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CSCI 104
Operator Overloading & Copy Semantics

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Get the Example Code

- Download the code
  - $ wget http://ee.usc.edu/~redekopp/cs104/str_ops.tar
  - $ tar xvf str_ops.tar
- This class should mimic the C++ string class
  - Properly handle memory allocation
  - Let you treat it like an array where you can do '[i]' indexing
  - Let you do comparison on string objects with '==' and other operators, etc.

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List/Array Indexing

- Arrays and vectors allow indexing using square brackets: [ ]
  - E.g. my_list[i] equivalent to my_list.at(i)
- It would be nice to allow that indexing notation for our List<T> class
- But if we just try it won't compile…How does the compiler know what to do when it sees a List<T> object followed by square brackets
- Enter C++ operator overloading
  - Allows us to write our own functions that will be "tied" to and called when a symbolic operator (+, -, *, [ ]) is used

```
// declaring templatized code
#ifndef LIST_H
#define LIST_H

template <typename T>
class List{
 public:
   List();  // Constructor
   ~List();  // Destructor
   void push_back(T newval); ...
 private:
   Item<T>* head_;
};
#endif


int main()
{
  List<int> my_list();
  my_list.push_back(5);
  my_list.push_back(7);


  cout << my_list[0] << endl;


  return 0;
}
```

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Function Overloading

- What makes up a signature (uniqueness) of a function
  - name
  - number and type of arguments
- No two functions are allowed to have the same signature; the following 3 functions are unique and allowable…
  - void f1(int); void f1(double); void f1(List<int>&);
  - void f1(int, int); void f1(double, int);
- We say that "f1" is overloaded 5 times

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Operator Overloading

- C/C++ defines operators (+,*,-,==,etc.) that work with basic data types like int, char, double, etc.
- C/C++ has no clue what classes we'll define and what those operators would mean for these yet-to-be-defined classes
  - Class complex {
    public:
    double real, imaginary;
    };
  - Complex c1,c2,c3;
    c3 = c1 + c2; // should add component-wise
  - Class List {
    …
    };
  - List l1,l2;
    l1 = l1 + l2; // should concatenate l2 items to l1

user.h

```
class User{
 public:
   User(string n);  // Constructor
   string get_name();
 private:
   int id_;
   string name_;
};
```

user.cpp

```
#include "user.h"
User::User(string n) {
  name_ = n;
}
string User::get_name(){
  return name_;
}
```

user_test.cpp

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

int main(int argc, char *argv[]) {
  User u1("Bill"), u2("Jane");
  // see if same username
  // Option 1:
  if(u1 == u2) cout << "Same";
  // Option 2:
  if(u1.get_name() == u2.get_name())
    {   cout << "Same" << endl; }
  return 0:
  }
```

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Operator Overloading

- C++ allows users to write functions that define what an operator should do for a class
  - Binary operators: +, -, *, /, ++, --
  - Comparison operators: ==, !=, <, >, <=, >=
  - Assignment: =, +=, -=, *=, /=, etc.
  - I/O stream operators: <<, >>
- Function name starts with 'operator' and then the actual operator
- Left hand side is the implied object for which the member function is called
- Right hand side is the argument

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

 private;
  int real, imag;
};

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

int main()
{
  Complex c1(2,3);
  Complex c2(4,5);
  Complex c3 = c1 + c2;
  // Same as c3 = c1.operator+(c2);
  cout << c3.real << ",” << c3.imag << endl;
  // can overload '<<' so we can write:
  // cout << c3 << endl;
  return 0;
}
```

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Binary Operator Overloading

- For binary operators, do the operation on a new object's data members and return that object
  - Don't want to affect the input operands data members
    - Difference between: x = y + z; vs. x = x + z;
- Normal order of operations and associativity apply (can't be changed)
- Can overload each operator with various RHS types…
  - See next slide

Binary Operator Overloading

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

 private:
  int real, imag;
};

