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About where are you on Homework 2?

- A. Haven't started yet
- B. Working on Part A (File Parser)
- C. Working on Part B (File Crawler and Indexer)
- D. Working on Part C (Query Processor)
- E. Done!
- F. Prefer not to say

Notes:

- ✓ Don't forget to do your "Check-In 1 (HW2)" assignment and submit to Gradescope!
- ✓ OHs get crowded – come prepared to describe (1) your incorrect behavior, (2) what you think the issue is, and (3) what you've tried

Systems Programming

C++ Class Details, Heap

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Relevant Course Information

- ❖ Exercise 6 due Wednesday; Exercise 7 released today, due Nov. 4
 - Ex6 should use *member functions ONLY*
 - Ex7 is a modified version of ex6 that incorporates *non-member, friend, & the heap*
- ❖ Homework 2 due Thursday (10/29)
 - Don't modify the header files! Don't forget to double-/triple-/quadruple-check your `hw2-submit` tag for compilation!
- ❖ Midterm: February 9 from 5:30–6:40 PM
 - [GUG 220](#) or [ARC 147](#), depending on your *registered* quiz section
 - [Reference sheet](#) and two-sided *handwritten* cheat sheet!
 - Midterm review session (hybrid) on Friday (10/30) from 4:30–6:20 PM

Lecture Outline (1/2)

❖ Class Details

- Filling in some gaps from last time

❖ Using the Heap

- `new` / `delete` / `delete[]`

Rule of Three

❖ If you define any of the

(1) destructor,

(2) copy constructor, or

(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

```
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)
```

Point_2011.h

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

	<u>Member</u>	<u>Non-member</u>
named {	double Point::Distance(Point&);	double Distance(Point&, Point&);
function }	pt1.Distance(pt2);	Distance(pt1, pt2);
operator {	float Vector::operator*(Vector&);	float operator*(Vector&, Vector&);
}	vec1 * vec2;	vec1 * vec2;

← can't tell! →

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

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

declaration only

Complex.h

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

definition outside of class

Complex.cc



When to use Nonmember and `friend`

- ❖ Member functions:
 - Operators that modify the object being called on (*e.g.*, `operator=`)
 - “Core” non-operator functionality that is part of the class interface
- ❖ Nonmember functions (only grant `friend` if you *absolutely need* to):
 - Commutative operators (*e.g.*, so `v1+v2` is invoked as `operator+(v1, v2)` instead of `v1.operator+(v2)`)
 - Operations with class on the right-hand side (*e.g.*, `cin >> complex;`)
 - Returning a “new” object and not modifying an existing one
- ❖ There is much more to C++ class design that we don’t have time for
 - These are good rules of thumb but be sure to think about your class carefully!

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

doesn't modify objects, commutative (with an arrow pointing to the == operator)

- Reminder that `Point` has getters and a setter
- no need for friend* (with an arrow pointing to the word getters)

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. We're lost...

Namespaces

- ❖ Each namespace is a separate scope

- Useful for avoiding symbol collisions!

ll::Iterator } same name, but
ht::Iterator } different namespace

- ❖ Namespace definition has unusual syntax and style:

- `namespace nsp_name {`
 // declarations go here
`}` *// namespace nsp_name*

- Name/tag should be *lowercase*
- *Doesn't add to the indentation* of its contents, so add comment to indicate end
- Doesn't end with a semi-colon
- Creates a new namespace name if it did not exist, otherwise *adds to the existing namespace (!)*
 - Components (e.g., classes, functions) of a namespace can be defined across 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 (2/2)

❖ Class Details

- Filling in some gaps from last time

❖ Using the Heap

- `new / delete / delete[]`



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.
- ★ 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 `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;
}

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;
}
```

heappoint.cc

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;`

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

- 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)

```
#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.cc

Arrays Example (class objects)

```
#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;
}
```

arrays.cc

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> (should be cast)	appropriate pointer type (doesn't need a cast) <code>new T</code>
When out of memory	returns <code>NULL</code>	throws an exception
Deallocating	<code>free()</code>	<code>delete</code> or <code>delete[]</code>

always given
a type

returns, `T*`

usually ignored

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

*class Foo has: int * foo_ptr_;*

- 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_; }
```

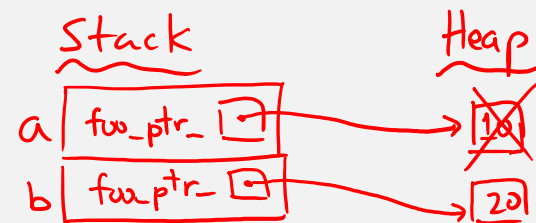
```
void Foo::Init(int val) {  
    foo_ptr_ = new int;  
    *foo_ptr_ = val;  
}
```

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

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

**this*

rhs



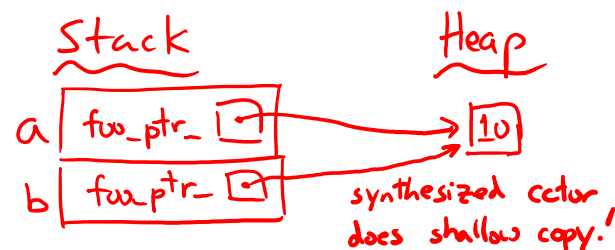
Rule of Three, Revisited

❖ 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;
}
```

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

↑ 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

```
#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.h

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

```
}
```