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Containers

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

CS106L - Spring 2024

Containers

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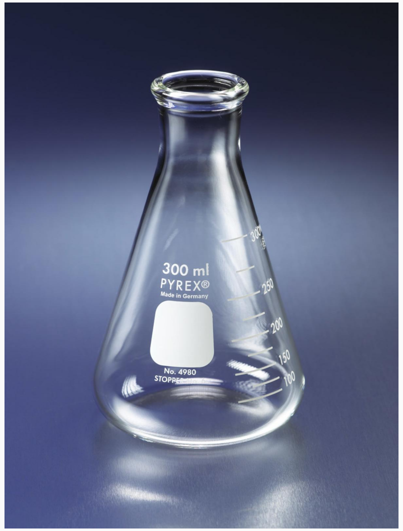
Attendance!

https://bit.ly/3U15HyT

bitly



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

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

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

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

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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Standardization

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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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- An **array** is the primitive form of a vector
  - Fixed size in a strict sequence
- A **deque** is a **d**ouble **e**nded **que**ue
- A **list** is a doubly linked list
  - Can loop through in either direction!

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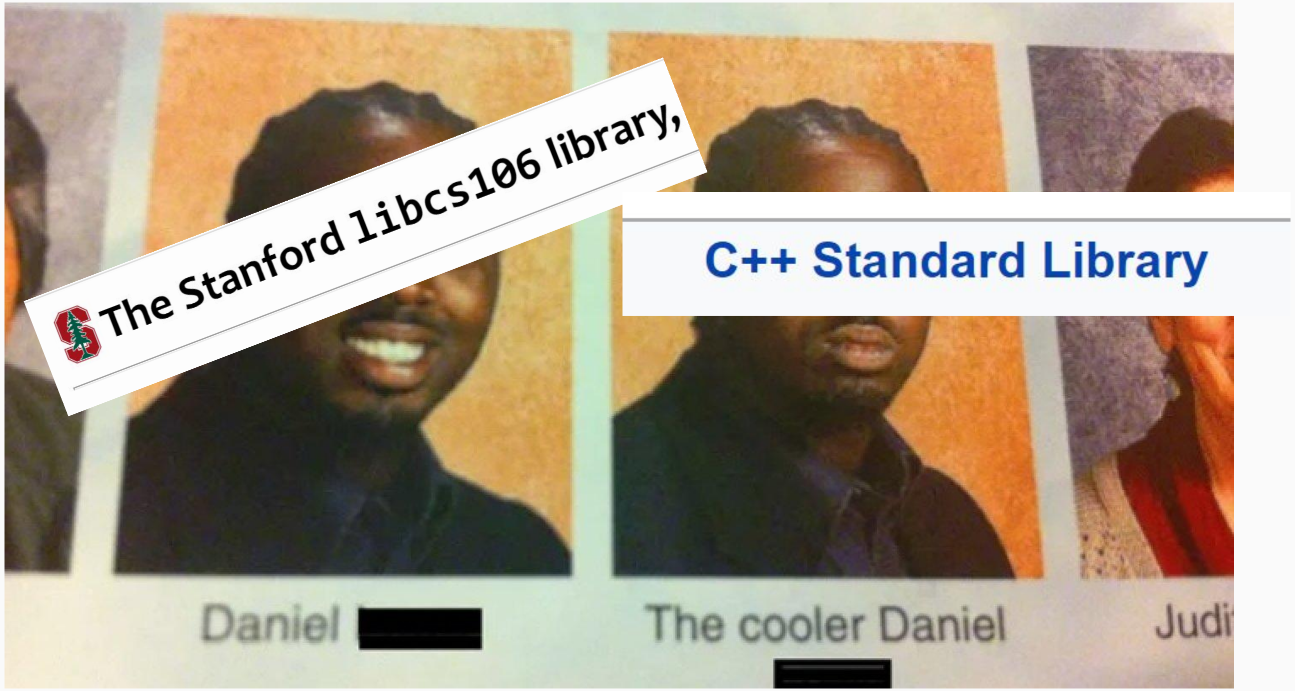
STL vs Stanford



