



Template Classes + Const Correctness

How do we make our classes general? How do we make them safe?

Attendance

bit.ly/446GZRK



CS 106B covers the barebones of C++ classes... we'll be covering the rest

**template classes • const-correctness • operator
overloading • special member functions • move semantics •**

RAII

**This lecture is incredibly
important for assn 2
But also very dense so ask
questions and we may use
the full time block**

Today



- **Classes Recap**
- Template Classes
- Const Correctness

Turning Student into a class: Header File

//student.h

```
class Student {  
    public:  
        std::string getName();  
        void setName(string  
            name);  
        int getAge();  
        void setAge(int age);  
  
    private:  
        std::string name;  
        std::string state;  
        int age;  
};
```

Public section:

- Users of the Student object can directly access anything here!
- Defines an **interface** for interacting with the private member variables!

Private section:

- Usually contains all member variables
- Users can't access or modify anything in the private section

Turning Student into a class: Header File + .cpp File

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```
class Student {  
    public:  
        std::string getName();  
        void setName(string  
name);  
        int getAge();  
        void setAge(int age);  
  
    private:  
        std::string name;  
        std::string state;  
        int age;  
};
```

//student.cpp

```
#include student.h  
std::string Student::getName() {  
    //implementation here!  
}  
  
void Student::setName() {  
}  
  
int Student::getAge() {  
}  
  
void Student::setAge (int age) {  
}
```

//student.cpp

```
#include student.h
std::string Student::getName() {
    return name; //we can access name here!
}
void Student::setName(std::string name) {
    name = name; //huh?
}
int Student::getAge() {

}
void Student::setAge(int age) {

}
```

//student.h

```
class Student {
    public:
        std::string getName();
        void setName(string
name);
        int getAge();
        void setAge(int age);

    private:
        std::string name;
        std::string state;
        int age;
};
```


The **this** keyword!

- Here, we mean “set the Student private member variable `name` equal to the parameter `name`”
- `this->element_name` means “the item in this Student object with name *element_name*”.
Use **this** for resolving naming conflicts!

```
void Student::setName(string name) {  
    this->name = name; //better!  
}
```



What if the object has member variables?

If we need to access a pointer's object's member variables,
instead of dereferencing (`*ptr`) and then accessing (`.var`),
there's a shorthand!

`(*ptr).var == ptr->var`

`this` is a pointer (`Student *`) to a `Student` object. Deference the pointer (`*this`) to get the actual object and then access the object's name private member variable
(`*this`).name = name; or `this->name = name;`

```
}  
void Student::setName(string name) {  
    this->name = name; //resolved!  
}  
  
int Student::getAge() {  
    return age;  
}  
  
void Student::setAge(int age) {  
    //We can define what "age" means!  
    if(age >= 0) {  
        this -> age = age;  
    }  
    else error("Age cannot be negative!");  
}
```

//student.h

```
class Student {  
    public:  
        std::string getName();  
        void setName(string  
            name);  
        int getAge();  
        void setAge(int age);  
  
    private:  
        std::string name;  
        std::string state;  
        int age;  
};
```

//student.cpp

```
#include student.h

std::string Student::getName() {
    return name; //we can access name here!
}

void Student::setName(string name) {
    this->name = name; //resolved!
}

int Student::getAge() {
    return age;
}

void Student::setAge(int age) {
    //We can define what "age" means!
    if(age >= 0) {
        this -> age = age;
    }
    else error("Age cannot be negative!");
}
```

//student.h

```
class Student {
    public:
        std::string getName();
        void setName(string
name);
        int getAge();
        void setAge(int age);

    private:
        std::string name;
        std::string state;
        int age;
};
```

Questions?

Today



- ~~Classes Recap~~
- **Template Classes**
- Const Correctness

The problem with StrVector

- Vectors should be able to contain any data type!

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Solution? Create IntVector, DoubleVector, BoolVector etc..

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Solution? Create IntVector, DoubleVector, BoolVector etc..

- What if we want to make a vector of `Students`?
 - How are we supposed to know about every custom class?
- What if we don't want to write a class for every type we can think of?

The problem with StrVector

- Vectors should be able to contain any data type!

~~Solution? Create IntVector, DoubleVector, BoolVector etc..~~

- What if we want to make a vector of `Students`?
 - How are we supposed to know about every custom class?
- What if we don't want to write a class for every type we can think of?

SOLUTION: Template classes!

Definition

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

A simpler class: My Int Pair (so specific)

