# C++ Class Details, Heap

## CSE 333 Spring 2023

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# Relevant Course Information

- Exercise 6 due Monday
- Exercise 7 out by Monday
  - Will build on Exercise 6 and use what a lot of is discussed today
- Homework 2 due Thursday (4/27)
  - File system crawler, indexer, and search engine
  - Don't forget to clone your repo to double-/triple-/quadruple-check compilation!
  - Don't modify the header files!

# Lecture Outline

- **Class Details**
  - **Filling in some gaps from last time**
- Using the Heap
  - `new` / `delete` / `delete[]`

# Rule of Three

- If you define any of:
  1) Destructor
  2) Copy Constructor
  3) Assignment (`operator=`)

- Then you should normally define all three
  - Can explicitly ask for default synthesized versions (C++11):

```
class Point {
 public:
  Point() = default;                                     // the default ctor
  ~Point() = default;                                    // the default dtor
  Point(const Point& copyme) = default;                  // the default cctor
  Point& operator=(const Point& rhs) = default;          // the default "="
  ...
```

# Dealing with the Insanity (C++11)

- C++ style guide tip:
  - Disabling the copy constructor and assignment operator can avoid confusion from implicit invocation and excessive copying

Point_2011.h

```
class Point {
 public:
  Point(const int x, const int y) : x_(x), y_(y) { }  // ctor
  ...
  Point(const Point& copyme) = delete;    // declare cctor and "=" as
  Point& operator=(const Point& rhs) = delete; // as deleted (C++11)
 private:
  ...
};  // class Point

Point w;           // compiler error (no default constructor)
Point x(1, 2);     // OK!
Point y = w;       // compiler error (no copy constructor)
y = x;             // compiler error (no assignment operator)
```

# Access Control

- Access modifiers for members:
  - `public`: accessible to *all* parts of the program
  - `private`: accessible to the member functions of the class
    - Private to *class*, not object instances
  - `protected`: accessible to member functions of the class and any *derived* classes (subclasses – more to come, later)

- Reminders:
  - Access modifiers apply to *all* members that follow until another access modifier is reached
  - If no access modifier is specified, `struct` members default to `public` and `class` members default to `private`

# Nonmember Functions

- "Nonmember functions" are just normal functions that happen to use some class
  - Called like a regular function instead of as a member of a class object instance
    - This gets a little weird when we talk about operators…
  - These do *not* have access to the class' private members (maybe through getters)
- Useful nonmember functions often included as part of interface to a class
  - Declaration goes in header file, but *outside* of class definition

| | Member | Non-member |
| --- | --- | --- |
| named function | `double Point::Distance(Point&);` | `double Distance(Point&, Point&);` |
| | `pt1.Distance(pt2);` | `Distance(pt1, pt2);` |
| operator | `float Vector::operator*(Vector&);` | `float operator*(Vector&, Vector&);` |
| | `vec1 * vec2;` ← can't tell! | → `vec1 * vec2;` |

# friend Nonmember Functions

- A class can give a nonmember function (or class) access to its non-public members by declaring it as a friend within its definition
  - Not a class member, but has access privileges as if it were
  - friend functions are usually unnecessary if your class includes appropriate "getter" public functions

Complex.h

```
class Complex {
  ...
  friend std::istream& operator>>(std::istream& in, Complex& a);
  ...
};  // class Complex
```

declaration only

```
std::istream& operator>>(std::istream& in, Complex& a) {
  ...
}
```

definition outside of class

Complex.cc

# When to use Nonmember and `friend`

STYLE TIP

There is more to C++ object design that we don't have time to get to; these are good rules of thumb, but be sure to think about your class carefully!

- Member functions:
  - Operators that modify the object being called on
    - Assignment operator (`operator=`)
  - "Core" non-operator functionality that is part of the class interface
- Nonmember functions:
  - Used for commutative operators
    - *e.g.*, so `v1 + v2` is invoked as `operator+(v1, v2)` instead of `v1.operator+(v2)`
  - If operating on two types and the class is on the right-hand side
    - *e.g.*, `cin >> complex;`
  - Returning a "new" object, not modifying an existing one
  - Only grant `friend` permission if you NEED to

# Poll Everywhere

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doesn't modify objects, commutative

**If we wanted to overload `operator==` to compare two `Point` objects, what type of function should it be?**

no need for friend

- Reminder that `Point` has getters and a setter

A. non-friend + member

B. ~~friend + member~~ this is not a thing, as member functions can always access non-public data members

C. non-friend + non-member

D. friend + non-member

E. I'm lost…

# Namespaces

Same name, but different namespace

- Each namespace is a separate scope
  - Useful for avoiding symbol collisions!

ll::Iterator
ht::Iterator

- Namespace definition:

lowercase

```
namespace name {
// declarations go here
} // namespace name
```

no ;

Namespace doesn't add indentation to contents

Comment to remind that this is end of namespace

  - Doesn't end with a semi-colon and doesn't add to the indentation of its contents
  - Creates a new namespace name if it did not exist, otherwise *adds to the existing namespace* (**!**)
    - This means that components (*e.g.*, classes, functions) of a namespace can be defined in multiple source files

