CS106L Lecture 8: Template Classes 🎁

Spring 2024

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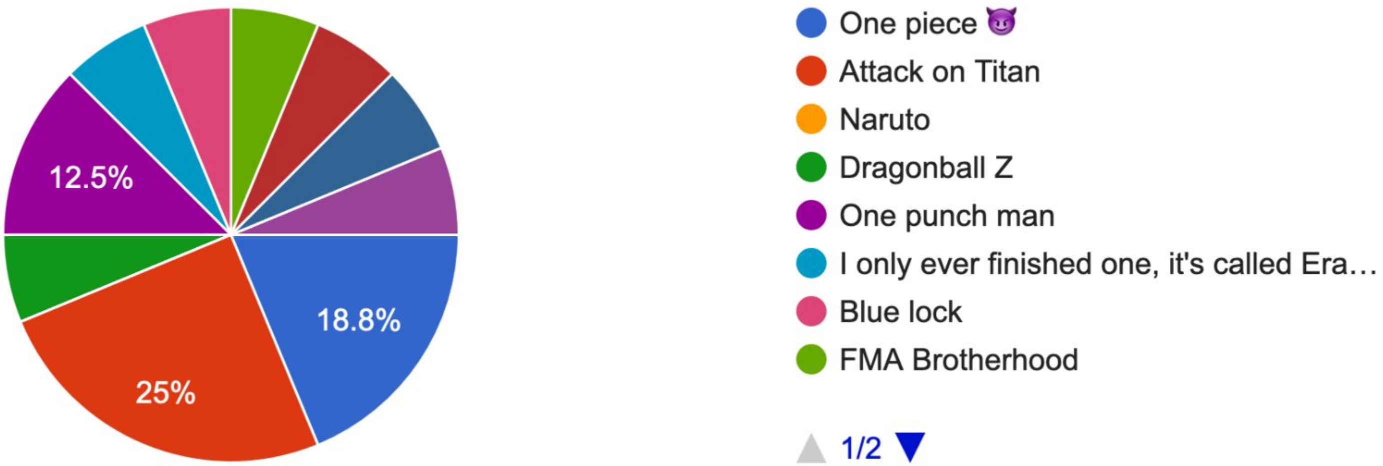
Attendance

Anime!

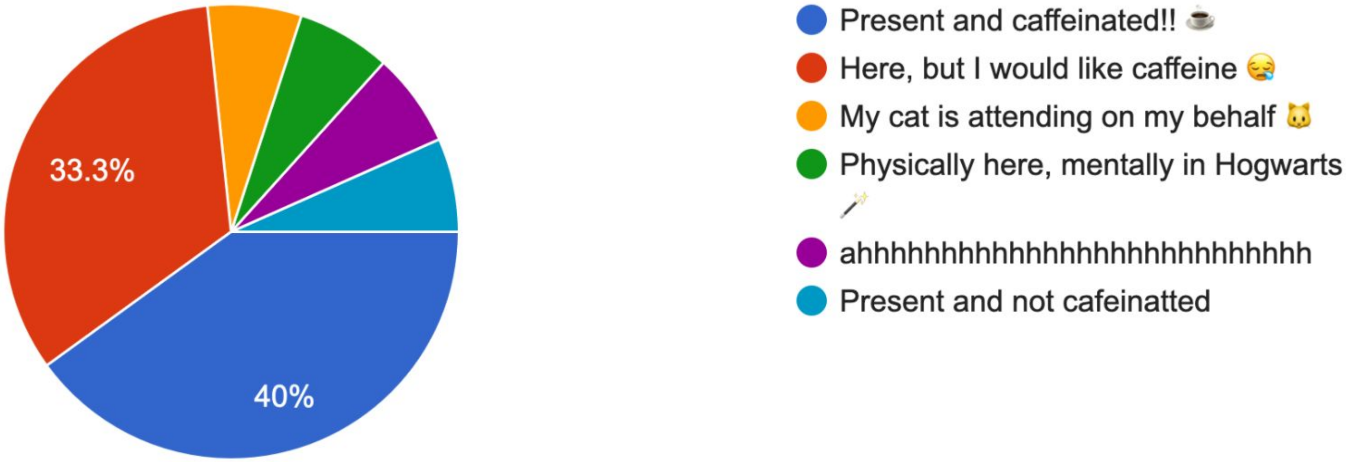
What's your favorite anime? If you don't have a favorite anime, what's your favorite show?

