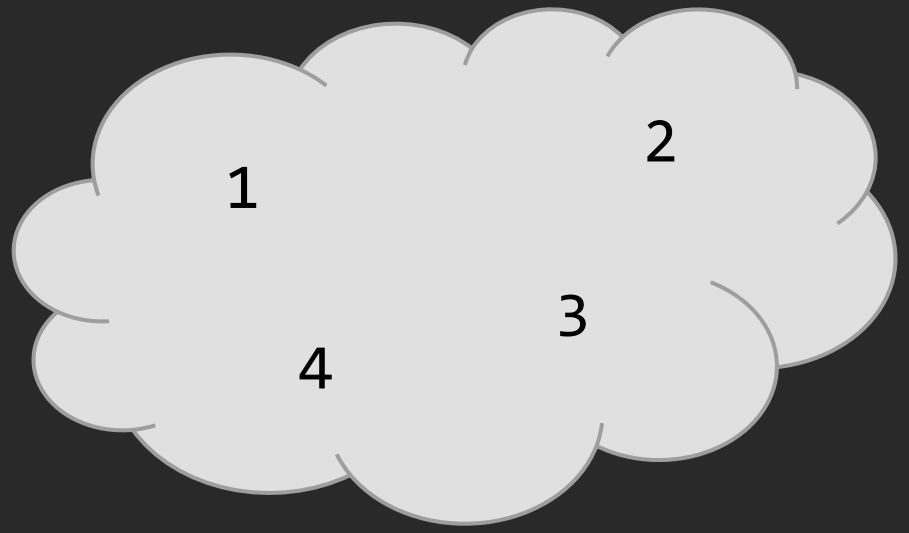


The Result

This could be a

`std::vector<Node> myVec`,

`std::set<int> mySet`, etc.



Iterators let us view a non-linear collection in a linear manner.

The Result

The Result

This means that we can use the exact same code to perform a logical action, *regardless of the data structure*!

The Result

This means that we can use the exact same code to perform a logical action, *regardless of the data structure*!

```
int numOccurrences(vector<int>& cont, int elemToCount) {
    int counter = 0;
    vector<int>::iterator iter;
    for(iter = cont.begin(); iter != cont.end(); ++iter) {
        if(*iter == elemToCount)
            ++counter;
    }
    return counter;
}
```

The Result

This means that we can use the exact same code to perform a logical action, *regardless of the data structure*!

```
int numOccurrences(list<int>& cont, int elemToCount) {
    int counter = 0;
    list<int>::iterator iter;
    for(iter = cont.begin(); iter != cont.end(); ++iter) {
        if(*iter == elemToCount)
            ++counter;
    }
    return counter;
}
```

The Result

This means that we can use the exact same code to perform a logical action, *regardless of the data structure*!

```
int numOccurrences(set<int>& cont, int elemToCount) {
    int counter = 0;
    set<int>::iterator iter;
    for(iter = cont.begin(); iter != cont.end(); ++iter) {
        if(*iter == elemToCount)
            ++counter;
    }
    return counter;
}
```

The Result

This means that we can use the exact same code to perform a logical action, *regardless of the data structure*!

```
int numOccurrences(???& cont, ??? elemToCount) {
    int counter = 0;
    ???::iterator iter;
    for(iter = cont.begin(); iter != cont.end(); ++iter) {
        if(*iter == elemToCount)
            ++counter;
    }
    return counter;
}
```

Map Iterators

Aside: The `std::pair` Class

A pair is simply two objects bundled together.

