

CS106L Lecture 12:

Special Member Functions

Autumn 2024

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Attendance (👻🎃)



<https://tinyurl.com/smfsF24>

First thing is first

Happy Halloween :)



Not to scare you 😈

Not to scare you 😊

🎉 But, we want you to pass this class! 🎉

A kind reminder

1. You **must** successfully complete **six out of seven assignments**.
2. You are allowed to **miss 2 of the 13** required lectures without penalty. Week 1 does not require attendance.

Today's Agenda

1. Recap
2. Special Member Functions
 - An overview
 - Copy and copy assignment
 - default and delete
 - Move and move assignment

Today's Agenda

1. Recap

2. Special Member Functions

- An overview
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- Move and move assignment

Non-member overloading

Non-member Operator Overloading

```
bool operator< (const StudentID& lhs, const StudentID& rhs);
```

Member Operator Overloading

```
bool StudentID::operator< (const StudentID& rhs) const {...}
```


Hello friend!

Non-member Operator Overloading

```
bool operator< (const StudentID& lhs, const StudentID& rhs);
```

The **friend** keyword allows non-member functions or classes to access private information in another class!

How do you use friend?

In the header of the target class you declare the operator overload function as a friend

So why is this even meaningful?

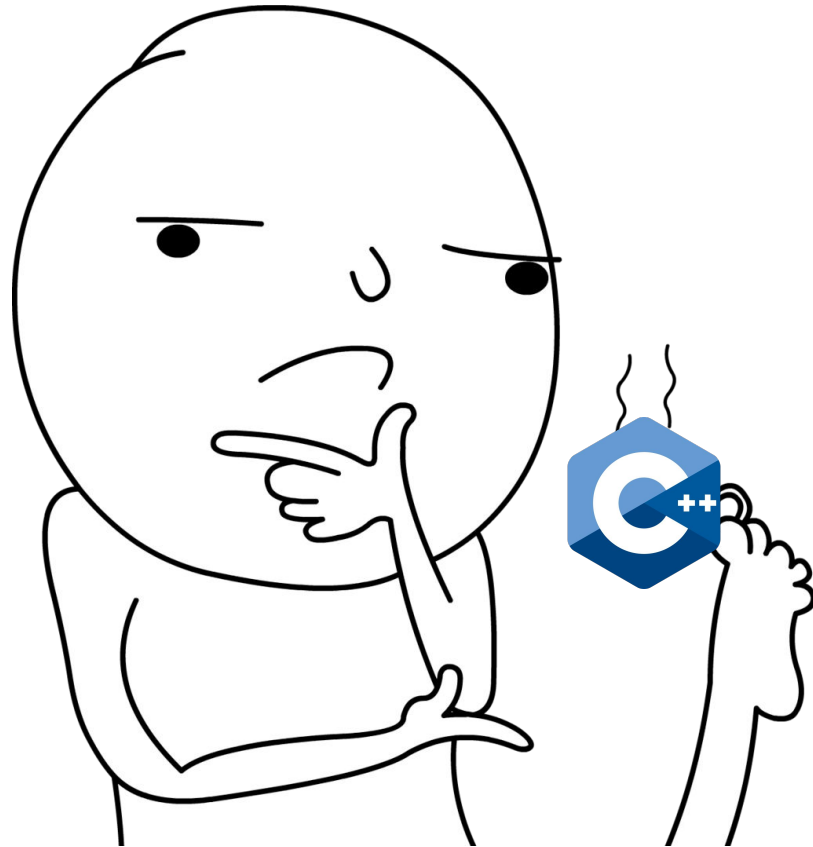
- There are many operators that you can define in C++ like we saw

+ - * / % ^ & | ~ ! , = < > <= >=
++ -- << >> == != && || += -= *=
/= %= ^= &= |= <<= >>= [] () ->
->* new new[] delete delete[]

A pattern

We're really diving *deep* into class design

What questions do we have?



