C++ Class Details, Heap

CSE 333 Spring 2019

Instructor: Justin Hsia

Teaching Assistants:

Aaron Johnston, Andrew Hu, Daniel Snitkovskiy

Forrest Timour, Kevin Bi, Kory Watson

Pat Kosakanchit, Renshu Gu, Tarkan Al-Kazily

Travis McGaha

Administrivia

- Exercise 10 released today, due Monday
  - Write a substantive class in C++!
  - Refer to `Complex.h`/`Complex.cc`
- Homework 2 due next Thursday (5/2)
  - File system crawler, indexer, and search engine

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++ style guide tip:
  - If possible, disable the copy constructor and assignment operator by declaring as private and not defining them (pre-C++11)

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)
```

Disabling in C++11

- C++11 add new syntax to do this directly
  - This is the better choice in C++11 code

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)
```

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

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
```

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

Namespaces

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

LL::Iterator
HT::Iterator
} same name, but in different namespaces

- 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 (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`

0 (int? pointer?)

- 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 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 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
  int* heap_int = new int;  // heap (garbage)
  int* heap_int_init = new int(12);  // heap (value 12)

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

  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[]`

Dynamically Allocated Class Members

class Foo has:
int * foo_ptr_;

- What will happen when we invoke **bar**()?
  - Vote at http://PollEv.com/justinh
  - 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_; }

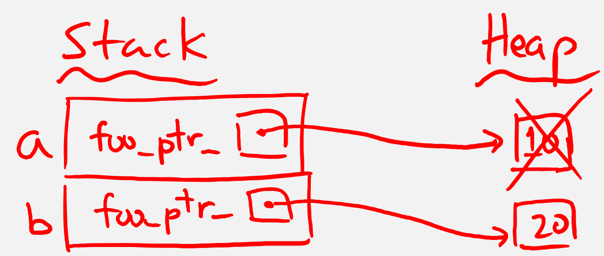
void Foo::Init(int val) {
  foo_ptr_ = new int;
  *foo_ptr_ = val;
}

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 = a;
}
```

accessing deleted memory!

*this, rhs



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

    ↳ 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 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_
  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

- Complete the **append**() member function:
  - `char* strcpy(char* dst, const char* src);`
  - `char* strcat(char* dst, const char* src);`

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

    see Str.cc

}
```

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!)