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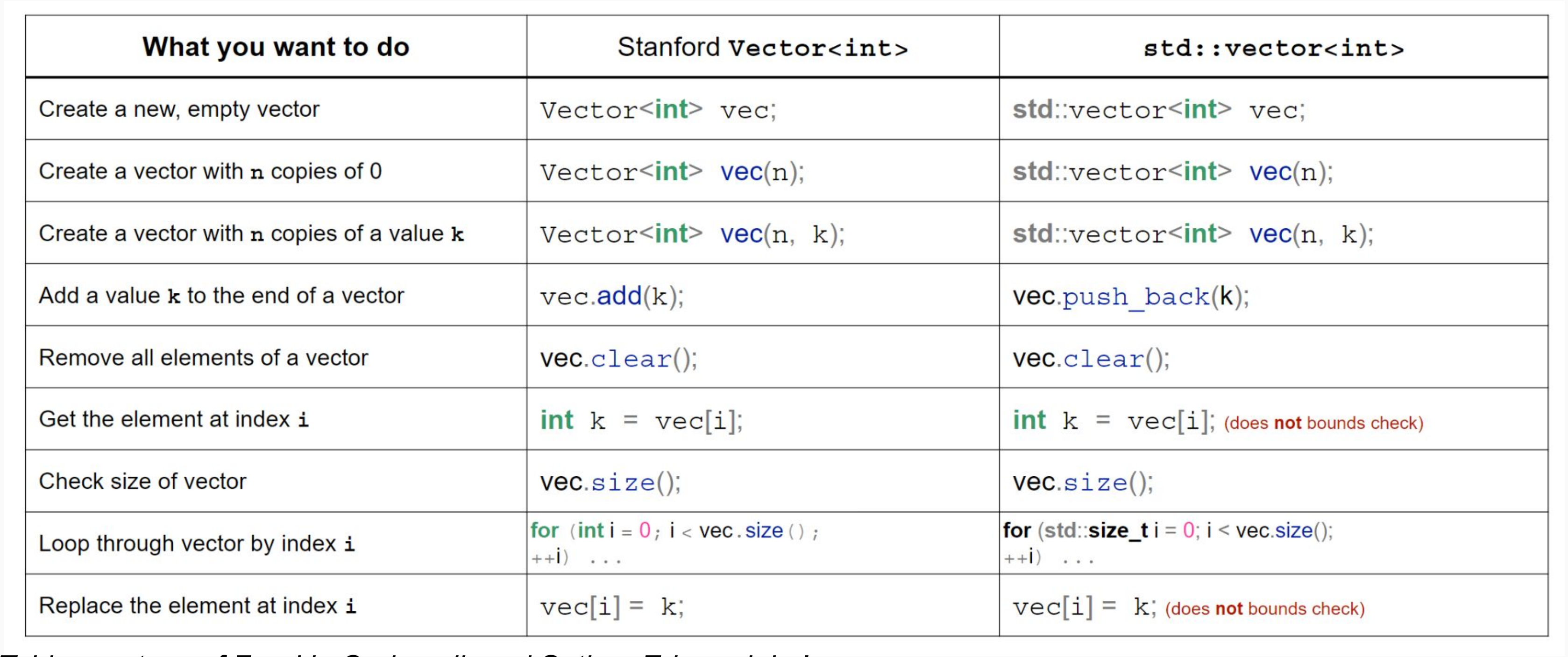
STL vs Stanford

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 `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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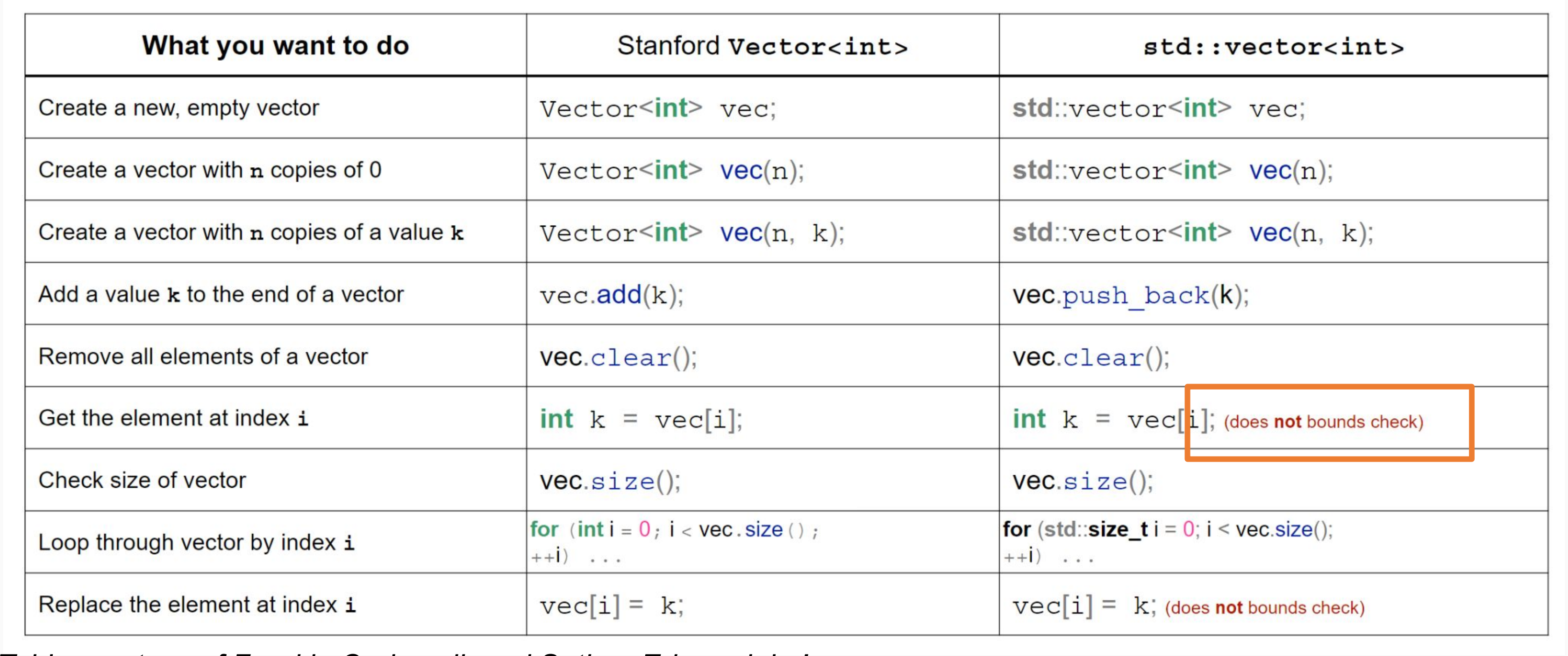

