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

Containers

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

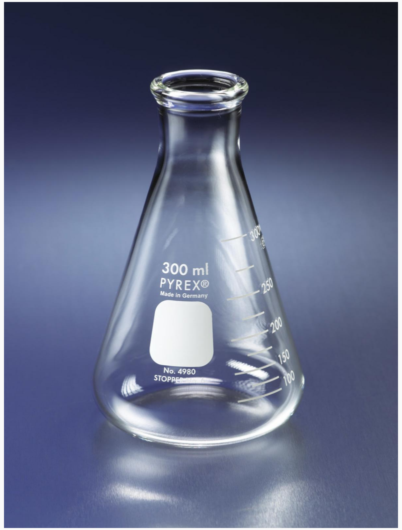
CS106L - Winter 2024

Containers

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

Attendance!

https://bit.ly/3vPFev0



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

Containers

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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 container types in programming languages?

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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;
};

Student s;
s.name = "Fabio";
s.state = "FL";
s.age = 21; // use . to access fields
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Student s;
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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!

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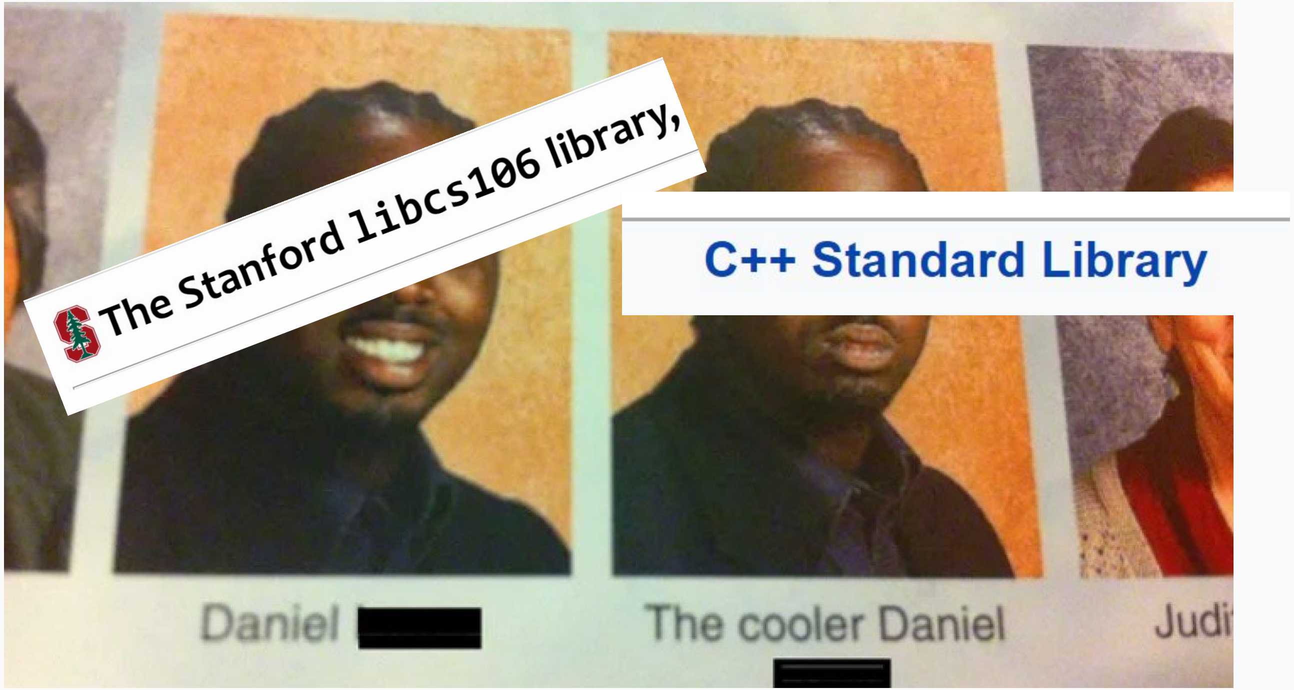
- A **list** is a doubly linked list
  - Can loop through in either direction!

