



 <http://web.stanford.edu/class/cs106l/>



Iterators and Pointers

How do we access elements in a container in order?
How do we reference existing data in our code?

CS106L - Spring 23

Attendance!

<https://bit.ly/3KTIFX0>



[https://www.facebook.com/groups/
StanfordMememes/posts/204302852
9057167/](https://www.facebook.com/groups/StanfordMememes/posts/2043028529057167/)



Agenda



01. Recap: Containers

02. Iterators

How to access container elements

03. Pointers

Accessing objects by address

04. Iterators + Pointers demo





Agenda



01. Recap: Containers

02. Iterators

How to access container elements

03. Pointers

Accessing objects by address

04. Iterators + Pointers demo



Containers

- Containers are ways to collect related data together and work with it logically
- Two types of containers: **sequence** and **associative**
- Container adaptors wrap existing containers to permit new/restrict access to the interface for the clients.

There are two types of containers:

Sequence:

- Containers that can be accessed sequentially
- Anything with an inherent order goes here!

Associative

- Containers that don't necessarily have a sequential order
- More easily searched
- Maps and sets go here!



Sequence Containers: Summary

- Sequence containers are for when you need to enforce some order on your information!
- Can usually use an **std::vector** for most anything
- If you need particularly fast inserts in the front, consider an **std::deque**
- For joining/working with multiple lists, consider an **std::list** (very rarely)

Choosing associative containers

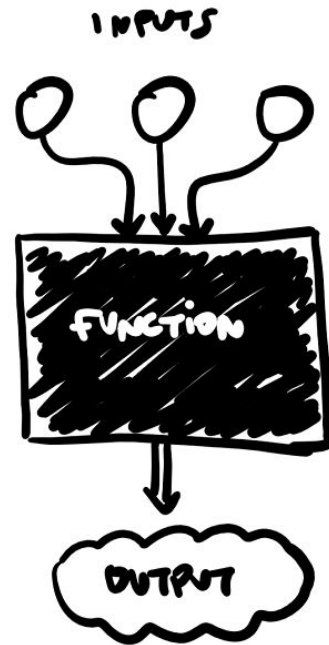
Lots of similarities between maps/sets! Broad tips:

- Unordered containers are **faster**, but can be difficult to get to work with nested containers/collections
- If using **complicated data types**/unfamiliar with hash functions, use an ordered container

Container Adaptors

Container adaptors are “wrappers” to existing containers!

- Wrappers **modify the interface** to sequence containers and change what the client is allowed to do/how they can interact with the container.



The STL

```
template <class T, class Container = deque<T> > class queue;
```

queues are implemented as **containers adaptors**, which are classes that use an encapsulated object of a specific container class as its **underlying container**, providing a specific set of member functions to access its elements. Elements are **pushed** into the **"back"** of the specific container and **popped** from its **"front"**.

The underlying container may be one of the standard container class template or some other specifically designed container class. This underlying container shall support at least the following operations:

empty

size

front

back

push_back

pop_front



Agenda



01. Recap: Containers

02. Iterators

How to access container elements

03. Pointers

Accessing objects by address

04. Iterators + Pointers demo





All containers are collections of objects...

So how do we access those objects?

- What if we want to print out everything in a vector?
- Or loop until we find a certain object in a set?



All containers are collections of objects...

So how do we access those objects?

- What if we want to print out everything in a vector?
- Or loop until we find a certain object in a set?

How is this done in the STL?



All containers are collections of objects...

We'd like to have a for-loop, probably!

What would that look like?



All containers are collections of objects...

We'd like to have a for-loop, probably!

What would that look like?

```
for (initialization; termination condition; increment) {
```


All containers are collections of objects...

We'd like to have a for-loop, probably!

What would that look like?

```
for (initialization; termination condition; increment) {
```



Where do we
start?

All containers are collections of objects...

We'd like to have a for-loop, probably!

What would that look like?

```
for (initialization; termination condition; increment) {
```



Where do we
start?



When do we
end?

All containers are collections of objects...

We'd like to have a for-loop, probably!

What would that look like?

```
for (initialization; termination condition; increment) {
```



Where do we
start?



When do we
end?



something...++???

Guess we're done!