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


Complex Complex::operator+( int real)
{
   Complex temp = *this;
   temp.real += real;
   return temp;
}
```

```
int main()
{
 Complex c1(2,3), c2(4,5), c3(6,7);

  Complex c4 = c1 + c2 + c3;
  // (c1 + c2) + c3
  // c4 = c1.operator+(c2).operator+(c3)
  //    = anonymous-ret-val.operator+(c3)



  c3 = c1 + c2;

  c3 = c3 + 5;

}
```

Relational Operator Overloading

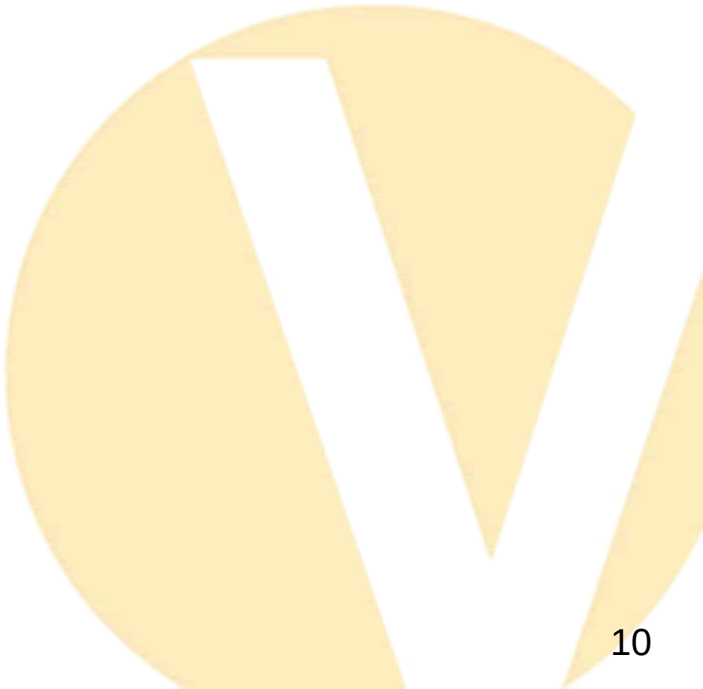
- Can overload ==, !=, <, <=, >, >=
- Return bool

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

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

int main()
{
  Complex c1(2,3);
  Complex c2(4,5);
  // equiv. to c1.operator==(c2);
  if(c1 == c2)
    cout << "C1 & C2 are equal!" << endl;

  return 0;
}
```

Nothing will be displayed

Practice

- Add the following operators to your Str class
  - Operator[]
  - Operator==(const Str& rhs);
  - Operator+(const Str& rhs);
  - Operator+(const char* rhs);



Non-Member Functions

- What if the user changes the order?
  - int on LHS & Complex on RHS
  - No match to a member function b/c to call a member function the LHS has to be an instance of that class
- We can define a non-member function (good old regular function) that takes in two parameters (both the LHS & RHS)
  - May need to declare it as a friend

```
int main()
{
  Complex c1(2,3);
  Complex c2(4,5);
  Complex c3 = 5 + c1;
              // ?? 5.operator+(c1) ??
              // ?? int.operator+(c1) ??
              // there is no int class we can
              //  change or write

  return 0;
}
```

Doesn't work

```
Complex operator+(const int& lhs, const Complex &rhs)
{
  Complex temp;
  temp.real = lhs + rhs.real;   temp.imag = rhs.imag;
  return temp;
}
int main()
{
  Complex c1(2,3);
  Complex c2(4,5);
  Complex c3 = 5 + c1;   // Calls operator+(5,c1)
  return 0;
}
```

Still a problem with this code
Can operator+(…) access Complex's private data?

