Lecture 13: Special Member Functions

CS 106L, Winter '21

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

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

Key questions we will answer today

- What are special member functions? When are they called?
- When should we declare a special member function?
- When should we not declare a special member function?

Agenda

- More info about mycollection::vector implementation
- Intro to special member functions
- Member initializer lists
- Why aren’t the default functions always sufficient?
- Copy assignment and construction
- Delete
- Rule of three/zero

Live Code Demo:
mycollection::vector implementation

Intro to special member functions

Special member functions are (usually) automatically generated by the compiler

Special Member Functions

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.


Questions?

What Special Member Function is Called on Each Line?

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy constructor (passing by value)

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Default constructor creates empty vector

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Not a special member function - creates a vector {0, 0, 0}

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Also not a special member function, uses initializer_list

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

This is a function declaration! (C++'s Most Vexing Parse)

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy constructor - vec created as a copy of another one

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Also the default constructor!

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy constructor

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy constructor - vec8 is newly constructed

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy assignment - vec8 is an existing object

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Copy constructor: copies vec8 to location outside of func

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

Destructors on all values (except return value) are called

```
vector<int> function(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{vec3 + vec4};
  vector<int> vec8 = vec4;
  vec8 = vec2;
  return vec8;
}
```

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.


Questions?

Member initializer lists

How we're used to writing constructors

```
template <typename T>
vector<T>::vector<T>() {
    _size = 0;
    _capacity = kInitialSize;
    _elems = new T[kInitialSize];
}
```

Members are first default constructed

Then each member is reassigned

Member initializer lists!

```
template <typename T>
vector<T>::vector<T>() {
    _size = 0;
    _capacity = kInitialSize;
    _elems = new T[kInitialSize];
}

template <typename T>
vector<T>::vector<T>() :
        _size(0), _capacity(kInitialSize),
    _elems(new T[kInitialSize]) { }
```

Directly construct each member with a starting value

Quick summary

- Prefer to use member initializer lists, which directly constructs each member with a given value.
  - Faster. Why construct, then immediately reassign?
  - Members might be a non-assignable type (we'll see by the end of lecture how this can be possible!)
- Important clarification: you can use member initializer lists for ANY constructor, not just a special member function. This means you can use it even if your constructor has parameters.

Why aren’t the default member functions always sufficient?

The default compiler-generated copy constructor and copy assignment functions work by copying each member variable

This is what default copy constructor would look like

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

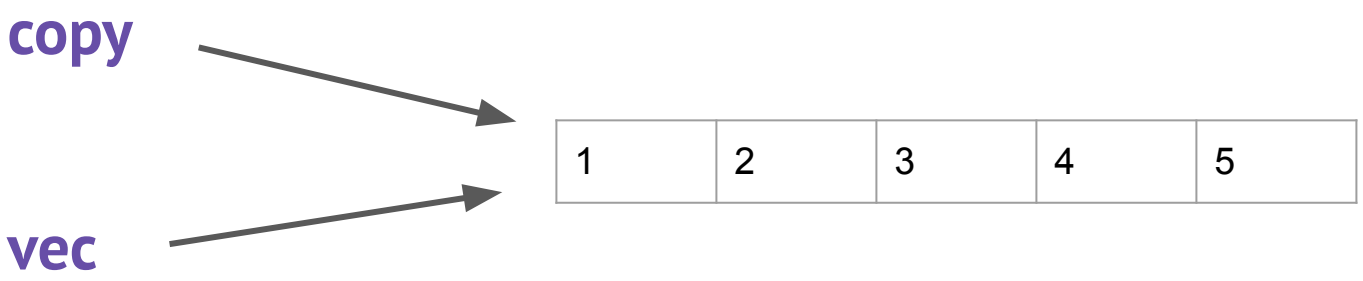
Consider the following code

This code, sadly, does not work!

```
vector<int> operator+(const vector<int>& vec, int elem) {
    vector<int> copy = vec; // uses default copy constructor
    copy += element; // assumes we've defined += operator
    return copy;
}
```

Both copy and vec will point to the same underlying array!

```
vector<int> operator+(const vector<int>& vec, int elem) {
    vector<int> copy = vec;
    copy += element;
    return copy;
}
```



The culprit? This line in the default copy constructor!

Remember, _elems is a pointer, so **this line makes a copy of a pointer**, which isn't the same as copying the underlying array!

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

The culprit? This line in the default copy assignment!

This is because when you copy a pointer, you copy the address saved in the pointer, not what's being pointed to!

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

Moral of the story: in many cases, copying is not as simple as copying each member variable

This is one example of when you might want to overwrite the default special member functions with your own implementation!


Questions?

Copy operations: fixing the issues we just saw

Recap about definitions

- Default construction: object created with no parameters.
- Copy construction: object is created as a copy of an existing object.
- Copy assignment: existing object replaced as a copy of another existing object.
- Destruction: object destroyed when it is out of scope.