```
//myintpair.h
```

```
class MyPair {  
    public:  
        int getFirst();  
        int getSecond();  
  
        void setFirst(int f);  
        void setSecond(int f);  
    private:  
        int first;  
        int second;  
};
```

Can only hold ints :(

Writing a Template Class: Syntax

//mypair.h

```
template<typename First, typename Second> class MyPair {  
    public:  
        First getFirst();  
        Second getSecond();  
  
        void setFirst(First f);  
        void setSecond(Second f);  
    private:  
        First first;  
        Second second;  
};
```

Generic! First and Second can be any type (including custom types) not just ints 😊

Use generic typename as placeholders!

Implementing a Template Class: Syntax

```
//mypair.cpp
```

```
#include "mypair.h"
```

```
First MyPair::getFirst() {  
    return first;  
}
```

Implementing a Template Class: Syntax

```
//mypair.cpp
```

```
#include "mypair.h"
```

```
First MyPair::getFirst() {  
    return first;  
}
```

```
//Compile error! Must announce every member function is templated :/
```

Implementing a Template Class: Syntax

//mypair.cpp

```
#include "mypair.h"
```

```
template<class First, typename Second>
```

```
First MyPair::getFirst(){
```

```
    return first;
```

```
}
```

```
// So are we good now????
```


Implementing a Template Class: Syntax

//mypair.cpp

```
#include "mypair.h"
```

```
template<class First, typename Second>
```

```
First MyPair::getFirst(){
```

```
    return first;
```

```
}
```

//Compile error! The namespace of the class isn't just MyPair

Implementing a Template Class: Syntax

//mypair.cpp

```
#include "mypair.h"
```

```
template<class First, typename Second>  
First MyPair<First, Second>::getFirst() {  
    return first;  
}
```

```
// Fixed!
```

Implementing a Template Class: Syntax

Template Function




```
template<class First, typename Second>  
First MyPair<First, Second>::getFirst() {  
    return first;  
}  
  
// Fixed!
```

Implementing a Template Class: Syntax

Template
Function

class and typename
interchangeable



```
template<class First, typename Second>
First MyPair<First, Second>::getFirst() {
    return first;
}
// Fixed!
```

Implementing a Template Class: Syntax

Template
Function

class and typename
interchangeable

List of template variables

```
template<class First, typename Second>
First MyPair<First, Second>::getFirst() {
    return first;
}
// Fixed!
```

C++ reference is like 10% less scary now!

std::vector

Defined in header `<vector>`

```
template<
    class T,
    class Allocator = std::allocator<T>
> class vector;
```

Less scary. Just saying
that vector is a template
class with 2 parameters

(1)

```
namespace pmr {
    template< class T >
    using vector = std::vector<T, std::pmr::polymorphic_allocator<T>>;
}
```

Still scary

17)

- 1) `std::vector` is a sequence container that encapsulates dynamic size arrays.
- 2) `std::pmr::vector` is an alias template that uses a `polymorphic allocator`.

Screenshot from: <https://en.cppreference.com/w/cpp/container/vector>

Questions?

Member Types

- Sometimes, we need a name for a type that is dependent on our template types
- Recall: iterators

```
std::vector<int> a = {1, 2};  
std::vector<int>::iterator it = a.begin();
```


Member Types

- Sometimes, we need a name for a type that is dependent on our template types
- Recall: iterators

```
std::vector<int> a = {1, 2};  
std::vector<int>::iterator it = a.begin();
```

- iterator is a **member type** of vector

Member Types: Syntax

```
//vector.h
template<typename T> class vector {
    public:
        using iterator = T*    // something internal like T*

        iterator begin();
}
```

Member Types: Syntax

//vector.h

```
template<typename T> class vector {  
    public:  
    using iterator = T*    // something internal like T*  
  
    iterator begin();  
}
```

//vector.cpp

```
template <typename T>  
iterator vector<T>::begin() {...}  
  
//compile error! Why?
```

Member Types: Syntax

//vector.h

```
template<typename T> class vector {  
    public:  
        using iterator = T*    // something internal like T*  
  
        iterator begin();  
}
```

//vector.cpp

```
template <typename T>  
iterator vector<T>::begin() {...}  
//iterator is a nested type in namespace vector<T>::
```

Member Types: Syntax

//vector.h

