



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



Containers

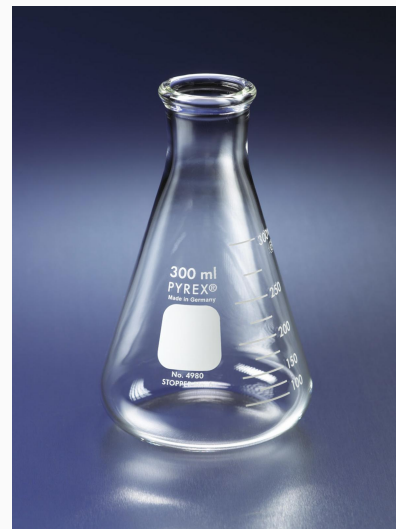
What are they? How do we use them? How do they differ from their Stanford Library counterparts?

CS106L - Spring 23



Attendance!

<https://bit.ly/3A9pp1L>



Recap:

- **Uniform Initialization**
 - A “uniform” way to initialize variables of different types!
- **References**
 - Allow us to assign aliases to variables
- **Const**
 - Allow us to specify that a variable can't be modified



Agenda



01. Defining Containers

What is a container in C++?

02. Containers in the STL vs Stanford

Types of containers and how they work

03. Container Adaptors

Abstracting container implementation



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Container: An object that allows us to collect other objects together and interact with them in some way.



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Think of **vectors**, **stacks**, or **queues**!



Why containers?

What is the purpose of
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Abstraction