Today's Agenda

1. Recap

2. Special Member Functions

- **An overview**
- Copy and copy assignment
- default and delete
- Move and move assignment

You may remember

Classes have

1. Constructor

2. Destructor

3. 🎉 Surprise 🎉, these are called **Special Member Functions**

4. **(SMFs)**

A **constructor** is called every time a new instance of the class is created, and the **destructor** is called when it goes out of scope

The Special 6 SMFs

These functions are generated only when they're called (and before any are explicitly defined by you):

- Default constructor: `T()`
- Destructor: `~T()`
- Copy constructor: `T(const T&)`
- Copy assignment operator: `T& operator=(const T&)`
- Move constructor: `T(T&&)`
- Move assignment operator: `T& operator=(T&&)`

Lets look at Widget :)

```
class Widget {  
    public:  
        Widget();                // default constructor  
        Widget (const Widget& w); // copy constructor  
        Widget& operator = (const Widget& w); // copy assignment operator  
        ~Widget();              // destructor  
        Widget (Widget&& rhs);    // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
}
```


There are 6 special member functions!

```
class Widget {  
    public:  
    Widget();                // default constructor  
    Widget (const Widget& w); // copy constructor  
    Widget& operator = (const Widget& w); // copy assignment operator  
    ~Widget();              // destructor  
    Widget (Widget&& rhs);    // move constructor  
    Widget& operator = (Widget&& rhs); // move assignment operator  
}
```

Takes no parameters and
creates a new object

There are 6 special member functions!

```
class Widget {  
    public:  
        Widget(); // default constructor  
        Widget (const Widget& w); // copy constructor  
        Widget& operator = (const Widget& w); // copy assignment operator  
        ~Widget(); // destructor  
        Widget (Widget&& rhs); // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
}
```

Creates a new object as a member-wise copy of another

When is the copy assignment operator invoked?

```
Widget widgetOne;  
Widget widgetTwo = widgetOne; // Copy constructor is called
```

There are 6 special member functions!

```
class Widget {  
    public:  
        Widget();                // default constructor  
        Widget (const Widget& w); // copy constructor  
        Widget& operator = (const Widget& w); // copy assignment operator  
        ~Widget();              // destructor  
        Widget (Widget&& rhs);    // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
};
```

Assigns an already existing object to another

When is the copy assignment operator invoked?

```
Widget widgetOne;  
Widget widgetTwo;  
widgetOne = widgetTwo
```

Note that here both objects are constructed before the use of the = operator

Copy Constructor vs Assignment Operator

Copy Constructor Invocation

```
Widget widgetOne;  
Widget widgetTwo = widgetOne;
```

Copy Assignment Operator Invocation

```
Widget widgetOne;  
Widget widgetTwo;  
widgetOne = widgetTwo
```

There are 6 special member functions!

```
class Widget {  
    public:  
        Widget();                // default constructor  
        Widget (const Widget& w); // copy constructor  
        Widget& operator = (const Widget& w); // copy assignment operator  
        ~Widget();              // destructor  
        Widget (Widget&& rhs);    // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
};
```

Called when the object goes
out of scope

There are 6 special member functions!

```
class Widget {  
    public:  
        Widget();                // default constructor  
        Widget (const Widget& w); // copy constructor  
        Widget& operator = (const Widget& w); // copy assignment operator  
        ~Widget();              // destructor  
        Widget (Widget&& rhs);    // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
}
```

