CSE 333 Section 5

C++ Intro, Classes, and Dynamic Memory

Logistics

- Exercise 9:
  - Due **10/25 (Friday) @ 10:00 AM**
- Homework 2
  - Due **10/29 (Tuesday) @ 10:00 PM**
- Homework 3:
  - Out soon, we have ~3 weeks

Pointers, References, & Const

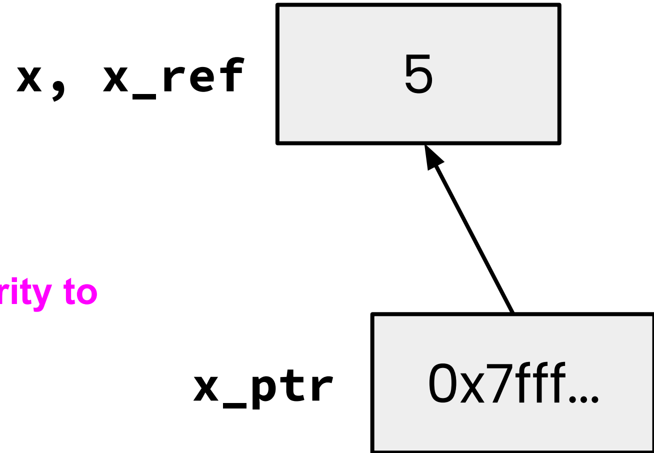
Example

Consider the following code:

```
int x = 5;
int& x_ref = x;
int* x_ptr = &x;
```

Note syntactic similarity to pointer declaration

Still the address-of operator!



What are some tradeoffs to using pointers vs references?

Pointers vs. References

Pointers

- Can move to different data via reassignment/pointer arithmetic
- Can be initialized to **NULL**
- Useful for output parameters:
  `MyClass* output`

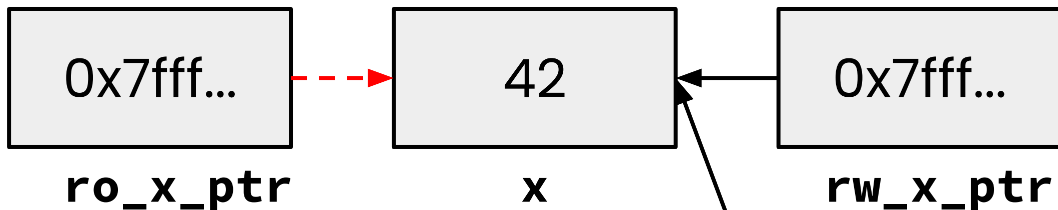
References

- References the same data for its entire lifetime - *can't reassign*
- No sensible "default reference," must be an alias
- Useful for input parameters:
  `const MyClass &input`

Pointers, References, Parameters

- `void func(int& arg)` vs. `void func(int* arg)`
- Use references when you don't want to deal with pointer semantics
  - Allows real pass-by-reference
  - Can make intentions clearer in some cases
- **STYLE TIP:** use references for input parameters and pointers for output parameters, with the output parameters declared last
  - Note: A reference can't be `NULL`

Const



- Mark a variable with `const` to make a compile time check that a variable is never reassigned
- Does not change the underlying write-permissions for this variable

```
int x = 42;

// Read only
const int* ro_x_ptr = &x;

// Can still modify x with
rw_x_ptr!
int* rw_x_ptr = &x;

// Only ever points to x
int* const x_ptr = &x;
```

0x7fff...