16 responses

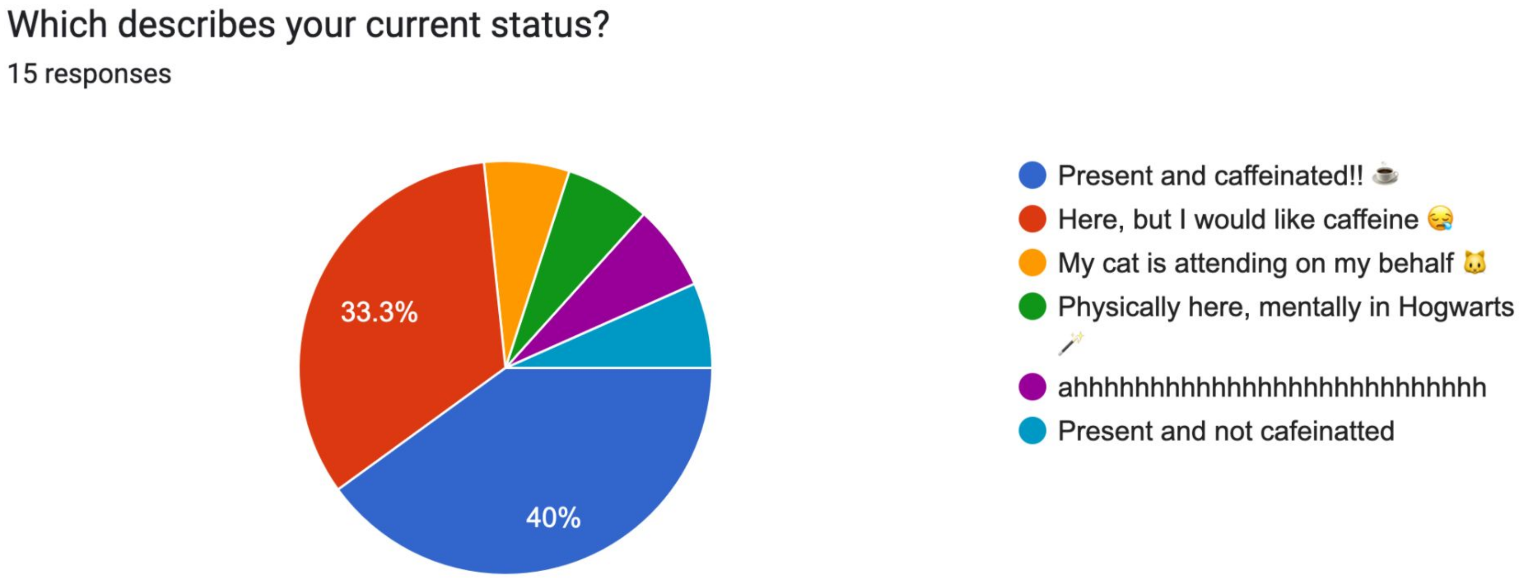


Which describes your current status?

15 responses



People are here!



80% of you are here! 🤗

Plan

1. A quick recap on classes
2. Template classes
3. Const correctness

A `point` on classes

```cpp
class Point {
public:
    Point(int x, int y, std::string color);
    int getX();
    int getY();
    std::string getColor();
    void setX(int x);
    void setY(int y);
    void setColor(std::string color);

private:
    int x;
    int y;
    std::string color;
};
```

```cpp
#include "Point.hh"

Point::Point(int x, int y, const std::string &color) {
  // ?
}
int Point::getX() {
  // ?
}
int Point::getY() {
  // ?
}
std::string Point::getColor() {
  // ?
}
void Point::setX(int x) {
  // ?
}
void Point::setY(int y) {
  // ?
}
void Point::setColor(std::string &color) {
  // ?
}
```

The importance of `this`

```cpp
std::string Point::getColor() {
  return color;
}
```

```cpp
std::string Point::getColor() {
  return this->color;
}
```

The importance of `this`

```cpp
std::string Point::getColor() {
  return color;
}
```

?

```cpp
std::string Point::getColor() {
  return this->color;
}
```

The same

✅

The importance of `this`

```cpp
void Point::setX(int x) {
  x = x;
}
```

```cpp
void Point::setX(int x) {
  this->x = x;
}
```

The importance of `this`

```cpp
void Point::setX(int x) {
  x = x;
}
```

❓

```cpp
void Point::setX(int x) {
  this->x = x;
}
```

Not the same ❌

What C++ thinks about this

In the `setX` function we're changing the member-variable value of `x` based on some passed in value.