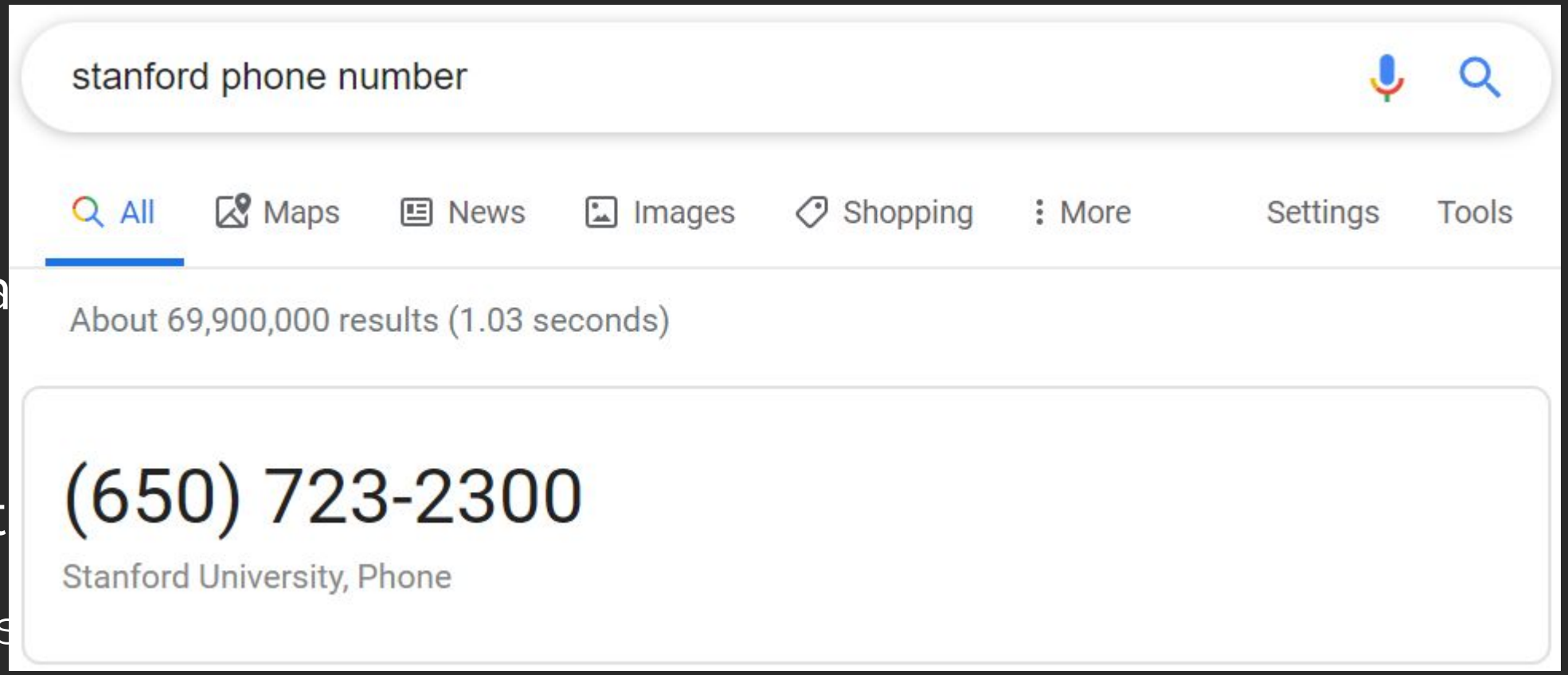
Syntax:

```
std::pair<string, int> p;
p.first = "Phone number";
p.second = 6507232300;
```

A pa

Synt

s




```
p.first = "Phone number";
p.second = 6507232300;
```

Aside: The `std::pair` Class

A pair is simply two objects bundled together.

Syntax:

```
std::pair<string, int> p;
p.first = "Phone number";
p.second = 6507232300;
```

Aside: The `std::pair` Class

Quicker ways to make a pair:

```
std::pair<string, int> p{"Phone number", 6507232300};
std::make_pair("Phone number", 6507232300);
```

What's the difference?

Aside: The `std::pair` Class

Quicker ways to make a pair:

```
std::pair<string, int> p{"Phone number", 6507232300};
std::make_pair("Phone number", 6507232300);
```

What's the difference?

`make_pair` automatically deduces the type!

This is a great place to use `auto`!

```
auto time = std::make_pair(1, 45);
```

Example: Multimaps

Recall: `std::multimap` is a map that permits multiple entries with the same key.

Doesn’t have `[]` operator!

Example: Multimaps

Recall: `std::multimap` is a map that permits multiple entries with the same key.

Doesn't have `[]` operator!

Instead, add elements by calling `.insert` on a key value `std::pair`.

```
std::multimap<int, int> myMMap;
myMMap.insert(make_pair(3, 3));
myMMap.insert({3, 12});  // shorter syntax
cout << myMMap.count(3) << endl; // prints 2
```

Map Iterators

Map iterators are slightly different because we have both keys and values.

