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Where are you so far 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

C++ Class Details, Heap

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Instructor: Justin Hsia

Teaching Assistants:

Adina Tung
Danny Agustinus
Edward Zhang
James Froelich
Lahari Nidadavolu
Mitchell Levy
Noa Ferman
Patrick Ho
Paul Han
Saket Gollapudi
Sara Deutscher
Tim Mandzyuk
Timmy Yang
Wei Wu
Yiqing Wang
Zhuochun Liu

Relevant Course Information

- Exercise 6 due Wednesday
- Exercise 7 out Wednesday
  - Will build on Exercise 6 and use what a lot of is discussed today
- Homework 2 due Thursday (2/2)
  - 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!
- Midterm: February 9 - 11
  - Take home (Gradescope) and open notes
  - Will involve reflecting on previous assignments
  - Individual, but high-level discussion allowed (“Gilligan’s Island Rule”)

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

- 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`

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

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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'm lost…

Namespaces

Same name, but different namespace

ll::Iterator
ht::Iterator

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

lowercase

- Namespace definition:

Namespace doesn't add indentation to contents

Comment to remind that this is end of namespace

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

  - 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];`
- 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"

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;
}
```

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;
}
```

`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 `void*` (*should be cast*)	appropriate pointer type (*doesn't need a cast*)
When out of memory	returns `NULL`	throws an exception
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?

```
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 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

- 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) {












}
```