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!

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Spot the difference!

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

Table courtesy of Frankie Cerkvenik and Sathya Edamadaka!

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What does this mean?

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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?

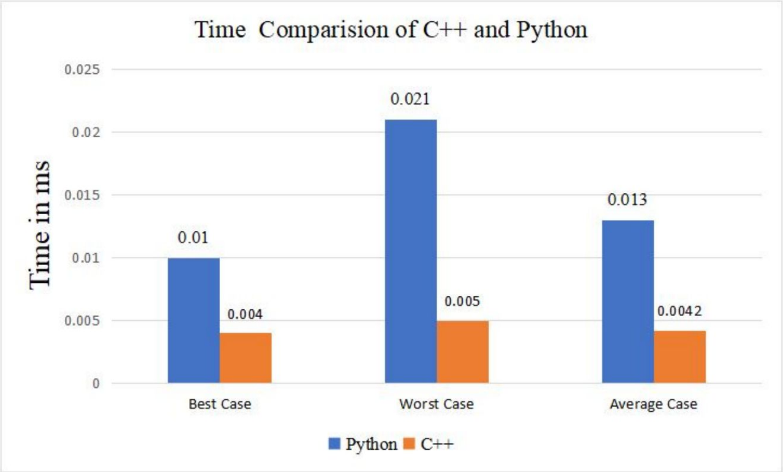

Fig. 13. Comparison of Time Utilization of Deletion Algorithm

C++ Design Philosophy

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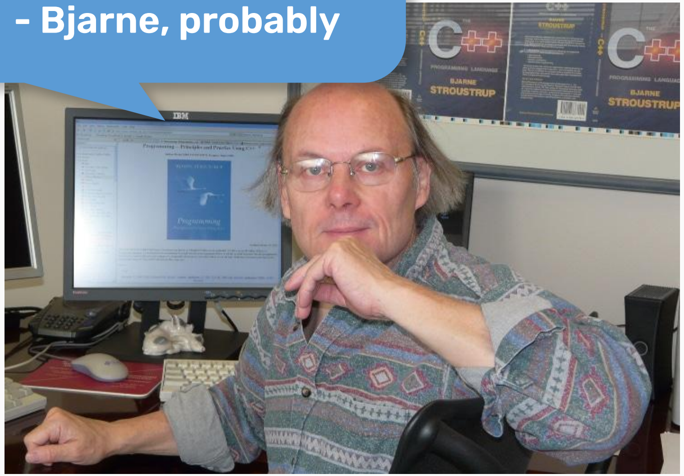
C++ Design Philosophy

“With great power comes great responsibility.”
- Bjarne, probably



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More differences

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

Shoutout to Frankie Cerkvenik and Sathya Edamadaka for these charts!

More differences

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

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Don’t confuse these two!

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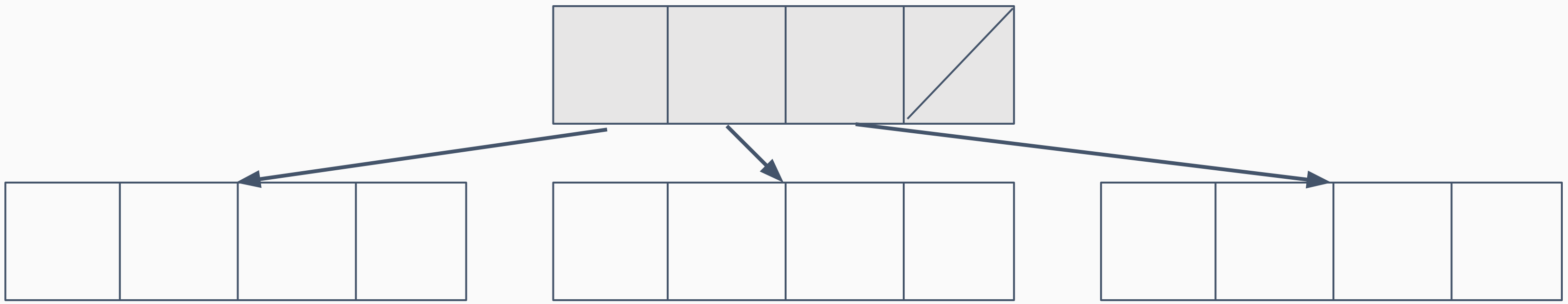