Friend Functions

- A friend function is a function that is not a member of the class but has access to the private data members of instances of that class
- Put keyword 'friend' in function prototype in class definition
- Don't add scope to function definition

```
class Dummy
{
 public:
  Dummy(int d) { dat = d };
  friend int inc_my_data(Dummy &dum);
 private:
  int dat;
};

// don't put Dummy:: in front of inc_my_data(...)
int inc_my_data(Dummy &dum)
{
  dum.dat++;
  return dum.dat;
}

int main()
{
  Dummy dumb(5);
  dumb.dat = 8;  // WON'T COMPILE
  int x = inc_my_data(dumb);
  cout<< x << endl;
}
```

Non-Member Functions

- Revisiting the previous problem.

```
class Complex
{
 public:
  Complex(int r, int i);
  ~Complex();
  // this is not a member function
  friend Complex operator+(const int&, const Complex& );
 private:
  int real, imag;
};

Complex operator+(const int& lhs, const Complex &rhs)
{
  Complex temp;
  temp.real = lhs + rhs.real;   temp.imag = rhs.imag;
  return temp;
}
int main()
{
  Complex c1(2,3);
  Complex c2(4,5);
  Complex c3 = 5 + c1;   // Calls operator+(5,c1)
  return 0;
}
```

Still a problem with this code
Can operator+(…) access Complex's private data?

Why Friend Functions?

- Can I do the following?
- error: no match for 'operator<<' in 'std::cout << c1'
- /usr/include/c++/4.4/ostream:108: note: candidates are: /usr/include/c++/4.4/ostream:165: note: std::basic_ostream<_CharT, _Traits>& std::basic_ostream<_CharT, _Traits>::operator<<(**long int**) [with _CharT = char, _Traits = std::char_traits<char>]
- /usr/include/c++/4.4/ostream:169: note: std::basic_ostream<_CharT, _Traits>& std::basic_ostream<_CharT, _Traits>::operator<<(**long unsigned int**) [with _CharT = char, _Traits = std::char_traits<char>]
- /usr/include/c++/4.4/ostream:173: note: std::basic_ostream<_CharT, _Traits>& std::basic_ostream<_CharT, _Traits>::operator<<(**bool**) [with _CharT = char, _Traits = std::char_traits<char>]
- /usr/include/c++/4.4/bits/ostream.tcc:91: note: std::basic_ostream<_CharT, _Traits>& std::basic_ostream<_CharT, _Traits>::operator<<(**short int**) [with _CharT = char, _Traits = std::char_traits<char>]

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

int main()
{
  Complex c1(2,3);
  cout << c1;  // equiv. to cout.operator<<(c1);
  cout << endl;
  return 0;
}
```

Why Friend Functions?

- cout is an object of type 'ostream'
- << is just an operator
- But we call it with 'cout' on the LHS which would make "operator<<" a member function of class ostream
- Ostream class can't define these member functions to print out user defined classes because they haven't been created
- Similarly, ostream class doesn't have access to private members of Complex

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

int main()
{
  Complex c1(2,3);
  cout << "c1 = " << c1;
  // cout.operator<<("c1 = ").operator<<(c1);

  // ostream::operator<<(char *str);
  // ostream::operator<<(Complex &src);

  cout << endl;
  return 0;
}
```

Ostream Overloading

- Can define operator functions as friend functions
- LHS is 1st arg.
- RHS is 2nd arg.
- Use friend function so LHS can be different type but still access private data
- Return the ostream& (i.e. os which is really cout) so you can chain calls to '<<' and because cout/os object has changed

```
class Complex
{
 public:
  Complex(int r, int i);
  ~Complex();
  Complex operator+(const Complex &rhs);
  friend ostream& operator<<(ostream&, const Complex &c);
 private:
  int real, imag;
};

ostream& operator<<(ostream &os, const Complex &c)
{
  os << c.real << ",," << c.imag << "j";
  //cout.operater<<(c.real).operator<<(",").operator<<...
  return os;
}

int main()
{
  Complex c1(2,3), c2(4,5);
  cout << c1 << c2;
  // operator<<(cout, c1);
  cout << endl;
  return 0;
}
```

