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What do you want more practice with?

- A. **cout, cin, iostream**
- B. **constructors of all shapes and sizes**
- C. **operator overloading**
- D. **POSIX and syscalls from C land**
- E. dealing with makefiles
- F. **not too fussed about anything in particular**

CSE333 Systems Programming

C++: More Class Details, The Heap

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Relevant Course Information

- ❖ Exercise 6 due Wednesday 11a (4/29)
- ❖ Homework 2 due Thursday 11:59p (4/30)
 - ★ Don't modify the header files!
 - Please double-/triple-/quadruple-check your hw2-submit tag for compilation 🙏
- ❖ **Midterm next Monday 5/4 11:30-12:20 in Gates G20 (this room)**
 - Covers material through end-of-lecture today
 - ➔ Reference sheet and two-sided 8.5x11" *handwritten* cheat sheet!
 - ➔ Midterm **review session** this **Friday 5/1 5:30-7:30p in Gates G04**
 - ➔ Practice midterms and solutions on the course website

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)

❖ Defaults:

- 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 interface to a class
 - Declaration goes in header file, but *outside* of class definition

,

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
```

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

Complex.cc



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

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!

Poll Everywhere

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

- ❖ Reminder that Point has getters and a setter
 - A. non-friend + member
 - B. ~~friend + member~~
 - C. non-friend + non-member
 - D. friend + non-member
 - E. I need to consult my ancestors before I can answer this question



Namespaces

- ❖ Namespaces are effectively named scopes
 - Useful for avoiding symbol collisions!

- ❖ Namespace definition:

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

Lowercase

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[]`**

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 if new failed
 - When an error is encountered, an exception is thrown (that we won't worry about in this class)

❖ delete behavior:

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

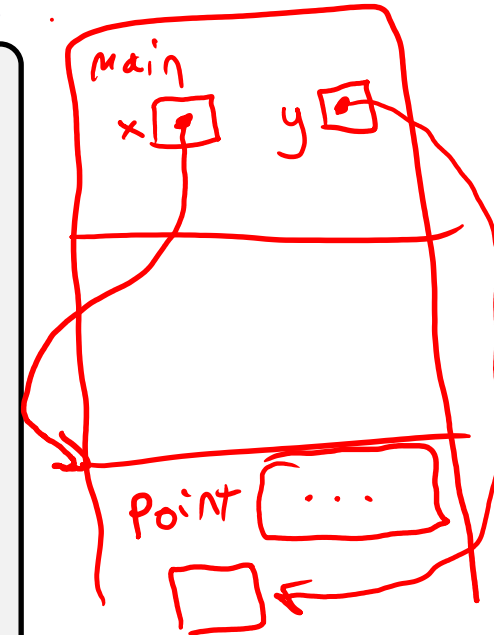
new/delete Example

```
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];`

construct "size" quantity
of adjacent "type"s

❖ To dynamically deallocate an array:

! ▪ Use `delete[] name;`

↳ can be
variable

▪ 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"

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

    int stack_arr[3];
    int* heap_arr = new int[3];

    int* heap_arr_init_val = new int[3]();
    int* heap_arr_init_lst = new int[3]{4, 5}; // C++11

    ...

    delete heap_int; //
    delete heap_int_init; //
    delete heap_arr; //
    delete[] heap_arr_init_val; //
    return EXIT_SUCCESS;
}
```

Handwritten annotations in red:

- An arrow points from the `new int[3]` line to the handwritten `[0, 0, 0]`.
- A circle is drawn around the `new int[3]()` line, with an arrow pointing to the handwritten `[4, 5, 0]`.
- The text `undefined behavior!` is written in red below the `new int[3]()` line.

Arrays Example (class objects)

arrays.cc

```
#include "Point.h"

int main() {
    ...

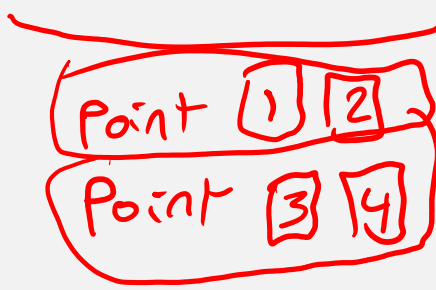
    Point stack_pt(1, 2);
    Point* heap_pt = new Point(1, 2);

    Point* heap_pt_arr_err = new Point[2];

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

    delete heap_pt;
    delete[] heap_pt_arr_init_lst;

    return EXIT_SUCCESS;
}
```






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 (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

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
Returns	a <code>void*</code> <i>(should be cast)</i>	appropriate pointer type <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>

```
class Foo {
public:
    Foo(int val) { Init(val); }
    ~Foo() { delete foo_ptr_; }
    Foo& operator=(const Foo& rhs) {
        delete foo_ptr_;
        Init(*(rhs.foo_ptr_));
        return *this;
    }

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

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

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What will happen when we invoke **Bar()**?

And if there is an error, how would you fix it?

- A. **Bad dereference**
- B. **Bad delete**
- C. **Memory leak**
- D. **“Works” fine**
- E. **Look hon, how am I supposed to know?**

Rule of Three, Revisited

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

```
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;
}
```

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 called 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
- ❖ What might we want to implement in the class?

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) {

}
}
```

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
```