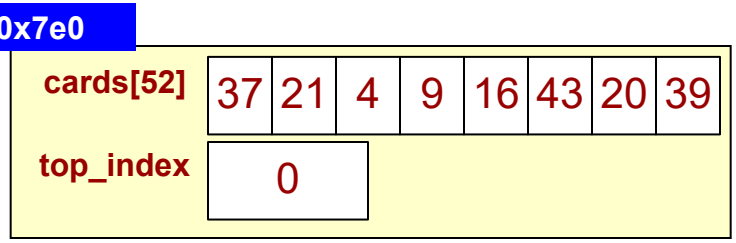
CS103 Unit 5b – Copy Semantics (Copy constructors and Assignment Operators)

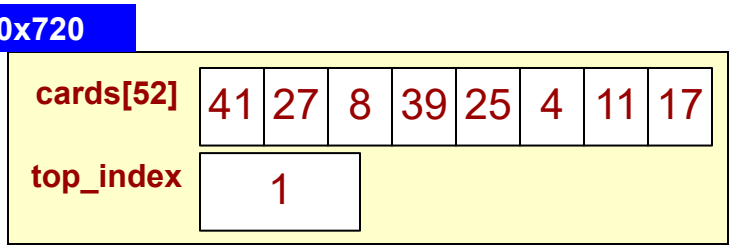
this pointer

SIDE TOPIC: HOW DOES AN OBJECT REFER TO ITSELF FROM INSIDE A MEMBER?

this Pointer

- How do member functions know which object's data to be operating on? (d1 or d2)
- d1 is implicitly passed via a special pointer call the 'this' pointer





d1 is implicitly passed to shuffle()

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

int main(int argc, char *argv[]) {
  Deck d1, d2;
  d1.shuffle();
```

poker.cpp

this

0x720

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

void Deck::shuffle()
{
  cut(); // calls cut()
         // for this object
  for(i=0; i < 52; i++){
    int r = rand() % (52-i);
    int temp = cards[r];
    cards[r] = cards[i];
    cards[i] = temp;
  }
}
```

deck.cpp

Actual code you write

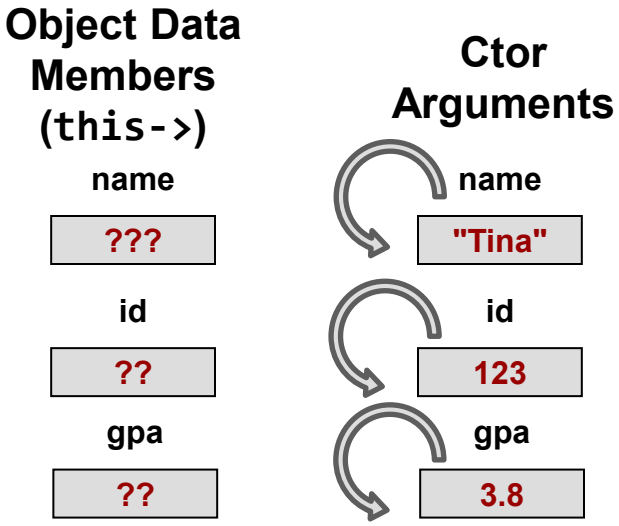
```
int main() {
  Deck d1;
  d1.shuffle();
}
void Deck::shuffle(Deck *this)
{
  this->cut(); // calls cut()
               // for this object
  for(i=0; i < 52; i++){
    int r = rand() % (52-i);
    int temp = this->cards[r];
    this->cards[r] = this->cards[i];
    this->cards[i] = temp;
  }
}
```