```
template<typename T> class vector {  
    public:  
    using iterator = T*    // something internal like T*  
  
    iterator begin();  
}
```

//vector.cpp

```
template <typename T>  
typename vector<T>::iterator vector<T>::begin() {...}
```

Aside: Type Aliases

- You can use `using type_name = type` in application code as well!
- When using it in a class interface, it defines a nested type, like `vector::iterator`
- When using it in application code, like `main.cpp`, it just creates another name for `type` within that scope (until the next unmatched `}`)

Member Types: Summary

- Used to make sure your clients have a standardized way to access important types.
- Lives in your namespace: **vector<T>::iterator**.
- After class specifier, you can use the alias directly (e.g. inside function arguments, inside function body).
- Before class specifier, use **typename**.

realVector.cpp

No more “this is the simplified version of the real thing”... We are writing the real thing (just a little simplified :p)

Recap: Template classes

- Add `template<class T1, T2..>` before class definition in .h

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- Add `template<class T1, T2..>` before class definition in .h
- Add `template<class T1, T2..>` before all function signatures in .cpp
- When returning nested types (like iterator types), put `typename ClassName<T1, T2..>::member_type` as return type, not just `member_type`

Recap: Template classes

- Add `template<class T1, T2..>` before class definition in .h
- Add `template<class T1, T2..>` before all function signatures in .cpp
- When returning nested types (like iterator types), put `typename ClassName<T1, T2..>::member_type` as return type, not just `member_type`
- Templates don't emit code until instantiated, so `#include` the .cpp file in the .h file, not the other way around!

Questions?

Today



- ~~— Finish StrVector~~
- ~~— Template Classes~~
- **Const Correctness**

Const and Const References

Definition

`const`: keyword
indicating a variable,
function or parameter
can't be modified

`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);
```

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

`const` variables can be references or not!

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

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vec.push_back(3);    // OKAY  
c_vec.push_back(3);  // BAD - const  
ref.push_back(3);  
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vec.push_back(3);    // OKAY  
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vec.push_back(3);    // OKAY  
c_vec.push_back(3);  // BAD - const  
ref.push_back(3);    // OKAY  
c_ref.push_back(3);  // BAD - const
```

Why const?

Why const? Find the typo in this code

```
void f(int x, int y) {  
    if ( (x==2 && y==3) || (x==1) )  
        cout << 'a' << endl;  
  
    if ( (y==x-1) && (x==-1 || y=-1) )  
        cout << 'b' << endl;  
  
    if ( (x==3) && (y==2*x) )  
        cout << 'c' << endl;  
}
```

Why const? Find the typo in this code

```
void f(const int x, const int y) {  
    if ( (x==2 && y==3) || (x==1) )  
        cout << 'a' << endl;  
    if ( (y==x-1) && (x==-1 || y=-1) )  
        cout << 'b' << endl;  
    if ( (x==3) && (y==2*x) )  
        cout << 'c' << endl;  
}
```


Const and Classes

Recall: Student class

//student.h

```
class Student {  
    public:  
        std::string getName();  
        void setName(string name);  
        int getAge();  
        void setAge(int age);  
  
    private:  
        std::string name;  
        std::string state;  
        int age;  
};
```

//student.cpp

```
#include student.h
std::string Student::getName() {
    return name; //we can access name here!
}
void Student::setName(string name) {
    this->name = name; //resolved!
}
int Student::getAge() {
    return age;
}
void Student::setAge(int age) {
    //We can define what "age" means!
    if(age >= 0) {
        this -> age = age;
    }
    else error("Age cannot be negative!");
}
```

//student.h

```
class Student {
    public:
        std::string getName();
        void setName(string
name);
        int getAge();
        void setAge(int age);

    private:
        std::string name;
        std::string state;
        int age;
};
```

Using a const Student

//main.cpp

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

Using a const Student

//main.cpp

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

//compile error!

Using a const Student

//main.cpp

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

//compile error!

- The compiler doesn't know getName and getAge don't modify s!

Using a const Student