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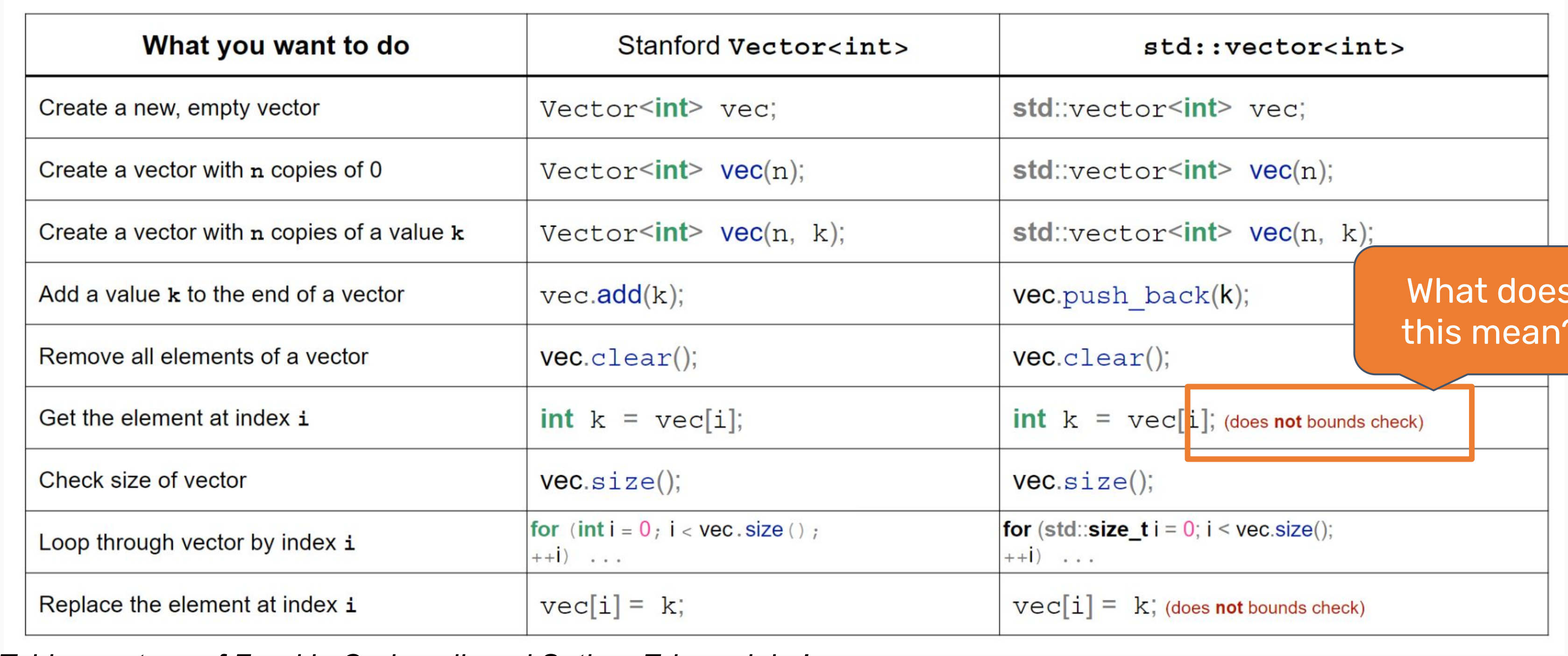

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What does this mean?

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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?