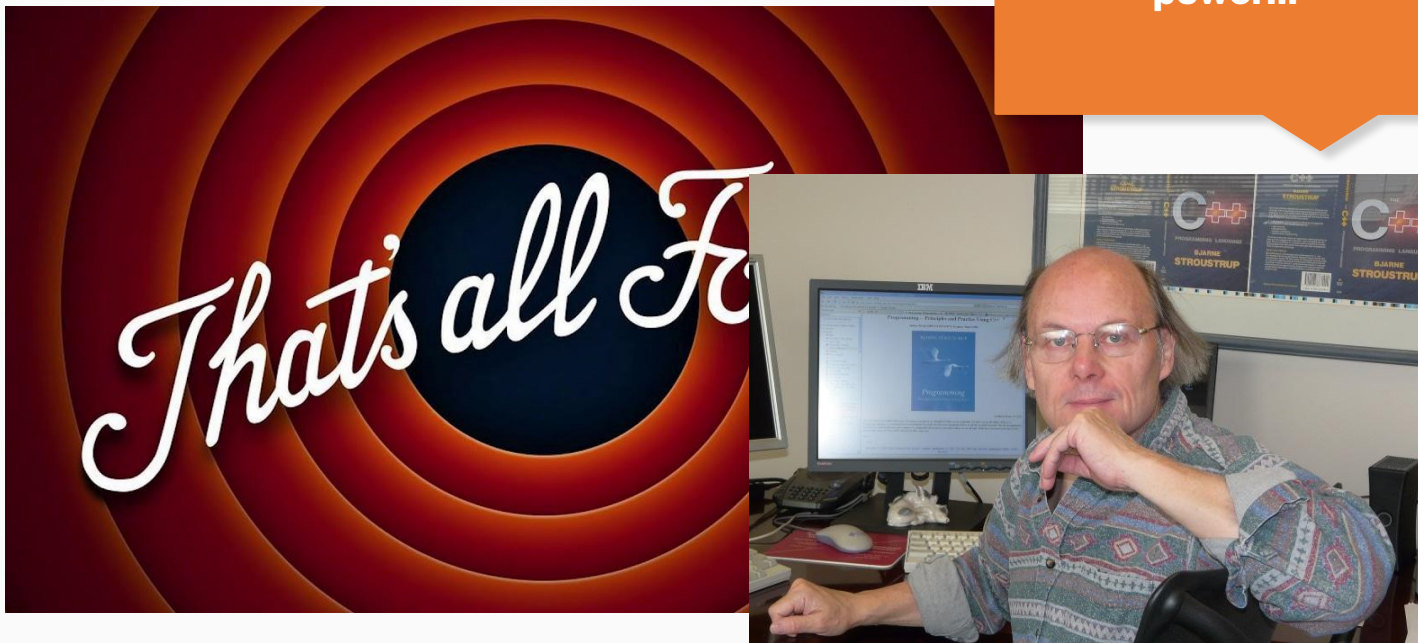


Guess we're done!



Guess we're done!

You underestimate my
power...





Introducing Iterators!

Containers all implement something called an iterator to do this!



Introducing Iterators!

Containers all implement something called an iterator to do this!

- Iterators let you access **all** data in containers programmatically!

Introducing Iterators!

Containers all implement something called an iterator to do this!

- Iterators let you access **all** data in containers programmatically!
- An iterator has a certain **order**; it “knows” what element will come next
 - Not necessarily the same each time you iterate!

Think of your container as a file cabinet!



Think of your container as a file cabinet!

An iterator lets you go through the files one at a time!



Think of your container as a file cabinet!

An iterator lets you go through the files one at a time!

- You can see where the front and back of your drawer are.



Think of your container as a file cabinet!

An iterator lets you go through the files one at a time!

- You can see where the front and back of your drawer are.
- You can move your finger from one to the next, because you kept your place.



Think of your container as a file cabinet!

An iterator lets you go through the files one at a time!

- You can see where the front and back of your drawer are.
- You can move your finger from one to the next, because you kept your place.
- You can take out any file you've your hand on, and read/write whatever you'd like in it.



Think of your container as a file cabinet!

An iterator lets you go through the files one at a time!

- You can see where the front and back of your drawer are.
- You can move your finger from one to the next, because you kept your place.
- You can take out any file you've your hand on, and read/write whatever you'd like in it.
- You can compare the relative location of any two files just by looking at where they are in the cabinet.





In the STL

All containers implement iterators, but they're not all the same!



In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`

begin() and **end()**
return iterators!

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing → `iter = s.begin();`
 - Incrementing

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`
 - Incrementing \longrightarrow `++iter;`

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`
 - Incrementing \longrightarrow `++iter;`
 - Dereferencing


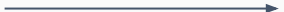

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`
 - Incrementing \longrightarrow `++iter;`
 - Dereferencing \longrightarrow `*iter;`

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing  `iter = s.begin();`
 - Incrementing  `++iter;`
 - Dereferencing  `*iter;`
 - Comparing





In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`
 - Incrementing \longrightarrow `++iter;`
 - Dereferencing \longrightarrow `*iter;`
 - Comparing \longrightarrow `iter != s.end();`

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing  `iter = s.begin();`
 - Incrementing  `++iter;`
 - Dereferencing  `*iter;`
 - Comparing  `iter != s.end();`
 - Copying

In the STL

All containers implement iterators, but they're not all the same!

- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing \longrightarrow `iter = s.begin();`
 - Incrementing \longrightarrow `++iter;`
 - Dereferencing \longrightarrow `*iter;`
 - Comparing \longrightarrow `iter != s.end();`
 - Copying \longrightarrow `new_iter = iter;`

In the STL

All containers implement iterators, but they're not all the same!

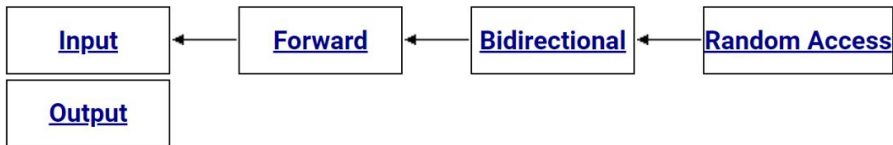
- Each container has its own iterator, which can have different behavior.
- All iterators implement a few shared operations:
 - Initializing → `iter = s.begin();`
 - Incrementing → `++iter;`
 - Dereferencing → `*iter;`
 - Comparing → `iter != s.end();`
 - Copying → `new_iter = iter;`

What other behaviors can iterators have?

That depends!

Let's check out the docs:

Iterators are classified into five categories depending on the functionality they implement:



[Input](#) and [output](#) iterators are the most limited types of iterators: they can perform sequential single-pass input or output operations.

[Forward iterators](#) have all the functionality of [input iterators](#) and -if they are not **constant iterators**- also the functionality of [output iterators](#), although they are limited to one direction in which to iterate through a range (forward). All [standard containers](#) support at least forward iterator types.

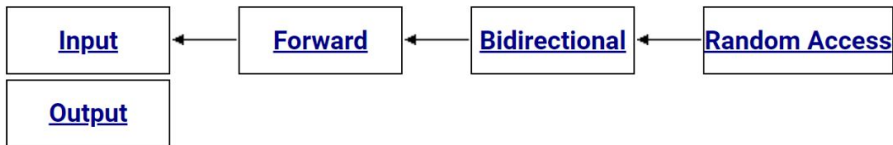
[Bidirectional iterators](#) are like [forward iterators](#) but can also be iterated through backwards.

[Random-access iterators](#) implement all the functionality of [bidirectional iterators](#), and also have the ability to access ranges non-sequentially: distant elements can be accessed directly by applying an offset value to an iterator without iterating through all the elements in between. These iterators have a similar functionality to standard pointers (pointers are iterators of this category).