What C++ thinks about this

In `getX` we're not modify anything, we're just *getting* some value.

What C++ thinks about this

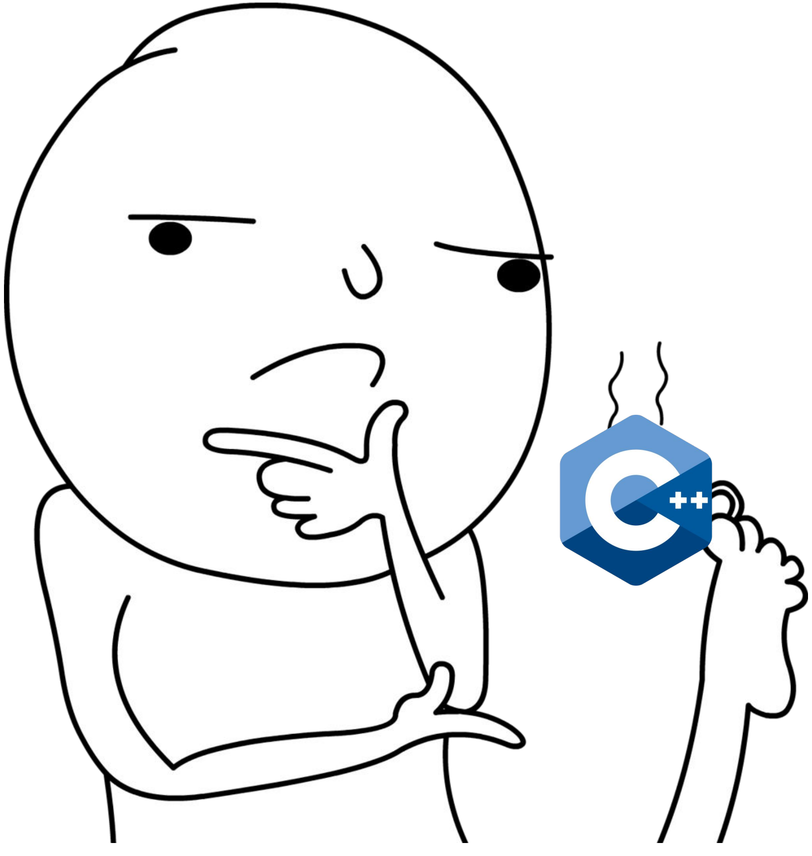
Point.hh

```cpp
class Point {
public:
    Point(int x, int y, std::string color);
    int getX();
    int getY();
    std::string getColor();
    void setX(int x);
    void setY(int y);
    void setColor(std::string color);

private:
    int x;
    int y;
    std::string color;
};
```