How do we fix the default copy constructor? (chat)

```
template <typename T>
vector::vector<T>(const vector<T>& other) :
    _size(other._size,
    _capacity(other._capacity),
    _elems(other._elems) {




}
```

Here's a fix: we can create a new array!

```
template <typename T>
vector::vector<T>(const vector<T>& other) :
    _size(other._size,
    _capacity(other._capacity),
    _elems(other._elems) {
   _elems = new T[other._capacity];
   std::copy(other._elems,
             other._elems + other._size, _elems);
}
```

Even better: let's move things to the initializer list!

```
template <typename T>
vector::vector<T>(const vector<T>& other) :
    _size(other._size,
    _capacity(other._capacity),
    _elems(new T[other._capacity]) {
   std::copy(other._elems,
             other._elems + other._size, _elems);
}
```

How do we fix the default copy assignment operator?

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    _size = other._size;
    _capacity = other._capacity;
    _elems = other._elems;

    return *this;
}
```

Attempt 1: Allocate a new array and copy over elements

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    _size = other._size;
    _capacity = other._capacity;
    _elems = new T[other._capacity];

    std::copy(other._elems,
              other._elems + other._size, _elems);
}
```

There's a problem here with memory leaks!

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    _size = other._size;
    _capacity = other._capacity;
    _elems = new T[other._capacity];

    std::copy(other._elems,
              other._elems + other._size, _elems);
}
```

Remember, we're changing the members of an existing object. What about the old array of elements that _elems pointed to?

Attempt 2: Deallocate the old array and make a new one

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    _size = other._size;
    _capacity = other._capacity;
    delete [] _elems;
    _elems = new T[other._capacity];

    std::copy(other._elems,
              other._elems + other._size, _elems);
}
```

Minor detail 1: return reference to vector itself

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    _size = other._size;
    _capacity = other._capacity;
    delete [] _elems;
    _elems = new T[other._capacity];

    std::copy(other._elems,
              other._elems + other._size, _elems);
    return *this;
}
```

Minor detail 2: Be careful about self-reassignment

```
template <typename T>
vector<T>& vector<T>::operator=(const vector<T>& other) {
    if (&other == this) return *this;
    _size = other._size;
    _capacity = other._capacity;
    delete [] _elems;
    _elems = new T[other._capacity];

    std::copy(other._elems,
              other._elems + other._size, _elems);
    return *this;
}
```

Summary: Steps to follow for an assignment operator

1. Check for self-assignment.
2. Make sure to free existing members if applicable.
3. Copy assign each automatically assignable member.
4. Manually copy all other members.
5. Return a reference to *this (that was just reassigned).

The copy operations must perform the following tasks

Copy constructor

- Use initializer list to copy members where simple copying does the correct thing.
  - int, other objects, etc.
- Manually copy all members where assignment does not work.
  - pointers to heap memory
  - non-copyable things

Copy assignment

- Clean up any resources in the existing object about to be overwritten.
- Copy members using direct assignment when assignment works.
- Manually copy members where assignment does not work.
- (Not necessarily in this order)


Questions?

Delete

How could you prevent copies from being created?

Explicitly delete the copy member functions!

```
class PasswordManager {
    public:
      PasswordManager();
      ~PasswordManager();
      // other methods
      PasswordManager(const PasswordManager& rhs) = delete;
      PasswordManager& operator=(const PasswordManager& rhs) = delete;

    private:
        // other stuff
}
```

How could you prevent copies from being created?

Explicitly delete the copy member functions!

```
class PasswordManager {
    public:
      PasswordManager();
      ~PasswordMa
      // other me
      PasswordMan                                    lete;
      PasswordManager& operator=(const PasswordManager& rhs) = delete;

    private:
        // other stuff
}
```

This was why we couldn't capture the `WikiScraper` by value in assignment 1!

Rule of three

When to define your own special member functions?

- When the default ones generated by the compiler won't work
- Most common reason: there's a resource that our class uses that's not stored inside of our class
  - E.g. dynamically allocated memory
    - Our class only stores the pointers, not the memory itself

Rule of three

- If you explicitly define a copy constructor, copy assignment, or destructor, you should define all three.
- What's the rationale?

Rule of three

- If you explicitly define a copy constructor, copy assignment, or destructor, you should define all three.
- What's the rationale?
  - The fact that you defined one of these means one of your members has ownership issues that need to be resolved.

Rule of 0

- If the default operations work, then don’t define your own custom ones

Summary

- The C++ compiler is powerful enough to generate special member functions for us
- In some cases, we may need to redefine these functions if the default behavior does not match our desired behavior
- We can delete special member functions to make certain behavior impossible (e.g., make it impossible to copy an object of our class)


Questions?

Next time

Move semantics