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

Containers

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

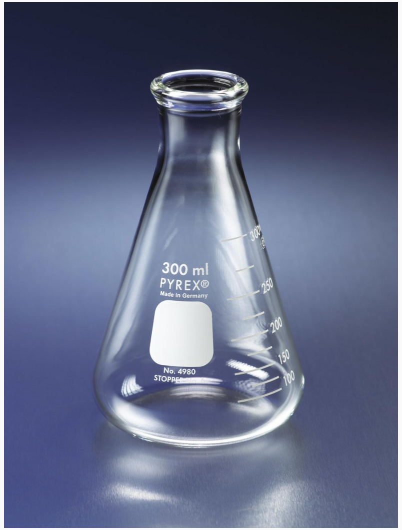
CS106L - Fall 22

Containers

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

Attendance!

https://bit.ly/3fS5Dku



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

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

CRASH COURSE: Const and Const References

`const` indicates a variable can't be modified!

`const` variables can be references or not!

```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};  // a const variable
std::vector<int>& ref = vec;         // a regular reference
const std::vector<int>& c_ref = vec;  // a const reference

vec.push_back(3);
c_vec.push_back(3);
ref.push_back(3);
c_ref.push_back(3);
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Can’t declare non-const reference to const variable!

```
const std::vector<int> c_vec{7, 8};  // a const variable

// BAD - can't declare non-const ref to const vector
std::vector<int>& bad_ref = c_vec;
```

Can’t declare non-const reference to const variable!

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const std::vector<int> c_vec{7, 8};  // a const variable

// fixed
const std::vector<int>& bad_ref = c_vec;
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Can’t declare non-const reference to const variable!

```
const std::vector<int> c_vec{7, 8};  // a const variable

// fixed
const std::vector<int>& bad_ref = c_vec;

// BAD - Can't declare a non-const reference as equal
// to a const reference!
std::vector<int>& ref = c_ref;
```

const & subtleties

```
std::vector<int> vec{1, 2, 3};
const std::vector<int> c_vec{7, 8};

std::vector<int>& ref = vec;
const std::vector<int>& c_ref = vec;