```
//main.cpp
```

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

```
//compile error!
```

- The compiler doesn't know getName and getAge don't modify s!
- We need to promise that it doesn't by defining them as **const functions**

Using a const Student

//main.cpp

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

//compile error!

- The compiler doesn't know getName and getAge don't modify s!
- We need to promise that it doesn't by defining them as **const functions**
- Add const to the **end** of function signatures!

Making Student const-correct

//student.cpp

```
#include student.h
std::string Student::getName()const{
    return name;
}
void Student::setName(string name){
    this->name = name;
}
int Student::getAge()const{
    return age;
}
void Student::setAge(int age){
    if(age >= 0){
        this -> age = age;
    }
    else error("No Negative Age!");
}
```

//student.h

```
class Student {
    public:
        std::string getName() const;
        void setName(string name);
        int getAge() const;
        void setAge(int age);

    private:
        std::string name;
        std::string state;
        int age;
};
```

Definition

const-interface: All member functions marked `const` in a class definition. Objects of type `const ClassName` may only use the const-interface.

Using a const Student

//main.cpp

```
std::string stringify(const Student& s){  
    return s.getName() + " is " + std::to_string(s.getAge()) +  
        " years old." ;  
}  
  
// With our new const-interface, this will work :)
```

Making StrVector's const-interface

```
class StrVector {
public:
    using iterator = std::string*;
    const size_t kInitialSize = 2;
    /*...*/
    size_t size();
    bool empty();
    void push_back(const std::string& elem);
    std::string& at(size_t indx); // like vec[] but with error checking

    iterator begin();
    iterator end();
    /*...*/
};
```

Making StrVector's const-interface

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class StrVector {  
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    using iterator = std::string*;  
    const size_t kInitialSize = 2;  
    /*...*/  
    size_t size();  
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    void push_back(const std::string& elem,  
        std::string& at(size_t indx); // like vec[] but with error checking  
  
    iterator begin();  
    iterator end();  
    /*...*/  
};
```

Questions to ask:

- 1.) Should this function be able available to a const object?
 - a.) Can I mark the function const as is (i.e. the function doesn't modify the object)?
 - b.) Otherwise, can I make a const version of the function?

Making StrVector's const-interface

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class StrVector {  
public:  
    using iterator = std::string*;  
    const size_t kInitialSize = 2;  
    /*...*/  
    size_t size();  
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    iterator begin();  
    iterator end();  
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 - b.) Otherwise, can I make a const version of the function?

Making StrVector's const-interface

```
class StrVector {  
public:    size_t StrVector::size() {  
        using      return logicalSize;  
        const      }  
        /*...*/
```

```
→ size_t size();  
    bool empty();  
    void push_back(const std::string& elem);  
    std::string& at(size_t indx); // like vec[] but with error checking  
  
    iterator begin();  
    iterator end();  
    /*...*/
```

Questions to ask:

- 1.) Should this function be able available to a const object?
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Making StrVector's const-interface

```
class StrVector {
public:
    using iterator = std::string*;
    const size_t kInitialSize = 2;
    /*...*/
    size_t size() const;
    bool empty();
    void push_back(const std::string& elem);
    std::string& at(size_t indx); // like vec[] but with error checking

    iterator begin();
    iterator end();
    /*...*/
}
```


Making StrVector's const-interface

```
class StrVector {  
public: bool StrVector::empty() {  
    return size() == 0;  
};  
size_t size() const;  
→ bool empty();  
void push_back(const std::string& elem);  
std::string& at(size_t indx); // like vec[] but with error checking  
  
iterator begin();  
iterator end();  
/*...*/
```

Questions to ask:

- 1.) Should this function be able available to a const object?
 - a.) Can I mark the function const as is (i.e. the function doesn't modify the object)?
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Making StrVector's const-interface

```
class StrVector {
public:
    using iterator = std::string*;
    const size_t kInitialSize = 2;
    /*...*/
    size_t size() const;
    → bool empty() const;
    void push_back(const std::string& elem);
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    iterator begin();
    iterator end();
    /*...*/
}
```