x_ptr

Legend

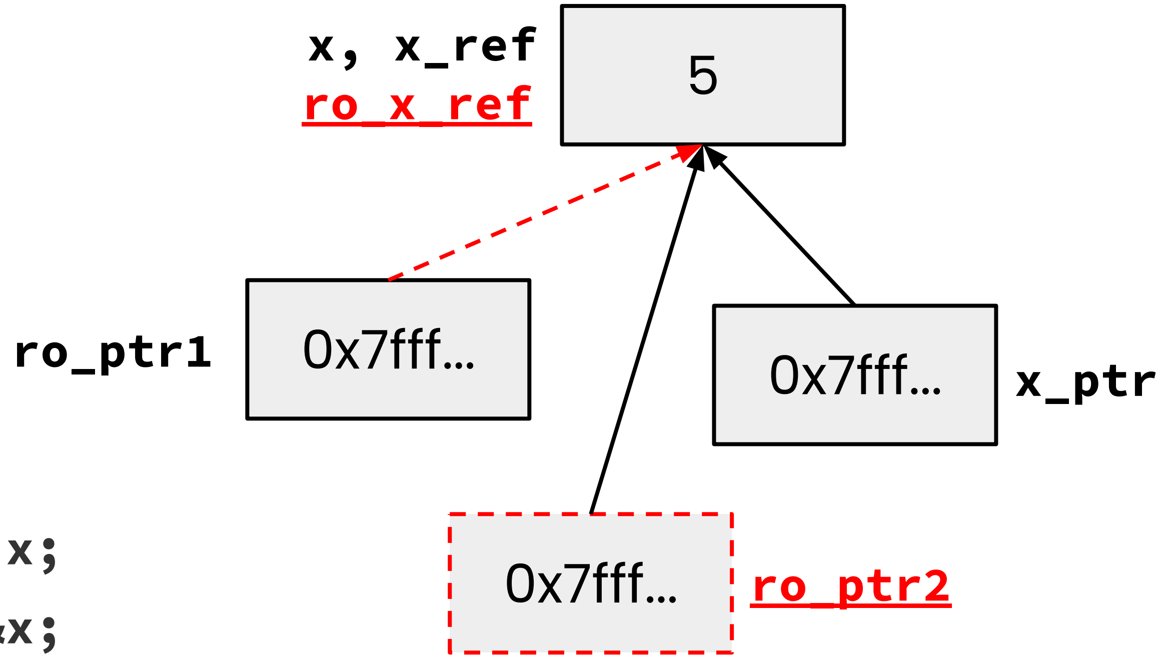
Red = can't change box it's next to

Black = read and write

Exercise 1

Exercise 1

```
int x = 5;
int& x_ref = x;
int* x_ptr = &x;
const int& ro_x_ref = x;
const int* ro_ptr1 = &x;
int* const ro_ptr2 = &x;
```



"Pointer to a const int"

"Const pointer to an int"

Tip: Read the declaration "right-to-left"

<u>Legend</u>

Red = can't change box it's next to

Black = read and write

Exercise 1

When would you prefer void Func(int &arg); to void Func(int *arg);? Expand on this distinction for other types besides int.

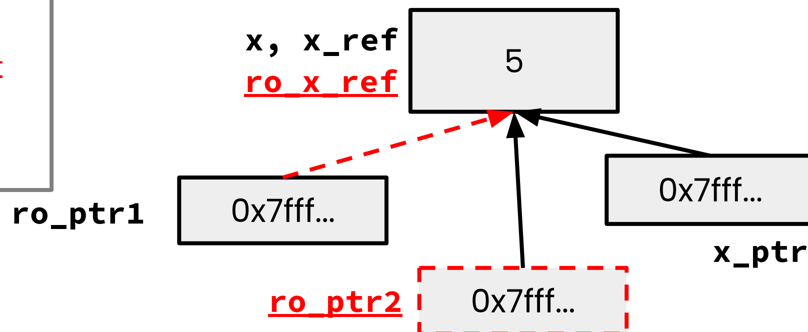
- When you don't want to deal with pointer semantics, use references
- When you don't want to copy stuff over (doesn't create a copy, especially for parameters and/or return values), use references
- Style wise, we want to use **references for input parameters** and **pointers for output parameters**, with the output parameters declared last

Exercise 1

Legend

Red = can't change box it's next to

Black = "read and write"




```
void foo(const int& arg);
void bar(int& arg);

int x = 5;
int& x_ref = x;
int* x_ptr = &x;
const int& ro_x_ref = x;
const int* ro_ptr1 = &x;
int* const ro_ptr2 = &x;
```

Which lines result in a compiler error?