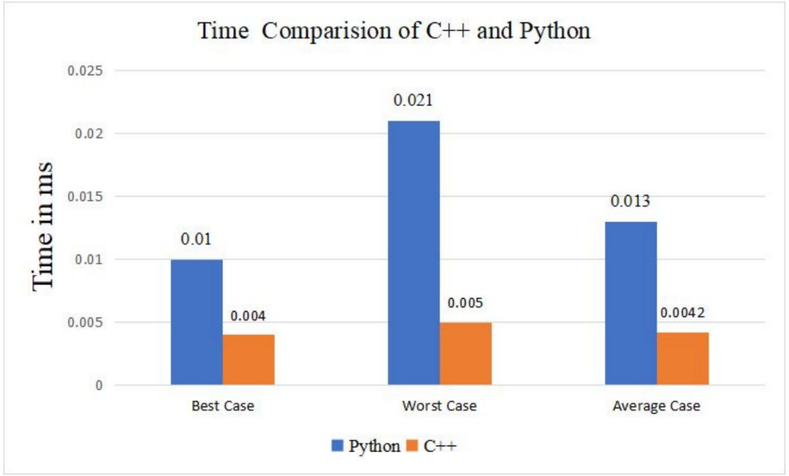

Fig. 13. Comparison of Time Utilization of Deletion Algorithm

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C++ Design Philosophy

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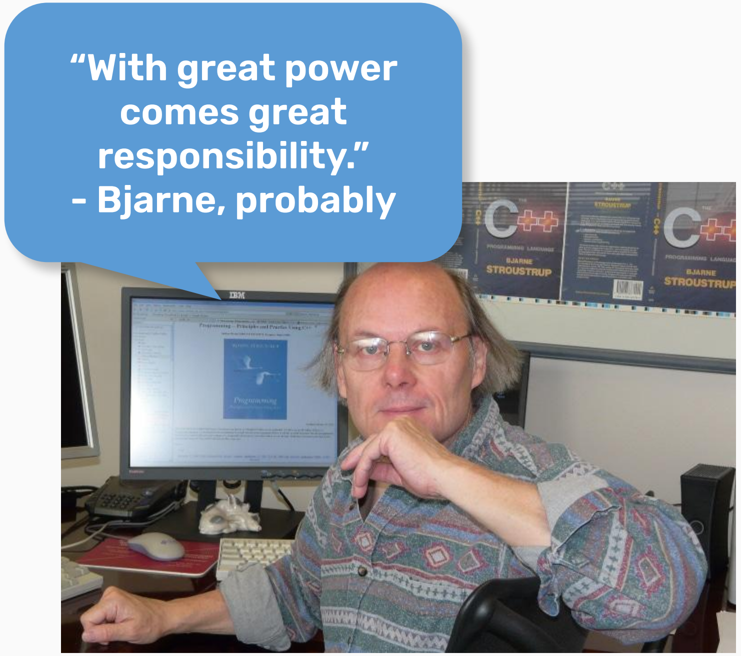

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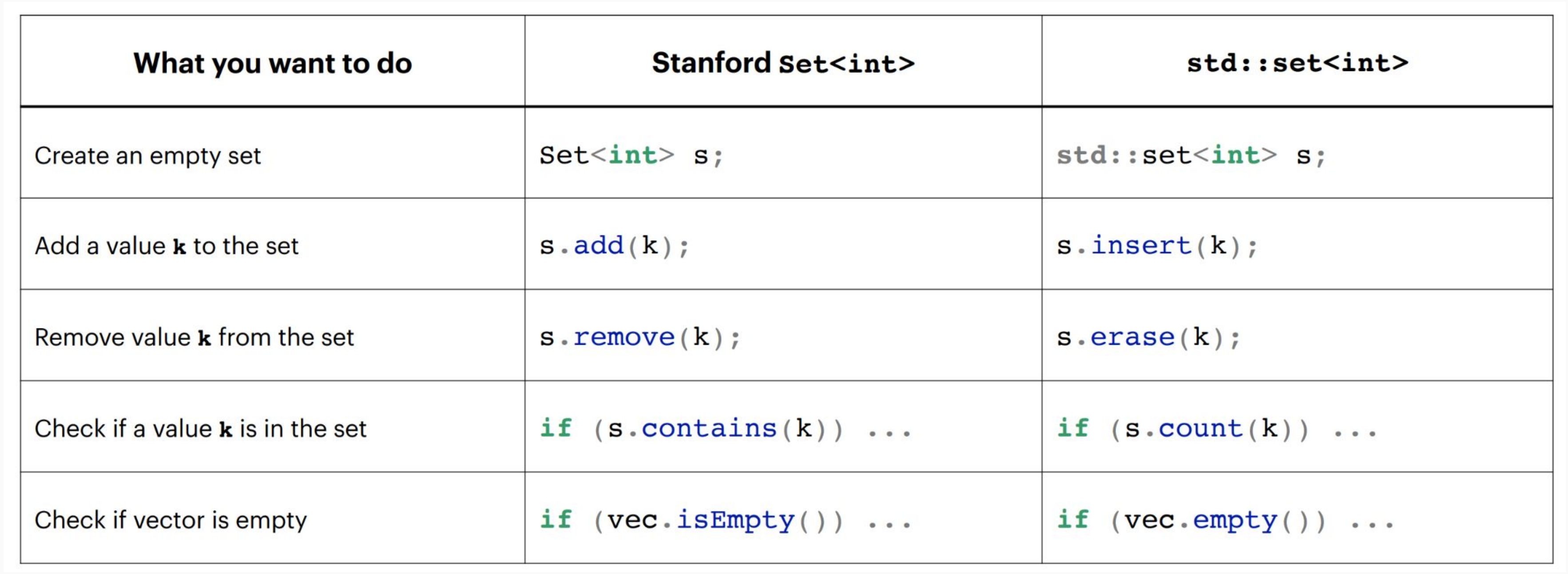
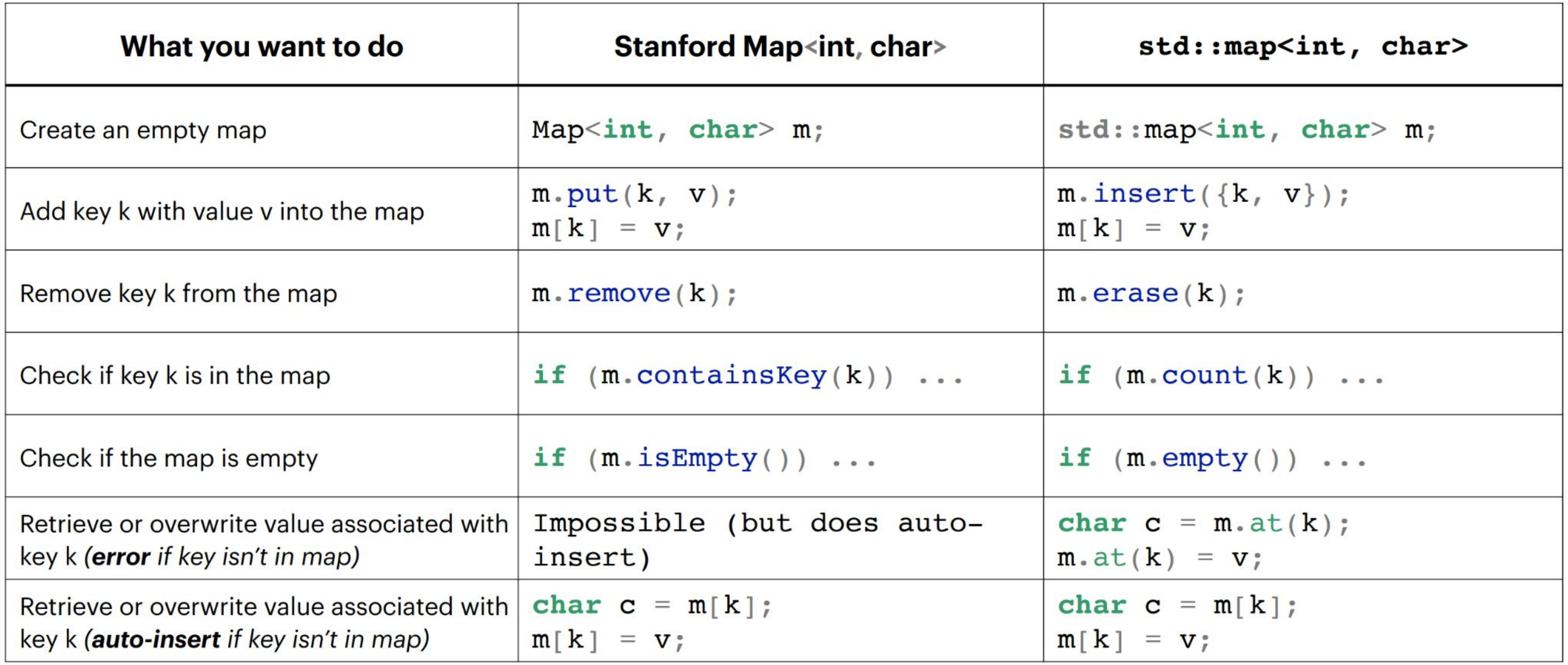