Making StrVector's const-interface

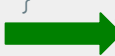
```
class StrVector {
public:
    using iterator = std::string*;
    const size_t kInitialSize = 2;
    /*...*/
    size_t size() const;
    bool empty() const;
    void push_back(const std::string& elem);
    std::string& at(size_t indx); // like vec[] but with error checking

    iterator begin();
    iterator end();
    /*...*/
}
```

Questions to ask:

- 1.) Should this function be able available to a const object?
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 - b.) Otherwise, can I make a const version of the function?

```
void StrVector::push_back(const std::string& elem)
{
    if (allocatedSize == size()) {
        grow();
    }
    *end() = elem;
    logicalSize++;
    // not empty (// const,
```



```
void push_back(const std::string& elem);
std::string& at(size_t indx); // like vec[] but with error checking
```

```
iterator begin();
iterator end();
/*...*/
```

Making StrVector's const-interface

```
class StrVector {  
public:  
    using iterator = std::string*;  
    const size_t kInitialSize = 2;  
    /*...*/  
    size_t size() const;  
    bool empty() const;  
    void push_back(const std::string& elem);  
    → std::string& at(size_t indx); // like vec[] but with error checking  
  
    iterator begin();  
    iterator end();  
    /*...*/  
};
```

Questions to ask:

- 1.) Should this function be able available to a const object?
 - a.) Can I mark the function const as is (i.e. the function doesn't modify the object)?
 - b.) Otherwise, can I make a const version of the function?

Making StrVector's const-interface

```
std::string& StrVector::at(size_t index)  {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

```
void push_back(const std::string& elem);
```

➡ `std::string& at(size_t indx);` // like `vec[]` but with error checking

```
iterator begin();
```

```
iterator end();
```

```
/*...*/
```

Making StrVector's const-interface

```
std::string& StrVector::at(size_t index)  {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[] (index); // operator[] = return *(begin() + index)  
}
```

```
void push_back(const std::string& elem);
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➡ `std::string& at(size_t indx);` // like `vec[]` but with error checking

```
iterator begin();  
iterator end();  
/*...*/
```

Seems like **at** doesn't modify the vector...
can we just mark `at` const like we did with
the other functions?

Making StrVector's const-interface

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std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
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void push_back(const std::string& elem);
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➡ `std::string& at(size_t indx);` // like `vec[]` but with error checking

```
iterator begin();  
iterator end();  
/*...*/
```

Seems like **at** doesn't modify the vector...
can we just mark **at** const like we did with
the other functions?

NO

const-interface

Problem: `at` returns a reference to an element in the vector. That element reference could be modified (thereby modifying the vector).

```
public:
    using iterator = std::string*;
    const size_t kInitialSize = 2;
    /*...*/
    size_t size() const;
    bool empty() const;
    void push_back(const std::string& elem);
    std::string& at(size_t indx); // like vec[] but with error checking
```

```
iterator begin();
iterator end();
/*...*/
```

const-interface

Problem: `at` returns a reference to an element in the vector. That element reference could be modified (thereby modifying the vector).

Example

```
// StrVector my_vec = {"sarah", "haven"};
std::string& elem_ref = my_vec.at(1);
elem_ref = "Now I'm Different";
// my_vec = {"sarah", "Now I'm Different"}
m);
```

➡ `std::string& at(size_t indx);` // like `vec[]` but with error checking

```
iterator begin();
iterator end();
/*...*/
```

Making StrVector's const-interface

```
class StrVector {  
public:  
    using iterator = std::string*;  
    const size_t kInitialSize = 2;  
    /*...*/  
    size_t size() const;  
    bool empty() const;  
    void push_back(const std::string& elem),  
    → std::string& at(size_t indx); // like vec[] but with error checking  
    const std::string& at(size_t indx) const;  
  
    iterator begin();  
    iterator end();  
    /*...*/  
};
```

Questions to ask:

- 1.) Should this function be able available to a const object?
 - a.) Can I mark the function const as is (i.e. the function doesn't modify the object)?
 - b.) Otherwise, can I make a const version of the function?

You might be tempted to do this...

DON'T DO THIS!!!!!!!!!!!!

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

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```
const std::string& StrVector::at(size_t index) const {  
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std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index);  
}
```

This is bad because you are **reimplementing the same logic multiple times** (i.e. copy-pasting). This **makes code harder to maintain** and is more **bug-prone** 😞

DON'T DO THIS!!!!!!!!!!!!

