CSE 333 Section 5

C++ Classes and Dynamic Memory
Logistics

● Exercise 7:
  ○ Due next Wednesday @ 10pm (11/1)

● Homework 2:
  ○ Due Monday @ 10pm (10/30)

● Midterm:
  ○ On Friday (TOMORROW) @ 11:30am (10/27)
  ○ See Exams page on the website
Review: Member vs. Non-Member Functions

- A **member function** is a part of the class and can be invoked on the objects of the class.
- A **non-member function** is a normal function that happens to use the class.
  - Often included in the module that defines the class.
- Some functionality *must* be defined one way or the other, but a lot can be defined either way, so let’s examine the differences…
Exercise 1
**Exercise 1: Member vs Non-Member Comparison**

<table>
<thead>
<tr>
<th>Access to Private Members:</th>
<th>Member</th>
<th>Non-member</th>
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</table>
|                           | Always | ● Through getters and setters  
|                           |        | ● Through friend keyword (do not use unless needed) |

<table>
<thead>
<tr>
<th>Function call (Func):</th>
<th>obj1.Func(obj2)</th>
<th>Func(obj1, obj2)</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Operator call (*):</th>
<th>obj1 * obj2</th>
<th>obj1 * obj2</th>
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</table>

| When preferred:           | Functions that *mutate* the object  
|                           | “Core” class functionality  
|                           | ● Non-mutating functions  
|                           | Commutative functions  
|                           | When the class must be on the right-hand side |
The “Big 4” of Classes (Review)

class Bar {
public:
    Bar(); // 0-arg ctor
    Bar(int num); // 1-arg ctor
    Bar(const Bar& other); // cctor
    Bar& operator=(const Bar& other); // op=
    ~Bar(); // dtor
...;
};

**Constructors (ctor):** Construct a new object (parameters must differ).

**Copy Constructor (cctor):** Constructs a new object based on another instance. Creates copies for pass-by-value (i.e., non-references).

**Assignment Operator (op=):** Updates existing object based on another instance.

**Destructor (dtor):** Cleans up the resources of an object when it falls out of scope or is deleted.
Construction and Destruction Details

Construction:
1. Construct/inititalize data members in order of declaration within the class.
   ○ If data member appears in the initialization list, apply the specified initialization, otherwise, default initialize.
2. Execute the constructor body.

Destruction:
When multiple objects fall out of scope simultaneously, they are destructed in the reverse order of construction.
1. Execute the destructor body.
2. Destruct data members in the reverse order of declaration within the class.
Exercise 2
Exercise 2: Foo Bar Ordering

class Bar {
public:
    Bar() : num_(0) { }  // 0-arg ctor
    Bar(int num) : num_(num) { }  // 1-arg ctor
    Bar(const Bar& other) : num_(other.num_) { }  //cctor
    ~Bar() { }  // dtor
    Bar& operator=(const Bar& other) = default;  // op=
    int get_num() const { return num_; }  // getter

private:
    int num_;
};

class Foo {
public:
    Foo() : bar_(5) { }  // 0-arg ctor
    Foo(const Bar& b) { bar_ = b; }  // 1-arg ctor
    ~Foo() { }  // dtor

private:
    Bar bar_;  
};
Exercise 2: Foo Bar Ordering

```c
int main() {
    Bar b1(3);
    Bar b2 = b1;
    Foo f1;
    Foo f2(b2);
    return EXIT_SUCCESS;
}
```

**Method Invocation Order:**
1. Bar 1-arg ctor (b1)
2. Bar cctor (b2)
3. Foo 0-arg ctor (f1)
4. Bar 1-arg ctor
5. Foo 1-arg ctor (f2)
6. Bar 0-arg ctor
7. Bar op=
8. Foo dtor (f2)
9. Bar dtor
10. Foo dtor (f1)
11. Bar dtor
12. Bar dtor (b2)
13. Bar dtor (b1)
Design Considerations

- What happens if you don’t define a copy constructor? Or an assignment operator? Or a destructor? Why might this be bad?
  - In C++, if you don’t define any of these, one will be synthesized for you
  - The synthesized copy constructor does a shallow copy of all fields
  - The synthesized assignment operator does a shallow copy of all fields
  - The synthesized destructor calls the default destructors of any fields that have them

- How can you disable the copy constructor/assignment operator/destructor?
  Set their prototypes equal to the keyword “delete”:
  ```cpp
  SomeClass(const SomeClass&) = delete;
  ```
New and Delete Operators

**new**: Allocates the type on the heap, calling specified constructor if it is a class type

Syntax:

```c
    type* ptr = new type;
    type* heap_arr = new type[num];
```

**delete**: Deallocates the type from the heap, calling the destructor if it is a class type. For anything you called **new** on, you should at some point call **delete** to clean it up