deck.cpp

Compiler-generated code

The Same Names

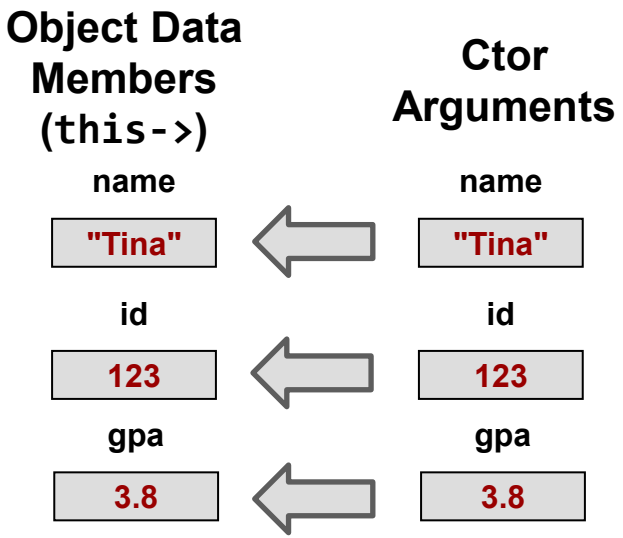
- If arguments and data members have the same name it will use the 'closest' defined variable




```
class Student {
 public:
  Student(string name, int id, double gpa);

   ~Student();  // Destructor
private:
   string name;
   int id;
   double gpa;
};

Student::Student(string name, int id, double gpa)
{ // which is the member and which is the arg?
  name = name;
  id = id;
  gpa = gpa;
}
```

One Place You Can Use 'this'

- `this` can be used to resolve scoping issues with similar named variables
  - Exercise: this_scope



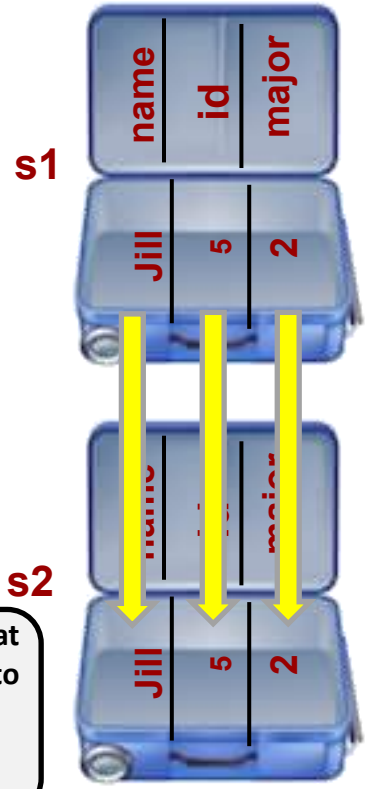

```
class Student {
 public:
  Student(string name, int id, double gpa);

   ~Student();  // Destructor
private:
   string name;
   int id;
   double gpa;
};


Student::Student(string name, int id, double gpa)
{ // Now it's clear
  this->name = name;
  this->id = id;
  this->gpa = gpa;
}
```

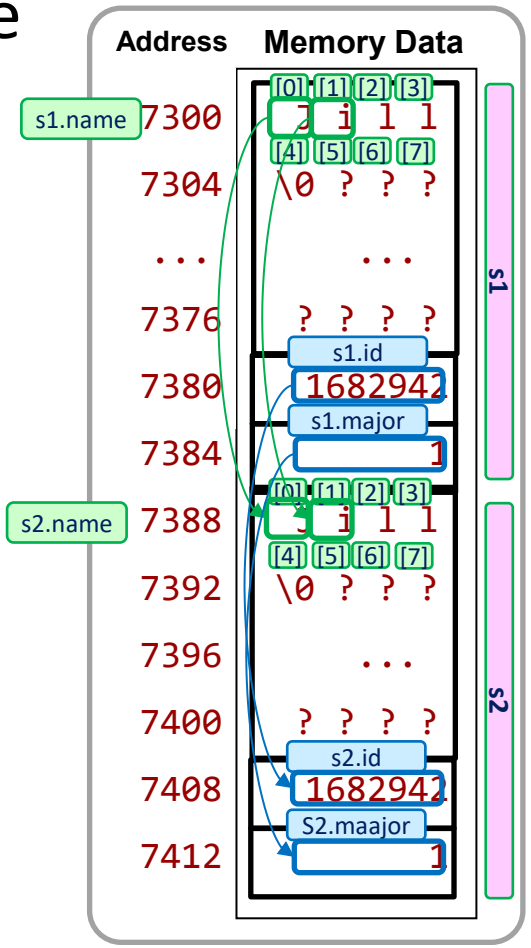
WHAT WE CURRENTLY KNOW ABOUT COPYING OBJECTS

Object assignment

- Assigning one object to another will perform a **member-by-member copy** of the entire source object to the destination object

```
#include<iostream>
using namespace std;

enum {CSCI=1, CECS };

struct student {
  char name[80];
  int id;
  int major;
};

int main(int argc, char *argv[])
{
  student s1,s2;
  strncpy(s1.name,"Jill",80);
  s1.id = 5; s1.major = CECS;
  s2 = s1;
  return 0;
}
```





Normally, C/C++ perform only one operation at a time, and make you write code if you want to do more. But object assignment is an exception (probably because we can't "loop through" the different members of a struct).