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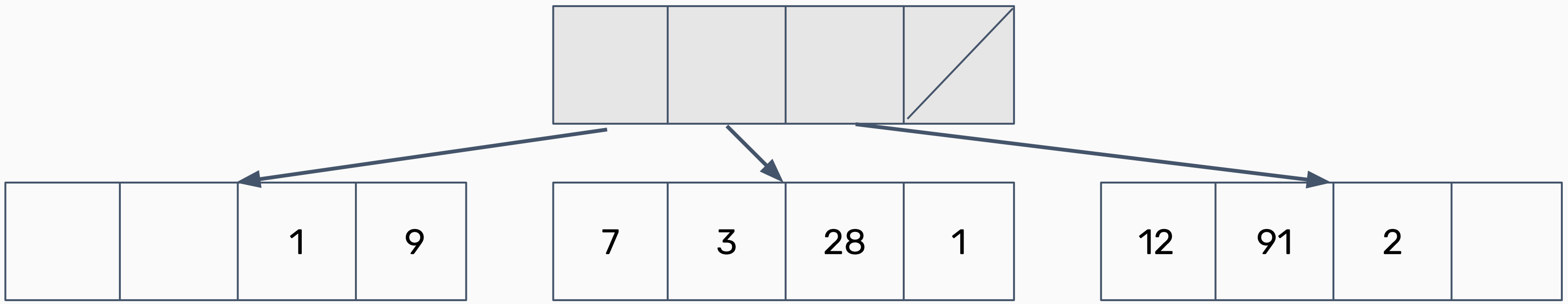

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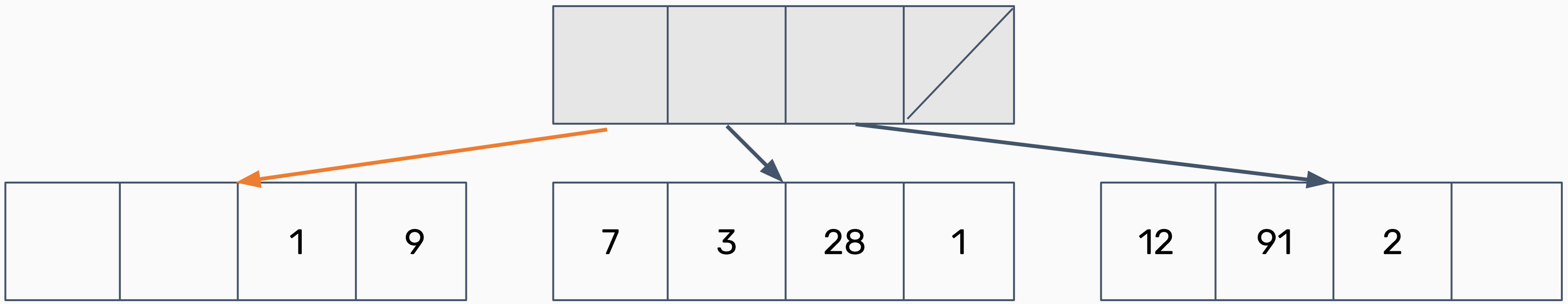

