CMSC 341

Lecture 2

Dynamic Memory and Pointers

Park—Sects. 01 & 02

Today's Topics

- Stack vs Heap
- Allocating and freeing memory
  - **`new`** and **`delete`**
  - Memory Leaks
    - Valgrind
- Pointers
- Dynamic Memory and Classes

Program Memory

The memory a program uses is typically divided into four different areas:

1. The .text section, where the executable code sits in memory.
2. The .data/.bss area, where global variables are stored.
3. The **stack**, where parameters and local variables are allocated from.
4. The **heap**, where dynamically allocated variables are allocated from.

From: http://www.learncpp.com/cpp-tutorial/79-the-stack-and-the-heap/

.data vs. Heap

- .data/.bss contains variables that are global or static
  - Things that exist over the entire lifetime of the program’s execution
  - .bss is for uninitialized data (technically, initialized to 0)
  - The size of the data section is fixed
- Heap holds data that is dynamically allocated during execution
  - The heap can grow and shrink during the life of the program

Stack vs Heap

What is stored:

- Stack is used to store:
  - Automatic variables: i.e., non-static local variables
  - Function arguments
  - Basically, the data relevant to a specific instance of a function call
  - Allows recursion (since each new call pushes a new “stack frame”)
- Heap stores things created with **`new`** or by calling **`malloc`**()
  - Must be accessed through pointers

Stack vs Heap

Space management:

- Stack space management is implicitly handled by the system/compiler:
  - grows automatically, every time a nested function/method is called
    - has an upper limit; heap growth must be requested
  - When a function returns, the stack frame is “deleted”
    - You *might* be still able to access it, but you *should* not!
- Heap space is managed by the programmer
  - Memory allocated with **`new`** must be cleared with **`delete`**; and **`malloc()`** calls mush have matching **`free()`**
  - Failing to free heap space when done causes *memory leaks*

Declaring Stack and Heap Variables

- Stack variable declaration

  What you've been doing all along

  ```
  int counter;
  double scores[10];
  ```

  (Note: "static int foo" would not be on the stack: it's in data section)

- Heap variable declaration

  Must use a pointer

  ```
  int *values = new int[numVals];
  ```

  (a technical point: the new array is in the heap, but the pointer **`values`** is actually still a stack variable)

Allocating and Freeing Memory

new and **delete**

Used to dynamically allocate and free memory on the heap

new must be assigned to a pointer variable

```
int *calendar = new int[12];
SomeClass *newItem = new SomeClass;
```

delete releases memory previously allocated with **new**

can only be used on pointer variables

```
delete newItem;
delete[] calendar;
```

Good Programming Practices

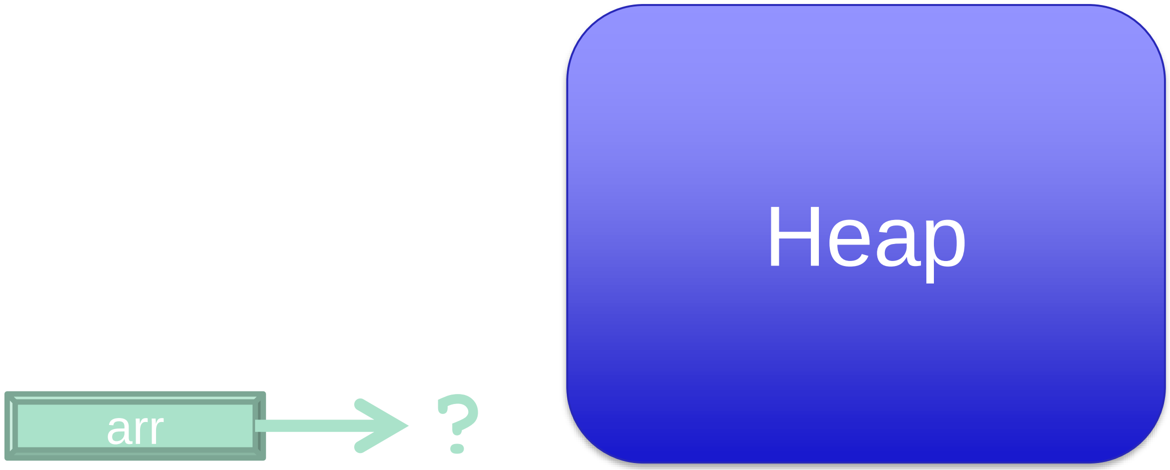
- C++ does not have garbage collection
- After memory has been freed, set the pointer equal to **`NULL`**
  - Must be done *after* **`delete`** is called
  - Why do this?