That depends!

Let's check out the docs:

Iterators are classified into five categories depending on the functionality they implement:



Input and output iterators are the most limited types of iterators: they can perform sequential single-pass input or output operations.

Forward iterators have all the functionality of input iterators and -if they are not **constant iterators**- also the functionality of output iterators, although they are limited to one direction in which to iterate through a range (forward). All standard containers support at least forward iterator types.

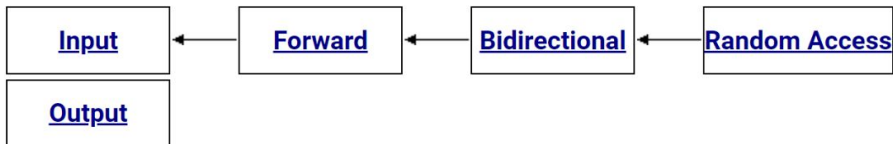
Bidirectional iterators are like forward iterators but can also be iterated through backwards.

Random-access iterators implement all the functionality of bidirectional iterators, and also have the ability to access ranges non-sequentially: distant elements can be accessed directly by applying an offset value to an iterator without iterating through all the elements in between. These iterators have a similar functionality to standard pointers (pointers are iterators of this category).

That depends!

Let's check out the docs:

Iterators are classified into five categories depending on the functionality they implement:



[Input](#) and [output](#) iterators are the most limited types of iterators: they can perform sequential single-pass input or output operations.

[Forward iterators](#) have all the functionality of [input iterators](#) and -if they are not **constant iterators**- also the functionality of [output iterators](#), although they are limited to one direction in which to iterate through a range (forward). All [standard containers](#) support at least forward iterator types.

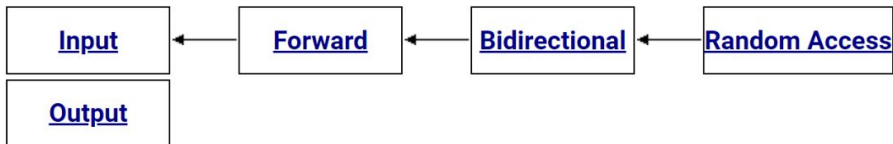
[Bidirectional iterators](#) are like [forward iterators](#) but can also be iterated through backwards.

[Random-access iterators](#) implement all the functionality of [bidirectional iterators](#), and also have the ability to access ranges non-sequentially: distant elements can be accessed directly by applying an offset value to an iterator without iterating through all the elements in between. These iterators have a similar functionality to standard pointers (pointers are iterators of this category).

That depends!

Let's check out the docs:

Iterators are classified into five categories depending on the functionality they implement:



[Input](#) and [output](#) iterators are the most limited types of iterators: they can perform sequential single-pass input or output operations.

[Forward iterators](#) have all the functionality of [input iterators](#) and -if they are not **constant iterators**- also the functionality of [output iterators](#), although they are limited to one direction in which to iterate through a range (forward). All [standard containers](#) support at least forward iterator types.

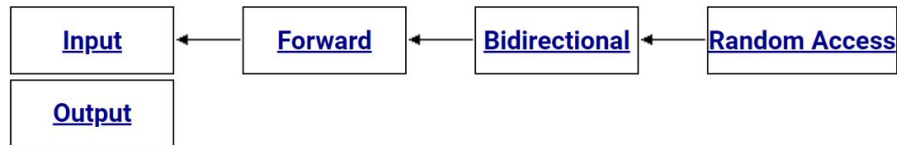
[Bidirectional iterators](#) are like [forward iterators](#) but can also be iterated through backwards.

[Random-access iterators](#) implement all the functionality of [bidirectional iterators](#), and also have the ability to access ranges non-sequentially: distant elements can be accessed directly by applying an offset value to an iterator without iterating through all the elements in between. These iterators have a similar functionality to standard pointers (pointers are iterators of this category).

That depends!

Let's check out the docs:

Iterators are classified into five categories depending on the functionality they implement:



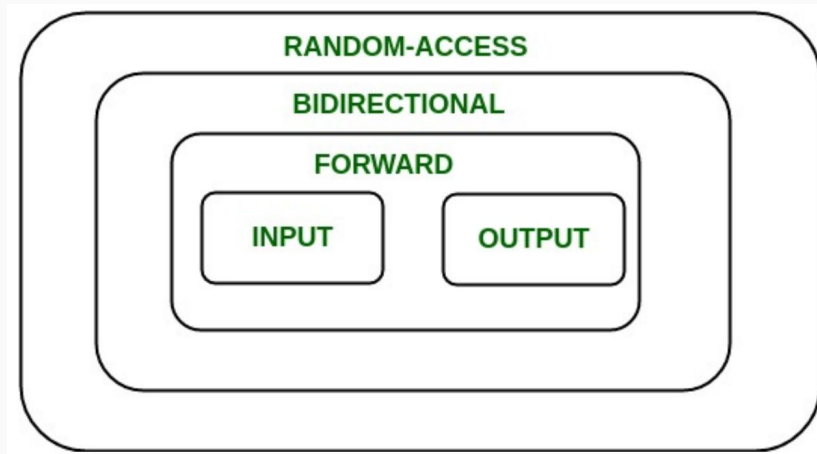
[Input](#) and [output](#) iterators are the most limited types of iterators: they can perform sequential single-pass input or output operations.

[Forward iterators](#) have all the functionality of [input iterators](#) and -if they are not **constant iterators**- also the functionality of [output iterators](#), although they are limited to one direction in which to iterate through a range (forward). All [standard containers](#) support at least forward iterator types.

[Bidirectional iterators](#) are like [forward iterators](#) but can also be iterated through backwards.