Complex ideas
made easier to
utilize by
clients



Motivating containers

We've been using the idea of a Student struct for the past few lectures:

```
struct Student {  
    string name; // these are called fields  
    string state; // separate these by semicolons  
    int age;  
};
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Student s;  
s.name = "Sarah";  
s.state = "CA";  
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Student s;  
s.name = "Sarah";  
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What if we had a whole class of students?



This is generalizable!

We shouldn't need to create an entire new system just to hold different types of data...

- What if we wanted class grades instead of students?



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We shouldn't need to create an entire new system just to hold different types of data...

- What if we wanted class grades instead of students?

...Or to store it in a different way!

- What if we wanted to sort by age, or state?



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More on this Thursday!

The STL has many types of containers:

Both familiar:

- Vector
- Stack
- Queue
- Set
- Map



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*Not a Python
list!*





New containers

- An **array** is the primitive form of a vector
 - Fixed size in a strict sequence



New containers

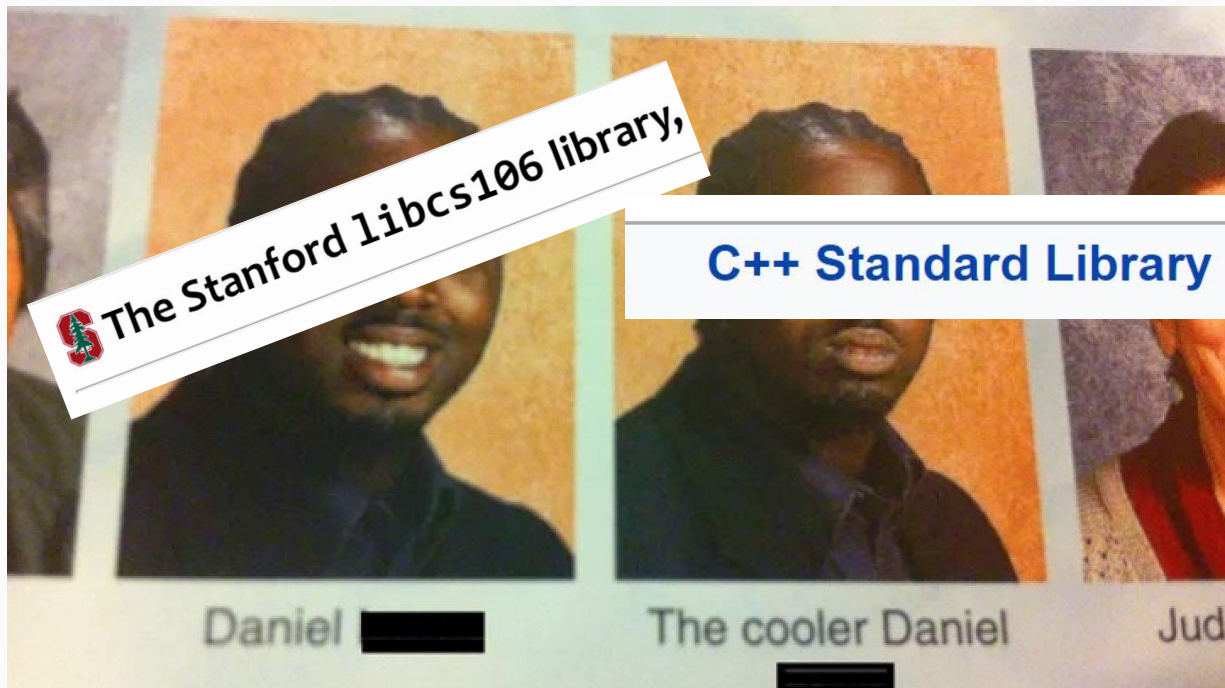
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New containers

- An **array** is the primitive form of a vector
 - Fixed size in a strict sequence
- A **deque** is a **double ended queue**
- A **list** is a doubly linked list
 - Can loop through in either direction!

STL vs Stanford





STL vs Stanford

The Stanford library and the STL containers have very similar functionality, but there can sometimes be **key differences** in both behavior and syntax!

Spot the difference!

What you want to do	Stanford <code>Vector<int></code>	<code>std::vector<int></code>
Create a new, empty vector	<code>Vector<int> vec;</code>	<code>std::vector<int> vec;</code>
Create a vector with <code>n</code> copies of 0	<code>Vector<int> vec(n);</code>	<code>std::vector<int> vec(n);</code>