We have an entire lecture
on these – not the focus of
today

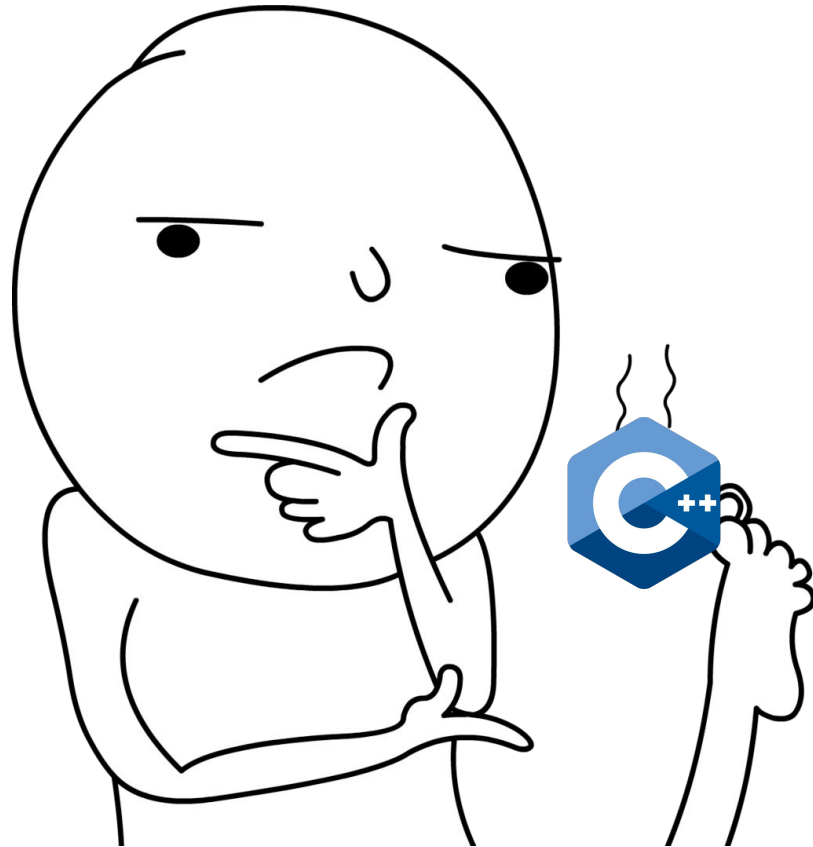
There are 6 special member functions!

```
class Widget {  
    public:  
        Widget();  
        Widget (const Widget& w);  
        Widget& operator = (const Widget& w);  
        ~Widget();  
        Widget (Widget&& rhs);  
        Widget& operator = (Widget&& rhs);  
}
```

We don't have to write out any of these! They all have default versions that are generated automatically!

```
// destructor  
// move constructor  
// move assignment operator
```

What questions do we have?



Today's Agenda

1. Recap

2. Special Member Functions

- An overview
- **Copy and copy assignment**
- default and delete
- Move and move assignment

Review: initialization

Remember our Vector from lecture 8?

```
template <typename T>
Vector<T>::Vector()
{
    _size = 0;
    _capacity = 4;
    _data = new T[_capacity];
}
```

When we create a constructor, we need to initialize all of our member variables.

Review: initialization

```
template <typename T>
Vector<T>::Vector()
{
    _size = 0;
    _capacity = 4;
    _data = new T[_capacity];
}
```

However, initializing them to be the default value and then reassigning is inefficient!



```
template <typename T>
Vector<T>::Vector()
{
    _size = 0;
    _capacity = 4;
    _data = new T[_capacity];
}
```

There are two steps
happening here

Step 1

```
template <typename T>
Vector<T>::Vector()
{
    _size = 0;
    _capacity = 4;
    _data = new T[_capacity]
}
```

There are two steps happening here: the first is that `_size`, `_capacity`, and `_data` may have been assigned a default variable

Step 2

```
template <typename T>  
Vector<T>::Vector()  
{  
    _size = 0;  
    _capacity = 4;  
    _data = new T[_capacity];  
}
```

Assignment to the variables,
which effectively doubles the
work.

Initializer Lists

```
template <typename T>  
Vector<T>::Vector() : _size(0), _capacity(4), _data(new  
T[_capacity]) { }
```

We can use **initializer lists** to declare and initialize them with desired values at once!

Initializer Lists

- It's quicker and more efficient to directly construct member variables with intended values
- What if the variable is a non-assignable type?
- Can be used for any constructor, even non-default ones with parameters!

```
template <typename T>  
Vector<T>::Vector() : _size(0), _capacity(4), _data(new  
T[_capacity]) { }
```

What if the variable is a non-assignable type?

```
template <typename T>
class MyClass {
    const int _constant;
    int& _reference;

public:
    // Only way to initialize const and reference members
    MyClass(int value, int& ref) : _constant(value),
    _reference(ref) { }
};
```

- This code **only** works with initializer lists
- Why? 🤔

Why should we override SMFs?

The compiler gives them to us for free.....?

- a. By default, the copy constructor will create copies of each member variable

This is **member-wise** copying!

Is this always good enough?

Consider Pointers

If your variable is a pointer, a memberwise copy will point to the same allocated data, not a fresh copy!

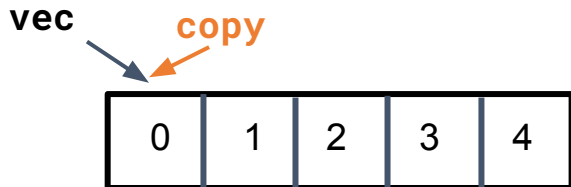
```
template <typename T>
Vector<T>::Vector<T>(const Vector<T>& other) :
    _size(other._size), _capacity(other._capacity),
    _data(other._data) { }
```

These pointers will point at the same underlying array!