auto copy = c_ref;              // a non-const copy
const auto copy = c_ref;        // a const copy
auto& a_ref = ref;              // a non-const reference
const auto& c_aref = ref;       // a const reference
```

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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.

Containers

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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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Common features are expected and implemented

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组织

Standardization

Common features are expected and implemented

标准化

Abstraction

Complex ideas made easier to utilize by clients

抽象

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 = "Sarah";
s.state = "CA";
s.age = 21; // use . to access fields
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```

What if we had a whole class of students?

This is generalizable!

What if we need to store other types of data?

- Class grades
- Coordinates in a graph
- Mountains

What if we want to store it in a different way?

- FIFO vs LIFO
- Ascending order by some value

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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
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New containers

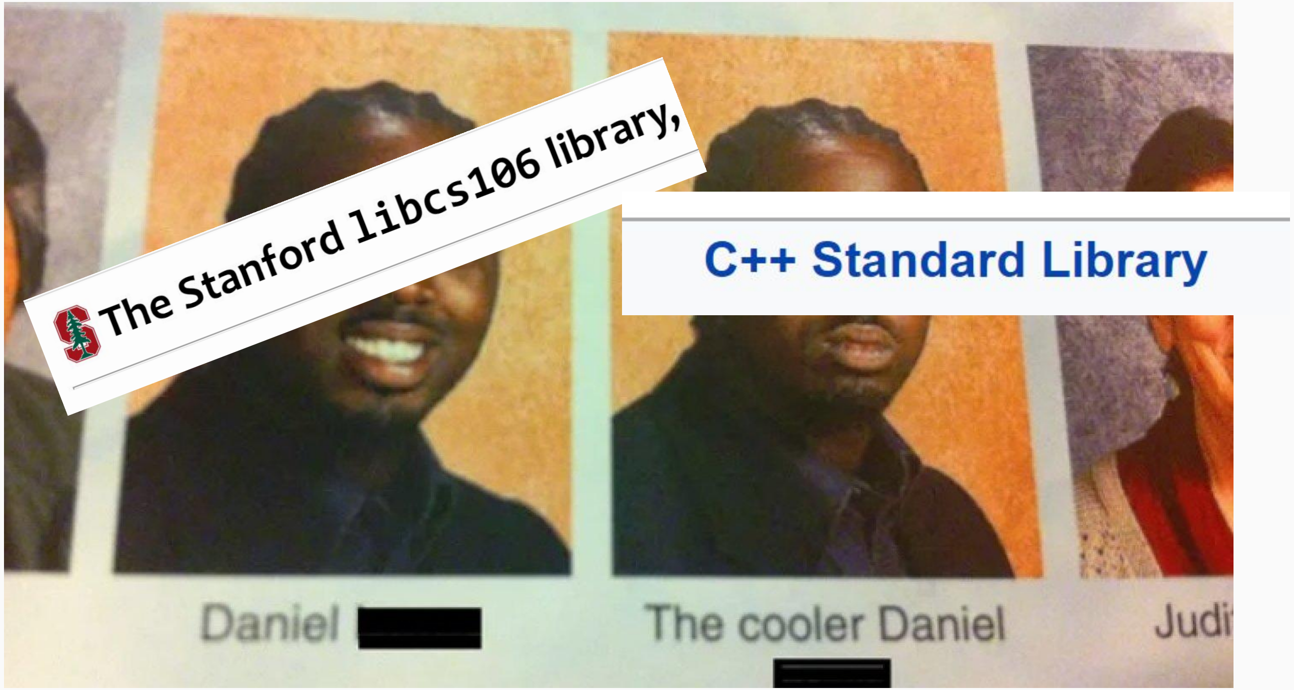
- An **array** is the primitive form of a vector
  - Fixed size in a strict sequence
- A **deque** is a **d**ouble **e**nded **que**ue
- A **list** is a doubly linked list
  - Can loop through in either direction!

array vs vector

deque = double ended queue

linked list

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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useless

