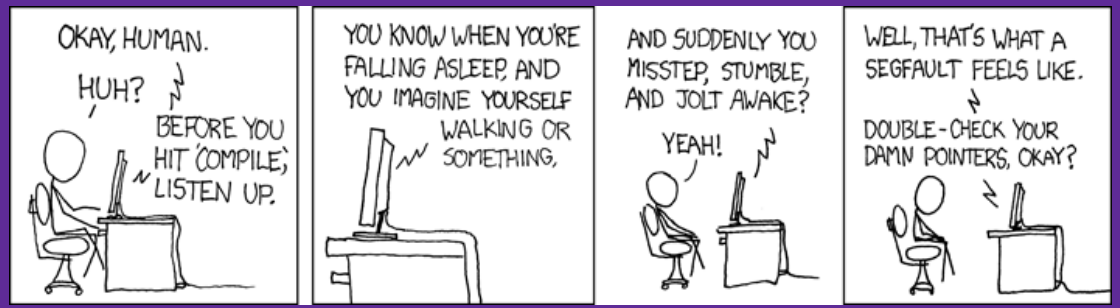
CSE 333 Section 5

C++ Classes and Dynamic Memory



Logistics

- Exercise 10:
  - Due **Tomorrow @ 11:00am (4/26)**
- Exercise 11:
  - Due **Monday @ 11:00am (4/29)**
- Homework 3:
  - Out soon, we have ~3 weeks

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

Member vs Non-Member Comparison

	Member	Non-member
Access to Private Members:	Always	• Through getters and setters • Through friend keyword (do not use unless needed)
Function call (Func):	obj1.Func(obj2)	Func(obj1, obj2)
Operator call (*):	obj1 * obj2	obj1 * obj2
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) and value return as well as variable declarations.**

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/initialize 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

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":

SomeClass(const SomeClass&) = delete;

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_;
};
```

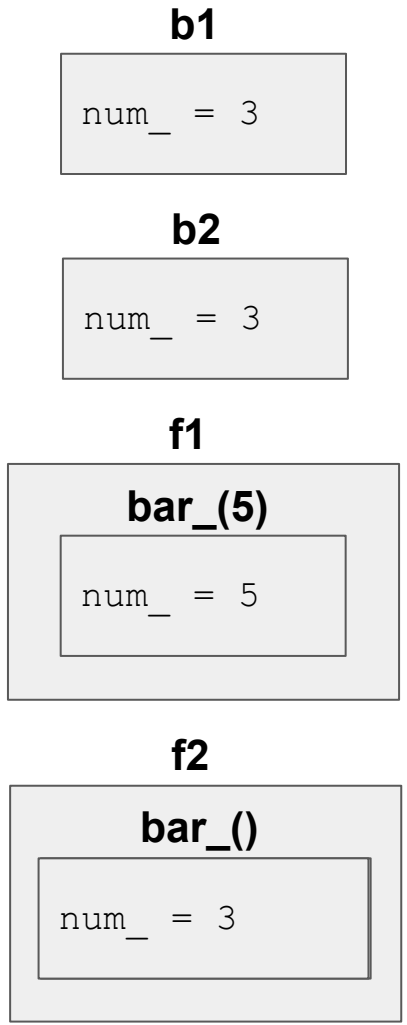
Given these class declarations, order the execution of the program (on the next slide)

Exercise 2: Foo Bar Ordering

```
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)



New and Delete Operators

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

Syntax:

```
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:

```
delete ptr;