Consider Pointers

If your variable is a pointer, a memberwise copy will point to the same allocated data, not a fresh copy!

```
template <typename T>
Vector<T>::Vector<T>(const Vector<T>& other) :
    _size(other._size), _capacity(other._capacity),
    _data(other._data) { }
```

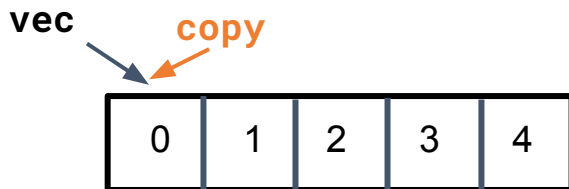


These pointers will point at the same underlying array!

Consider Pointers

If your variable is a pointer, a memberwise copy will point to the same allocated data, not a fresh copy!

```
template <typename T>
Vector<T>::Vector<T>(const Vector<T>& other) :
    _size(other._size), _capacity(other._capacity),
    _data(other._data) { }
```



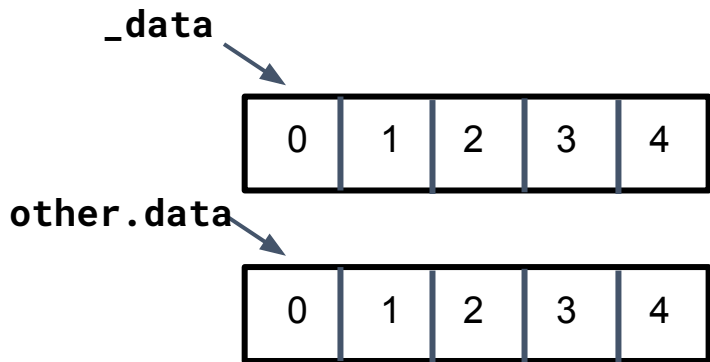
This is problematic because anything done to one pointer affects the other

Copying isn't always so simple!

- Many times, you will want to create a copy that does more than just copies the member variables.
- Deep copy: an object that is a complete, **independent** copy of the original
- In these cases, you'd want to override the default special member functions with your own implementation!
- Declare them in the header and write their implementation in the `.cpp`, like any function!

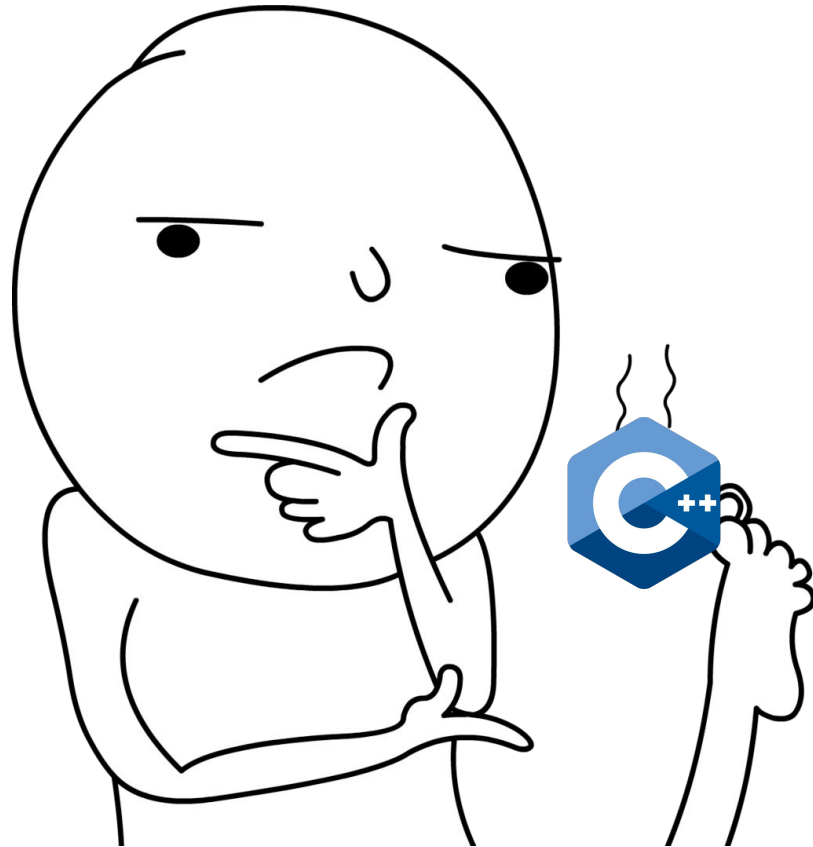
Fixing the pointer issue

```
Vector<T>::Vector(const Vector<T>& other)
    : _size(other._size), _capacity(other._capacity), _data(new
T[other._capacity]) {
    for (size_t i = 0; i < _size; ++i) {
        _data[i] = other._data[i];
    }
}
```