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)

push_back(k)
clear( )

Table courtesy of Frankie Cerkvenik and Sathya Edamadaka!

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What does this mean?

Table courtesy of Frankie Cerkvenik and Sathya Edamadaka!

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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?

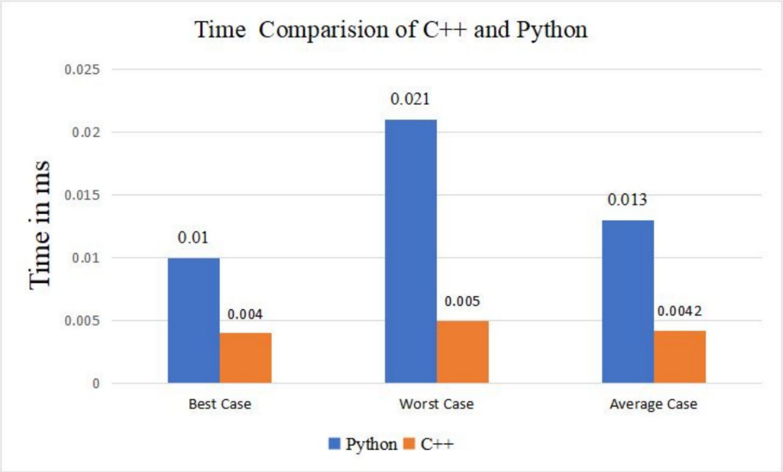

Fig. 13. Comparison of Time Utilization of Deletion Algorithm

C++ Design Philosophy

- Only provide the checks/safety nets that are necessary

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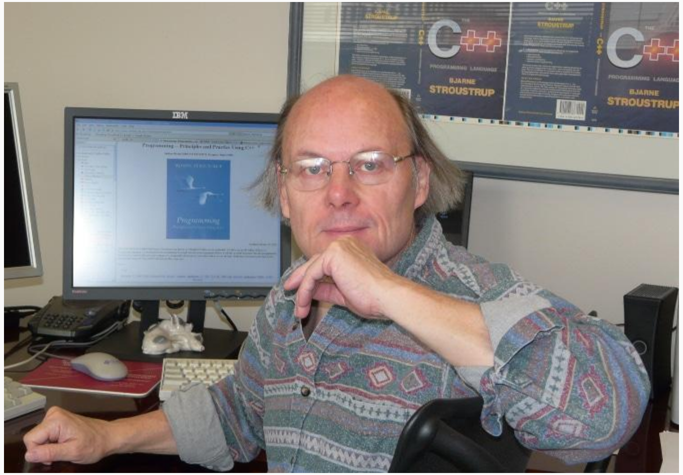

More differences

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);` insert(k)
Remove value **k** from the set	`s.remove(k);`	`s.erase(k);` erase(k)
Check if a value **k** is in the set	`if (s.contains(k)) ...`	`if (s.count(k)) ...` count(k)
Check if vector is empty	`if (vec.isEmpty()) ...`	`if (vec.empty()) ...` empty()

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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Sequence:

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map, set

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Don’t confuse these two!

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

Let's find out!

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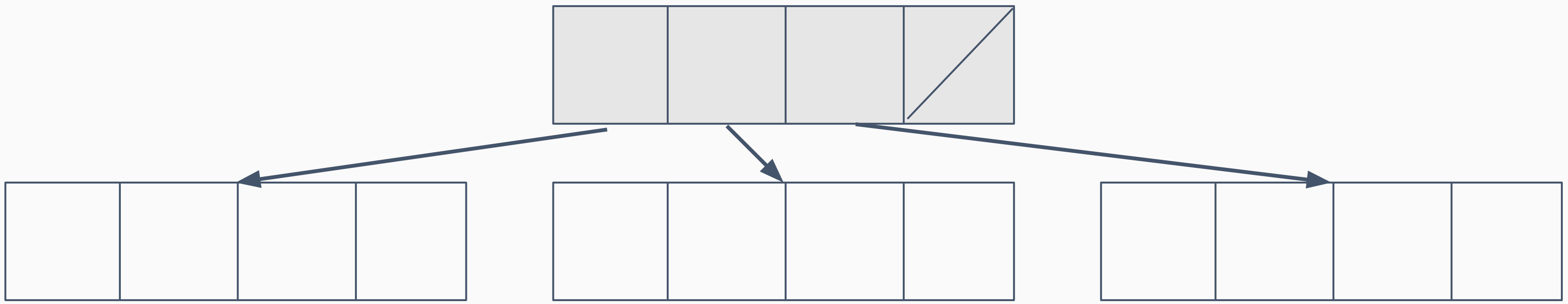

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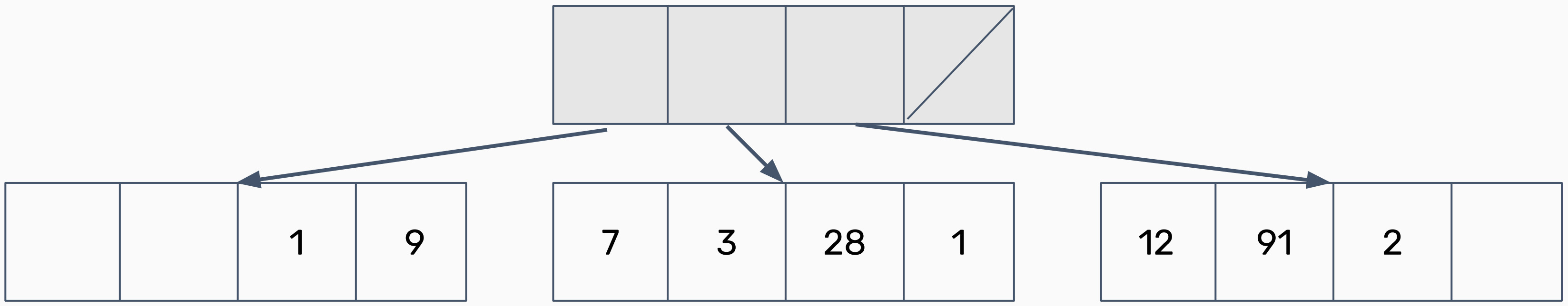

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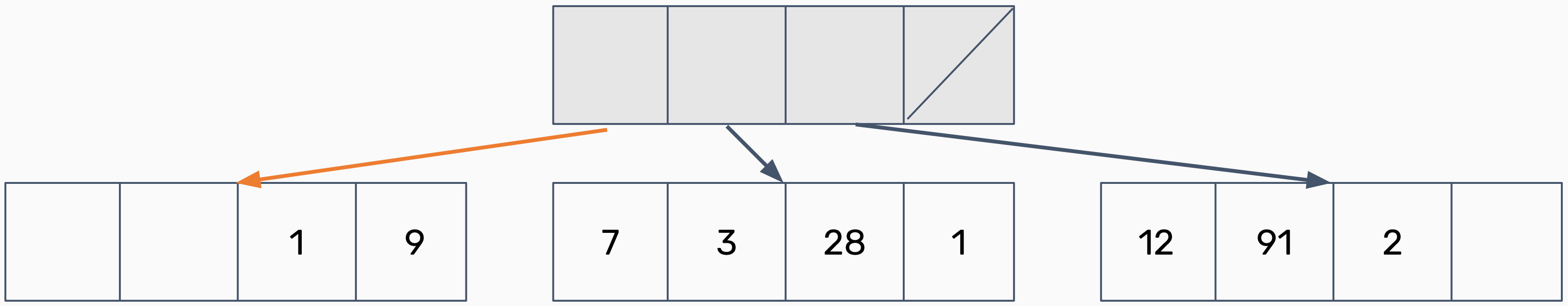

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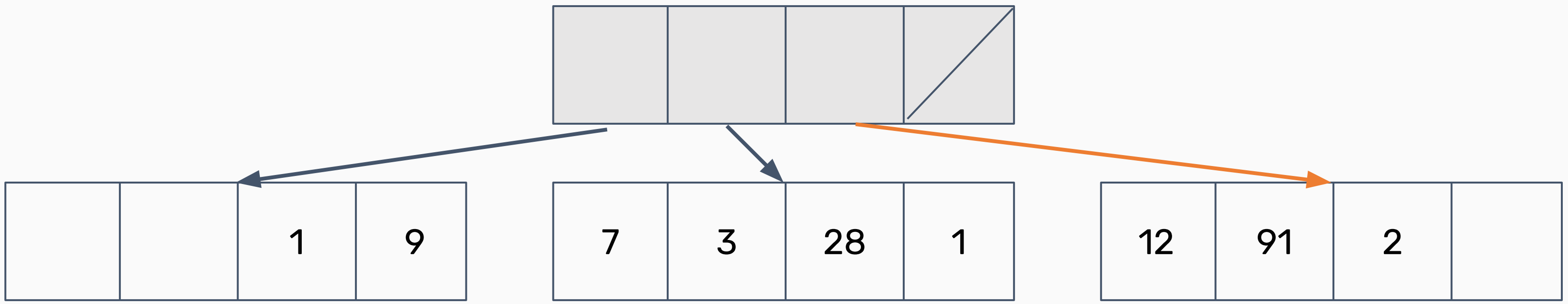

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Choosing sequence containers