Create a vector with <code>n</code> copies of a value <code>k</code>	<code>Vector<int> vec(n, k);</code>	<code>std::vector<int> vec(n, k);</code>
Add a value <code>k</code> to the end of a vector	<code>vec.add(k);</code>	<code>vec.push_back(k);</code>
Remove all elements of a vector	<code>vec.clear();</code>	<code>vec.clear();</code>
Get the element at index <code>i</code>	<code>int k = vec[i];</code>	<code>int k = vec[i];</code> (does not bounds check)
Check size of vector	<code>vec.size();</code>	<code>vec.size();</code>
Loop through vector by index <code>i</code>	<code>for (int i = 0; i < vec.size(); ++i) ...</code>	<code>for (std::size_t i = 0; i < vec.size(); ++i) ...</code>
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Table courtesy of Frankie Cerkenik and Sathya Edamadaka!

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What does this mean?



Safety vs Speed

In choosing a programming language, there's always a tradeoff between **speed**, **power**, and **safety**.

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C++ is really fast! Why is that?

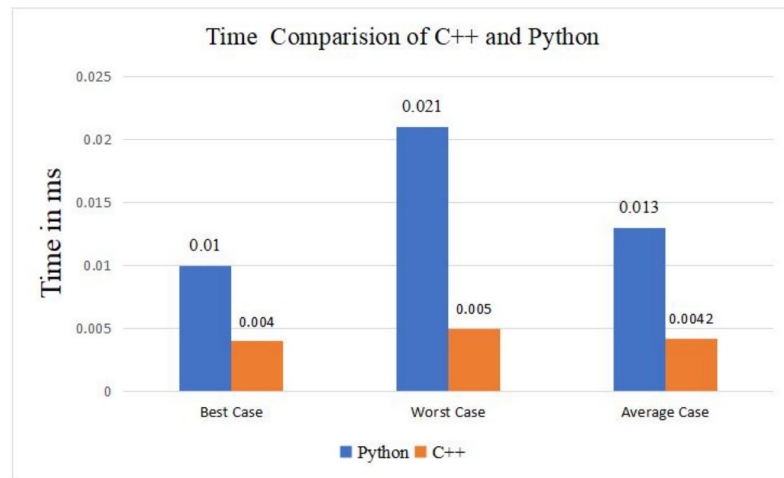


Fig. 13. Comparison of Time Utilization of Deletion Algorithm



C++ Design Philosophy

- Only provide the checks/safety nets that are necessary



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- The programmer knows best!



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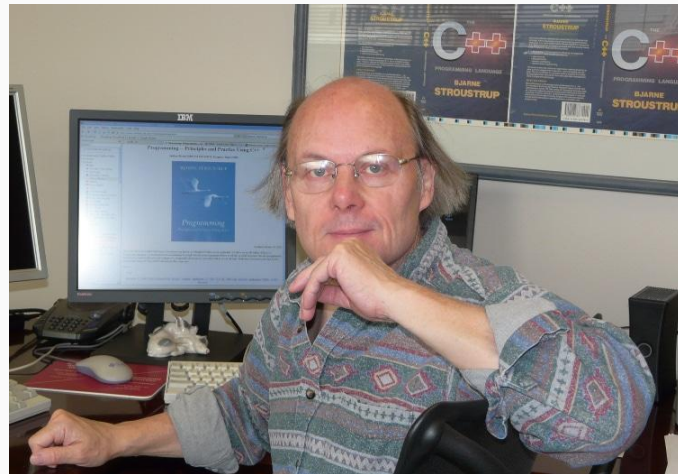
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More differences

What you want to do	Stanford <code>Set<int></code>	<code>std::set<int></code>
Create an empty set	<code>Set<int> s;</code>	<code>std::set<int> s;</code>
Add a value <code>k</code> to the set	<code>s.add(k);</code>	<code>s.insert(k);</code>
Remove value <code>k</code> from the set	<code>s.remove(k);</code>	<code>s.erase(k);</code>
Check if a value <code>k</code> is in the set	<code>if (s.contains(k)) ...</code>	<code>if (s.count(k)) ...</code>
Check if vector is empty	<code>if (vec.isEmpty()) ...</code>	<code>if (vec.empty()) ...</code>

More differences

What you want to do	Stanford Map<int, char>	std::map<int, char>
Create an empty map	<code>Map<int, char> m;</code>	<code>std::map<int, char> m;</code>
