C++ Heap
CSE 333 Spring 2023

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Relevant Course Information

- Exercise 7 out today, due next Monday (5/1)
  - Will build on Exercise 6 and use what a lot of is discussed today
- Homework 2 due Thursday (4/27)
  - 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: May 3 - 5
  - Take home (Gradescope) and open notes
  - Will involve reflecting on previous assignments
  - Individual, but high-level discussion allowed ("Gilligan's Island Rule")

Lecture Outline

- **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 (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;
}
```

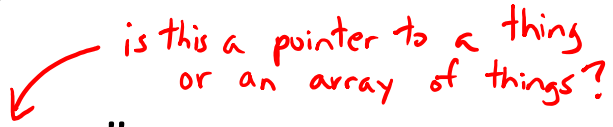
heappoint.cc

```
#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;  // 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 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[]`

Poll Everywhere

pollev.com/cse333sp

class Foo has: int * foo_ptr_;

What will happen when we invoke Bar()?

- If there is an error, how would you fix it?

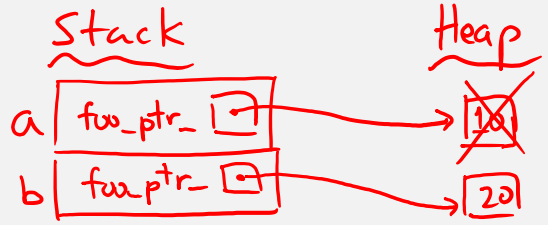
A. Bad dereference
B. Bad delete
C. Memory leak
D. "Works" fine
E. We're lost…

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

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

accesing deleted memory!

*this

rhs



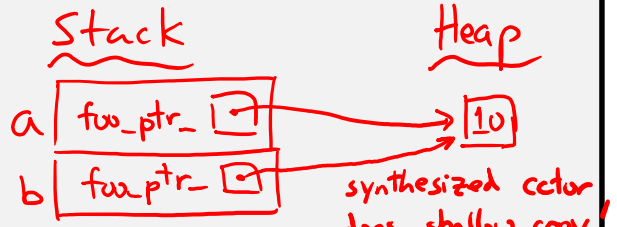
Rule of Three, Revisited

- 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!)