Multiple Constructors

- Can have multiple constructors with different argument lists to provide options to client software for how they'd like to initialize the object
  - Constructor with NO ARGUMENTS is known as the **DEFAULT** constructor

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

int main()
{
  Student s1;  // calls default ctor
  string myname;
  cin >> myname;
  s1.setname_(myname);
  s1.setid_(214952);
  s1.setgpa_(3.67);

  Student s2(myname, 32421, 4.0);
              // calls "initializing" ctor

}
```

student.h

```
class Student {
 public:
   Student();   // Default ctor
   Student(string name, int id, double gpa);
                // "Initializing" ctor
   ~Student();  // Destructor
   string get_name();
   int get_id();
   double get_gpa();

   void set_name(string name);
   void set_id(int id);
   void set_gpa(double gpa);
 private:
   std::string name_;
   int id_;
   double gpa_;
};
```

Note: Often name data members with special decorator (id_ or gpa_) to make it obvious to other programmers that this variable is a data member

student.cpp

```
Student::Student()
{
  name_ = "", id_ = 0; gpa_ = 2.0;
}

Student::Student(string name, int id, double gpa)
{
  name_ = name; id_ = id; gpa_ = gpa;
}
```

Copy constructors and assignment operators

COPY SEMANTICS

Copy Constructors

- Write a prototype for the constructor that would want to be called by the red line of code
- Realm of Reasonable Answers:

- We want a constructor that will build a new Complex object (c3) by making a copy of another (c1)

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);

  // What constructor definition do I
  // need for c3's declaration below

 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);


}
```

Copy Constructors

- Write a prototype for the constructor that would want to be called by the red line of code
- Realm of Reasonable Answers:
  - **`Complex(Complex);`**
    - **We will see that this can't be right…**
  - `Complex(Complex &)`
    - **Possible**
  - **`Complex(const Complex &)`**
    - **Best! (Making a copy shouldn't change the input argument, thus 'const')**
- We want a constructor that will build a new Complex object (c3) by making a copy of another (c1)

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);

  // What constructor definition do I
  // need for c3's declaration below

 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);


}
```

Assignment Operators

- The assignment operator (`operator=(…)`) is called when an object that is **ALREADY in-scope is reassigned**.
- It's signature is:

```
Complex& operator=(const Complex& other);
```

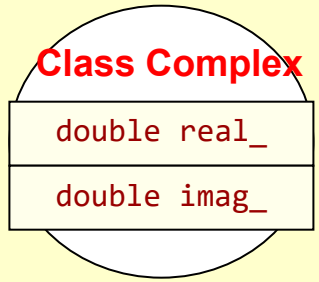
- Why does it return by reference… we will see soon.
- Do we need to define this function in our class?

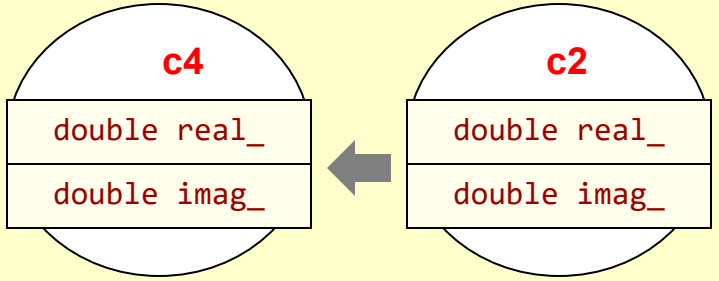
```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);
  Complex(const Complex& );


 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);  // Copy ctor
  c3 = c2;         // Assignment op.
    // translates to c3.operator=(c2);


}
```

Assignment & Copy Constructors

- C++ compiler automatically generates a ***default*** copy constructor
  - Constructor called when an object is allocated and initializes the object to be a copy of another object of the same type
  - Signature would look like **Complex(const Complex &);**
  - Called by either of the options shown in the code
  - **Simply performs an element by element copy**
- C++ compiler automatically generates a ***default*** assignment function
  - Called when you assign to an object that is already allocated (memory already exists)
  - **Simply performs an element by element copy**
  - **Complex& operator=(const Complex &);**