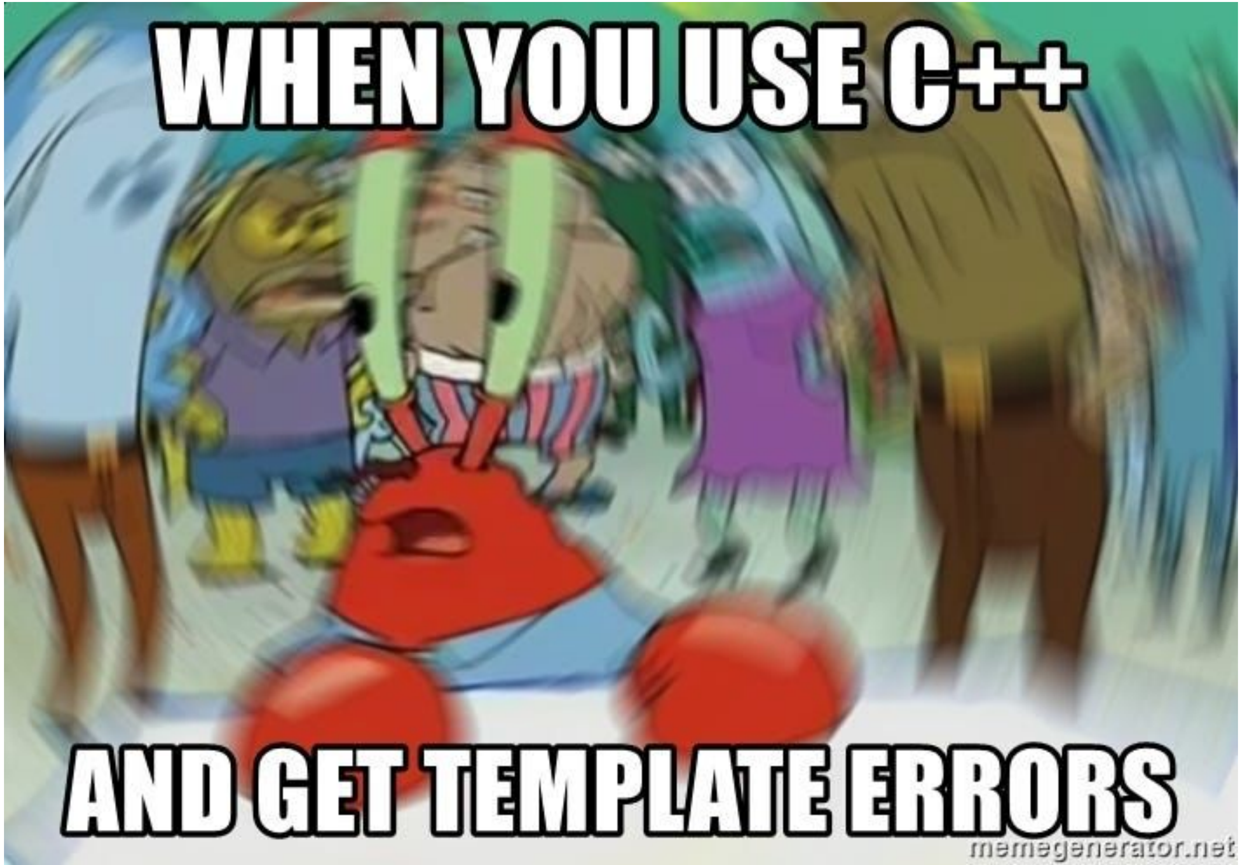
Point.cpp

```cpp
#include "Point.hh"
Point::Point(int x, int y, std::string &color) {
  this->x = x;
  this->y = y;
  this->color = color;
}

int Point::getX() {
  return x;
}

int Point::getY() {
  return y;
}

std::string Point::getColor() {
  return color;
}

void Point::setX(int x) {
  this->x = x;
}

void Point::setY(int y) {
  this->y = y;
}

void Point::setColor(std::string &color) {
  this->color = color;
}
```

What questions do we have?



Template Classes



Plan

1. ~~A quick recap on classes~~
2. Template classes
3. Const correctness

Motivation

You were working at a graphics startup in 1998, and you needed a simple data structure to manage **`Point`** objects.

Wallah, with your knowledge of pointer arithmetic and classes you create this **`PointVector`**:

```
class PointVector {
public:
    // methods for adding, removing, accessing Points
    // take a look at the lecture code if intersted!
private:
    Point* elements;
    int size;
};
```

Motivation

You realized that you also need to keep track of `bool, char, int, short, long, long long, unsigned int, unsigned char, unsigned short, unsigned long, unsigned long long, float, double, long double, std::size_t, ptrdiff_t, int8_t, int16_t, int32_t, int64_t, uint8_t, uint16_t, uint32_t, uint64_t, char16_t, char32_t, wchar_t, void, nullptr, and finally, enum types,`

That's A LOT of types!

Templates entered the chat

Template Class: A class that is parametrized over some number of types; it is comprised of member variables of a general type/types.

TL;DR

Solved!

You realized that you also need to keep track of `bool, char, int, short, long, long long, unsigned int, unsigned char, unsigned short, unsigned long, unsigned long long, float, double, long double, std::size_t, ptrdiff_t, int8_t, int16_t, int32_t, int64_t, uint8_t, uint16_t, uint32_t, uint64_t, char16_t, char32_t, wchar_t, void, nullptr, and finally, enum types,`

That's A LOT of types!

A {template} container .h

```cpp
class IntContainer {
public:
  IntContainer(int val);
  int getValue();

private:
  int value;
};
```

```cpp
template <typename T>
class Container {
public:
  Container (T val);
  T getValue();

private:
  T value;
};
```

A {template} container .h

```cpp
class IntContainer {
public:
  IntContainer(int val);
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private:
  int value;
};
```

Only for `ints`

```cpp
template <typename T>
class Container {
public:
  Container (T val);
  T getValue();

private:
  T value;
};
```

A template

A {template} container .h

```
template <typename T>
```

This is a **template declaration** and allows us to create template classes

```
template <typename T>
class Container {
public:
  Container (T val);
  T getValue();

private:
  T value;
};
```