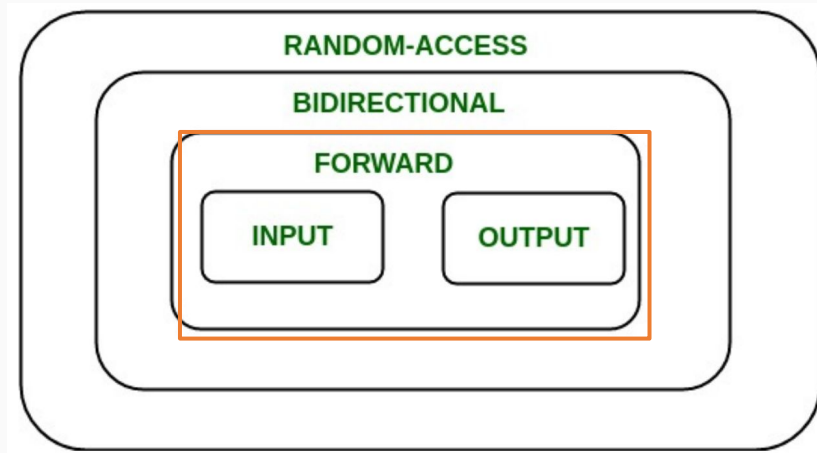
[Random-access iterators](#) implement all the functionality of [bidirectional iterators](#), and also have the ability to access ranges non-sequentially: distant elements can be accessed directly by applying an offset value to an iterator without iterating through all the elements in between. These iterators have a similar functionality to standard pointers (pointers are iterators of this category).

What does that mean?



What does that mean?

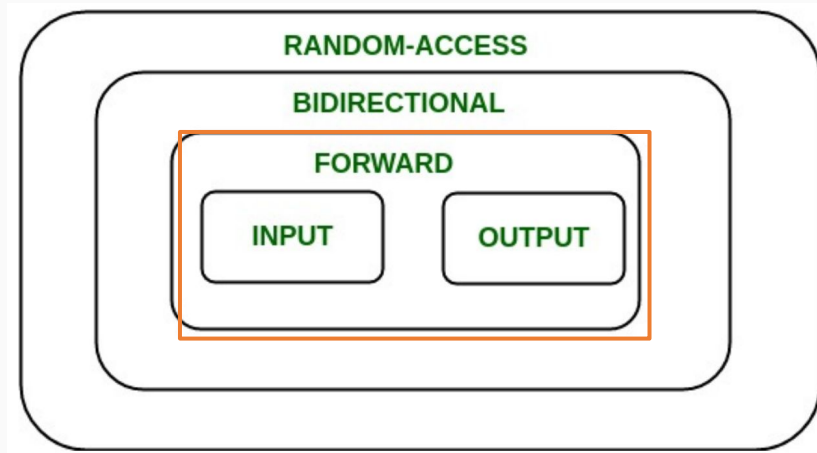
Forward iterators are the minimum level of functionality for standard containers.



What does that mean?

Forward iterators are the minimum level of functionality for standard containers.

- **Input** iterators can appear on the RHS (right hand side) of an = operator

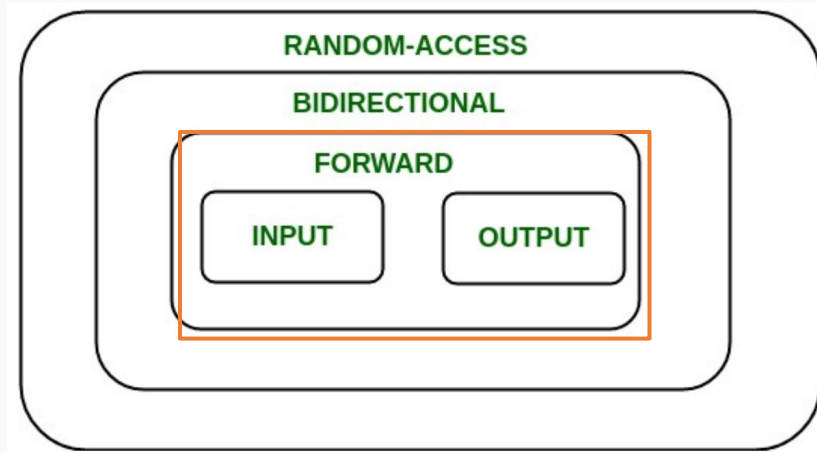


What does that mean?

Forward iterators are the minimum level of functionality for standard containers.

- **Input** iterators can appear on the RHS (right hand side) of an = operator

```
auto elem = *it;
```



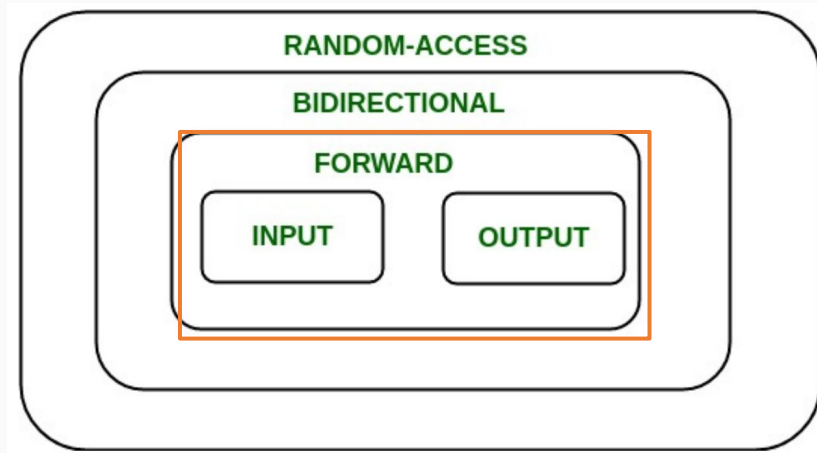
What does that mean?

Forward iterators are the minimum level of functionality for standard containers.

- **Input** iterators can appear on the RHS (right hand side) of an = operator

```
auto elem = *it;
```

- **Output** iterators can appear on the LHS (left hand side) of an = operator



What does that mean?