Memory Leaks

- Occur when data is allocated, but not freed
  - Calling **`new`** over and over, but never **`delete`**
  - Not freeing new memory before exiting a function
- Access to the previous memory is lost
  - The location of that memory was overwritten
- Eventually the program runs out of memory, and the program will crash

Memory Leak Example

```
int *arr, var = 1000;
for (int i = 0; i < var; i++) {
  arr = new int[100000000]);
}
```



Memory Leak Example

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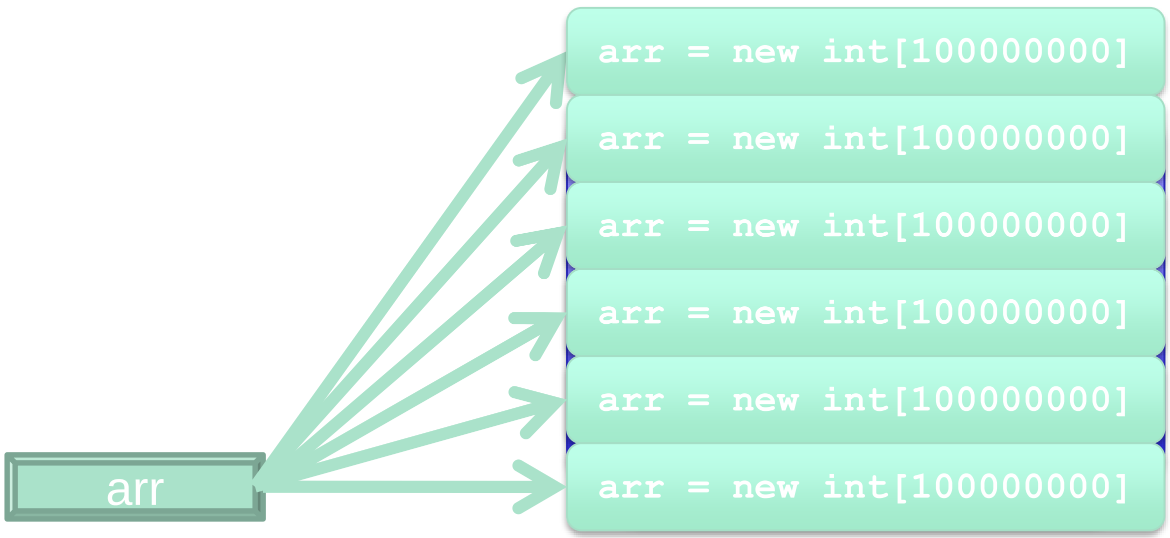