What you want to do	Stanford `Set<int>`	`std::set<int>`
Create an empty set	`Set<int> s;`	`std::set<int> s;`
Add a value **k** to the set	`s.add(k);`	`s.insert(k);`
Remove value **k** from the set	`s.remove(k);`	`s.erase(k);`
Check if a value **k** is in the set	`if (s.contains(k)) ...`	`if (s.count(k))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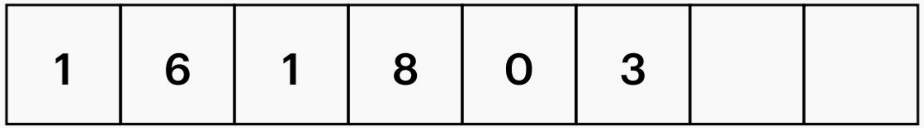

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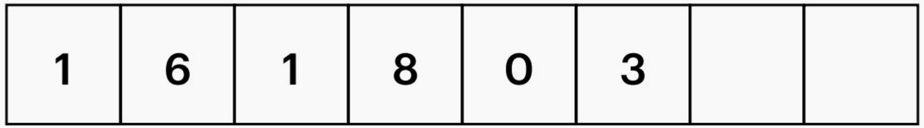

Don't confuse these two!

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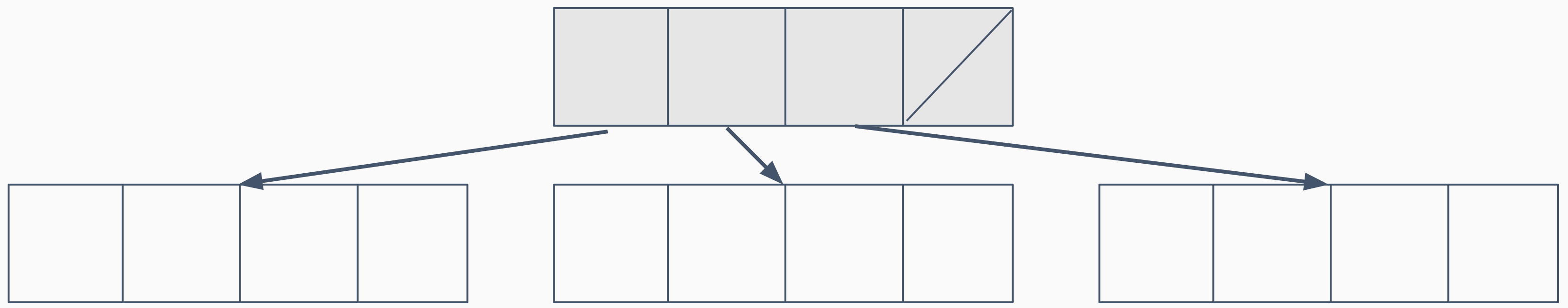