```
class Complex
{
 public:
  Complex(int r, int i);
  // compiler will provide by default:
  // Complex(const Complex& );
  // Complex& operator=(const Complex&);
  ~Complex()
 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1); // copy constructor
  Complex c4(5,7);
  c4 = c2;   // default assignment oper.
  // c4.operator=(c2)

}
```

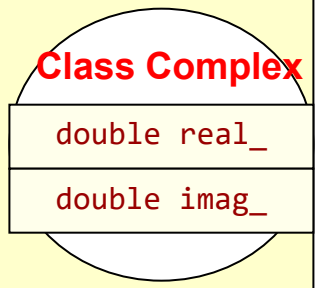




What Gets Called?

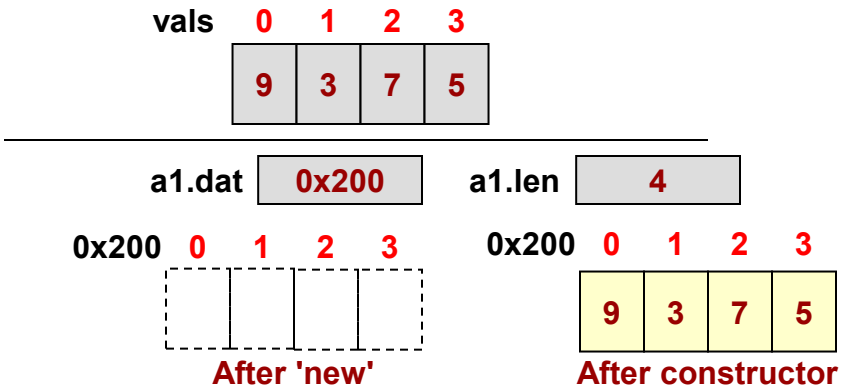
- What get's called when we use `=` when creating a new object?
- It may look like an assignment operator.
- But C++ will call the Copy Constructor!!

```
class Complex
{
 public:
  Complex(int r, int i);
  // compiler will provide by default:
  // Complex(const Complex& );
  // Complex& operator=(const Complex&);
  ~Complex()
 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1); // copy constructor
  Complex c4 = c1;

}
```



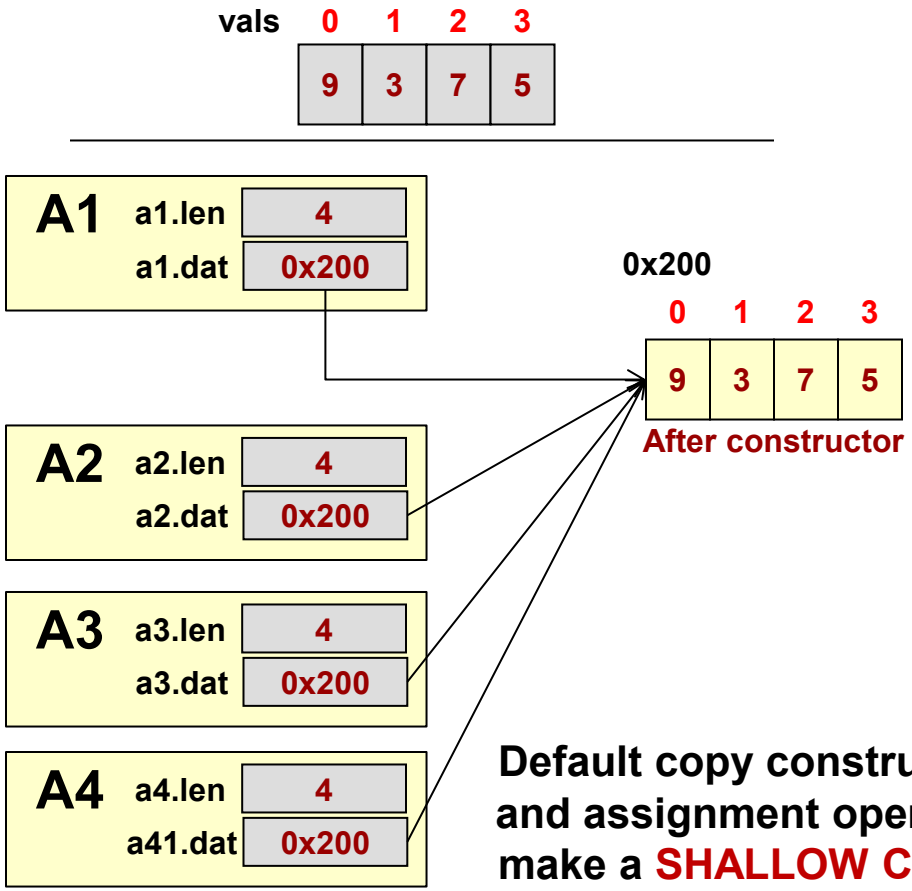
Assignment & Copy Constructors

- C++ compiler automatically generates a ***default*** copy constructor
- C++ compiler automatically generates a ***default*** assignment function
- See picture below of what a1 looks like as it is constructed