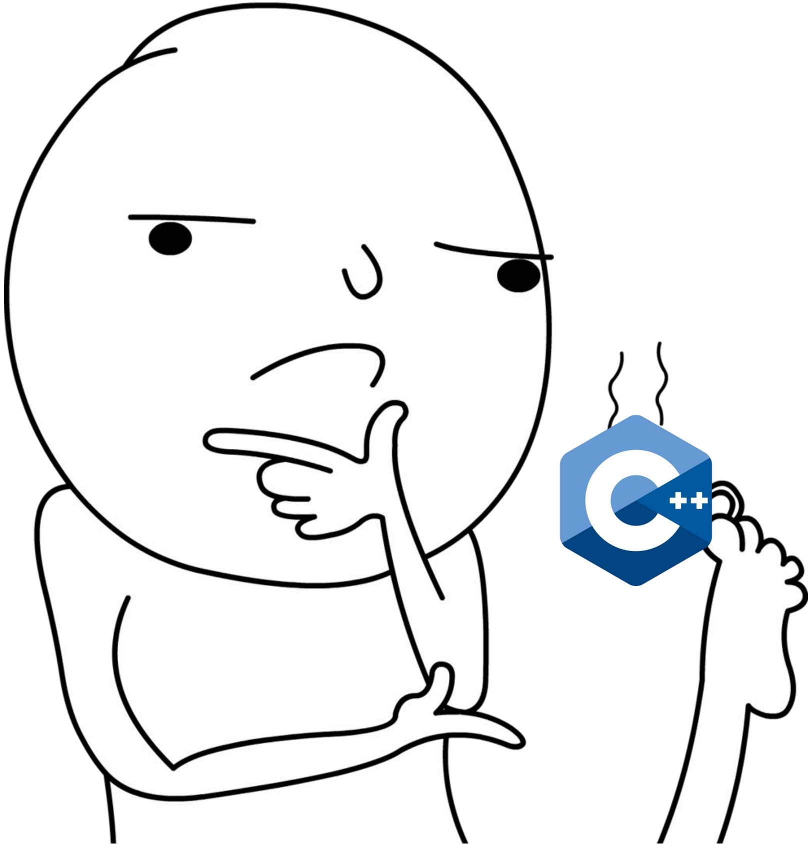
A template

Template declarations

```
template <typename T, typename U>
```

This is a template declaration list which can have various template parameters representing different types.

What questions do we have?



A {template} container .cpp

```cpp
#include "IntContainer.hh"

IntContainer::IntContainer(int val) {
  this->value = val;
}

int IntContainer::getValue() {
  return value;
}
```

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
  this->value = val;
}

template <typename T>
T Container<T>::getValue() {
  return value;
}
```

A {template} container .cpp

```cpp
#include "IntContainer.hh"

IntContainer::IntContainer(int val) {
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int IntContainer::getValue() {
  return value;
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Only for `ints`

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
  this→value = val;
}

template <typename T>
T Container<T>::getValue() {
  return value;
}
```

A template

Template functions

When doing our implementation for our template classes, we need to create **template functions**

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
  this->value = val;
}

template <typename T>
T Container<T>::getValue() {
  return value;
}
```

A template

What’s the difference here?

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
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  return value;
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```

On the right we don’t pass in the template parameter in the class namespace

```cpp
#include "Container.hh"

template <class T>
Container::Container(T val) {
  this->value = val;
}

template <typename T>
T Container::getValue() {
  return value;
}
```

Why is this important? 🤔

C++ wants us to specify our template parameters in our namespace because, based on the parameters our class may behave differently!

Note: there is no "one" Container, there is one for an int, bool, char, etc., there is one for an int, bool, char, etc.

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
  this->value = val;
}

template <typename T>
T Container<T>::getValue() {
  return value;
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```

Why is this important? 🤔

Some syntax stuff

```cpp
template <typename T>
class Container {
public:
  Container (T val);
  T getValue();

private:
  T value;
};
```