Dereferencing a `set<string>` iterator gives you a `string`.

Dereferencing a `map<string, int>` iterator gives you an `std::pair<string, int>`.

Map Iterators

Example:

```
map<int, int> m;
map<int, int>::iterator i = m.begin();
map<int, int>::iterator end = m.end();
while(i != end) {
  cout << (*i).first << (*i).second << endl;
  ++i;
}
```

Map Iterators

Example:

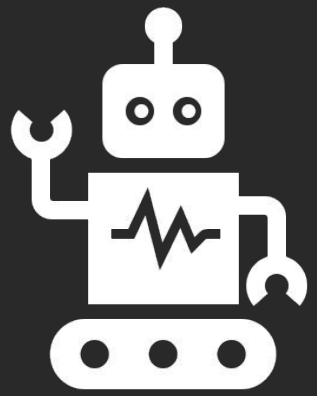
```
map<int, int> m;
map<int, int>::iterator i = m.begin();
map<int, int>::iterator end = m.end();
while(i != end) {
  cout << (*i).first << (*i).second << endl;
  ++i;
}
```

Further Iterator Usages

Iterator Uses

Iterators are useful for more than just looping through an entire container!

Let’s take a look...



Example

Iterator Uses

Iterator Uses - Sorting

For example, we sorted a vector using

```
std::sort(vec.begin(), vec.end());
```

Iterator Uses - Find

Finding elements

```
const int elemToFind = 5;
vector<int>::iterator it = std::find(vec.begin(),
                                     vec.end(), elemToFind);
if(it != vec.end()) {
   cout << "Found: " << *it << endl;
} else {
   cout << "Element not found!" << endl;
}
```

Aside: find vs. count

If you recall from last lecture, associative containers have a method called count(key)

- Equivalent of Stanford myMap.containskey(key):
  - `myMap.count(key)`
    - `if (myMap.count(key) == 0) cout << “Not Found”;`

Aside: find vs. count

If you recall from last lecture, associative containers have a method called count(key)

- Equivalent of Stanford myMap.containskey(key):
  - `myMap.count(key)`
    - `if (myMap.count(key) == 0) cout << "Not Found";`
  - `std::find(myMap.begin(), myMap.end(), key);`
    - `if (find(myMap.begin(), myMap.end(), key) == myMap.end())`
      `cout << "Not Found";`

Aside: find vs. count

If you recall from last lecture, associative containers have a method called count(key)

- Equivalent of Stanford myMap.containskey(key):
  - `myMap.count(key)`
  - `std::find(myMap.begin(), myMap.end(), key);`

Aside: find vs. count

If you recall from last lecture, associative containers have a method called count(key)

- Equivalent of Stanford myMap.containskey(key):
  - `myMap.count(key)`
  - `std::find(myMap.begin(), myMap.end(), key);`

- `count` is actually just a call to the `find` function! So `find` is marginally faster

Of course, C++20 will bring a new contains(key) method... but until then, use find.

Iterator Uses - Ranges

Finding elements

```
set<int>::iterator iter = mySet.lower_bound(7);
set<int>::iterator end = mySet.lower_bound(26);
while (iter != end) {
   cout << *i << endl;
   ++i;
}
```

Iterator Uses - Ranges

We can iterate through different ranges

	[a, b]	[a, b)	(a, b]	(a, b)
begin	lower_bound(a)	lower_bound(a)	upper_bound(a)	upper_bound(a)
end	upper_bound(b)	lower_bound(b)	upper_bound(b)	lower_bound(b)

Range Based for Loop

```
map<string, int> myMap;
for(auto thing : myMap) {
    doSomething(thing.first, thing.second);
}
```

Range Based `for` Loop

A range based `for` loop is (more or less) a shorthand for iterator code:

```
map<string, int> myMap;
for(auto thing : myMap) {
    doSomething(thing.first, thing.second);
}
```

```
map<string, int> myMap;
for(auto iter = myMap.begin(); iter != myMap.end(); ++iter) {
    auto thing = *iter;
    doSomething(thing.first, thing.second);
}
```

Range Based `for` Loop

A range based `for` loop is (more or less) a shorthand for iterator code:

6.5.4 The range-based `for` statement **[stmt.ranged]**

1 For a range-based `for` statement of the form

`for` (*for-range-declaration* : *expression*) *statement*

let *range-init* be equivalent to the *expression* surrounded by parentheses[86]

(*expression*)

and for a range-based `for` statement of the form

`for` (*for-range-declaration* : *braced-init-list*) *statement*

let *range-init* be equivalent to the *braced-init-list*. In each case, a range-based `for` statement is equivalent to

```
{
auto && __range = range-init;
for ( auto __begin = begin-expr,
           __end = end-expr;
      __begin != __end;
      ++__begin ) {
  for-range-declaration = *__begin;
  statement
```

Announcements

Announcements

- Office hours for Assignment 1 on Piazza!
- Feedback form #1 released! Fill out by next Thursday (1/30) for an extra late day.

https://bit.ly/2vfV4As

Quick Review of Structs

for Assignment 1!

General Struct Syntax

```
// Declaring the struct definition
struct Object {
   type var1;
   type var2;
}

// Initializing a struct object using uniform initialization
struct Object objName{value1, value2};
      // “struct” keyword is optional in C++

// Operating on the struct object - in this case, assigning a
value
objName.var1 = newvalue1;
```

General Struct Syntax

```
struct SimpleGraph {
   vector<Node> nodes;
   vector<Edge> edges;
}
```

```
struct Node {
   double x;
   double y;
}
```

General Struct Syntax

```
struct SimpleGraph {
   vector<Node> nodes;
   vector<Edge> edges;
}
```

```
struct Node {
   double x;
   double y;
}
```

```
struct SimpleGraph graph{};
// How would you add a Node to the graph?
```

General Struct Syntax

```
struct SimpleGraph {
   vector<Node> nodes;
   vector<Edge> edges;
}
```

```
struct Node {
   double x;
   double y;
}
```

```
struct SimpleGraph graph{};
// How would you add a Node to the graph?

graph.nodes.push_back( {someXValue, someYValue} );
     // automatically creates Node object + adds to vector
```

Iterator Types

Iterator Types

So far we have only really incremented iterators.

But for some containers, we should be able to do things like:

```
std::vector<int> v(10);
auto mid = v.begin() + v.size()/2;

std::deque<int> d(13);
auto some_iter = d.begin() + 3;
```

Iterator Types

So far we have only really incremented iterators.

But for some containers, we should be able to do things like:

```
std::vector<int> v(10);
auto mid = v.begin() + v.size()/2;
```

Seems right!

```
std::deque<int> d(13);
auto some_iter = d.begin() + 3;
```

Iterator Types

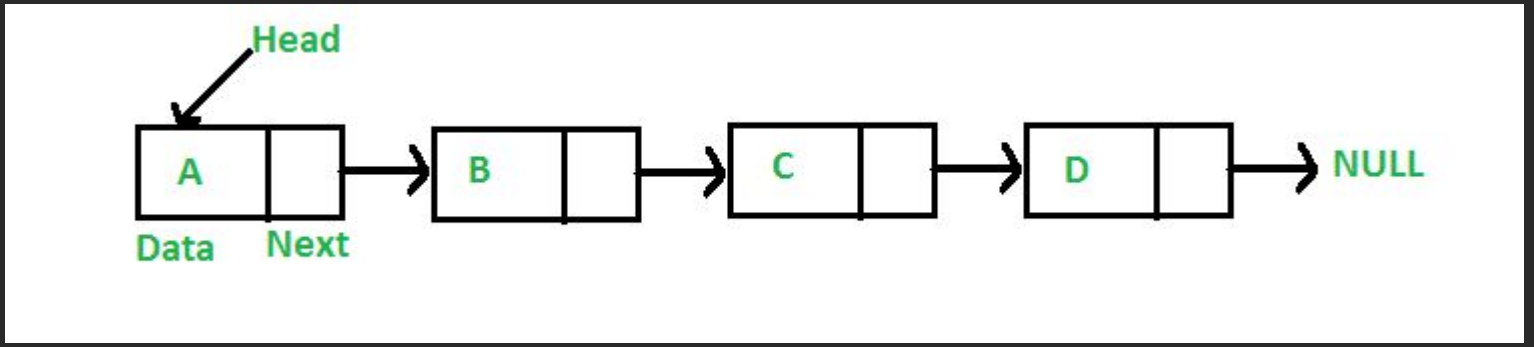
But what about `std::list` (doubly linked list)?

```
std::list<int> myList(10);
auto some_iter = myList.begin() + 3;
```

Iterator Types

But what about `std::list` (doubly linked list)?