# Classes vs. Namespaces

- They seems somewhat similar, but classes are *not* namespaces:
  - There are no instances/objects of a namespace; a namespace is just a group of logically-related things (classes, functions, etc.)
  - To access a member of a namespace, you must use the fully qualified name (*i.e.*, `nsp_name::member`)
    - Unless you are `using` that namespace
    - You only used the fully qualified name of a class member when you are defining it outside of the scope of the class definition

# Complex Example Walkthrough

See:

`Complex.h`

`Complex.cc`

`testcomplex.cc`

# Lecture Outline

- Class Details
  - Filling in some gaps from last time
- **Using the Heap**
  - **`new` / `delete` / `delete[]`**

# C++11 `nullptr`

STYLE TIP

- C and C++ have long used `NULL` as a pointer value that references nothing

- C++11 introduced a new literal for this: `nullptr`
  - New reserved word
  - Interchangeable with `NULL` for all practical purposes, but it has type `T*` for any/every `T`, and is not an integer value
    - Avoids funny edge cases (see C++ references for details)
    - Still can convert to/from integer `0` for tests, assignment, etc.
  - Advice: prefer `nullptr` in C++11 code
    - Though `NULL` will also be around for a long, long time

# `new`/`delete`

- To allocate on the heap using C++, you use the `new` keyword instead of `malloc()` from `stdlib.h`
  - You can use new to allocate an object (*e.g.*, `new Point`)
  - You can use new to allocate a primitive type (*e.g.*, `new int`)

- To deallocate a heap-allocated object or primitive, use the `delete` keyword instead of `free()` from `stdlib.h`
  - Don’t mix and match!
    - *Never* `free()` something allocated with `new`
    - *Never* `delete` something allocated with `malloc()`
    - Careful if you’re using a legacy C code library or module in C++

# `new`/`delete` Behavior

- `new` behavior:
  - When allocating you can specify a constructor or initial value
    - *e.g.*, `new Point(1, 2)`, `new int(333)`
  - If no initialization specified, it will use default constructor for objects and uninitialized ("mystery") data for primitives
  - You don't need to check that `new` returns `nullptr`
    - When an error is encountered, an exception is thrown (that we won't worry about)

- `delete` behavior:
  - If you `delete` already `delete`d memory, then you will get undefined behavior (same as when you double **`free`** in C)

# new/delete Example

```
int* AllocateInt(int x) {
  int* heapy_int = new int;
  *heapy_int = x;
  return heapy_int;
}
```

```
Point* AllocatePoint(int x, int y) {
  Point* heapy_pt = new Point(x,y);
  return heapy_pt;
}
```

heappoint.cc

```
#include "Point.h"

...  // definitions of AllocateInt() and AllocatePoint()

int main() {
  Point* x = AllocatePoint(1, 2);
  int* y = AllocateInt(3);

  cout << "x's x_ coord: " << x->get_x() << endl;
  cout << "y: " << y << ", *y: " << *y << endl;

  delete x;
  delete y;
  return EXIT_SUCCESS;
}
```

# Dynamically Allocated Arrays

- To dynamically allocate an array:
  - Default initialize: `type* name = new type[size];`

    new still returns a pointer

- To dynamically deallocate an array:
  - Use `delete[] name;`
  - It is an *incorrect* to use "`delete name;`" on an array

    is this a pointer to a thing or an array of things?

    - The compiler probably won't catch this, though (!) because it can't always tell if `name*` was allocated with `new type[size];` or `new type;`
      - Especially inside a function where a pointer parameter could point to a single item or an array and there's no way to tell which!
    - Result of wrong `delete` is undefined behavior

# Arrays Example (primitive)

arrays.cc

```
#include "Point.h"

int main() {
  int stack_int;   // stack (uninitialized)
  int* heap_int = new int;   // heap (uninitialized)
  int* heap_int_init = new int(12);   // heap (value 12)

  int stack_arr[3];   // stack (uninitialized)
  int* heap_arr = new int[3];   // heap (uninitialized)

  int* heap_arr_init_val = new int[3]();   // heap (values 0)
  int* heap_arr_init_lst = new int[3]{4, 5};   // C++11
                                               // heap (initialized to {4,5,0})
  ...

  delete heap_int;              // correct!
  delete heap_int_init;         // correct!
  delete heap_arr;              // incorrect! should be delete[]
  delete[] heap_arr_init_val;   // correct!
  // memory leak of heap_arr_init_lst!
  return EXIT_SUCCESS;
}
```

# Arrays Example (class objects)

arrays.cc

```
#include "Point.h"

int main() {
  ...

  Point stack_pt(1, 2);           //stack object
  Point* heap_pt = new Point(1, 2);     // heap object

X Point* heap_pt_arr_err = new Point[2];  // default constructed objects
                                          // error! no default constructor in Point

  Point* heap_pt_arr_init_lst = new Point[2]{{1, 2}, {3, 4}};
                                                        // C++11

  ...

  delete heap_pt;                     // correct
  delete[] heap_pt_arr_init_lst;      // correct

  return EXIT_SUCCESS;
}
```

# malloc vs. new

| | malloc() | new |
|---|---|---|
| What is it? | a function | an operator or keyword |
| How often used (in C)? | often | never |
| How often used (in C++)? | rarely | often |
| Allocated memory for | anything | arrays, structs, objects, primitives always given a type |
| Returns | a void* (*should be cast*) | new T returns T* appropriate pointer type (*doesn't need a cast*) |
| When out of memory | returns NULL | throws an exception usually ignored |
| Deallocating | free() | delete or delete[] |

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# What will happen when we invoke Bar()?