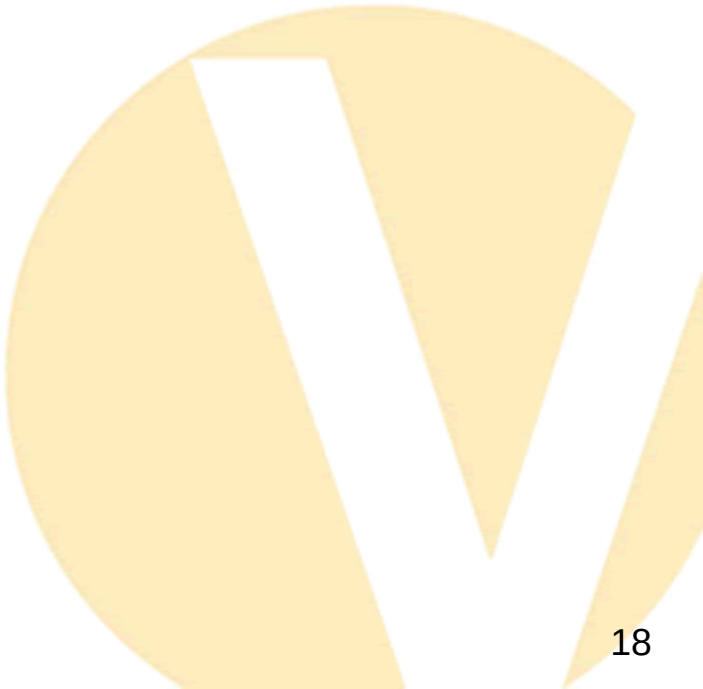
Template for adding ostream capabilities:
friend ostream& operator<<(ostream &os, const T &rhs);
(where T is your user defined type)

Summary

- Make the operator a member function of a class…
  - IF the **left hand side** of the operator is an instance of **that class**
  - The member function should only take in one argument which is the RHS object
- Make the operator a friend function of a class if…
  - IF the **left hand side** of the operator is an instance of **another class** and **right hand side** is an instance of **the class**
  - This function requires two arguments, first is the LHS object and second is the RHS object

Practice

- Add an ostream operator ('<<') to your Str class



Exercises For Home

- Write a '[]' operator member function for you List class
  - Have it throw an exception if the index is out of bounds
- Write an '==' operator to check if two lists have exactly the same contents in the exactly the same order
- Write a '+' operator to append one list to the end of another