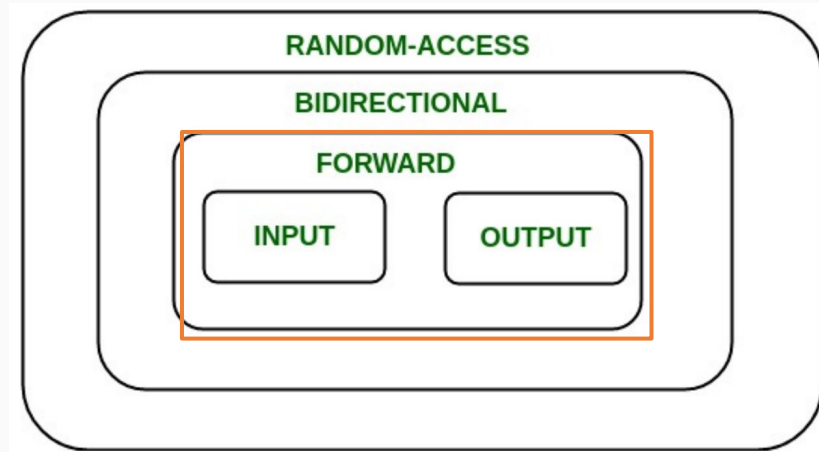
Forward iterators are the minimum level of functionality for standard containers.

- **Input** iterators can appear on the RHS (right hand side) of an = operator

```
auto elem = *it;
```

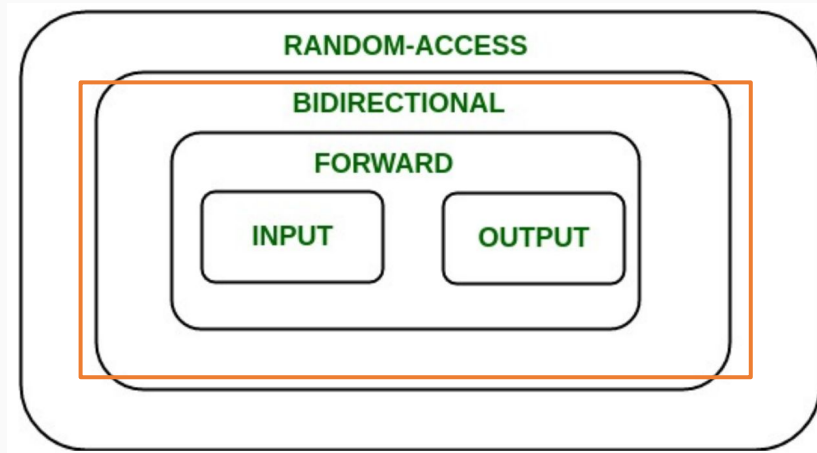
- **Output** iterators can appear on the LHS (left hand side) of an = operator

```
*elem = value;
```



What does that mean?

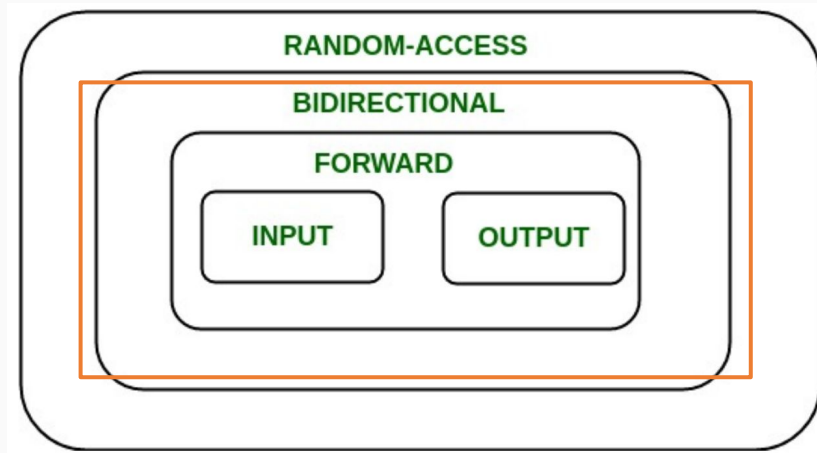
Bidirectional iterators can go forward as well as backward!



What does that mean?

Bidirectional iterators can go forward as well as backward!

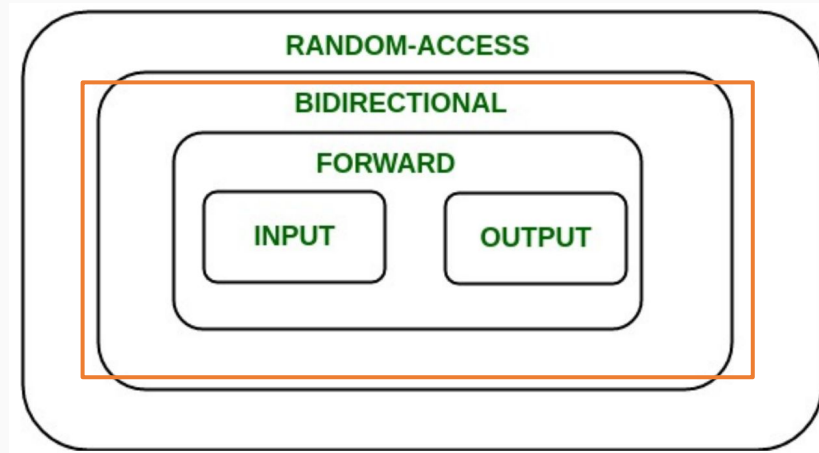
- `--iter;`



What does that mean?