Syntax:

```c
    delete ptr;
    delete[] heap_arr;
```
Exercise 3
class Leaky {
    public:
        Leaky() { x_ = new int(5); }
    private:
        int* x_;  
};

int main(int argc, char** argv) {
    Leaky** dbl_ptr = new Leaky*;
    Leaky* lky_ptr = new Leaky();
    *dbl_ptr = lky_ptr;
    delete dbl_ptr;
    return EXIT_SUCCESS;
}
class Leaky {
public:
    Leaky() { x_ = new int(5); }
private:
    int* x_;}

int main(int argc, char** argv) {
    Leaky** dbl_ptr = new Leaky*;
    Leaky* lky_ptr = new Leaky();
    *dbl_ptr = lky_ptr;
    delete dbl_ptr;
    return EXIT_SUCCESS;
}

Exercise 3: Memory Leaks

Stack

Heap

How can we fix this leak?
delete lky_ptr;
~Leaky() { delete x_; }
An Acronym to Know: RAII

- Stands for “Resource Acquisition Is Initialization”
- Any resources you acquire (locks, files, heap memory, etc.) should happen in a constructor (i.e., during initialization)
- Then freeing those resources should happen in the destructor (and handled properly in cctor, assignment operator, etc.)
- Prevents forgetting to call free/delete, the dtor is called automatically for you when the object managing the resource goes out of scope.
- For more: https://en.cppreference.com/w/cpp/language/raii
Exercise 4
Exercise 4: Bad Copy

class BadCopy {
public:
    BadCopy() { arr_ = new int[5]; }
    ~BadCopy() { delete [] arr_; }
private:
    int* arr_;  
};

int main(int argc, char** argv) {
    BadCopy* bc1 = new BadCopy;
    BadCopy* bc2 = new BadCopy(*bc1);
    delete bc1;
    delete bc2;
    return EXIT_SUCCESS;  
}
The “Rule of Three”

- If your class needs its own destructor, assignment operator, or copy constructor, it almost certainly needs all three!
- **BadCopy** is a good example why, we need a destructor to **delete arr**, and so we needed a copy constructor too because otherwise we end up with a double **delete**
- **BadCopy** also needs its own assignment operator for the same reason, even with a fixed copy constructor, **b1 = b2;** would still break!
Exercise 4: Bad Copy

class BadCopy {
public:
    BadCopy() { arr_ = new int[5]; }
    ~BadCopy() { delete [] arr_; }
private:
    int* arr_;
};

int main(int argc, char** argv) {
    BadCopy* bc1 = new BadCopy;
    BadCopy* bc2 = new BadCopy(*bc1); // cctor
    delete bc1;
    delete bc2;
    return EXIT_SUCCESS;
}
Review Questions

● What do the following access modifiers mean?

**public:** Member is accessible by anyone

**protected:** Member is accessible by this class and any derived classes

**private:** Member is only accessible by this class

**friend:** Allows access of private/protected members to foreign functions and/or classes where this modifier is present

● What is the default access modifier for struct members in C++?

A struct can be thought of as a class where all members are default public instead of default private. In C++, it is also possible to give member functions (such as a constructor) to a struct.
Review: Member Functions

class Foo {
    public:
        // ctor, cctor, dtor...
        // Member function
        void MemberFunction();

        // Member operator overload
        Foo& operator*=(const Foo& rhs);
    }

    foo.h
    foo.cc

    Foo obj1;
    obj1.MemberFunction(); // call a member function

    Foo obj2;
    obj1 *= obj2; // call the member operator overload function
class Foo {
    public:
        // ctor, cctor, dtor...
    }

    void NonMemberFunction(const Foo& f);

    Foo operator*(const Foo& f1, const Foo& f2);

    Foo obj1;
    NonMemberFunction(obj1); // invoke a nonmember function
    Foo obj2;
    Foo obj3 = obj1 * obj2; // invoke the nonmember operator function
## Review: Member vs Non-Member

<table>
<thead>
<tr>
<th>Member</th>
<th>Non-member</th>
</tr>
</thead>
<tbody>
<tr>
<td>● Used when modifying the object (reassigning and accessing data members)</td>
<td>● Used for non-modifying and/or commutative functions.</td>
</tr>
<tr>
<td>● “Core” class functionality</td>
<td>● When operating with the class on the right-hand side</td>
</tr>
<tr>
<td>● Allows access to private functions/data members</td>
<td>● Does NOT give access to private functions/data members</td>
</tr>
<tr>
<td>● Function call: <code>obj1.Function(obj2);</code></td>
<td>● Only give <code>friend</code> keyword if <strong>NEEDED</strong></td>
</tr>
<tr>
<td>● Operator Overloads: <code>obj1 *= obj2;</code></td>
<td>○ <code>friend</code> allows for non-member private access</td>
</tr>
<tr>
<td></td>
<td>● Function call: <code>Func(obj1, obj2);</code></td>
</tr>
<tr>
<td></td>
<td>● Operator Overloads: <code>obj1 * obj2;</code></td>
</tr>
</tbody>
</table>
Constructors Revisited

class Int {
public:
    Int() { ival_ = 17; cout << "default(" << ival_ << ")" << endl; }
    Int(int n) { ival_ = n; cout << "ctor(" << ival_ << ")" << endl; }
    Int(const Int& n) {
        ival_ = n.ival_;  
        cout << "cctor(" << ival_ << ")" << endl;
    }
    ~Int() { cout << "dtor(" << ival_ << ")" << endl; }
};

Constructor (ctor): Can define any number as long as they have different parameters. Constructs a new instance of the class.

