

# C++ Class Details, Heap

## CSE 333 Winter 2024

**Instructor:** Hal Perkins

**Teaching Assistants:**

Ann Baturytski

Noa Ferman

Hannah Jiang

Humza Lala

Leanna Nguyen

Varun Pradeep

Justin Tysdal

Deeksha Vatwani

Yiqing Wang

Wei Wu

Jennifer Xu

# Administrivia (1)

- ❖ Yet another exercise released today, due Wed.
  - Rework exercise 9 but with dynamic memory for the instance variables and no getters this time
    - Fine to use ex9 solution as a starting point for ex10
  
- ❖ ...Homework 2 due Thursday night
  - File system crawler, indexer, and search engine
  - **Check your work!!** Clone the repo when you're done, do git checkout hw2-final; cd hw1 and copy/build libhw1.a; cd hw2; make; then test
  - Reminder: **do not modify header files**
  - Reminder: commit/push your work regularly, not all at once at the end

(no exercise due Friday.... 😊)

# Administrivia (2)

- ❖ Midterm exam in a week: Thursday 2/8, 5-6 pm, Kane 110
  - Topic list and old exams on website now (see exams link on resources page)
  - Closed book, slides, etc., but you may have one 5x8 notecard with whatever handwritten notes you want on both sides
    - Free blank cards available in class later this week and next 😊
  - Review in sections next week
  
- ❖ Please submit regrades promptly after feedback is published
  - Will shut off old regrades and upload scores to canvas soon

# 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 & later):

```
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 instanity

## ❖ C++ style guide tip:

- If possible, **disable** the copy constructor and assignment operator if not needed – avoids implicit invocation and excessive copying. C++11 and later have direct syntax to indicate this:

[Point\\_2011.h](#)

```
class Point {
public:
    Point(const int x, const int y) : x_(x), y_(y) { } // ctor
    ...
    Point(const Point& copyme) = delete; // declare ctor 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)
```

# If you're dealing with old code...

- ❖ In pre-C++11 code the copy constructor and assignment were often disabled by making them private and not implementing them (you may see this)...

Point.h

```
class Point {
public:
    Point(const int x, const int y) : x_(x), y_(y) { } // ctor
    ...
private:
    Point(const Point& copyme); // disable cctor (no def.)
    Point& operator=(const Point& rhs); // disable "=" (no def.)
    ...
}; // 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)
```

# CopyFrom

## ❖ C++11 style guide tip:

- If you disable them, then you instead may want an explicit “CopyFrom” function that can be used when occasionally needed

- Google advice has changed over time – these days prefer copy ctr, op=  
[Point.h](#)

```
class Point {
public:
    Point(const int x, const int y) : x_(x), y_(y) { } // ctor
    void CopyFrom(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.CopyFrom(y); // OK
```



# struct vs. class

- ❖ In C, a `struct` can only contain data fields
  - Has no methods and all fields are always accessible
  - In `struct foo`, the `foo` is a “struct tag”, not an ordinary data type
- ❖ In C++, `struct` and `class` are (nearly) the same!
  - Both define a new type (the `struct` or `class` name)
  - Both can have methods and member visibility (public/private/protected)
  - Only real (minor) difference: members are default *public* in a `struct` and default *private* in a `class`
- ❖ Common style/usage convention:
  - Use `struct` for simple bundles of data
    - Convenience constructors can make sense though
  - Use `class` for abstractions with data + functions

# 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
- ❖ Useful nonmember functions often included as part of the interface to a class
  - Declaration goes in header file, but *outside* of class definition
    - But *inside* the same namespace as the class, if it has one
  - Super useful for class-related things like overloaded operators (`operator+`, etc.), stream I/O (`operator<<`), etc. ...

# Review: Operator Overloading

- ❖ Can overload operators using **member functions**
  - Restriction: left-hand side argument must be a class you are implementing

```
Complex& operator+=(const Complex &a) { ... }
```

- ❖ Can overload operators using **nonmember functions**
  - No restriction on arguments (can specify any two)
    - **Our only option** when the left-hand side is a class you do not have control over, like `ostream` or `istream`.
  - But no access to private data members

```
Complex operator+(const Complex &a, const Complex &b) { ... }
```

# friend Nonmember Functions

- ❖ A class can give a nonmember function (or class) access to its `nonpublic` members by declaring it as a `friend` within its definition
  - `friend` function is 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
```

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

Complex.cc 13

# When to use Nonmember and `friend`

- ❖ 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

# Namespaces

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

- ❖ Namespace definition:

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

- Creates a new namespace name if it did not exist, otherwise *adds to the existing namespace (!)*
  - This means that components (classes, functions, etc.) of a namespace can be defined in multiple source files
    - All of the standard library is in namespace `std` but it has many 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 or individual member item
    - You only used the fully qualified name of a class member when you are defining it outside of the scope of the class definition



# Lecture Outline

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

# C++11 `nullptr`

- ❖ 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, especially with function overloading (`f(int)` vs `f(T*)`); 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`)
    - Will execute appropriate constructor as part of object allocate/create
  - 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 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"  
using namespace std;  
  
... // 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 0;  
}
```

# 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 `deleted` memory, then you will get undefined behavior (same as when you double `free` in C)

# Dynamically Allocated Arrays

## ❖ To dynamically allocate an array:

- Default initialize: `type* name = new type[size];`

## ❖ To dynamically deallocate an array:

- Use `delete [] name;`

- It is an *incorrect* to use “`delete name;`” on an array

- 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"
using namespace std;

int main() {
    int stack_int;
    int* heap_int = new int;
    int* heap_init_int = new int(12);

    int stack_arr[10];
    int* heap_arr = new int[10];

    int* heap_init_arr = new int[10](); // uncommon usage
    int* heap_init_error = new int[10](12); // bad syntax
    int* heap_init_error = new int[10]{12}; // C++11 allows
    ...                                     // (uncommon)

    delete heap_int; // ok
    delete heap_init_int; // ok
    delete heap_arr; // error - must be delete[]
    delete[] heap_init_arr; // ok

    return 0;
}
```

# Arrays Example (class objects)

arrays.cc

```
#include "Point.h"
using namespace std;

int main() {
    ...

    Point stack_point(1, 2);
    Point* heap_point = new Point(1, 2);

    Point* err_pt_arr = new Point[10]; // bug-no Point() ctr

    Point* err2_pt_arr = new Point[10](1,2); // bad syntax
    Point* err2_pt_arr = new Point[10]{1,2}; // C++11 allows
    ...                                     // (uncommon)

    delete heap_point;

    ...

    return 0;
}
```



# malloc vs. new

|                          | <code>malloc()</code>                           | <code>new</code>                                         |
|--------------------------|-------------------------------------------------|----------------------------------------------------------|
| 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                     |
| Returns                  | a <code>void*</code><br><i>(should be cast)</i> | appropriate pointer type<br><i>(doesn't need a cast)</i> |
| When out of memory       | returns <code>NULL</code>                       | throws an exception                                      |
| Deallocating             | <code>free()</code>                             | <code>delete</code> or <code>delete[]</code>             |

# Heap Member Example

- ❖ Let's build a class to simulate some of the functionality of the C++ string
  - Internal representation: c-string to hold characters
- ❖ What might we want to implement in the class?

# Str Class Walkthrough

Str.h

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

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_ on heap
    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 Example Walkthrough

See:

`Str.h`

`Str.cc`

`strtest.cc`

- ❖ Look carefully at assignment `operator=`
  - self-assignment test is especially important here

# 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!)