class and **type name** are interchangeable in the template declaration list

```cpp
#include "Container.hh"

template <class T>
Container<T>::Container(T val) {
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Another quirk of templates

When making template classes you *need* to **`#include`** the .cpp implementation in the **`.h`** file.

Another quirk of templates

When making template classes you *need* to **`#include`** the .cpp implementation in the **`.h`** file.

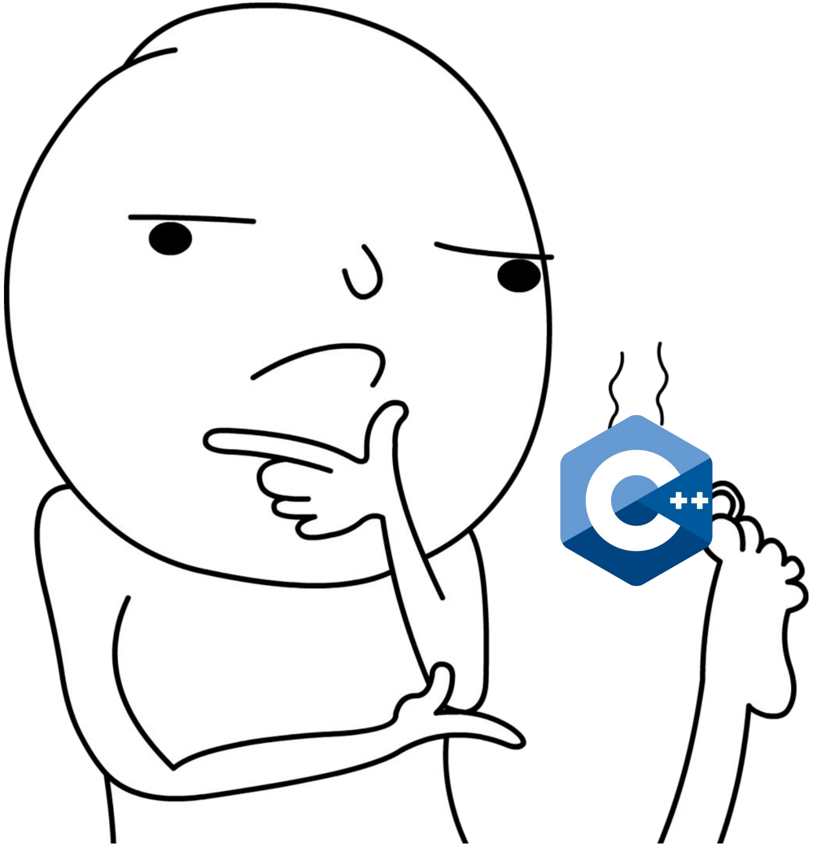
This is a compiler quirk — not super important for this class, but just keep it in mind when working with templates.

Another quirk of templates

```cpp
template <typename T>
class Container {
  public:
    Container(T val);
    T getValue();
  private:
    T value;
}

// must include this!
#include "Container.cpp"
```

What questions do we have?



Plan

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2. ~~Template classes~~
3. Const correctness

Const Correctness!

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We saw a few weeks ago that `const` is a qualifier for objects that states they cannot be changed!

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We saw a few weeks ago that `const` is a qualifier for objects that states they cannot be changed!

But const correctness is much more than that!

Remember our student class

.h file

```
class Student {
Private:
    /// An example of type aliasing
    using String = std::string;
    String name;
    String state;
    int age;

public:
    Student(String name, String state, int age);
    /// Added a ‘setter’ function
    void setName(String name);
    String getName();
    String getState();
    int getAge();
}
```

Remember our student class

.h file

```
std::string stringify(const Student& s){
    return s.getName() + " is " + std::to_string(s.getAge()) +
                                                      " years old." ;
}
```

Remember our student class

main() function

```
std::string stringify(const Student& s){
    return s.getName() + " is " + std::to_string(s.getAge()) +
                                                  " years old." ;
}
//compile error!
```

- By passing in `s` as **`const`** we made a promise to *not* modify `s`.

Remember our student class

main() function

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- The compiler doesn't know whether or not **`getName()`** and **`getAge()`** modify **`s`**

Remember our student class

main() function

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```

- By passing in `s` as **`const`** we made a promise to *not* modify `s`.
- The compiler doesn't know whether or not **`getName()`** and **`getAge()`** modify **`s`**
- Remember, member functions *can* access and modify member variables

Remember our student class

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    String name;
    String state;
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public:
    Student(String name, String state, int age);
    /// Added a 'setter' function
    void setName(String name);
    String getName() const;
    String getState();
    int getAge() const;
}
```

Implemented members

.cpp file (implementation)

```
#include “Student.h”
#include <string>

std::string Student::getName() {
    return this->name;
}

std::string Student::getState() {
    return this->state;
}

int Student::getAge() {
    return this->age;
}
```

Implemented members

.cpp file (implementation)

```
#include "Student.h"
#include <string>

std::string Student::getName() const {
    return this->name;
}

std::string Student::getState() {
    return this->state;
}

int Student::getAge() const {
    return this->age;
}
```

Implemented members

.cpp file (implementation)

```
#include "Student.h"
#include <string>

std::string Student::getName() const {
    return this->name;
}

std::string Student::getState() {
    return this->state;
}

int Student::getAge() const {
    return this->age;
}
```

You also have to make the implementation **`const`**. Otherwise the compiler will scream.