- If there is an error, how would you fix it?

A. Bad dereference

B. Bad delete

C. Memory leak

D. "Works" fine

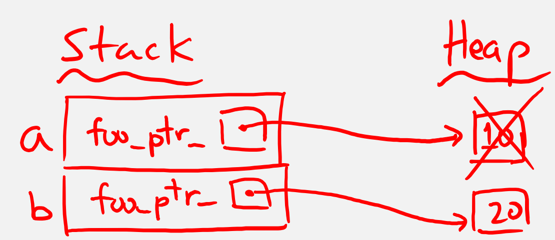
E. We're lost…

```
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
  foo_ptr_ = new int;
  *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  delete foo_ptr_;
  Init(*(rhs.foo_ptr_));
  return *this;
}

void Bar() {
  Foo a(10);
  Foo b(20);
  a = a;
}
```



# Rule of Three, Revisited

- Now what will happen when we invoke `Bar()`?
  - If there is an error, how would you fix it?

double delete error!

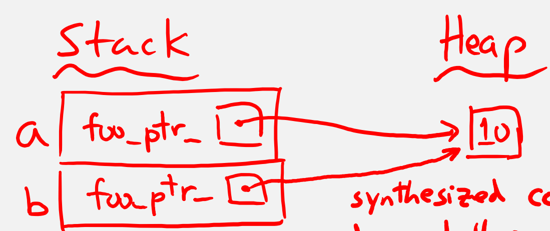
should define cctor to dynamically allocate space for copy of int

```
Foo::Foo(int val) { Init(val); }
Foo::~Foo() { delete foo_ptr_; }

void Foo::Init(int val) {
   foo_ptr_ = new int;
  *foo_ptr_ = val;
}

Foo& Foo::operator=(const Foo& rhs) {
  if (&rhs != this) {
    delete foo_ptr_;
    Init(*(rhs.foo_ptr_));
  }
  return *this;
}

void Bar() {
  Foo a(10);
  Foo b = a;
}
```




synthesized cctor does shallow copy!

# Extra Exercise #1

- Write a C++ function that:
  - Uses `new` to dynamically allocate an array of strings and uses `delete[]` to free it
  - Uses `new` to dynamically allocate an array of pointers to strings
    - Assign each entry of the array to a string allocated using `new`
  - Cleans up before exiting
    - Use `delete` to delete each allocated string
    - Uses `delete[]` to delete the string pointer array
    - (whew!)

# BONUS SLIDES

An extra example for practice with class design and heap-allocated data: a C-string wrapper class classed `Str`.

# Heap Member (extra example)

- Let's build a class to simulate some of the functionality of the C++ string
  - Internal representation: c-string to hold characters
    - ↑ null-terminated char *
- What might we want to implement in the class?
  - default constructor → "" string is '\0'
  - constructor from char*
  - print to ostream
  - length → reminder: this doesn't count the null terminator
  - concatenation → we'll do append instead, which is similar
  - copy constructor
  - destructor → clean up internal mem!

# Str Class

Str.h

```
#include <iostream>
using namespace std;    // should replace this

class Str {
 public:
  Str();                 // default ctor
  Str(const char* s);    // c-string ctor
  Str(const Str& s);     // copy ctor
  ~Str();                // dtor

  int length() const;    // return length of string
  char* c_str() const;   // return a copy of st_
  void append(const Str& s);

  Str& operator=(const Str& s);  // string assignment

  friend std::ostream& operator<<(std::ostream& out, const Str& s);

 private:
  char* st_;  // c-string on heap (terminated by '\0')
};  // class Str
```

# Str::append (extra example)

- Complete the **append()** member function:
  - `char* strncpy(char* dst, char* src, size_t num);`
  - `char* strncat(char* dst, char* src, size_t num);`

```
#include <cstring>
#include "Str.h"
// append contents of s to the end of this string
void Str::append(const Str& s) {

                    see   Str.cc

}
```

# Clone

- C++11 style guide tip:
  - If you disable them, then you instead may want an explicit "Clone" function that can be used when occasionally needed

Point_2011.h

```
class Point {
 public:
  Point(const int x, const int y) : x_(x), y_(y) { }  // ctor
  void Clone(const Point& copy_from_me);
  ...
  Point(Point& copyme) = delete;              // disable cctor
  Point& operator=(Point& rhs) = delete;  // disable "="
 private:
  ...
};  // class Point
```

sanepoint.cc

```
Point x(1, 2);  // OK
Point y(3, 4);  // OK
x.Clone(y);  // OK
```