delete[] heap_arr;
```

Exercise 3

Exercise 3: Memory Leaks

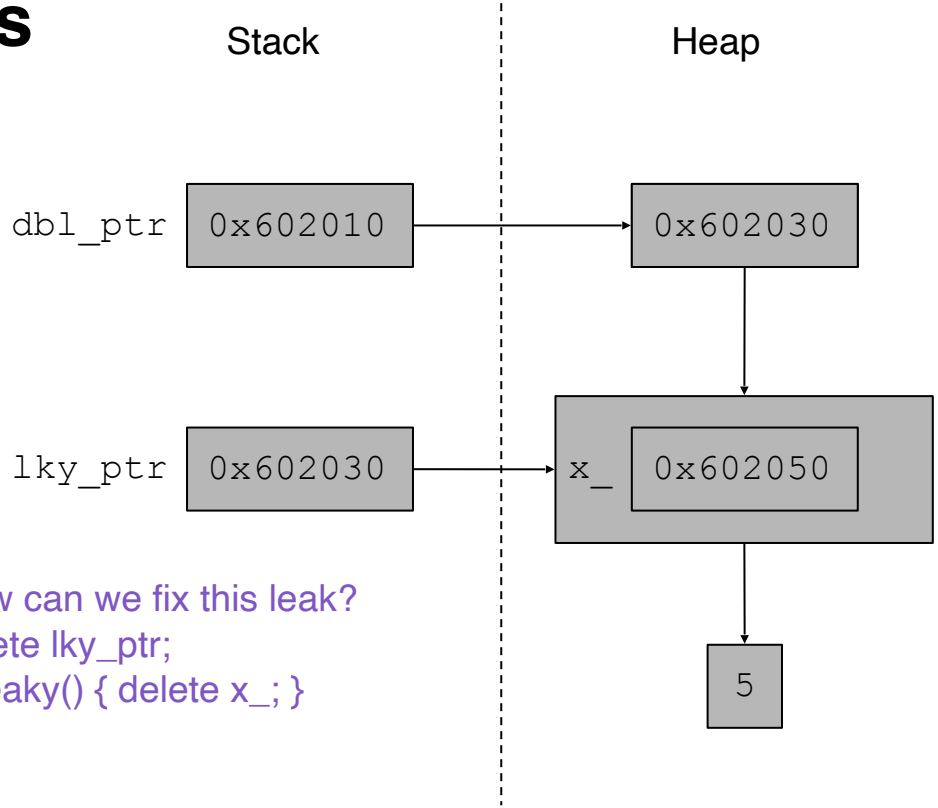
Stack

Heap

```
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

```
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;
}
```



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

Stack

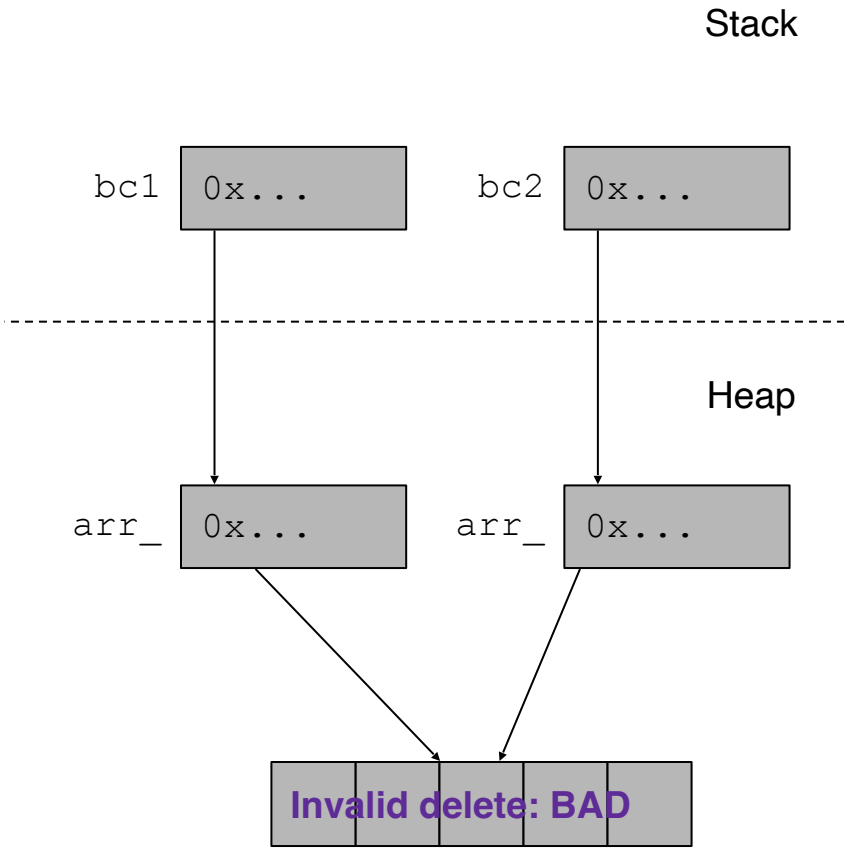
Heap

```
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;
}
```

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;
}
```

as if!



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!
- For more info/examples, see https://en.cppreference.com/w/cpp/language/rule_of_three

Q&A