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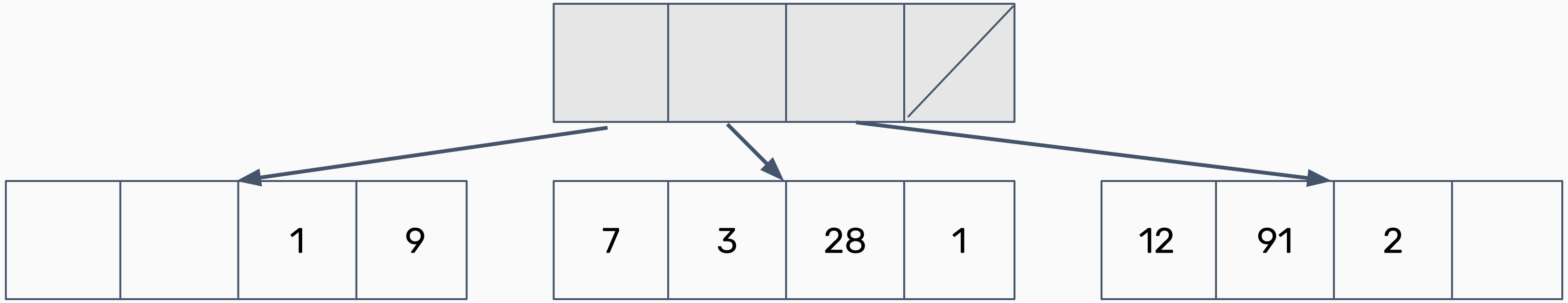

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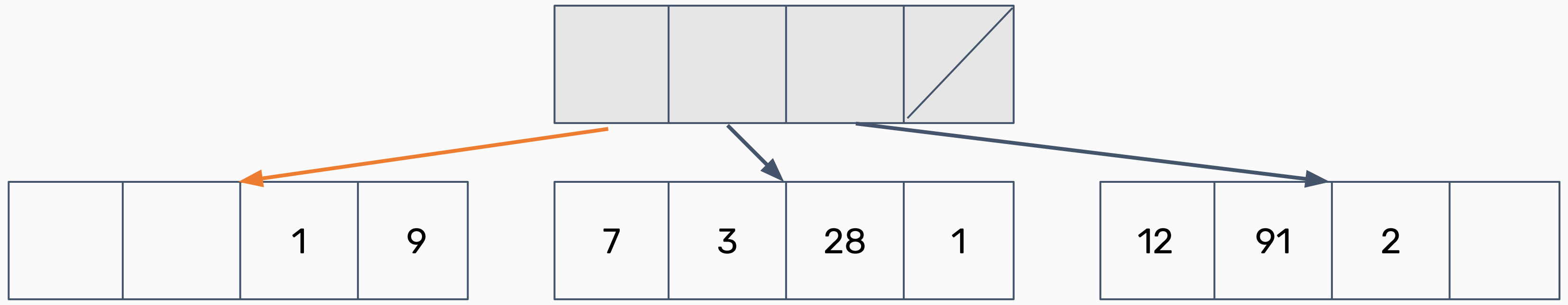

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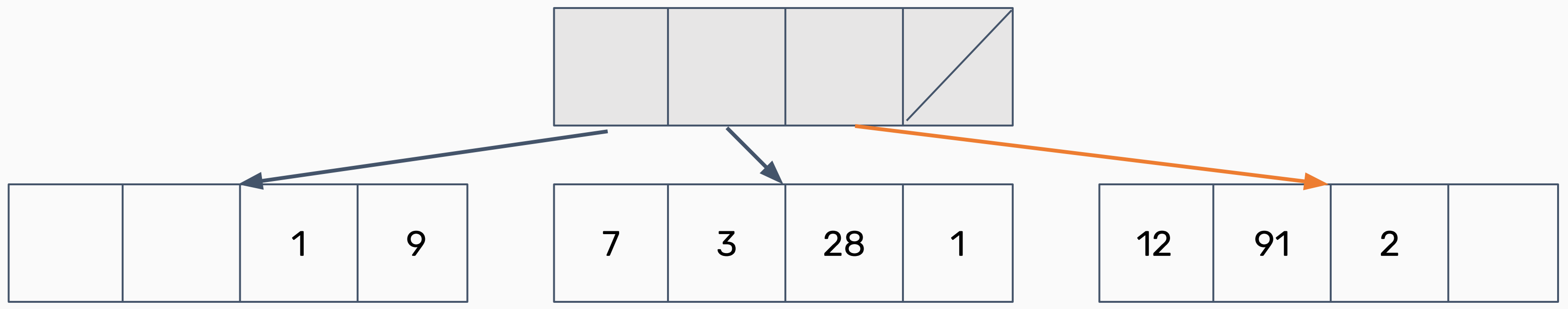

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All containers can hold all types of information! How do we choose which to use?

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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- 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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Map implementation

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.

Unordered maps/sets

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Unordered maps/sets are usually faster than ordered ones!