```
class MyArray
{
 public:
  MyArray(int d[], int num); //normal
  ~MyArray();
  int len; int *dat;

};
// Normal constructor
MyArray::MyArray(int d[], int num)
{
  dat = new int[num]; len = num;
  for(int i=0; i < len; i++){
    dat[i] = d[i];
  }
}

int main()
{
  int vals[] = {9,3,7,5};
  MyArray a1(vals,4);
  MyArray a2(a1); // calls default copy
  MyArray a3 = a1; // calls default copy
  MyArray a4;
  a4 = a1; // calls default assignment
  // how are the contents of a2, a3, a4
  // related to a1
}
```

Assignment & Copy Constructors



Default copy constructor and assignment operator make a SHALLOW COPY (data members only) rather than a DEEP copy (data members + what they point at)

```
class MyArray
{
 public:
  MyArray(int d[], int num); //normal
  ~MyArray();
  int len; int *dat;

};
// Normal constructor
MyArray::MyArray(int d[], int num)
{
  dat = new int[num]; len = num;
  for(int i=0; i < len; i++){
    dat[i] = d[i];
  }
}

int main()
{
  int vals[] = {9,3,7,5};
  MyArray a1(vals,4);
  MyArray a2(a1); // calls default copy
  MyArray a3 = a1; // calls default copy
  MyArray a4;
  a4 = a1; // calls default assignment
  // how are the contents of a2, a3, a4
  // related to a1
}
```

When to Write Copy Constructor

- Default copy constructor and assignment operator ONLY perform SHALLOW copies
  - **SHALLOW COPY (data members only)**
  - **DEEP copy (data members + what they point at)**
  - [Like saving a webpage to your HD…it makes a shallow copy and doesn't copy the pages linked to]
- You SHOULD/MUST define your own copy constructor and assignment operator when a DEEP copy is needed
  - When you have pointer data members that point to data that should be copied when a new object is made
  - Often times, if your data members are pointing to dynamically allocated data, you need a DEEP copy
- Corollary: If a Shallow copy is acceptable, then you do NOT need to define a copy constructor

Defining Copy Constructors

- Same name as normal constructor but should take in an argument of the object type:
  - Usually a const reference
- **MyArray(const MyArray&);**

```
class MyArray
{public:
  MyArray(int d[], int num);
  MyArray(const MyArray& rhs);
  ~MyArray();
 private:
  int *dat; int len;
}
// Normal constructor
MyArray::MyArray(int d[], int num)
{
  dat = new int[num]; len = num;
  // copy values from d to dat
}
// Copy constructor
MyArray::MyArray(const MyArray &rhs){
{
  len = rhs.len; dat = new int[len];
  // copy from rhs.dat to dat
}

int main()
{
  intvals[] = {9,3,7,5};
  MyArray a1(vals,4);
  MyArray a2(a1);
  MyArray a3 = a1;
  // how are the contents of a2 and a1 related?
}
```

Implicit Calls to Copy Constructor

- Recall pass-by-value passes a copy of an object…If defined the copy constructor will automatically be called to make this copy otherwise the default copy will perform a shallow copy

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);
  Complex Complex(const Complex &rhs);
  ~Complex();
  double real, imag;
};
// Copy constructor
Complex::Complex(const Complex &c)
{
  cout << "In copy constructor" << endl;
  real = c.real; imag = c.imag;
}
// ** Copy constructor called for pass-by-value
int dummy(Complex rhs)
{
   cout << "In dummy" << endl;
}

intmain()
{
  Complex c1(2,3), c2(4,5);
  int x = dummy(c1);
  //     ** Copy Constructor called on c1 **

}
```