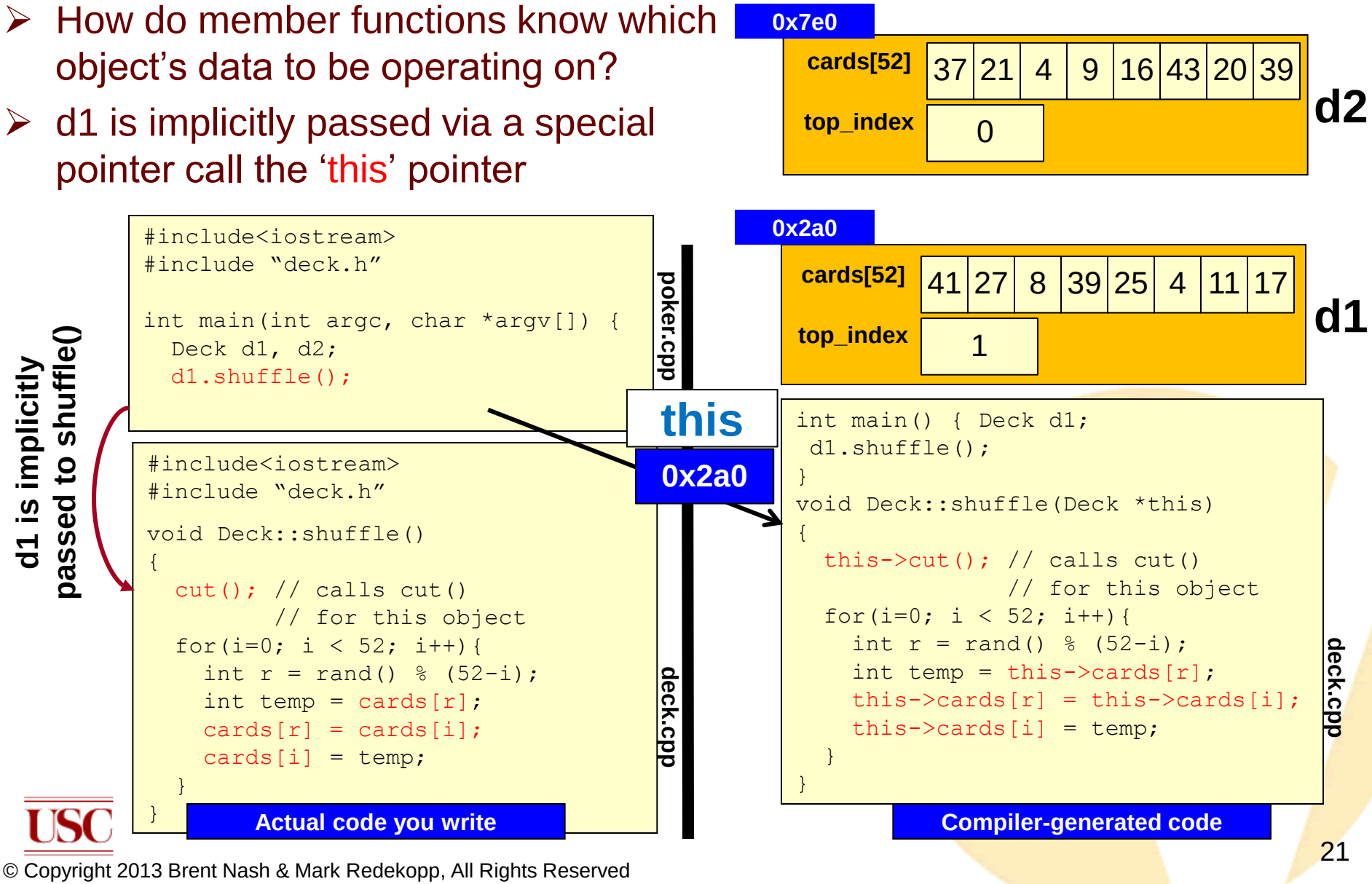
```
#include <iostream>
#include "listint.h"

using namespace std;

int main()
{
  List<int> m1, m2;

  m1.push_back(5);
  m2.push_back(5);
  if(m1 == m2){
    cout << "Should print!";

  }

  cout << "0-th item is " << m1[0];

  cout << endl;


  m1[0] = 7;

  if(m1 == m2){

    cout << "Should not print!"; << endl;

  }
  return 0;
}
```

Copy constructors and assignment operators

COPY SEMANTICS

this Pointer

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



Another Use of 'this'

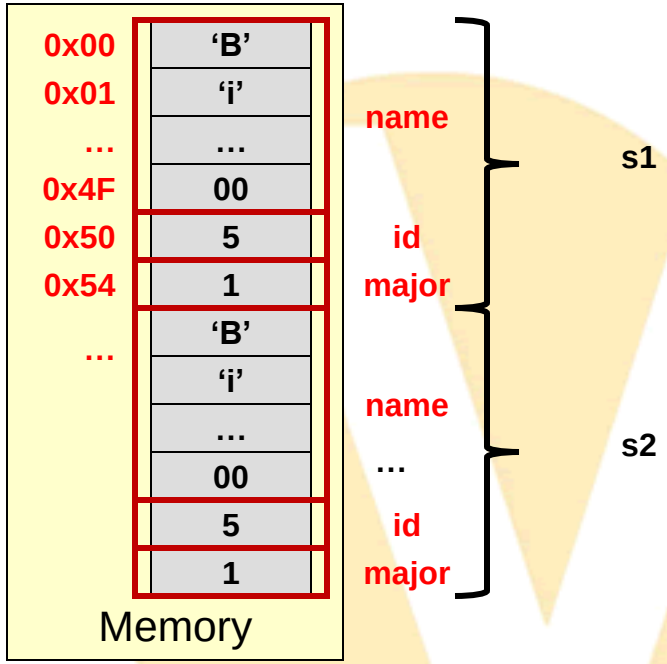
- This can be used to resolve scoping issues with similar named variables

```
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;
}


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

Struct/Class Assignment

- Assigning one struct or class object to another will perform an element by element copy of the source struct/class to the destination struct/class

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

enum {CS, CECS };

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

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



Multiple Constructors

- Can have multiple constructors with different argument lists

Sutdent.h