```
const std::string& StrVector::at(size_t index) const {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

DON'T DO THIS!!!!!!!!!!!!

Key Idea: Don't reimplement logic unnecessarily

DO THIS!

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

DO THIS!

DO THIS!

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));  
}
```

Key Idea: Don't reimplement logic unnecessarily

DO THIS!

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

DO THIS!

DO THIS!

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_ca  
}
```

This fancy static_cast/const_cast trick allows us to reuse the non-const version to implement the const version! YAY! 🎉💖👏🥳

Let's break down this incredibly dense line

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

1. Casts **this** (i.e. the current object) from **const StrVector*** to **StrVector*** (i.e. removes the const)

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));
```


ense line

```
void printidx2(const StrVector& const_vec) {  
    cout << "Item: " << const_vec.at(2) << endl;  
}  
  
int main(){ // omitted return 0 for space  
    StrVector myVec;  
    myVec.push_back("Sarah");  
    myVec.push_back("Haven");  
    printidx2(myVec);  
}
```

```
in at.");
```

```
*(begin() + index)
```

1. Casts **this** (i.e. the current object) from **const StrVector*** to **StrVector*** (i.e. removes the const)

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));
```

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```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[] (index); // operator[] = return *(begin() + index)  
}
```

2. Calls the non-const version of `at` on `this` (remember `this` is now a `StrVector*`)

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));
```



Let's break down this incredibly dense line

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range in at.");  
    }  
    return operator[](index); // operator[] = return *(begin() + index)  
}
```

3. Casts the return of `at` from **`std::string&`** to a **`const std::string&`**

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));
```

Let's break down this incredibly dense line

```
std::string& StrVector::at(size_t index) {  
    if (index >= size()) {  
        throw std::out_of_range("Index out of range");  
    }  
    return operator[](index); // operator[] =  
}
```

In general, this fancy `static_cast/const_cast` trick allows us to reuse the non-const version to implement the const version! YAY! 🧡👏🎉

The idea is to

1. Cast this (i.e. the current object, which in this situation is const) so it's pointing to a non-const object
2. Call the non-const version of the function
3. And then cast the non-const return from the function call to a const version

```
const std::string& StrVector::at(size_t index) const {  
    return static_cast<const  
std::string&>(const_cast<StrVector*>(this)->at(index));
```

Aside: static_cast and const_cast

- **static_cast<new-type>(expression);**
 - Used to convert from one type to another
 - Example: `int my_int = static_cast<int>(3.1);`
 - CANNOT BE USED WHEN conversion would cast away constness

Aside: `static_cast` and `const_cast`

- **`static_cast<new-type>(expression);`**
 - Used to convert from one type to another
 - Example: `int my_int = static_cast<int>(3.1);`
 - CANNOT BE USED WHEN conversion would cast away constness
- **`const_cast<new-type>(expression);`**
 - `const_cast` can be used to cast away (remove) constness
 - Allows you to make non-const pointer or reference to const-object

```
const int const_int = 3;
```

```
int& my_int = const_cast<int&>(const_int);
```

Making StrVector's const-interface

```
class StrVector {  
public:  
    using iterator = std::string*;  
    const size_t kInitialSize = 2;  
    /*...*/  
    size_t size() const;  
    bool empty() const;  
    void push_back(const std::string& elem);  
    std::string& at(size_t indx); // like vec[] but with error checking  
    const std::string& at(size_t indx) const;  
  
    → iterator begin();  
    iterator end();  
    /*...*/  
};
```

Should `begin()` **and** `end()` **be**
`const`?

Consider a function with a `const StrVector` param...

```
void printVec(const StrVector& vec) {  
    cout << "{ ";  
    for(auto it = vec.begin(); it != vec.end(); ++it) {  
        cout << *it << endl;  
    }  
    cout << " }" << endl;  
}
```

These seem like reasonable
calls! Let's mark them `const`.
What could go wrong? :)

Consider a function with a `const StrVector` param...

```
void printVec(const StrVector& vec) {  
    cout << "{ ";  
    for(auto it = vec.begin(); it != vec.end(); ++it) {  
        *it = "dont mind me modifying a const vector :D";  
    }  
    cout << " }" << endl;  
}
```

This code will compile!
begin() and end() don't
explicitly change vec, but
they give us an iterator that
can!

