Containers

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

CS106L - Spring 2024

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

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

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

Why containers?

What is the purpose of container types in programming languages?

Organization

Related data can be packaged together!

Standardization

Common features are expected and implemented

Abstraction

Complex ideas made easier to utilize by clients

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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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```

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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  - Maybe allow iteration through all of the objects

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More on this Thursday!

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The STL has many types of containers:

Both familiar:
- Vector
- Stack
- Queue
- Set
- Map

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- List
- Unordered set
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Not a Python list!

New containers

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New containers

- An **array** is the primitive form of a vector
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- 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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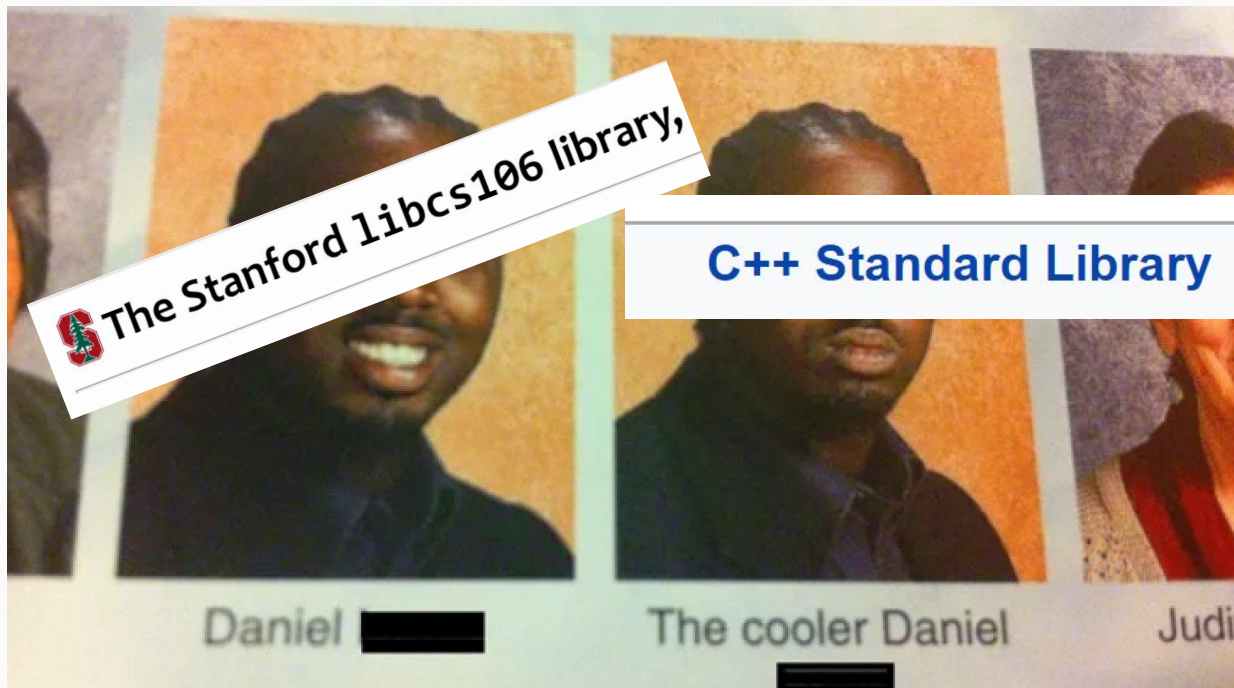
STL vs Stanford

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

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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?

Table courtesy of Frankie Cerkvenik and Sathya Edamadaka!

Safety vs Speed

In choosing a programming language, there's always a tradeoff between **speed**, **power**, and **safety**.
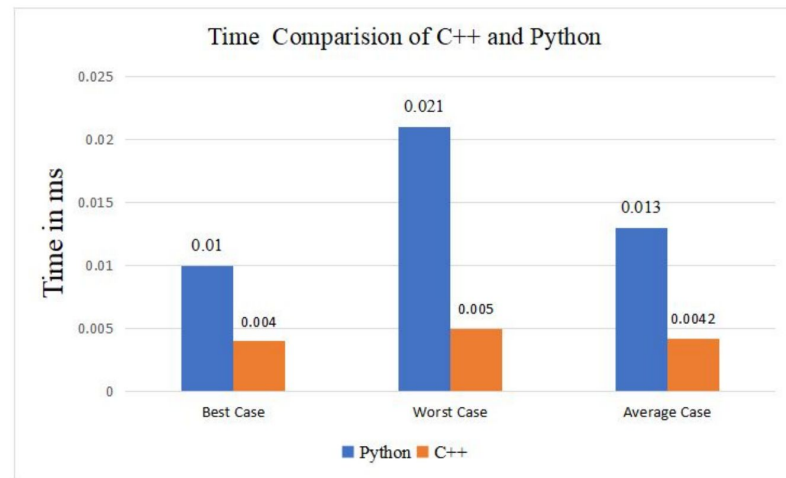
C++ is really fast! Why is that?