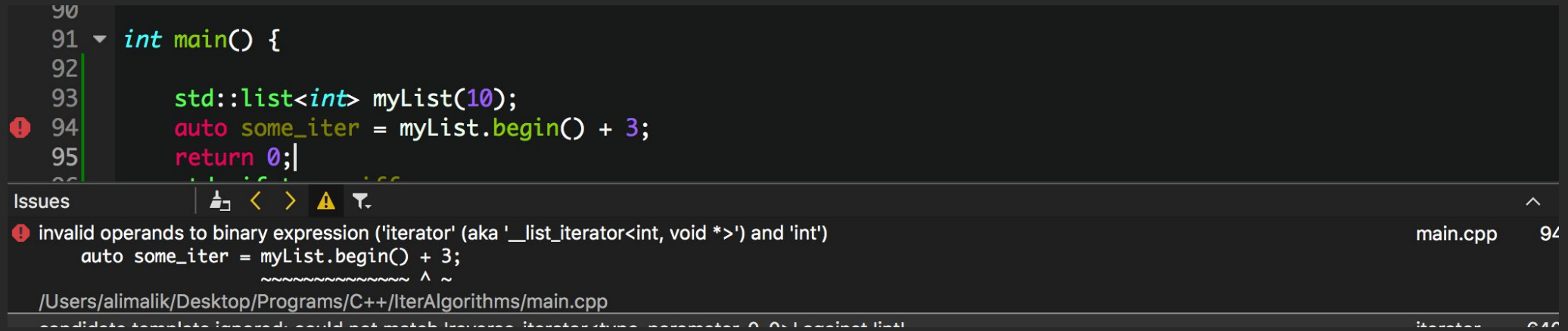
```
std::list<int> myList(10);
auto some_iter = myList.begin() + 3;
```



Iterator Types

But what about `std::list` (doubly linked list)?

```
std::list<int> myList(10);
auto some_iter = myList.begin() + 3;
```



Iterator Types

But what about `std::list` (doubly linked list)?

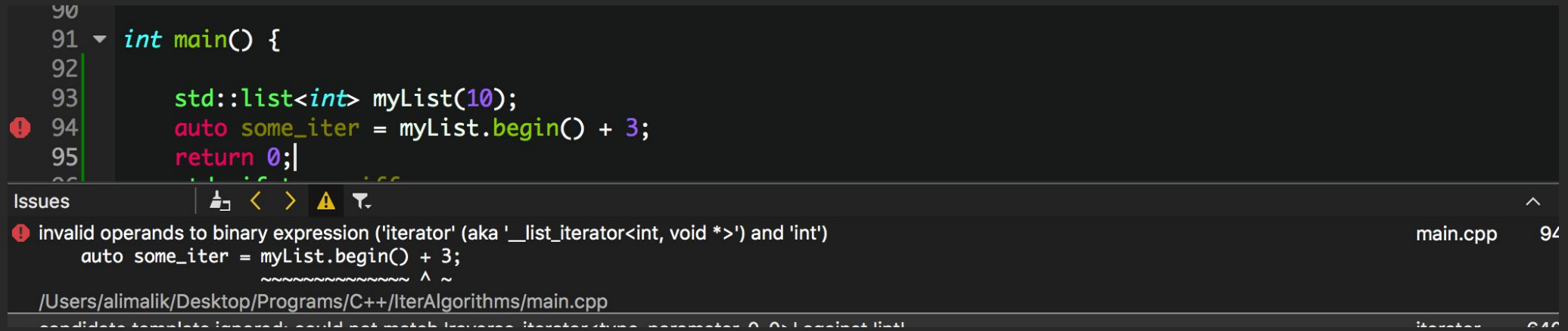
```
std::list<int> myList(10);
auto some_iter = myList.begin() + 3;
```

Iterator Types

But what about `std::list` (doubly linked list)?

```
std::list<int> myList(10);
auto some_iter = myList.begin() + 3;
```

What's going on here?