Copy Constructor (cctor): Creates a new instance based on another instance (must take a reference!). Invoked when passing/returning a non-reference object to/from a function.

Destructor (dtor): Cleans up the class instance. Deletes dynamically allocated memory (if any).
What is getting called here?

```c
int main(int argc, char** argv) {
    int p;          // 1. default ctor
    int q(p);       // 2. copy ctor
    int r(5);       // 3. 1 arg ctor
    int s = r;      // 4. copy ctor
    p = s;          // 5. assignment operator
}
```
Initialization Lists

```cpp
class Foo {
public:
    Foo(int x, int y) : x_(x), y_(y) {}
    // cctor, dtor...

    // Member function
    void MemberFunction();

    // Member operator overload
    void operator*=(const Foo& rhs);
private:
    int x_, y_;}
```

- Initialization lists allow a shorthand for initializing members of a class instance.
- Prevents the members from being default initialized (which can be beneficial if the default initialization is expensive).
Initialization Lists

- When is the initialization list of a constructor run, and in what order are data members initialized?

  The initialization list is run before the body of the ctor, and data members are initialized in the order that they are defined in the class, not by initialization list ordering.

- What happens if data members are not included in the initialization list?

  Data members that don’t appear in the initialization list are default initialized/constructed before ctor body is executed.
Destructors Review

- When are destructors invoked? In what order are they invoked when multiple objects are getting destructed?
  - An object’s destructor is run when it falls out of scope, or when the `delete` keyword is used on heap objects constructed with `new`
  - When a scope exits, local variables are destructed in reverse order of construction
- What happens when a destructor actually executes? (Hint: what happens to class members?)
  - Destructors are run in reverse order of construction: (1) run destructor body (2) destruct remaining members in reverse order of declaration
When are these destructors run?

```c
int main(int argc, char** argv) {
    Int p;
    Int q(p);
    Int r(5);
    Int s = r;
    p = s;
}
```
Exercise 2: Constructors and Destructors

```c
int main(int argc, char** argv) {
    Int p;
    Int q(p);
    Int r(5);
    Int s = r;
    q.set(p.get()+1);
    return EXIT_SUCCESS;
}
```

Output:
- default(17)
- cctor(17)
- ctor(5)
- cctor(5)
- get(17)
- set(18)
- dtor(5)
- dtor(5)
- dtor(18)
- dtor(17)

p
ival_ = 17

q
ival_ = 18

r
ival_ = 5

s
ival_ = 5
Exercise 5: IntArrayList

class IntArrayList {
  public:
    IntArrayList();
    IntArrayList(const int* const arr, size_t len);
    IntArrayList(const IntArrayList &rhs);
    // synthesized destructor
    // synthesized assignment operator

  private:
    int* array_;  // array_ will always point to somewhere on the heap!
    size_t len_;  
    size_t maxsize_;  
};

Note: Implementation details on the worksheet
Exercise 5: IntArrayList

```c
int main() {
    IntArrayList a;
    int copy_me[3] = {3, 1, 4};
    IntArrayList b(copy_me, 3);
    IntArrayList c(b);
}
```
Exercise 5: Wrap

class Wrap {
   public:
      Wrap() : p_(nullptr) {} 
      Wrap(IntArrayList* p) : p_(p) { *p_ = *p; }
      IntArrayList* p() const { return p_; }
   private:
      IntArrayList* p_; 
};
Exercise 5: struct List

```c
struct List {
    IntArrayList v;
};
```
Exercise 5: Classes Usage

```c
int main(int argc, char** argv) {
    IntArrayList a;
    IntArrayList* b = new IntArrayList();
    struct List l { a };
    struct List m { *b };
    Wrap w(b);
    delete b;
    return EXIT_SUCCESS;
}
```
Exercise 5: Classes Usage

```c
int main(int argc, char** argv) {
    IntArrayList a;
    IntArrayList* b = new IntArrayList();
    struct List l { a };
    struct List m { *b };
    Wrap w(b);
    delete b;
    return EXIT_SUCCESS;
}
```
Exercise 5: Classes Usage

```c
int main(int argc, char** argv) {
    IntArrayList a;
    IntArrayList* b = new IntArrayList();
    struct List l { a };
    struct List m { *b };
    Wrap w(b);
    delete b;
    return EXIT_SUCCESS;
}
```

Implement the destructor:
```c
IntArrayList::~IntArrayList() { delete[] array_; }
```