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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! What are the problems with these hash functions (if any)? 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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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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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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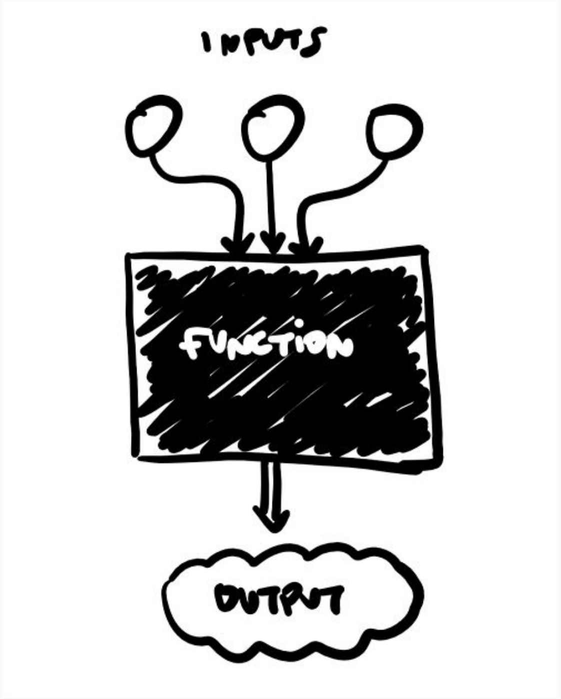
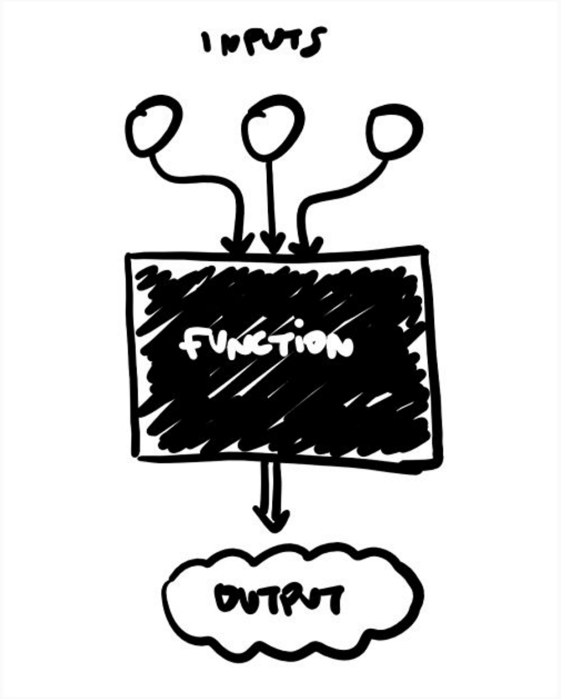


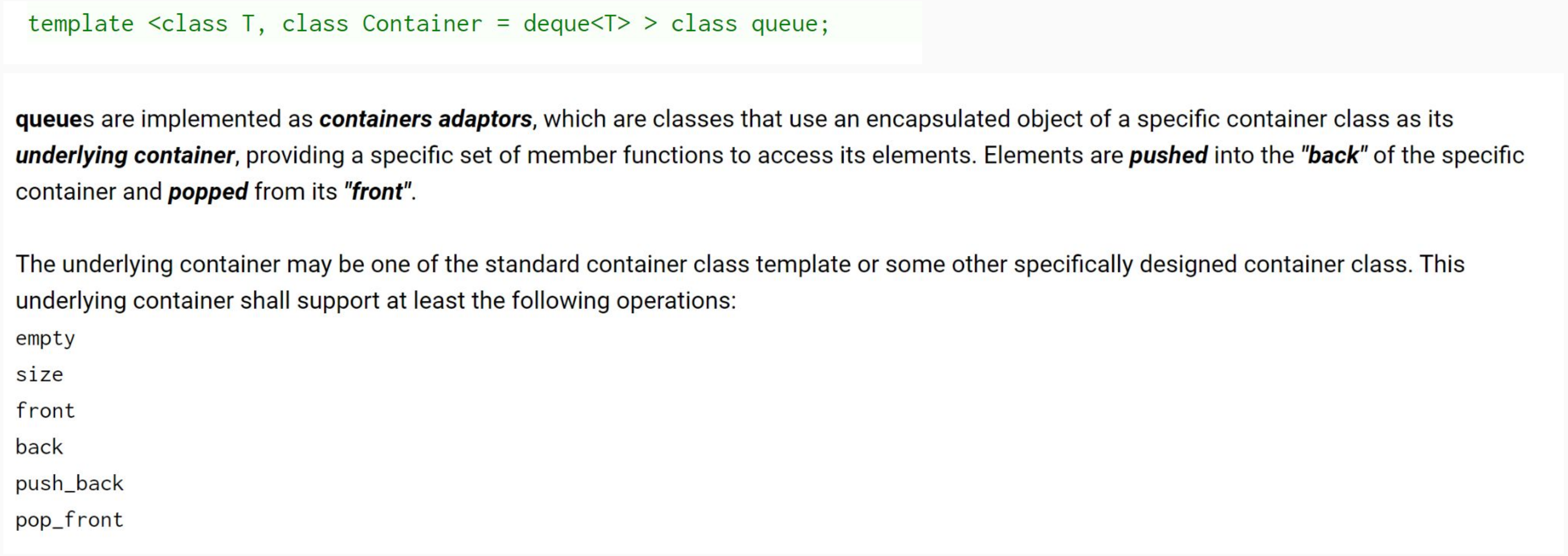
Container Adaptors

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?



Let’s ask the STL!