Consider a function with a const StrVector param...

```
void printVec(const StrVector& vec) {  
    cout << "{ ";  
for(auto it = vec.begin(); it != vec.end(); ++it){  
    *it = "dont mind me modifying a const vector :D";  
}  
    cout << " }" << endl;  
}
```

Problem: we need a way to
iterate through a const vec
just to access it

Solution: const_iterator









```
class StrVector {  
public:  
    using iterator = std::string*;  
    using const_iterator = const std::string*;  
    /*...*/  
    size_t size() const;  
    bool empty() const;  
    /*...*/  
    void push_back(const std::string& elem);  
    const std::string& at(size_t indx) const;  
    iterator begin();  
    iterator end();  
    const_iterator begin() const;  
    const_iterator end() const;  
    /*...*/  
};
```

Consider a function with a const StrVector param...

```
void printVec(const StrVector& vec) {  
    cout << "{ ";  
    for(auto it = vec.begin(); it != vec.end(); ++it) {  
        *it = "HELLO"; //compile error!  
    }  
    cout << " }" << endl;  
}
```

Fixed! And now we can't set
*it equal to something: it
will be a compile error!

Abilities of Iterator Permutations

Iterator Type	Increment Iterator?	Change underlying value?
<code>iterator</code>		
<code>const_iterator</code>		
<code>const iterator</code>		
<code>const const_iterator</code>		

const iterator vs const_iterator: Nitty Gritty

```
using iterator = std::string*;  
using const_iterator = const std::string*;
```

```
const iterator it_c = vec.begin(); //string * const, const ptr to non-const obj  
*it_c = "hi"; //OK! it_c is a const pointer to non-const object  
it_c++; //not ok! can't change where a const pointer points!
```

const iterator vs const_iterator: Nitty Gritty

```
using iterator = std::string*;
using const_iterator = const std::string*;
```

```
const iterator it_c = vec.begin(); //string * const, const ptr to non-const obj
*it_c = "hi"; //OK! it_c is a const pointer to non-const object
it_c++; //not ok! can't change where a const pointer points!
```

```
const_iterator c_it = vec.begin(); //const string*, a non-const ptr to const obj
c_it++; // totally ok! The pointer itself is non-const
*c_it = "hi" // not ok! Can't change underlying const object
cout << *c_it << endl; //allowed! Can always read a const object, just can't change
```


const iterator vs const_iterator: Nitty Gritty

```
using iterator = std::string*;
using const_iterator = const std::string*;
```

```
const iterator it_c = vec.begin(); //string * const, const ptr to non-const obj
*it_c = "hi"; //OK! it_c is a const pointer to non-const object
it_c++; //not ok! can't change where a const pointer points!
```

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const_iterator c_it = vec.begin(); //const string*, a non-const ptr to const obj
c_it++; // totally ok! The pointer itself is non-const
*c_it = "hi" // not ok! Can't change underlying const object
cout << *c_it << endl; //allowed! Can always read a const object, just can't change
```

```
//const string * const, const ptr to const obj
const const_iterator c_it_c = vec.begin();
cout << c_it_c << " points to " << *c_it_c << endl; //only reads are allowed!
c_it_c++; //not ok! can't change where a const pointer points!
*c_it_c = "hi" // not ok! Can't change underlying const object
```

realVector.cpp


No more “this is the simplified version of the real thing”... We are writing the real thing (just a little simplified :p)

Recap: Const and Const-correctness

- Use const parameters and variables wherever you can in application code
- Every member function of a class that doesn't change its member variables should be marked **const**
- **Don't reinvent the wheel! Use our fancy static_cast/const_cast trick to use the non-const version to implement a const version of a function**
- **auto** will drop all const and &, so be sure to specify
- Make iterators and const_iterators for all your classes!

Recap: Template classes

- Add `template<class T1, T2..>` before class definition in `.h`
- Add `template<class T1, T2..>` before all function signatures in `.cpp`
- When returning nested types (like iterator types), put `typename ClassName<T1, T2..>::member_type` as return type, not just `member_type`
- Templates don't emit code until instantiated, so `#include` the `.cpp` file in the `.h` file, not the other way around!



An unintuitive (at first!) bug

(if time)



The Takeaway

**Templates don't emit
code until instantiated,
so include the .cpp in the
.h instead of the other
way around!**

A compile error....