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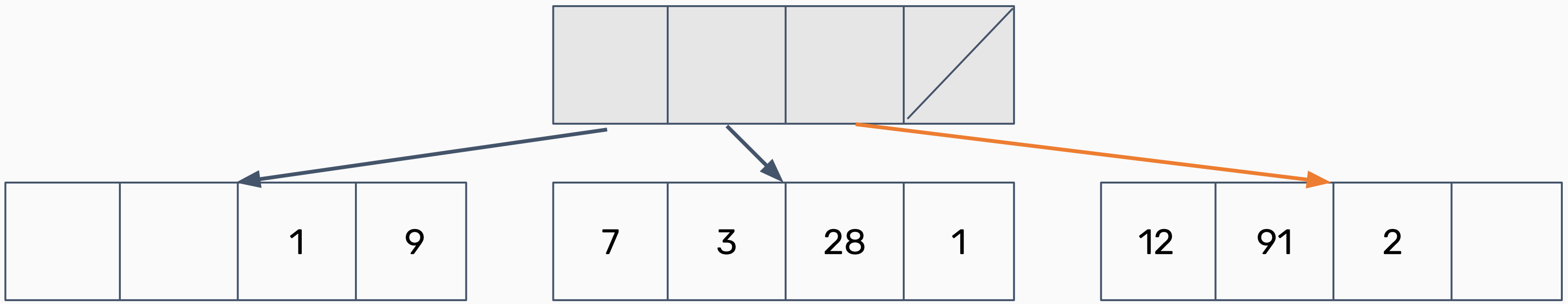

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All containers can hold all types of information! How do we choose which to use?

Choosing sequence containers

What you want to do	`std::vector`	`std::deque`	`std::list`
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

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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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- 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!

Aside: Hashing

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You can hash most anything if you can figure out a good hash function!

- Strings
- Structs
- Objects
- Even other numbers!

Choosing a hash function

How do we pick a good hash function?

A good hash function should:

- Be fast to compute
- Always map the same input to the same output
- Avoid collisions wherever possible

`hashFn(x) = 1` is a bad hash function!

Good vs Bad Hashes

Pop quiz! Which of these hash functions are good and which are bad? Why?

```
hashFn1(string x) = x.size()

hashFn2(int x) = std::rand() + x / 10

hashFn3(string x) = x % m \\ where m = table size
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Choosing associative containers

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- 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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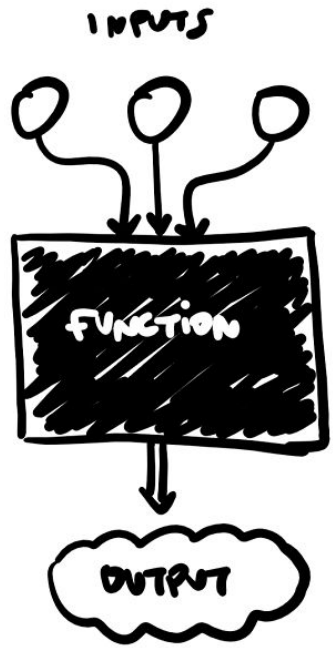
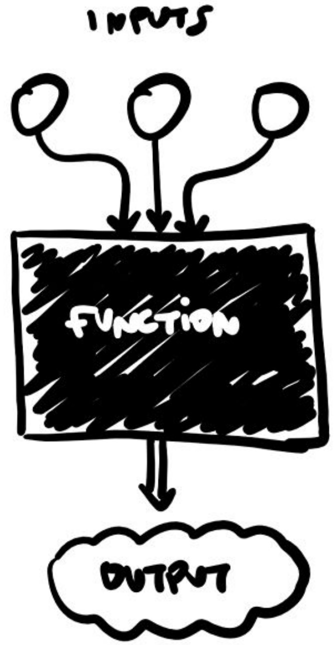


Container Adaptors

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.
- How could we make a wrapper to implement a queue from a deque?



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Let's ask the STL!

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

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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
```

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

Containers

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

Why?

Abstraction again!

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

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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!

Containers

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Thanks!

Next up: Iterators and Pointers!