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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:

`empty`
`size`
`front`
`back`
`push_back`
`pop_front`

Containers

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

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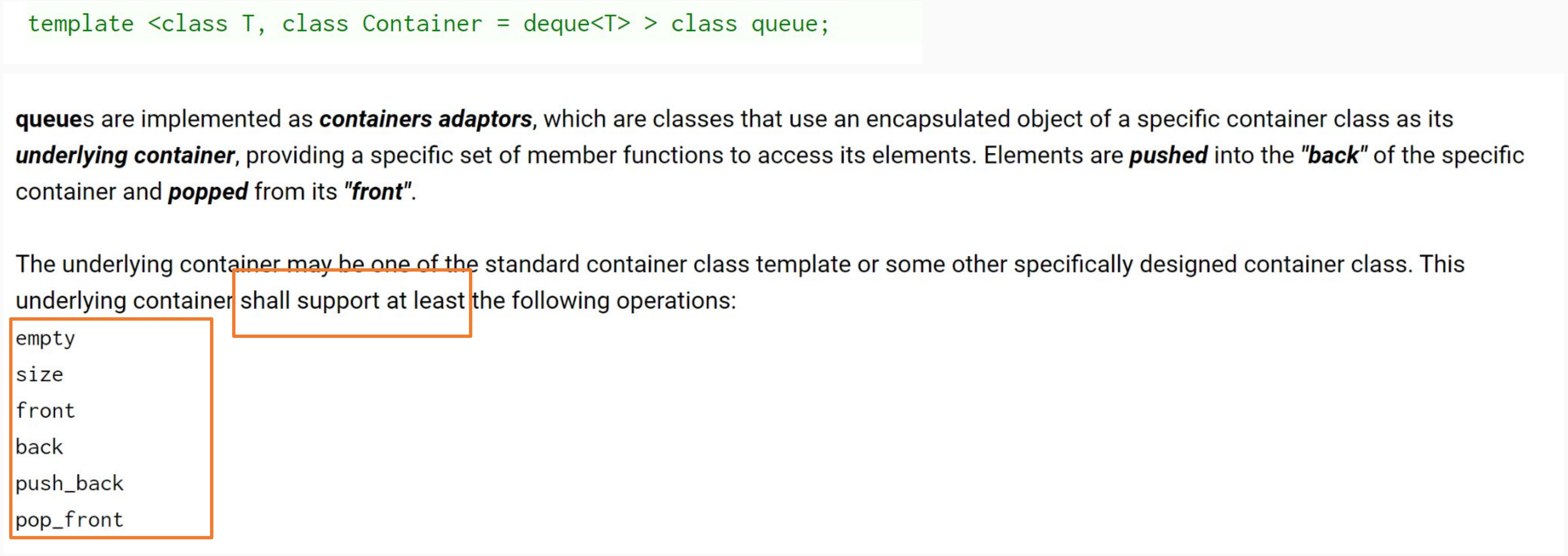

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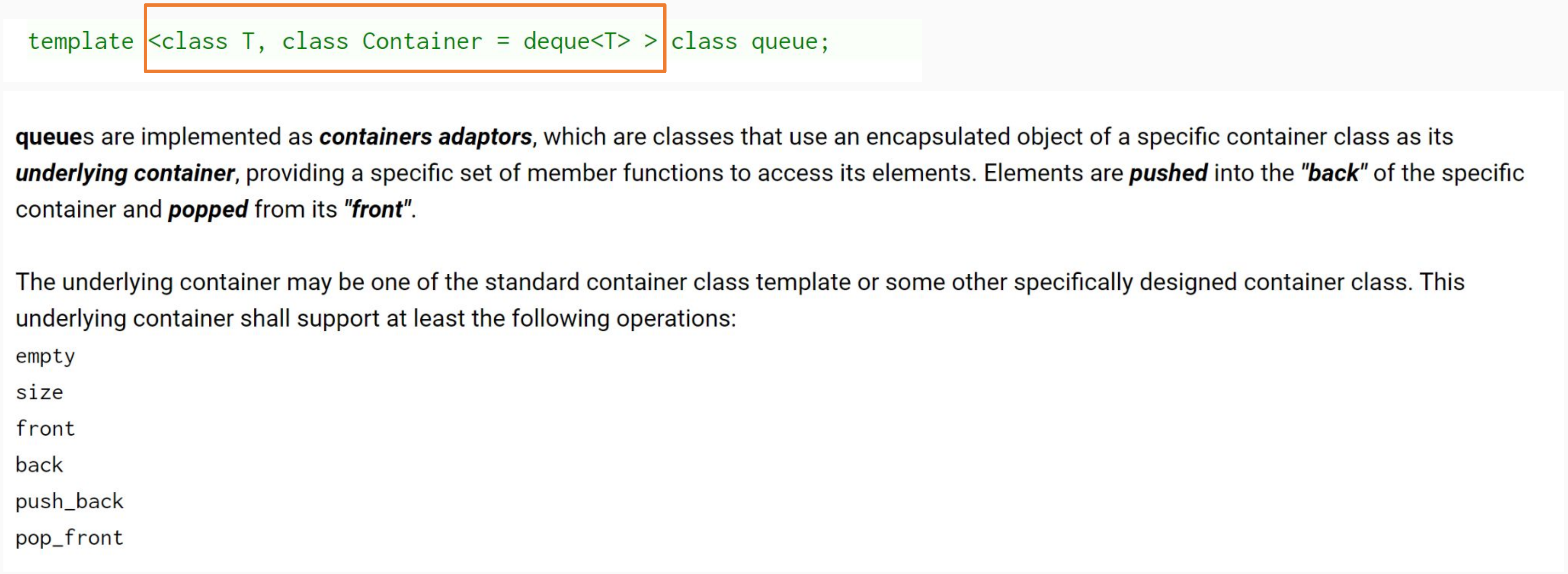

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```
std::queue<int> stack_deque;                     // Container = std::deque
std::queue<int, std::list<int>> stack_list;      // Container = std::list
```

Why?

Abstraction again!

Containers

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Abstraction again!

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

Containers

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

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!

Containers

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Thanks!

Next up: Iterators and Pointers!