✔ OK ❌ ERROR

- ✔ `bar(x_ref);`
- ❌ `bar(ro_x_ref);` ro_x_ref is const
- ✔ `foo(x_ref);`
- ✔ `ro_ptr1 = (int*) 0xDEADBEEF;`
- ❌ `x_ptr = &ro_x_ref;` ro_x_ref is const
- ❌ `ro_ptr2 = ro_ptr2 + 2;` ro_ptr2 is const
- ❌ `*ro_ptr1 = *ro_ptr1 + 1;` (*ro_ptr1) is const

Objects and const Methods

```cpp
#ifndef POINT_H_
#define POINT_H_

class Point {
 public:
  Point(const int x, const int y);
  int  get_x() const { return x_; }
  int  get_y() const { return y_; }
  double  Distance(const Point& p) const;
  void  SetLocation(const int& x, const int& y);

 private:
  int  x_;
  int  y_;
};  // class Point

#endif  // POINT_H_
```

Cannot mutate the object it's called on.

Trying to change x_ or y_ inside will produce a compiler error!

A **const** class object can only call member functions that have been declared as **const**

Exercise 2

Exercise 2

Which *lines* of the snippets of code below would cause compiler errors?

✔ OK ❌ ERROR

```
class MultChoice {
  public:
    MultChoice(int q, char resp) : q_(q), resp_(resp) { }  // 2-arg ctor
    int get_q() const { return q_; }
    char get_resp() { return resp_; }
    bool Compare(MultChoice &mc) const;  // do these MultChoice's match?

  private:
    int  q_;      // question number
    char resp_;   // response: 'A','B','C','D', or 'E'
};  // class MultChoice
```

✔ `const MultChoice m1(1,'A');`
✔ `MultChoice m2(2,'B');`
❌ `cout << m1.get_resp();`
✔ `cout << m2.get_q();`

✔ `const MultChoice m1(1,'A');`
✔ `MultChoice m2(2,'B');`
✔ `m1.Compare(m2);`
❌ `m2.Compare(m1);`

What would you change about the class declaration to make it better?

```
class MultChoice {
  public:
    MultChoice(int q, char resp) : q_(q), resp_(resp) { }  // 2-arg ctor
    int get_q() const { return q_; }
    char get_resp() { return resp_; }
    bool Compare(MultChoice &mc) const;  // do these MultChoice's match?

  private:
    int  q_;     // question number
    char resp_;  // response: 'A','B','C','D', or 'E'
};  // class MultChoice
```

```
class MultChoice {
  public:
    MultChoice(int q, char resp) : q_(q), resp_(resp) { }  // 2-arg ctor
    int get_q() const { return q_; }
    char get_resp() const { return resp_; }
    bool Compare(const MultChoice &mc) const;  // do these match?

  private:
    int  q_;     // question number
    char resp_;  // response: 'A','B','C','D', or 'E'
};  // class MultChoice
```

- Make get_resp() const
- Make the parameter to Compare() const
- Stylistically:
  - Add a setter method and default constructor
  - Disable copy constructor and assignment operator

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…

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.

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 3

Exercise 3: 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 3: 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)

b1

num_ = 3

b2

num_ = 3

f1

bar_(5)

num_ = 5

f2

bar_()