Fig. 13. Comparison of Time Utilization of Deletion Algorithm

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C++ Design Philosophy

- Only provide the checks/safety nets that are necessary
- The programmer knows best!

Making sure what you're doing is allowed is **your** job!

"With great power comes great responsibility."
- Bjarne, probably

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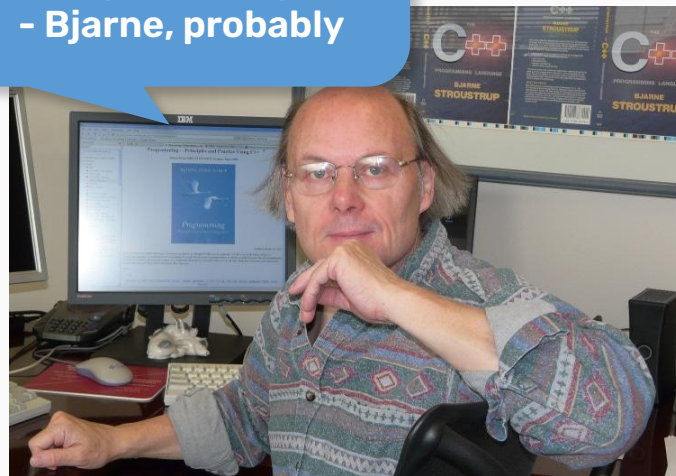
More differences

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!

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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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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!

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Vector implementation

How do vectors actually work?

- At a high level, a vector is an **ordered** collection of elements of the **same type** that can grow and shrink in size.

Internally, vectors implement an array!

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Vector implementation

We keep track of a few member variables:

- **_size** = number of elements in the vector

- **_capacity** = space allocated for elements

1	6	1	8	0	3		

Don't confuse these two!

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What about a deque?

Deques can be implemented many different ways! Here's one:

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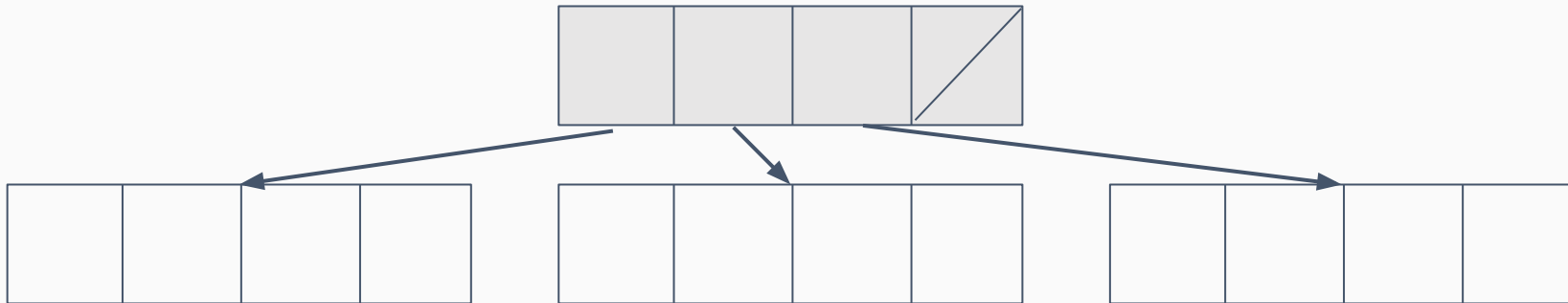Deques can be implemented many different ways! Here's one:

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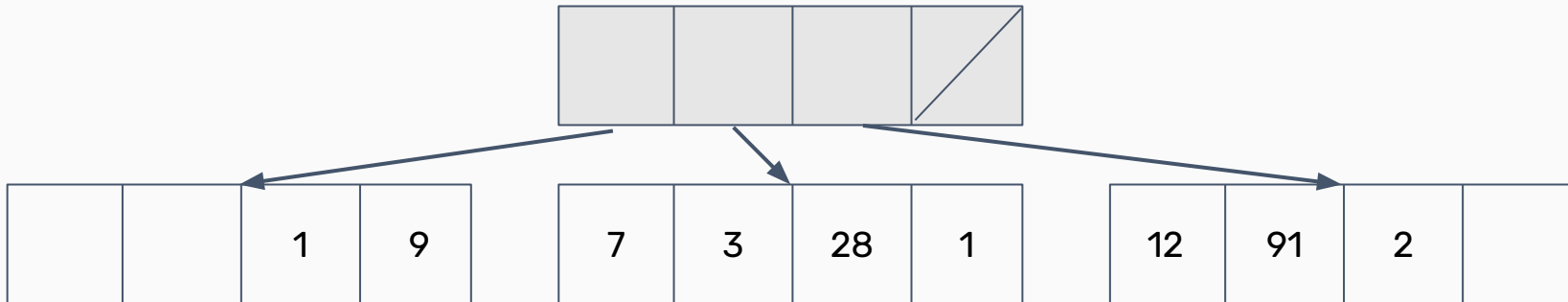Deques can be implemented many different ways! Here's one:
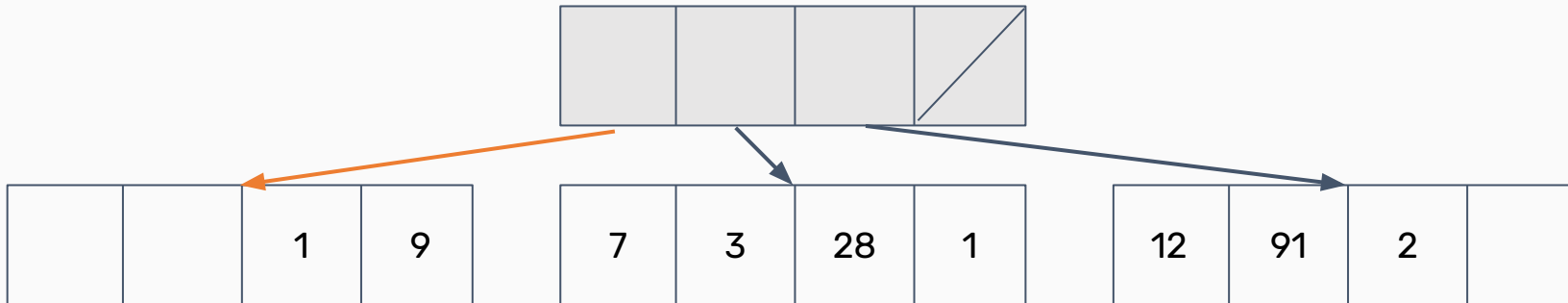
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All containers can hold all types of information! How do we choose which to use?

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

- Sequence containers are for when you need to enforce some order on your information!
- <mark>Can usually use an **std::vector** for most anything</mark>
- <mark>If you need particularly fast inserts in the front, consider an **std::deque**</mark>
- 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.

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Unordered maps/sets

Both maps and sets in the STL have an unordered version!

- **Ordered** maps/sets require a <mark>comparison operator</mark> to be defined.
- **Unordered** maps/sets require a <mark>hash function to be defined.</mark>

→

Simple types are already natively supported; anything else will need to be defined yourself.

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Unordered maps/sets are usually faster than ordered ones!

Simple types are already natively supported; anything else will need to be defined yourself.

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Aside: Hashing

Hash functions essentially provides a mapping from some complex object to a number!

- The act of calculating one such mapping is known as hashing.

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

- Strings
- Structs
- Objects
- Even other numbers!

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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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hashFn1(string x) = x.size()  BAD! Collisions!

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hashFn3(string x) = x % m \\ where m = table size  GOOD!
```

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Choosing associative containers

Lots of similarities between maps/sets! Broad tips:

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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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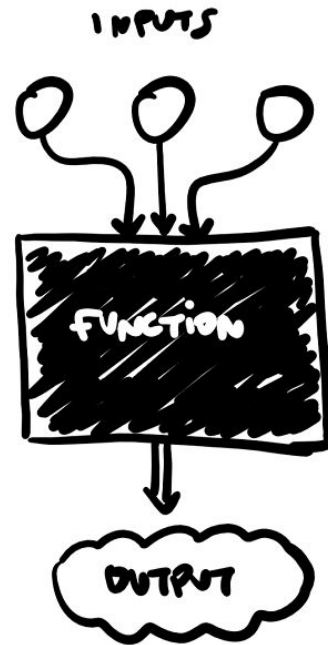
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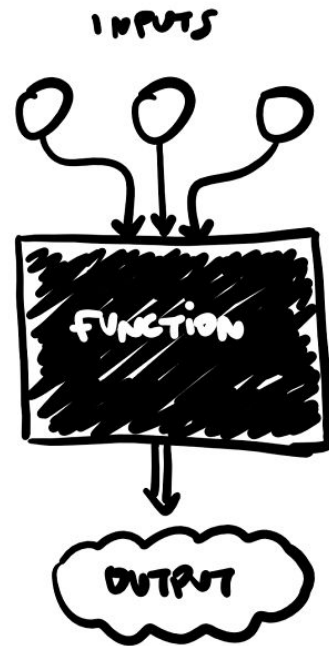
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Container Adaptors

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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?

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

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

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Why?

Abstraction again!

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

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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.