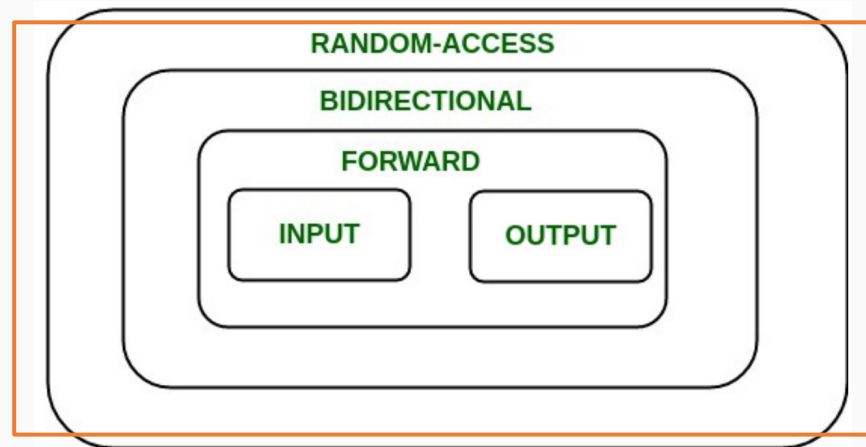
Bidirectional iterators can go forward as well as backward!

- **--iter;**
- Still has the same functionality of forward iterators!



What does that mean?

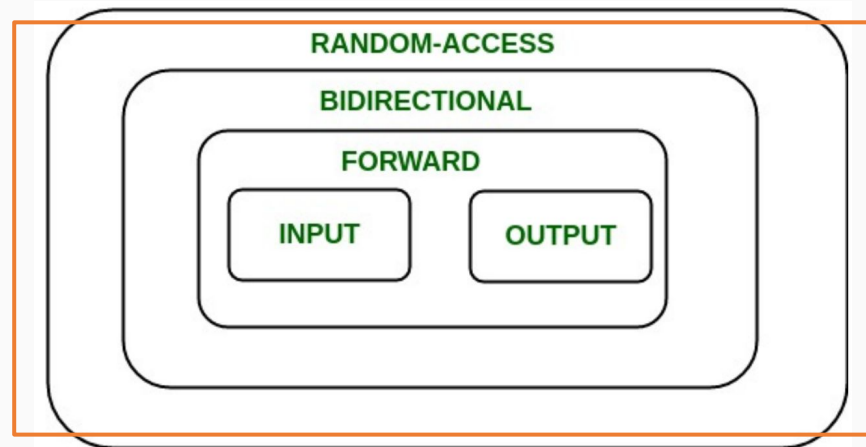
Random-access iterators allow you to directly access values without visiting all elements sequentially.



What does that mean?

Random-access iterators allow you to directly access values without visiting all elements sequentially.

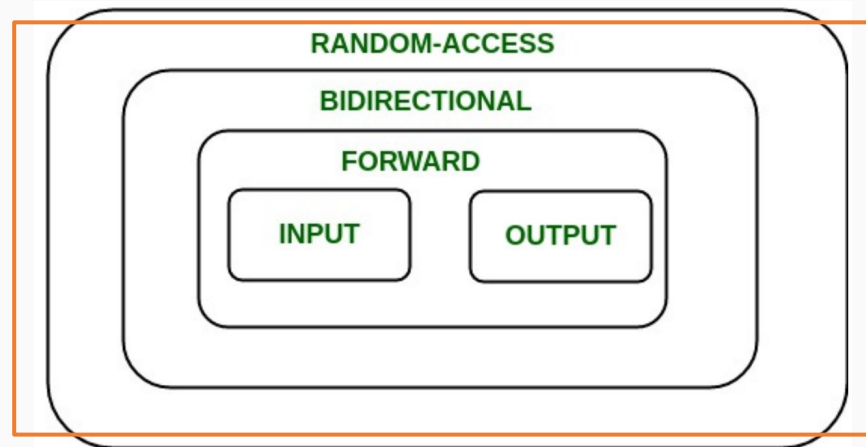
- `iter += 5;`



What does that mean?

Random-access iterators allow you to directly access values without visiting all elements sequentially.

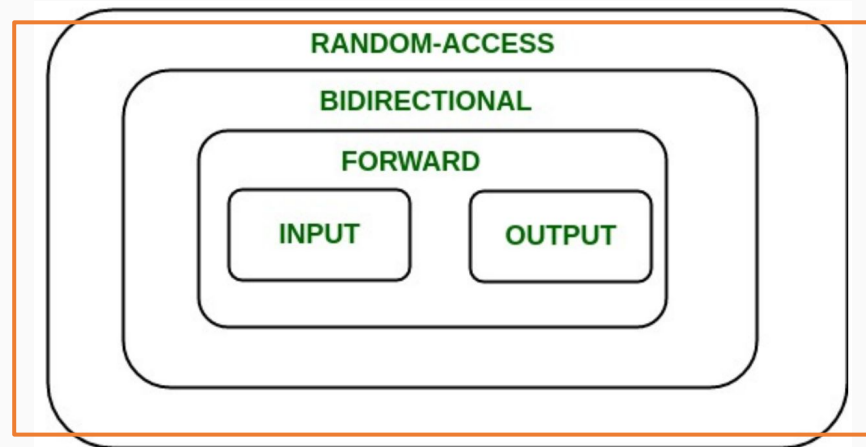
- **iter += 5;**
- Think of vectors; `vec[1]` or `vec[17]` or...



What does that mean?

Random-access iterators allow you to directly access values without visiting all elements sequentially.

- **iter += 5;**
- Think of vectors; `vec[1]` or `vec[17]` or...
- Be careful not to go out of bounds!

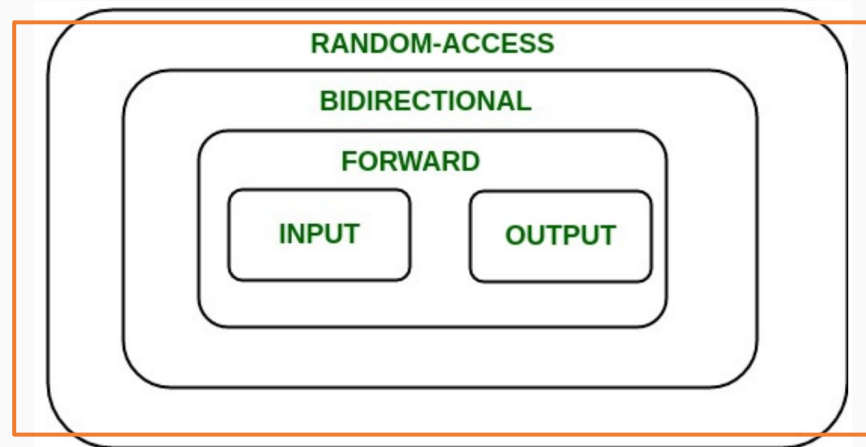


What does that mean?