Now we have a “deep” copy
of the data in our Vector.

What questions do we have?



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1. Recap

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- An overview
- Copy and copy assignment
- **default and delete**
- Move and move assignment

How do you prevent copies?

Let's say you have a class that handles all of your passwords:

```
class PasswordManager {  
    public:  
        PasswordManager();  
        ~PasswordManager();  
        // other methods ...  
        PasswordManager(const PasswordManager& rhs);  
        PasswordManager& operator = (const PasswordManager& rhs);  
  
    private:  
        // other important members ...  
}
```



We can delete special member functions

Setting a special member function to **delete** removes its functionality!

```
class PasswordManager {  
    public:  
        PasswordManager();  
        PasswordManager(const PasswordManager& pm);  
        ~PasswordManager();  
        // other methods ...  
        PasswordManager(const PasswordManager& rhs) = delete;  
        PasswordManager& operator = (const PasswordManager& rhs) = delete;  
  
    private:  
        // other important members ...  
}
```

We can delete special member functions

Setting a special member function to **delete** removes its functionality!

```
class PasswordManager {  
    public:  
        PasswordManager();  
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        ~PasswordManager();  
        // other methods ...  
        PasswordManager(const PasswordManager& rhs) = delete;  
        PasswordManager& operator = (const PasswordManager& rhs) = delete;  
  
    private:  
        // other important members ...  
}
```

Now copying isn't a possible operation!

Why?

We can selectively allow functionality of special member functions!

- This has lots of uses – what if we only want one copy of an instance to be allowed?
- This is how classes like `std::unique_ptr` work

You may see this in `cppreference` which specifies this!

The class satisfies the requirements of *MoveConstructible* and *MoveAssignable*, but of neither *CopyConstructible* nor *CopyAssignable*.

default

We can also keep the default copy constructor if we declare other constructors!

```
class PasswordManager {  
    public:  
        PasswordManager();  
        PasswordManager(const PasswordManager& pm) = default;  
        ~PasswordManager();  
        // other methods ...  
        PasswordManager(const PasswordManager& rhs) = delete;  
        PasswordManager& operator = (const PasswordManager& rhs) = delete;  
  
    private:  
        // other important members ...  
}
```

Declaring any user-defined constructor will make the default, compiler produced one, disappear without this!

Philosophy time



Rule of Zero

If the default SMFs work, **don't define your own!**

We should only define new ones when the default ones generated by the compiler won't work.

- This usually happens when we work with dynamically allocated memory, like pointers to things on the heap!

Rule of Zero

If you don't need a constructor or a destructor or copy assignment etc. Then simply don't use it!

If your class relies on objects/classes that already have these SMFs implemented, then there's no need to reimplement this logic!

```
class a_string_with_an_id() {  
    public:  
        /// getter and setter methods for our private variables  
    private:  
        int id;  
        std::string str;  
}  
a_string_with_an_id object;
```

Our class
a_string_with_an_id has self
managing variables.

Rule of Zero

If you don't need a constructor or a destructor or copy assignment etc. Then simply don't use it!

If your class relies on objects/classes that already have these SMFs implemented, then there's no need to reimplement this logic!

```
class a_string_with_an_id() {  
    public:  
        /// getter and setter methods for our private variables  
    private:  
        int id;  
        std::string str;  
}  
a_string_with_an_id object;
```

std::string **already** has copy constructor, copy assignment, move constructor, and move assignment!

Rule of Three

If you need a custom destructor, then you also probably **need** to define a copy constructor and a copy assignment operator for your class

Why is this the case?