Copy Constructors

- Write a prototype for the constructor that would want to be called by the red line of code
- Now we see why the first option can't be right…because to pass c1 by value requires a call to the copy constructor which we are just now defining (circular reference/logic)
  - Complex(Complex)
    - We will see that this can't be right…
- The argument must be passed by reference
  - Complex(const Complex &)

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);
  Complex(Complex c); // Bad b/c pass
     // by value req. copy to be made
     //  ...chicken/egg problem
  Complex(const Complex &c); // Good
  ~Complex()
 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);


}
```

Defining Copy Assignment Operator

- `operator=()` is called when an object already exists and then you assign to it
  - Copy constructor called when you assign during a declaration:
  - E.g. MyArray a2=a1;
- Can define operator for '=' to indicate how to make a copy via assignment
- **Gotchas?**

```
class MyArray
{
 public:
  MyArray();
  MyArray(int d[], int num);
  MyArray(const MyArray& rhs);
  MyArray& operator=(const MyArray& rhs);
  ~MyArray();
  int*dat; intlen;
}

MyArray::MyArray(const MyArray &rhs){
{
  len = rhs.len; dat = new int[len];
  // copy from rhs.dat to dat
}

MyArray& MyArray::operator=(const MyArray &rhs){
{
  len = rhs.len; dat = new int[len];
  // copy from rhs.dat to dat
}

int main()
{
  intvals[] = {9,3,7,5};
  MyArray a1(vals,4);
  MyArray a2;
  a2 = a1; // operator=() since a2 already exists
}
```

Defining Copy Assignment Operator

- **Gotchas?**
  - Dest. object may already be initialized and simply overwriting data members may lead to a memory leak
  - Self assignment (which may also lead to memory leak or lost data)

```
class MyArray
{
 public:
  MyArray();
  MyArray(int d[], int num);
  MyArray(const MyArray& rhs);
  MyArray& operator=(const MyArray& rhs);
  ~MyArray();
  int *dat; int len;
}

MyArray::MyArray(const MyArray &rhs){
{ len = rhs.len; dat = new int[len];
  // copy from rhs.dat to dat
}
MyArray& MyArray::operator=(const MyArray &rhs){
{
  if(this == &rhs) return *this;
  if(dat) delete dat;
  len = rhs.len; dat = new int[len];
  // copy from rhs.dat to dat
  return *this;
}

int main()
{
  int vals1[] = {9,3,7,5}, vals2[] = {8,3,4,1};
  MyArray a1(vals1,4);
  MyArray a2(vals2,4);
  a1 = a1;  a2 = a1;
}
```

Assignment Operator Practicals

- RHS should be a const reference
  - Const so we don't change it
  - Reference so we don't pass-by-value and make a copy (which would actually call a copy constructor)
- Return value should be a reference
  - Allows for chained assignments
  - Should return (*this)
  - Reference so another copy isn't made

```
class Complex
{
 public:
  Complex(int r, int i);
  ~Complex()
  Complex operator+(Complex right_op);
  Complex& operator=(const Complex &rhs);
 private:
  int real, imag;
};


Complex& Complex::operator=(const Complex & rhs)
{
   real = rhs.real;
   imag = rhs.imag;
   return *this;
}

int main()
{
  Complex c1(2,3), c2(4,5);

  Complex c3, c4;
  c4 = c3 = c2;
  // same as c4.operator=( c3.operator=(c2) );
}
```

Assignment Operator Overloading

- If a different type argument can be accepted we can overload the = operator

```
class Complex
{
 public:
  Complex(int r, int i);
  ~Complex();
  Complex operator+(const Complex &rhs);
  Complex &operator=(const Complex &r);
  Complex &operator=(const int r);
  int real, imag;
};