Random-access iterators allow you to directly access values without visiting all elements sequentially.

- `iter += 5;`
- Think of vectors; `vec[1]` or `vec[17]` or...
- Be careful not to go out of bounds!

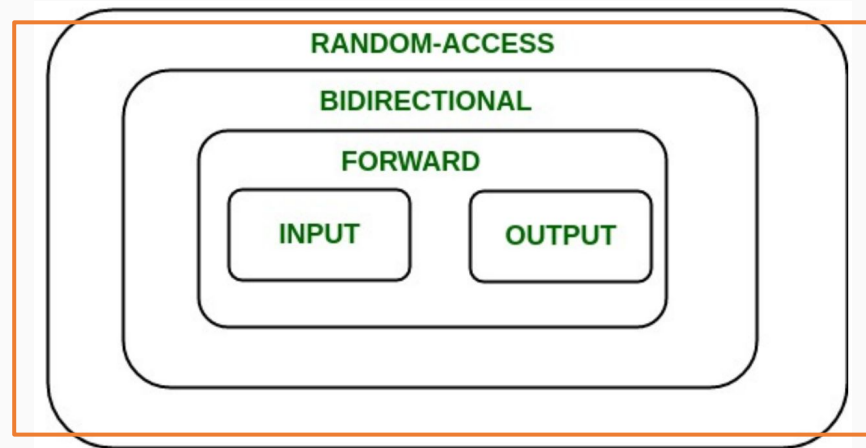
0	1	2	3	4	5	6
---	---	---	---	---	---	---



What does that mean?

Random-access iterators allow you to directly access values without visiting all elements sequentially.

- **iter += 5;**
- Think of vectors; `vec[1]` or `vec[17]` or...
- Be careful not to go out of bounds!



iter += 3; ?

Categorizing STL iterators

Vectors and deques have the most powerful iterators!

Container	Type of Iterator
Vector	Random-Access
Deque	Random-Access
List	Bidirectional
Map	Bidirectional
Set	Bidirectional
Stack	No Iterator
Queue	No Iterator
Priority Queue	No Iterator

Categorizing STL iterators

Vectors and deques have the most powerful iterators!

- Creating your own containers means creating their iterators as well.

Container	Type of Iterator
Vector	Random-Access
Deque	Random-Access
List	Bidirectional
Map	Bidirectional
Set	Bidirectional
Stack	No Iterator
Queue	No Iterator
Priority Queue	No Iterator

Categorizing STL iterators

Vectors and deques have the most powerful iterators!

- Creating your own containers means creating their iterators as well.
- You can access elements in stacks and queues one-by-one, but you have to change the container to do so!

Container	Type of Iterator
Vector	Random-Access
Deque	Random-Access
List	Bidirectional
Map	Bidirectional
Set	Bidirectional
Stack	No Iterator
Queue	No Iterator
Priority Queue	No Iterator

Categorizing STL iterators

Vectors and deques have the most powerful iterators!

- Creating your own containers means creating their iterators as well.
- You can access elements in stacks and queues one-by-one, but you have to change the container to do so!
- Iteration with iterators is **const**

Container	Type of Iterator
Vector	Random-Access
Deque	Random-Access
List	Bidirectional
Map	Bidirectional
Set	Bidirectional
Stack	No Iterator
Queue	No Iterator
Priority Queue	No Iterator



Why `++iter;` ?

Why not `iter++;` ? There's a difference in when the value is returned!

Why `++iter` ?

Why not `iter++` ? There's a difference in when the value is returned!

- `iter++` returns the value **before** being incremented.
- `++iter` returns the value **after** being incremented.



Why `++iter` ?

Why not `iter++` ? There's a difference in when the value is returned!

- `iter++` returns the value **before** being incremented.
- `++iter` returns the value **after** being incremented.

Using an iterator, we already have the previous value! It's slightly more inefficient to use `iter++`;

Why `++iter` ?

Why not `iter++` ? There's a difference in when the value is returned!

- `iter++` returns the value **before** being incremented.
- `++iter` returns the value **after** being incremented.

Using an iterator, we already have the previous value! It's slightly more inefficient to use `iter++`;

**This is now outdated!
`iter++` to your heart's content!**



Let's check out that for loop again!

```
for (initialization; termination condition; increment) {
```



Let's check out that for loop again!

```
for ( auto iter=set.begin() ; iter != set.end(); ++iter ) {
```

Let's check out that for loop again!

```
for ( auto iter=set.begin() ; iter != set.end(); ++iter ) {
```

Now we can access each element individually!

If we want the element and not just a reference to it, we dereference (*iter).

Let's check out that for loop again!

```
for ( auto iter=set.begin() ; iter != set.end(); ++iter ) {
```

Now we can access each element individually!

If we want the element and not just a reference to it, we dereference (*iter).

```
const auto& elem = *iter;
```



Let's check out that for loop again!

If we have a map, we can use structured binding to be more efficient while dereferencing!

Let's check out that for loop again!

If we have a map, we can use structured binding to be more efficient while dereferencing!

```
std::map<int, int> map{{1, 6}, {2, 8}, {0, 3}, {3, 9}};  
for(auto iter = map.begin(); iter != map.end(); iter++) {  
    const auto& [key, value] = *iter;    // structured binding!  
}
```


Let's check out that for loop again!