Const interface

Definition:
Objects that are `const` can only interact with the const-interface.

The const interface is simply the functions that are const/do not modify the object/instance of the class.

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In our example:

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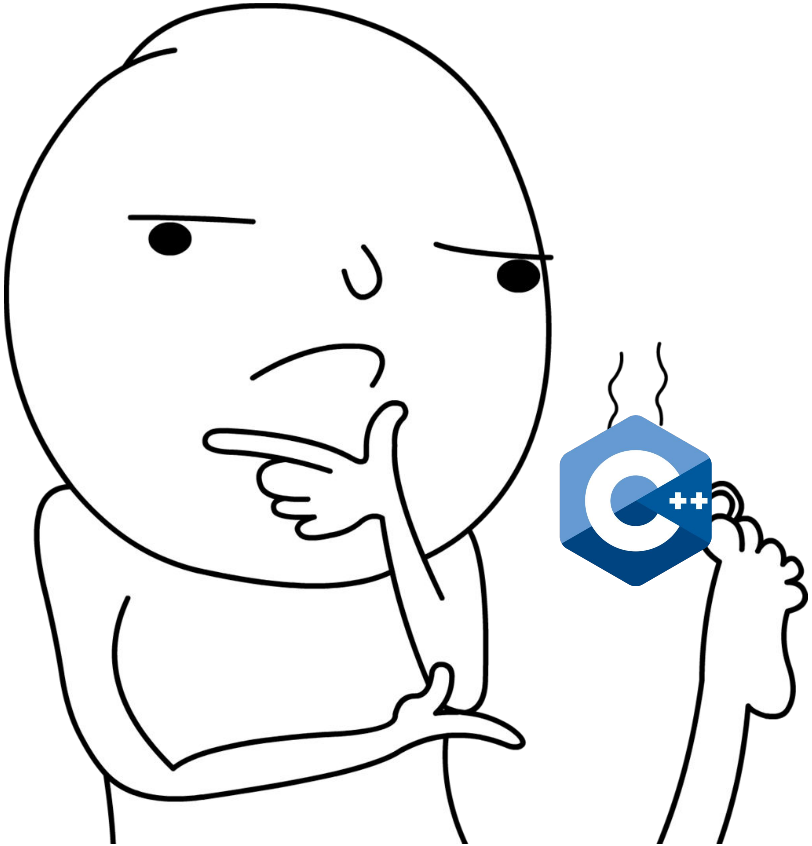
The const interface is simply the functions that are const/do not modify the object/instance of the class.

In our example:

```
std::string stringify(const Student& s){
    return s.getName() + " is " + std::to_string(s.getAge()) +
                                                    " years old." ;
}
```

This works now!

What questions do we have?



A new class **IntArray**

.h file

```
class IntArray {
Private:
    int* _array
    size_t _size

Public:
    // constructor
    IntArray(size_t size);
    ~IntArray();
    int& at(size_t index);
    int size();
}
```

A new class **IntArray**

.cpp file

```
IntArray::IntArray(size_t size) : _size(size), _array(new int[size]);

IntArray::~IntArray() {
    delete [] _array;
}

/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

int size() {
    return this->_size;
}
```

A new class `IntArray`

`main()`

```
#include "IntArray.h"
#include <iostream>

static void printElement(const IntArray& arr, size_t index) {
    std::cout << arr.at(index) << std::endl;
}

int main() {
    IntArray arr = IntArray(10);
    int& secondVal = arr.at(1);
    /// actually changes the value of arr at index '1'.
    secondVal = 19;
    printElement(arr, 1);
    return 0;
}
```

A new class `IntArray`

main()

```
#include "IntArray.h"
#include <iostream>

static void printElement(const IntArray& arr, size_t index) {
    std::cout << arr.at(index) << std::endl;
}

int main() {
    IntArray arr = IntArray(10);
    int& secondVal = arr.at(1);
    /// actually changes the value of arr
    secondVal = 19;
    printElement(arr, 1);
    return 0;
}
```

Anyone see a problem here?