Complex& Complex::operator=(const int& r)
{
  real = r; imag = 0;
  return *this;
}

int main()
{
  Complex c1(3,5);
  Complex c2,c3,c4;
  c2 = c3 = c4 = 5;
  // c2 = (c3 = (c4 = 5) );
  // c4.operator=(5);  // Complex::operator=(int&)
  // c3.operator=(c4); // Complex::operator=(Complex&)
  // c2.operator=(c3); // Complex::operator=(Complex&)
  return 0;
}
```

Copy Constructor Summary

- If you are okay with a shallow copy, you don't need to define a copy constructor or assignment operator
- Rule of Three:
  - If you need more than the default of any of the following: a **copy constructor**, an **assignment operator**, and a **destructor** **then you need all 3 (i.e. if you need 1 you need all 3)**
    - Usually if you have dynamically allocated memory
- Copy constructor should accept a **const reference** of the same object type
- Assignment operators should be careful to cleanup initialized members and check for self-assignment
- Assignment operators should return a reference type and return *this

Exercises For Home

- Suppose you are given a class that implements a singly-linked of integers (with a head pointer data member)
- Write a '-=' operator that takes one element and removes it from the list if it exists
- Write a '==' operator that checks whether the contents and order of one list matches another
- Write a copy constructor and assignment operator

```
#include <iostream>
#include "listint.h"
using namespace std;

int main()
{
  IntList m1, m2;
  m1.push_back(5);
  m2.push_back(5);

  if(m1 == m2){
    cout << "Should print!";
  }
  m2.push_back(7);
  m2 -= 5; // now m2 would just have [7]

  if(m1 == m2){
    cout << "Should not print!"; << endl;
  }

  IntList m3(m1);  // make a copy of m1
  m3.push_back(8); // m3 should have [5,8]
  m2 = m1;
  if(m1 == m2){
    cout << "Should print!"; << endl;
  }
  return 0;
}
```

REVIEW

Review [1]

- What is the correct prototype for the copy constructor call when c3 is created in the code to the right?
  - **Complex(Complex);**
  - Complex(Complex &)
  - **Complex(const Complex &)**

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);

  // What constructor definition do I
  // need for c3's declaration below

 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);


}
```

Review [2]

Which function?

- For each of the following, identify whether the copy constructor is called or the assignment operator
  - **`Complex c1;`**
    `Complex c2 = c1;`
  - **`Complex c1;`**
    `Complex c2(c1);`
  - **`Complex c1, c2;`**
    `c2 = c1;`

Default Versions

- What kind of copy does the default copy constructor and assignment operator perform?

```
class MyArray
{
  ...
 private:
  int* data; // ptr to dynamic array
  size_t len;
};
```

Review [3]

State the Rule of 3

- The rule of 3:

Assignment Operator Specifics?

- What extra considerations does the assignment operator need to handle vs. the copy constructor?
- What should operator= return?

```
class MyArray
{



 private:
  int* data; // ptr to dynamic array
};

MyArray& operator=(const MyArray& other)
{



}
```

SOLUTIONS

Review [1]

- What is the correct prototype for the copy constructor call when c3 is created in the code to the right?
  - **Complex(Complex);**
    - **We will see that this can't be right…**
  - Complex(Complex &)
    - **Possible**
  - **Complex(const Complex &)**
    - **Best! (Making a copy shouldn't change the input argument, thus 'const')**

```
class Complex
{
 public:
  Complex();
  Complex(double r, double i);

  // What constructor definition do I
  // need for c3's declaration below

 private:
  double real, imag;
};

int main()
{
  Complex c1(2,3), c2(4,5)
  Complex c3(c1);


}
```

Review [2]

Which function?

- For each of the following, identify whether the copy constructor is called or the assignment operator
  - `Complex c1;`
    `Complex c2 = c1;`
    - Copy constructor
  - `Complex c1;`
    `Complex c2(c1);`
    - Copy constructor
  - `Complex c1, c2;`
    `c2 = c1;`
    - Assignment operator

Default Versions

- What kind of copy does the default copy constructor and assignment operator perform?
  - Shallow copy (member by member copy)

```
class MyArray
{
  ...
 private:
  int* data; // ptr to dynamic array
  size_t len;
};
```

Review [3]

State the Rule of 3

- The rule of 3:
  - If a class needs a user-defined version of any one of the 3: copy constructor, assignment operator, or destructor, it needs ALL 3.

```
class MyArray
{



 private:
  int* data; // ptr to dynamic array
};

MyArray& operator=(const MyArray& other)
{



}
```

Assignment Operator Specifics?

- What extra considerations does the assignment operator need to handle vs. the copy constructor?
  - Must clean up old resources before copying
  - Beware of self assignment
- What should operator= return?
  - A reference to an instance of the class which should be *this;