If we have a map, we can use structured binding to be more efficient while dereferencing!

```
std::map<int, int> map{{1, 6}, {2, 8}, {0, 3}, {3, 9}};  
for(auto iter = map.begin(); iter != map.end(); iter++) {  
    const auto& [key, value] = *iter;    // structured binding!  
}
```

This is a C++ **for-each loop**!



Agenda



01. Recap: Containers

02. Iterators

How to access container elements

03. Pointers

Accessing objects by address

04. Iterators + Pointers demo





Introducing Pointers!

Iterators are a particular type of pointer!



Introducing Pointers!

Iterators are a particular type of pointer!

- Iterators “point” at particular elements in a **container**.

Introducing Pointers!

Iterators are a particular type of pointer!

- Iterators “point” at particular elements in a **container**.
- Pointers can “point” at **any objects** in your code!



Memory and You

Variables created in your code take up space on your computer.



Memory and You

Variables created in your code take up space on your computer.

They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!



Memory and You

Variables created in your code take up space on your computer.

```
int val = 18;
```

They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!

Memory and You

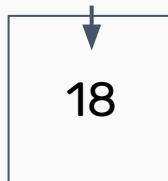
Variables created in your code take up space on your computer.

They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!

```
int val = 18;
```

int val



Memory and You

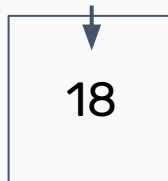
Variables created in your code take up space on your computer.

They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!

```
int val = 18;
```

int val



#0106

Memory and You

Variables created in your code take up space on your computer.

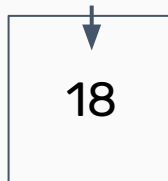
They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!

```
int val = 18;
```

```
int* ptr = &val;
```

int val



#0106

Memory and You

Variables created in your code take up space on your computer.

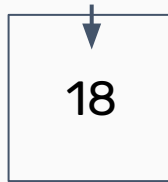
They live in memory at specific addresses.

Pointers reference those memory addresses and not the object themselves!

```
int val = 18;
```

```
int* ptr = &val;
```

int val



#0106

int* ptr





Dereferencing

Pointers are marked by the asterisk (*) next to the type of the object they're pointing at when they're declared.



Dereferencing

Pointers are marked by the asterisk (*) next to the type of the object they're pointing at when they're declared.

The address of a variable can be accessed by using & before its name, same as when passing by reference!



Dereferencing

Pointers are marked by the asterisk (*) next to the type of the object they're pointing at when they're declared.

The address of a variable can be accessed by using & before its name, same as when passing by reference!

If you want to access the data stored at a pointer's address, dereference it using an asterisk again.

Dereferencing

Pointers are marked by the asterisk (*) next to the type of the object they're pointing at when they're declared.

The address of a variable can be accessed by using & before its name, same as when passing by reference!

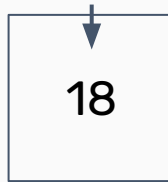
If you want to access the data stored at a pointer's address, dereference it using an asterisk again.

```
std::cout >> *ptr >> std::endl;
```

```
int val = 18;
```

```
int* ptr = &val;
```

int val



#0106

int* ptr



Dereferencing

Pointers are marked by the asterisk (*) next to the type of the object they're pointing at when they're declared.

The address of a variable can be accessed by using & before its name, same as when passing by reference!

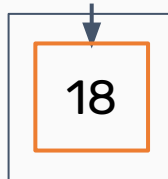
If you want to access the data stored at a pointer's address, dereference it using an asterisk again.

```
std::cout >> *ptr >> std::endl;
```

```
int val = 18;
```

```
int* ptr = &val;
```

int val



#0106

int* ptr





What if the object has member variables?

If we need to access a pointer's object's member variables,
instead of dereferencing (`*ptr`) and then accessing (`.var`),
there's a shorthand!



What if the object has member variables?

If we need to access a pointer's object's member variables,
instead of dereferencing (`*ptr`) and then accessing (`.var`),
there's a shorthand!

`*ptr.var = ptr->var`



What if the object has member variables?

If we need to access a pointer's object's member variables,
instead of dereferencing (`*ptr`) and then accessing (`.var`),
there's a shorthand!

`*ptr.var == ptr->var`



What's the difference?

- Iterators are a type of pointer!

What's the difference?

- Iterators are a type of pointer!
- Iterators have to point to elements in a container, but pointers can point to any object!



What's the difference?

- Iterators are a type of pointer!
- Iterators have to point to elements in a container, but pointers can point to any object!
 - Why is this? All objects stored inside the big container known as **memory**!

What's the difference?

- Iterators are a type of pointer!
- Iterators have to point to elements in a container, but pointers can point to any object!
 - Why is this? All objects stored inside the big container known as **memory**!
- Can access memory addresses with **&** and the data at an address/pointer using *****



Agenda



01. Recap: Containers

02. Iterators

How to access container elements

03. Pointers

Accessing objects by address

04. Iterators vs. Pointers





What does that look like?

Live code demo
demonstrating pointers!

Exercise

We've created a .csv file containing some CS faculty, their university, and the year they graduated. Write a function called

```
std::map<std::string, ... > createMap(std::string filename)
```

That takes this information and create a map that relates their name to a struct containing their university and year, where `...` is the type of the struct you use!

Then, write a function called

```
void printMap(std::map<std::string, ...> csMap)
```

that prints each professor and whether they're a Stanford alum or not!

Exercises

We've created a .csv file containing some CS faculty who graduated. Write a function called

```
std::map<std::string, ... > createMap(std::string filename)
```

That takes this information and create a map that relates their name to a struct containing their university and year, where `...` is the type of the struct you use!

Then, write a function called

```
void printMap(std::map<std::string, ...> csMap)
```

that prints each professor and whether they're a Stanford alum or not!

Tips:

- **Review streams!**
- **Use an iterator to loop through the map, like we talked about today!**
- **A pair might be a useful way to keep track of year and university!**



↻ <http://web.stanford.edu/class/cs106l/>



Thanks!

Next up: Classes!