Add key k with value v into the map	<code>m.put(k, v);</code> <code>m[k] = v;</code>	<code>m.insert({k, v});</code> <code>m[k] = v;</code>
Remove key k from the map	<code>m.remove(k);</code>	<code>m.erase(k);</code>
Check if key k is in the map	<code>if (m.containsKey(k)) ...</code>	<code>if (m.count(k)) ...</code>
Check if the map is empty	<code>if (m.isEmpty()) ...</code>	<code>if (m.empty()) ...</code>
Retrieve or overwrite value associated with key k (error if key isn't in map)	Impossible (but does auto-insert)	<code>char c = m.at(k);</code> <code>m.at(k) = v;</code>
Retrieve or overwrite value associated with key k (auto-insert if key isn't in map)	<code>char c = m[k];</code> <code>m[k] = v;</code>	<code>char c = m[k];</code> <code>m[k] = v;</code>



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Sequence:

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



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Don't confuse these two!



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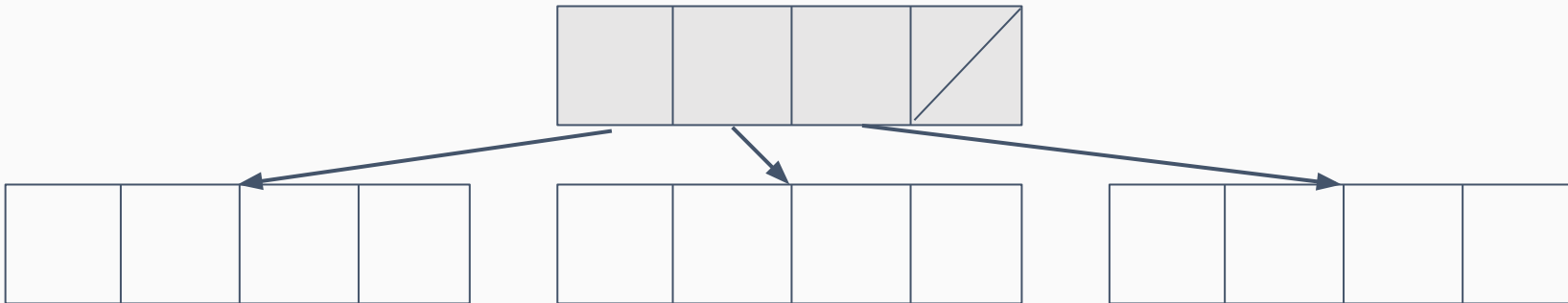
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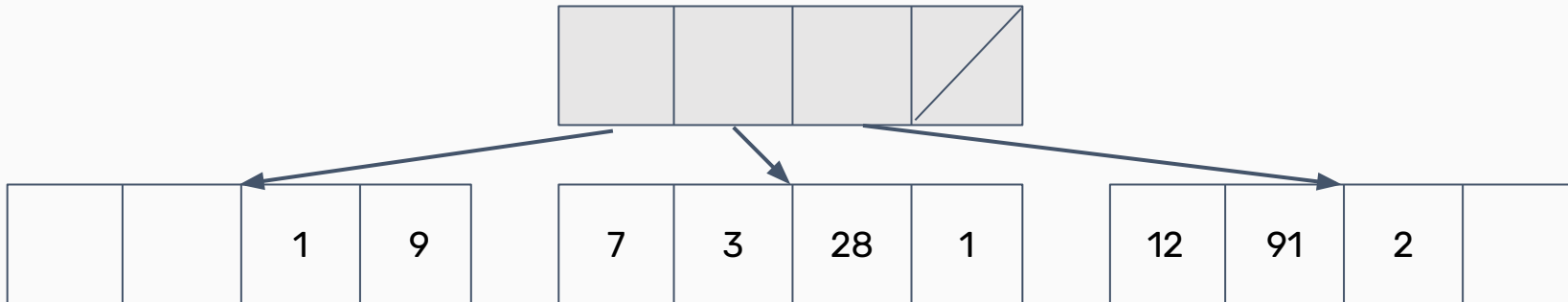
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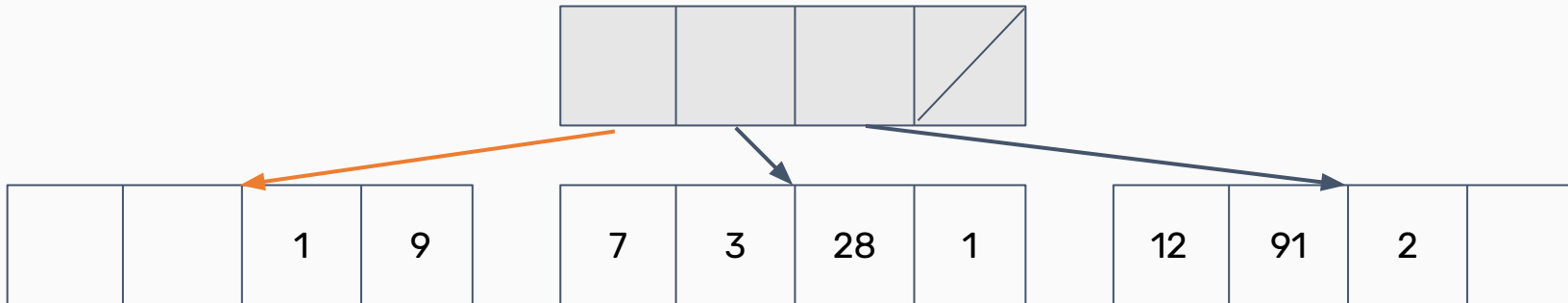
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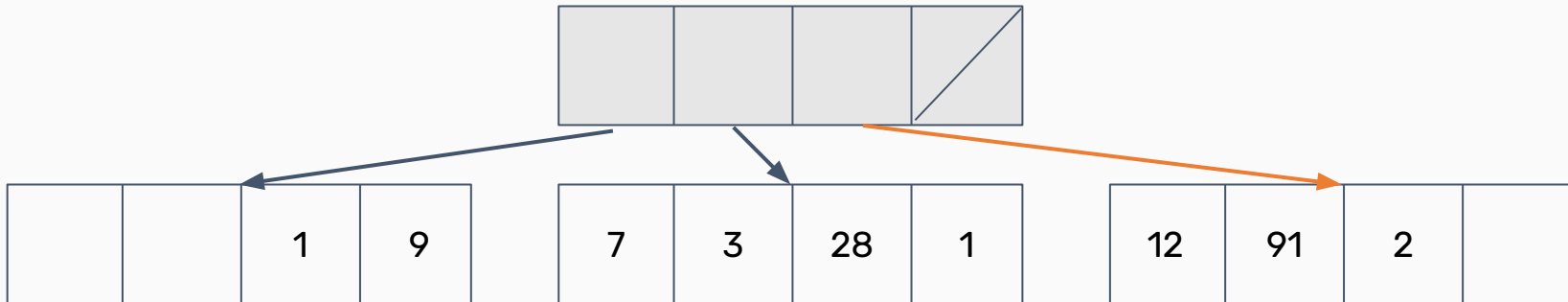
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All containers can hold all types of information! How do we choose which to use?



**So why can't we use vectors
all the time?**

Let's find out!

Choosing sequence containers

What you want to do	<code>std::vector</code>	<code>std::deque</code>	<code>std::list</code>
Insert/remove in the front	Slow	Fast	Fast
Insert/remove in the back	Super Fast	Very Fast	Fast
Indexed Access	Super Fast	Fast	Impossible
Insert/remove in the middle	Slow	Fast	Very Fast
Memory usage	Low	High	High
Combining (splicing/joining)	Slow	Very Slow	Fast
Stability* (iterators/concurrency)	Bad	Very Bad	Good



Sequence Containers: Summary

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- 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)

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Maps are implemented with pairs! (`std::pair<const key, value>`)

- Note the const! Keys must be immutable.