```
class Student {
 public:
   Student();    // Constructor 1
   Student(string name, int id, double gpa);
                 // Constructor 2
   ~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:
   string _name;
   int _id;
   double _gpa;
};
```

Student.cpp

```
Student::Student()
{
  _name = "", _id = 0; _gpa = 2.0;
}

Student::Student(string name, int id, double
gpa)
{
  _name = name; _id = id; _gpa = gpa;
}
```

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

int main()
{
  Student s1;  // calls Constructor 1
  string myname;
  cin >> myname;
  s1.set_name(myname);
  s1.set_id(214952);
  s1.set_gpa(3.67);

  Student s2(myname, 32421, 4.0);
             // calls Constructor 2

}
```

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

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

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

  ~Complex()
 private:
  int real, imag;
};


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


}
```

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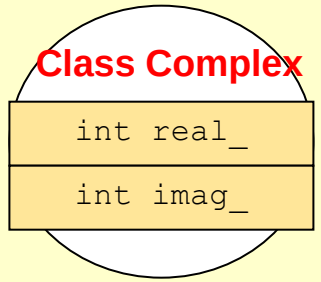
Assignment & Copy Constructors

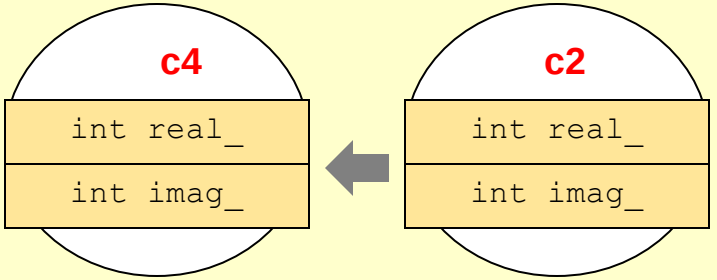
- C++ compiler automatically generates a ***default*** copy constructor
  - Constructor called when an object is allocated and initializes the object to be a copy of another object of the same type
  - Signature would look like **Complex(const Complex &);**
  - Called by either of the options shown in the code
  - **Simply performs an element by element copy**
- C++ compiler automatically generates a ***default*** assignment function
  - **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:
  int real, imag;
};


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

}
```