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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key → value

- Note the const! Keys must be immutable.
- Why a pair and not a tuple?

Unordered maps/sets

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Unordered maps/sets are usually faster than ordered ones!

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- If using **complicated data types**/unfamiliar with hash functions, use an ordered container

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So far:

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

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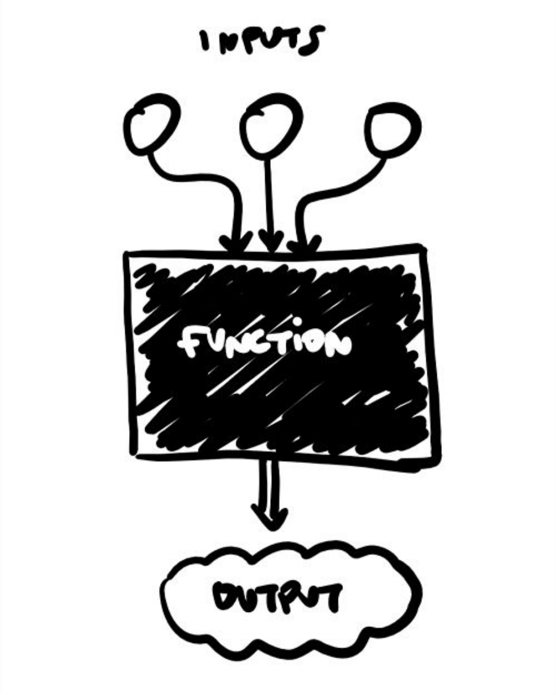

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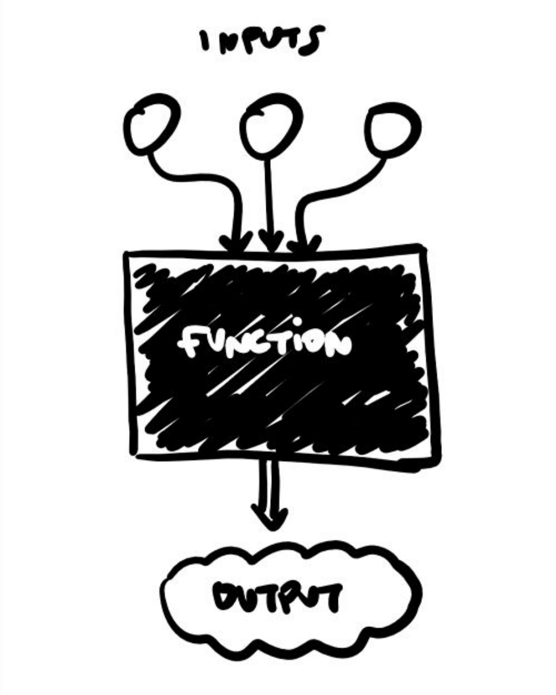
Container Adaptors

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;
```

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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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 $\boxed{\text{shall support at least}}$ the following operations:

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

Containers

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

Let’s ask the STL!

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- `size`
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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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Why?

Abstraction again!

- 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

Containers

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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.

Containers

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Thanks!

Next up: Iterators and Pointers!