- Indexing into the map (`myMap[key]`) searches through the underlying collection of pairs first attribute for the key and will return its second attribute.



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Unordered maps/sets are usually faster than ordered ones!

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Choosing associative containers

Lots of similarities between maps/sets! Broad tips:



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

So far:

- Sequence containers:
 - Arrays, vectors, deques, lists
- Associative containers:
 - Sets and maps
 - Unordered vs. ordered



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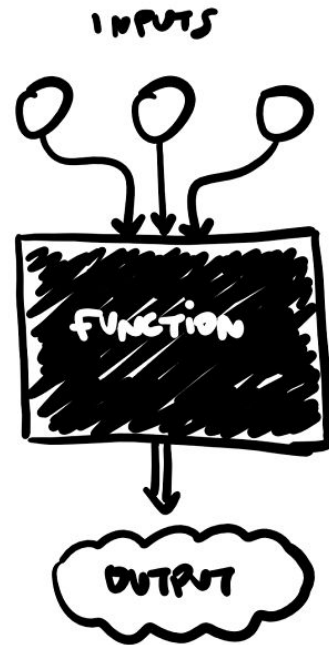
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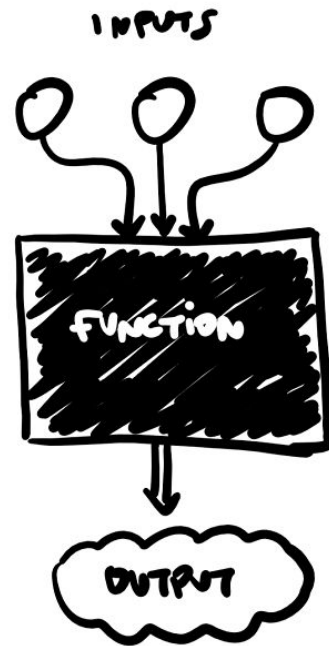
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Container Adaptors

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- Wrappers **modify the interface** to sequence containers and change what the client is allowed to do/how they can interact with the container.
- How could we make a wrapper to implement a queue from a deque?



Let's ask 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

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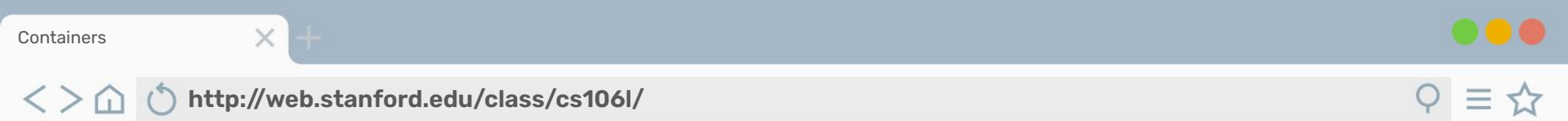
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```
std::queue<int> stack_deque; // Container = std::deque
```

```
std::queue<int, std::list<int>> stack_list; // Container = std::list
```



Why?

Abstraction again!



Why?

Abstraction again!

- Commonly used data structures made easy for the client to use



Why?

Abstraction again!

- Commonly used data structures made easy for the client to use
- Can use different backing containers based on use type

Summary

- 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.

Exercises

- Run a few time tests of different containers yourself!
How exactly do unordered sets/maps compare to ordered?
- Think about how you might implement a stack using a vector as the backing container. How would different operations work? (NOTE: You might have an easier time with this after our lecture on classes!)
- Poke around on the C++ documentation on your own!



Thanks!

Next up: Iterators and Pointers!