```
// vector.h
template <typename T>
class vector<T> {
    T& at(int i);
};
```

```
// vector.cpp
#include "vector.h"
template <typename T>
T& vector<T>::at(int i) {
    // oops
}
```

```
// main.cpp
#include "vector.h"
vector<int> a;
a.at(5);
```

A compile error....

```
// vector.h
template <typename T>
class vector<T> {
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```

```
// vector.cpp
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T& vector<T>::at(int i) {
    // oops
}
```

```
// main.cpp
#include "vector.h"
vector<int> a;
a.at(5);
```


What the C++ compiler does with **non-template** classes

```
// main.cpp
#include "vectorint.h"
vectorInt a;
a.at(5);
```

1. `g++ -c vectorint.cpp main.cpp`: Compile and create all the code in `vectorint.cpp` and `main.cpp`. All the functions in `vectorint.h` have implementations that have been compiled now, and `main` can access them because it included `vectorint.h`

What the C++ compiler does with **non-template** classes

```
// main.cpp
#include "vectorint.h"
vectorInt a;
a.at(5);
```

1. `g++ -c vectorint.cpp main.cpp`: Compile and create all the code in `vectorint.cpp` and `main.cpp`. All the functions in `vectorint.h` have implementations that have been compiled now, and `main` can access them because it included `vectorint.h`
2. “Oh look she used `vectorInt::at`, sure glad I compiled all that code and can access `vectorInt::at` right now!”

What the C++ compiler does with **template** classes

```
// main.cpp
#include "vector.h"
vector a;
a.at(5);
```

1. `g++ -c vector.cpp main.cpp`: Compile and create all the code in `main.cpp`. Compile `vector.cpp`, but since it's a template, don't create any code yet.

What the C++ compiler does with **template** classes

```
// main.cpp
#include "vector.h"
vector a;
a.at(5);
```

1. `g++ -c vector.cpp main.cpp`: Compile and create all the code in `main.cpp`. Compile `vector.cpp`, but since it's a template, don't create any code yet.
2. "Oh look she made a `vector<int>`! Better go generate all the code for one of those!"

What the C++ compiler does with **template** classes

```
// main.cpp
#include "vector.h"
vector a;
a.at(5);
```

1. `g++ -c vector.cpp main.cpp`: Compile and create all the code in `main.cpp`. Compile `vector.cpp`, but since it's a template, don't create any code yet.
2. "Oh look she made a `vector<int>`! Better go generate all the code for one of those!"
3. "Oh no! All I have access to is `vector.h`! There's no implementation for the interface in that file! And I can't go looking for `vector<int>.cpp`!"

The fix...

```
// vector.h
template <typename T>
class vector<T> {
    T& at(int i);
};
```

```
// vector.cpp
#include "vector.h"
template <typename T>
T& vector<T>::at(int i) {
    // oops
}
```

```
// main.cpp
#include "vector.h"
vector<int> a;
a.at(5);
```

Include vector.cpp in vector.h!

```
// vector.h  
#include "vector.cpp"  
template <typename T>  
class vector<T> {  
    T& at(int i);  
};
```

```
// vector.cpp
```

```
template <typename T>  
T& vector<T>::at(int i) {  
    // oops  
}
```

```
// main.cpp
```

```
#include "vector.h"  
vector<int> a;  
a.at(5);
```

What the C++ compiler does with template classes

```
// main.cpp
#include "vector.h"
vector<int> a;
a.at(5);
```

1. “Oh look she included vector.h! That’s a template, **I’ll wait to link the implementation until she instantiates a specific kind of vector**”
2. “Oh look she made a vector<int>! Better go generate all the code for one of those!”
3. “vector.h includes all the code in vector.cpp, which tells me how to create a vector<int>::at function :)”

The Takeaway

**Templates don't emit
code until instantiated,
so include the .cpp in the
.h instead of the other
way around!**

Practice with Template Classes!

- Implement Vector yourself!
- We got you started with some basic functionality but you can write many more methods including: [insert](#), [erase](#), [pop_back](#). See [documentation](#) for notes about functionality



Thanks for coming!

Next time: Template Functions