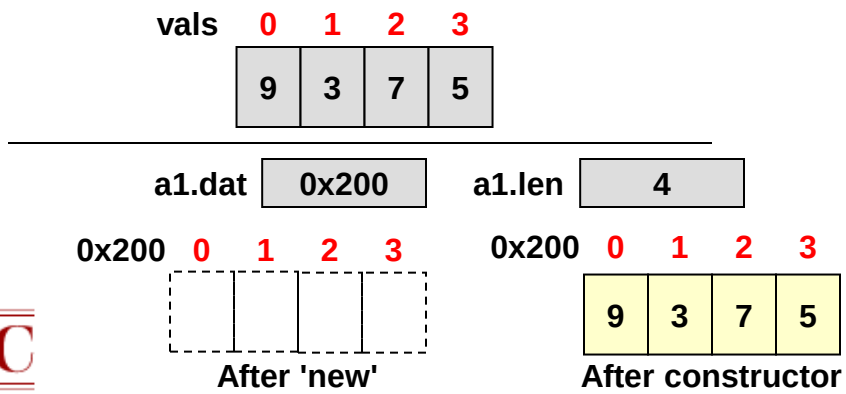
Assignment & Copy Constructors

- 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

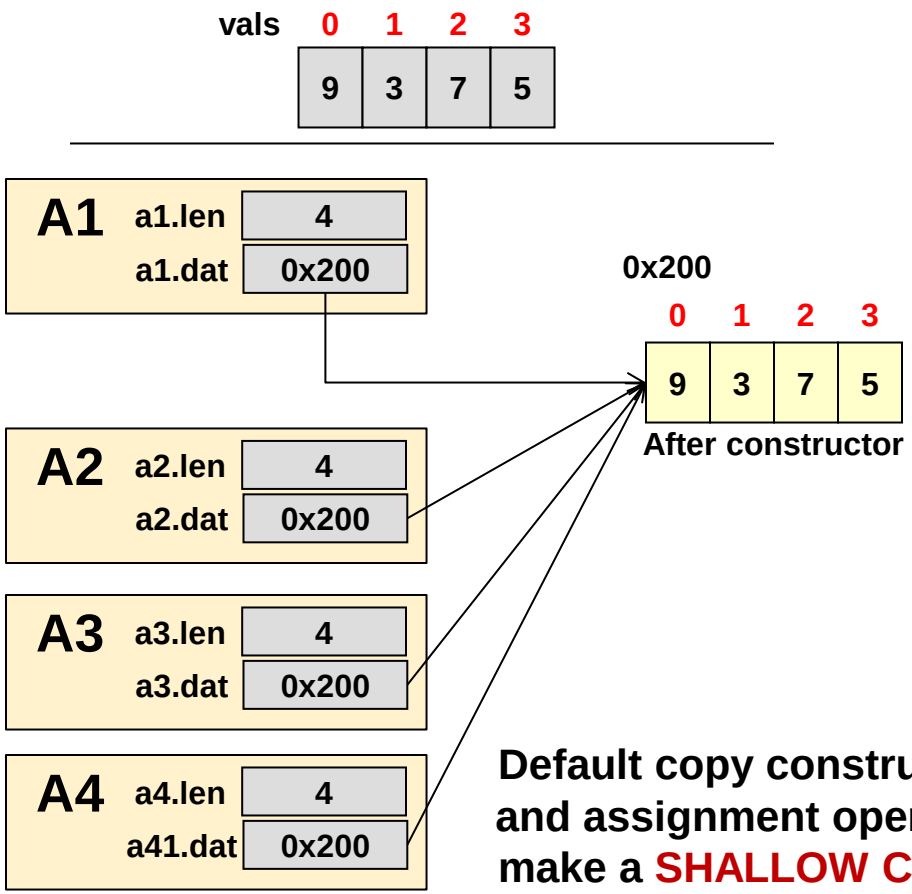
```
class MyArray
{
 public:
  MyArray(int d[], int num); //normal
  ~MyArray();
  int len; int *dat;

};
// 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 you data members pointing to dynamically allocated data, you need a DEEP copy
- If a Shallow copy is acceptable, 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
  - Can be just a reference if the original needs to be changed for some strange reason
- **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(intr, inti);
  Complex Complex(const Complex &rhs);
  ~Complex();
  int 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 **

}
```

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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(int r, int 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:
  int real, imag;
};


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


}
```

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Practice

- Add a copy constructor to your Str class

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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
}
```

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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;
}
```

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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 = right_op.real;
   imag = right_op.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
- Usually if you have dynamically allocated memory, you'll need a copy constructor, an assignment operator, (and a destructor)
- 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

- Add an assignment operator to your Str class
- Also add a '+=' operator to your Str class