If you use a destructor, that often means that you are manually dealing with dynamic memory allocation/are generally just handling your own memory.

If this is the case:

The compiler will not be able to automatically generate these for you, because of the manual memory management.

Recap

The four special member functions discussed so far:

- **Default Constructor**
 - Object created with no parameters, no member variables instantiated
- **Copy Constructor**
 - Object created as a copy of existing object (member variable-wise)
- **Copy Assignment Operator**
 - Existing object replaced as a copy of another existing object.
- **Destructor**
 - Object destroyed when it is out of scope.

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

What type of operation or function is each of these lines?

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Default Constructor

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

**Custom constructor,
not SMF**

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

**Uniform initialization,
not an SMF**

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Tricky, this is a
function definition

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Copy Constructor

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

**Default initialization –
initializer list is empty**

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

List initialization

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Copy constructor

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Copy assignment
operator

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Copy constructor

Pop Quiz

```
vector<int> func(vector<int> vec0) {  
    vector<int> vec1;  
    vector<int> vec2(3);  
    vector<int> vec3{3};  
    vector<int> vec4();  
    vector<int> vec5(vec2);  
    vector<int> vec6{};  
    vector<int> vec7{static_cast<int>(vec2.size() + vec6.size())};  
    vector<int> vec8 = vec2;  
    vec8 = vec2;  
    return vec8;  
}
```

Tricky bonus one:

Copy constructor

Today's Agenda

1. Recap

2. Special Member Functions

- An overview
- Copy and copy assignment
- default and delete
- **Move and move assignment**

Is copying enough?

We've learned about the default constructor, destructor, and the copy constructor and assignment operator.

- We can create an object, get rid of it, and copy its values to another object!
- Is this ever insufficient?

This can be wasteful

These functions are generated only when they're called
(and before any are explicitly defined by you):

```
class Widget {  
    public:  
        Widget(); //  
        Widget (const Widget& w); //  
        Widget& operator = (const Widget& w); //  
        ~Widget(); // destructor  
        Widget (Widget&& rhs); // move constructor  
        Widget& operator = (Widget&& rhs); // move assignment operator  
}
```

Let's motivate move semantics

This can be wasteful

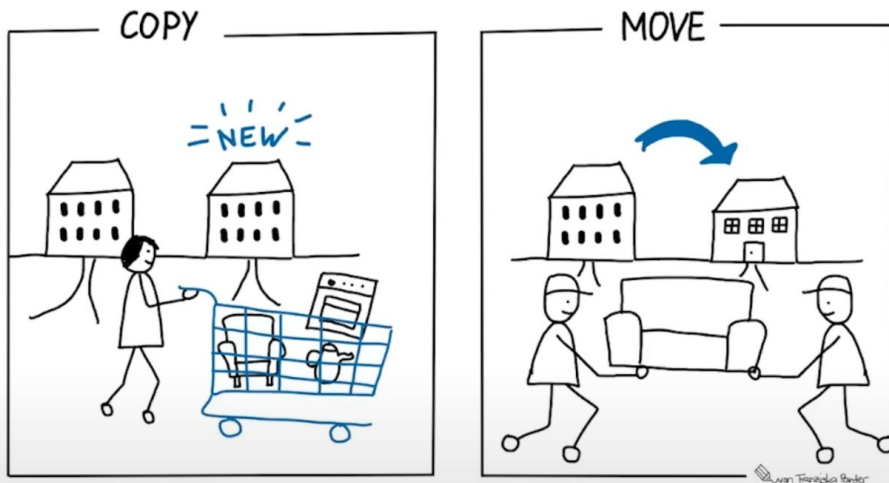
Let's say we had to copy our current StringTable into another, whose reference is given to us, and we have no use for our StringTable afterwards.

```
class StringTable {  
    public:  
        StringTable() {}  
        StringTable(const StringTable& st) {}  
        // functions for insertion, erasure, lookup, et  
        // but no move/dtor functionality  
        // ...  
  
    private:  
        std::map<int, std::string> values;  
}
```

**The copy constructor will
copy every value in the
values map one by one!
Very slowly!**

A good way to prime move semantics

Move semantics: move or duplicate



I really like
this way of
thinking
about move
semantics:

Watch the
full video
[here](#)

Jacob will tell you next Thursday



Enjoy your weekend, and happy Halloween!