Iterator Types

There are 5 different types of iterators!

1. Input
2. Output
3. Forward
4. Bidirectional
5. Random access

Iterator Types

There are 5 different types of iterators!

1. Input
2. Output
3. Forward
4. Bidirectional
5. Random access

Iterator Types - Similarities

All iterators share a few common traits:

- Can be created from existing iterator
- Can be advanced using ++
- Can be compared with == and !=

Input Iterators

For sequential, single-pass input.

Read only i.e. can only be dereferenced on right side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
```

Input Iterators

For sequential, single-pass input.

Read only i.e. can only be dereferenced on right side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
```

We've seen these already!

```
template< class InputIt, class T >
InputIt find( InputIt first, InputIt last, const T& value );
```

```
template< class InputIt, class T >
typename iterator_traits<InputIt>::difference_type
    count( InputIt first, InputIt last, const T &value );
```

Input Iterators

For sequential, single-pass input.

Read only i.e. can only be dereferenced on right side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
```

We've seen these already!

```
template< class InputIt, class T >
InputIt find( InputIt first, InputIt last, const T& value );
```

```
template< class InputIt, class T >
typename iterator_traits<InputIt>::difference_type
    count( InputIt first, InputIt last, const T &value );
```

Use cases:

- `find` and `count`
- input streams

Input Iterators

For sequential, single-pass input.

Read only i.e. can only be dereferenced on right side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
```

Output Iterators

For sequential, single-pass output.

Write only i.e. can only be dereferenced on left side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
*itr = 12;
```

Output Iterators

For sequential, single-pass output.

Write only i.e. can only be dereferenced on left side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
*itr = 12;
```

Use cases:

- copy:

```
template< class InputIt, class OutputIt >
OutputIt copy( InputIt first, InputIt last, OutputIt d_first );
```

- output streams

Output Iterators

For sequential, single-pass output.

Write only i.e. can only be dereferenced on left side of expression.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
*itr = 12;
```

Forward Iterators

Combines input and output iterators, + can make multiple passes.

Can read from and write to (if not const iterator).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
*itr = 12;
```

Forward Iterators

Combines input and output iterators, + can make multiple passes.

Can read from and write to (if not const iterator).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
*itr = 12;
```

Use cases:

- replace:

```
template< class ForwardIt, class T >
void replace( ForwardIt first, ForwardIt last,
              const T& old_value, const T& new_value );
```

- std::forward_list (sequence container, think of as singly-linked list)

Forward Iterators

Combines input and output iterators, + can make multiple passes.

Can read from and write to (if not const iterator).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
*itr = 12;
```

Bidirectional Iterators

Same as forward iterators, + can go backwards with the decrement operator (`--`).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
++itr;
int val = *itr;
--itr;
int val2 = *itr;
```

Bidirectional Iterators

Same as forward iterators, + can go backwards with the decrement operator (`--`).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
++itr;
int val = *itr;
--itr;
int val2 = *itr;
```

Use cases:

- reverse:

```
template< class BidirIt >
void reverse( BidirIt first, BidirIt last );
```

- std::map, std::set
- std::list (sequence container, think of as doubly-linked list)

Bidirectional Iterators

Same as forward iterators, + can go backwards with the decrement operator (`--`).

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
++itr;
int val = *itr;
--itr;
int val2 = *itr;
```

Random Access Iterators

Same as bidirectional iterators, + can be incremented or decremented by arbitrary amounts using + and −.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
itr = itr + 3;
int val2 = *itr;
```

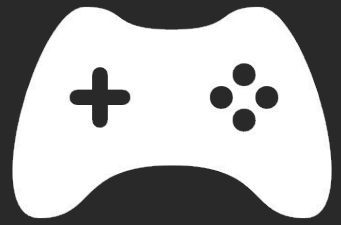
Random Access Iterators

Same as bidirectional iterators, + can be incremented or decremented by arbitrary amounts using + and −.

```
vector<int> v = ...
vector<int>::iterator itr = v.begin();
int val = *itr;
itr = itr + 3;
int val2 = *itr;
```

Use cases:

- std::vector, std::deque, std::string
- Pointers!



Next time

Templates!