num_ = 3

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 4

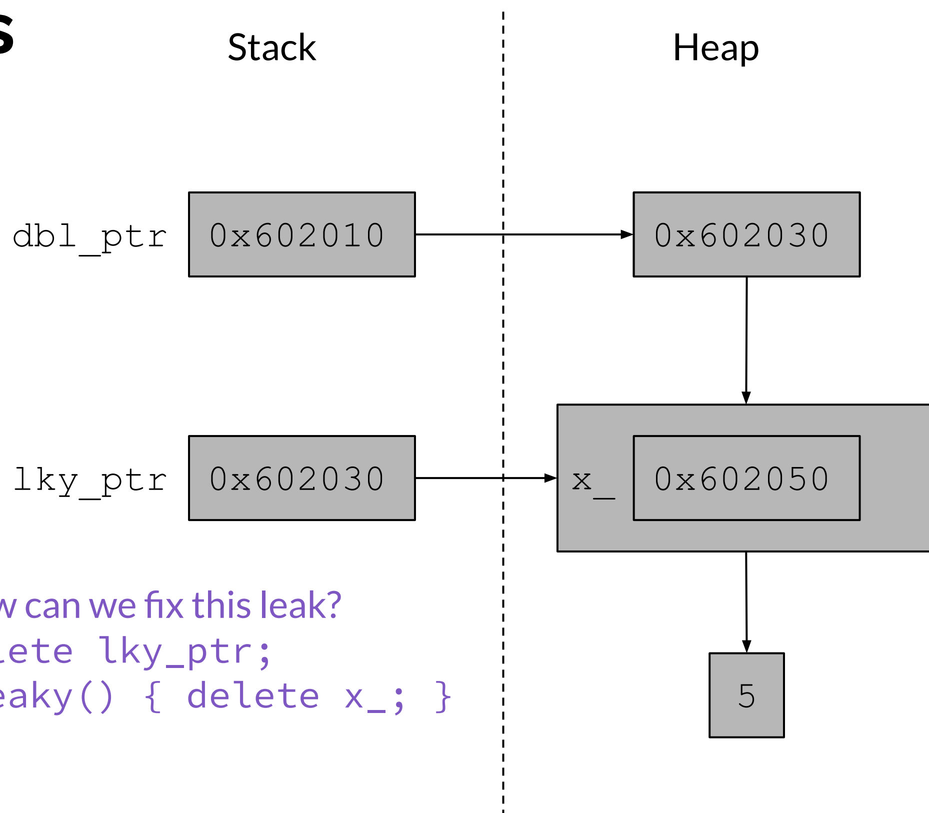
Exercise 4: Memory Leaks

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 4: 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 5

Exercise 5: Bad Copy

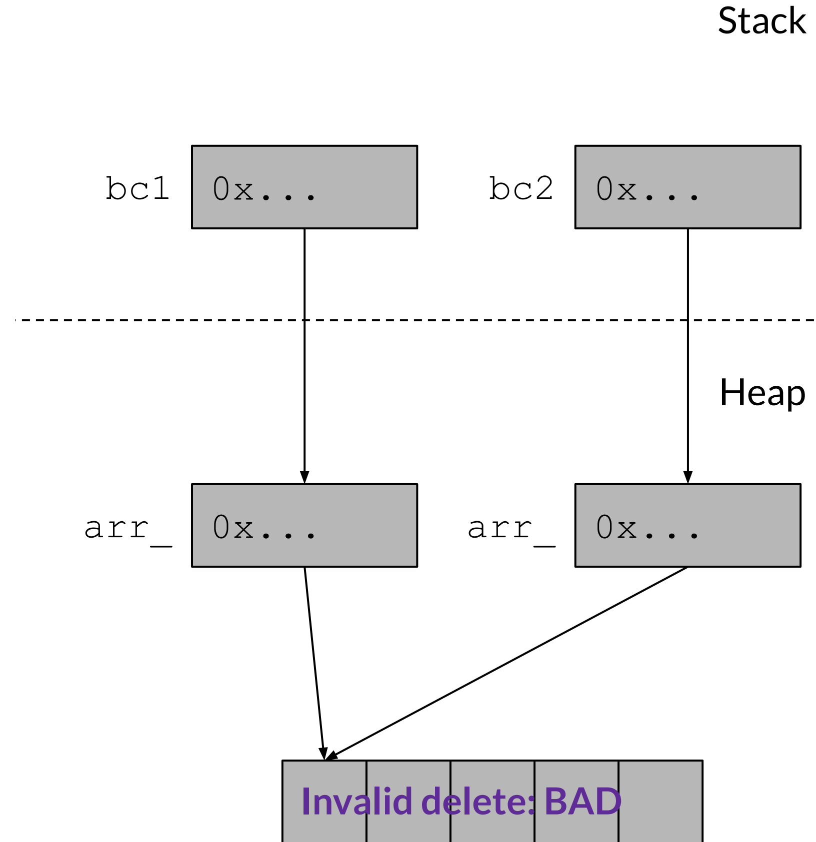
Stack | Heap

```
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 5: 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