A new class `IntArray`

main()

```
#include “IntArray.h”
#include <iostream>

static void printElement(const IntArray& arr, size_t index) {
    std::cout << arr.at(index) << std::endl;
}

int main() {
    IntArray arr = IntArray(10);
    int& secondVal = arr.at(1);
    /// actually changes the value of arr at index
    secondVal = 19;
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    return 0;
}
```

Hint

A new class IntArray

.cpp file

```
IntArray::IntArray(size_t size) : _size(size), _array(new int[size]);

IntArray::~IntArray() {
    delete [] _array;
}

/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

int size() {
    return this->_size;
}
```

Hint #2

A new class `IntArray`

`main()`

```
#include "IntArray.h"
#include <iostream>

static void printElement(const IntArray& arr, size_t index) {
    std::cout << arr.at(index) << std::endl;
}

int main() {
    IntArray arr = IntArray(10);
    int& secondVal = arr.at(1);
    /// actually changes the value of arr at index `
    secondVal = 19;
    printElement(arr, 1);
    return 0;
}
```

It turns out that we're passing **`arr`** as a constant. What did we say about **`const`** objects?

A new class `IntArray`

main()

```
#include "IntArray.h"
#include <iostream>

static void printElement(const IntArray& arr, size_t index) {
    std::cout << arr.at(index) << std::endl;
}

int main() {
    IntArray arr = IntArray(10);
    int& secondVal = arr.at(1);
    /// actually changes the value of arr at index `
    secondVal = 19;
    printElement(arr, 1);
    return 0;
}
```

const objects must use the const interface.

A new class `IntArray`

.cpp file

```
IntArray::IntArray(size_t size) : _size(size), _array(new int[size]);

IntArray::~IntArray() {
    delete [] _array;
}

/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

int size() {
    return this->_size;
}
```

Our `.at()` function is not const!

A new class `IntArray`

.cpp file

```
IntArray::IntArray(size_t size) : _size(size), _array(new int[size]);

IntArray::~IntArray() {
    delete [] _array;
}

/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

int size() {
    return this->_size;
}
```

Ok. What do we do?
Any ideas? 🤔

A new class `IntArray`

.cpp file

```
IntArray::IntArray(size_t size) : _size(size), _array(new int[size]);

IntArray::~IntArray() {
    delete [] _array;
}

/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

int size() {
    return this->_size;
}
```

Ok. What do we do?
Any ideas? 🤔

A new class `IntArray`

.cpp file

```
Other member functions
. . . . .
/// assumes that index is valid
int& at(size_t index) {
    return _array[index];
}

/// we can make a const version
int& at(size_t index) const {
    return _array[index];
}
```

We can create a const version of our `.at()`

A new class `IntArray`

.cpp file

```
Other member functions
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```

This might be slightly painful though

A new class `IntArray`

.cpp file

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Other member functions
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int& at(size_t index) {
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```

In this example we only have to rewrite a function that has one line of code

A new class `IntArray`

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}
```

What if we had another function that we needed a const version of like this

A new class **IntArray**

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}
const int& findItem(int value) const {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}
```

Like sure. We *could* do this, but the level of pain/annoying scales linearly with the length of the function

A slight (but useful) aside

Casting:
The process of converting types, there are many ways to do this.

A slight (but useful) aside

Casting:
The process of converting types, there are many ways to do this.

const_cast:

- **`const_cast<`*`target-type`*`> ( expression )`**
- We can use **`const_cast`** to cast away **`const`**-ness.
- So why is this useful?

A new class `IntArray`

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

Less pain here

A new class `IntArray`

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

This is dense though, let's break this down

A new class **IntArray**

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

The **const_cast** is casting away the **const**

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.cpp file

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int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
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    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
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}
```

This text here is the key this is our target. A non-const reference

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.cpp file

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    for (auto& elem: arr) {
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    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

What in the bjarne is this?

A new class **IntArray**

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

this is really a pointer.

A new class IntArray

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(value)
}
```

Here we're dereferencing **this** so that we can cast it as non-const.

A new class **IntArray**

.cpp file

```
int& findItem(int value) {
    for (auto& elem: arr) {
        if (elem == value) return elem;
    }

    throw std::out_of_range("value not found")
}

const int& findItem(int value) const {
    /// one-liners ftw :)
    return const_cast<IntArray&>(*this).findItem(val
}
```

1. Cast so that it is pointing to a non-const object
2. Call the non-const version of the function (this is legal now)
3. Then cast the non-const return from the function call to a const version

What questions do we have?