Memory Leak Example

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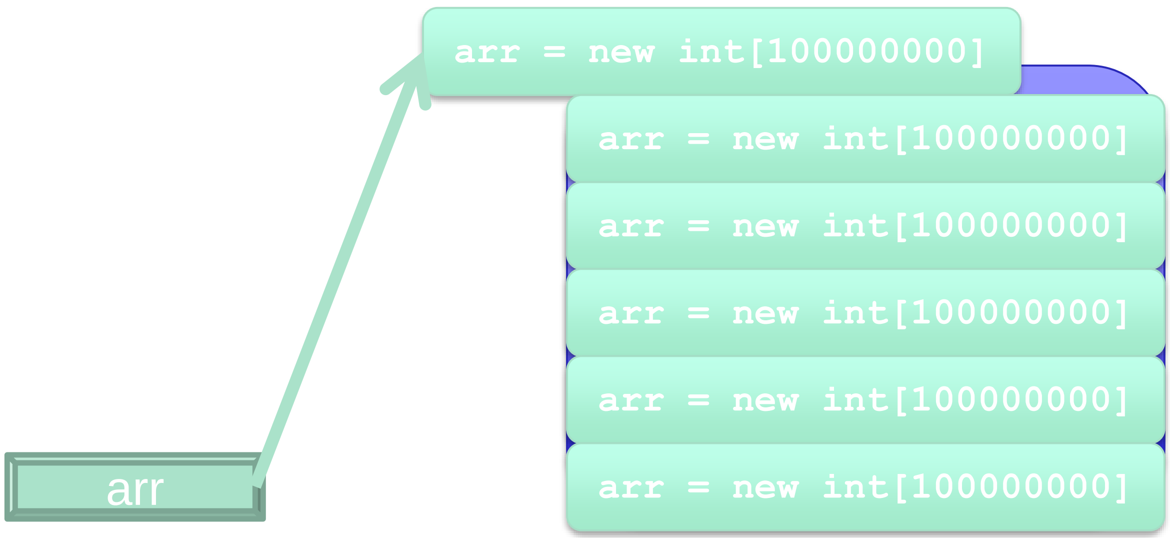

Valgrind

- Assists with dynamic memory management
  - Memory allocated using **`new`**
    - And therefore on the heap
- Must compile with the **`-g`** flag (for debugging)

- Detects memory leaks and write errors
  - Running valgrind significantly slows program down

program to run on

```
valgrind --leak-check=yes proj1 arg
```

Example `valgrind` Run – Code

```
#include <stdlib.h>

void f(void)
{
   int* x = malloc(10 * sizeof(int));
   x[10] = 0;         // problem 1: heap block overrun
}                     // problem 2: memory leak--x not freed

int main(void)
{
     f();
     return 0;
}
```

Please note:
This is C code, not C++.

Source: http://valgrind.org/docs/manual/quick-start.html/

Example `valgrind` Run–Results 1

Describes problem 1 (heap block overrun)

```
==19182== Invalid write of size 4
==19182==    at 0x804838F: f (example.c:6)
==19182==    by 0x80483AB: main (example.c:11)
==19182==  Address 0x1BA45050 is 0 bytes after a block
           of size 40 alloc'd
==19182==    at 0x1B8FF5CD: malloc
             (vg_replace_malloc.c:130)
==19182==    by 0x8048385: f (example.c:5)
==19182==    by 0x80483AB: main (example.c:11)
```

Example **valgrind** Run–Results 1

Describes problem 1 (heap block overrun)

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==19182==    by 0x80483AB: main (example.c:11)
```

First line: type of error

Stack trace
(read from bottom up)

Example `valgrind` Run–Results 2

Describes problem 2 (memory leak)

```
==19182== 40 bytes in 1 blocks are definitely lost in
          loss record 1 of 1
==19182==    at 0x1B8FF5CD: malloc
==19182==    by 0x8048385: f (a.c:5)
==19182==    by 0x80483AB: main (a.c:11)
```

Example `valgrind` Run–Results 2

Describes problem 2 (memory leak)

First line: type of error

```
==19182== 40 bytes in 1 blocks are definitely lost in
          loss record 1 of 1
==19182==    at 0x1B8FF5CD: malloc
==19182==    by 0x8048385: f (a.c:5)
==19182==    by 0x80483AB: main (a.c:11)
```

Stack trace tells you where the leaked memory was allocated *(in function ‘`f`’ on line 5 of file `a.c`)*

Your program is **definitely** leaking memory! *(May also see “probably,” “possibly,” or “indirectly.”)*

Pointers: Quick Review

(Not meant to teach you the concept from scratch!)

Pointers

- Used to "point" to locations in memory

```
int  x;
int *xPtr;
x = 5;
xPtr = &x;  /* xPtr points to x */
*xPtr = 6;  /* x's value is 6 now */
```

- Pointer type <u>must</u> match the type of the variable whose location in memory it points to

Pointers – Ampersand

Ampersand (‘&’) returns the address of a variable

Asterisk (“*”) dereferences a pointer to get to its value (also used when initially declaring a pointer)

```
int  x = 5, y = 7;
int *varPtr;
varPtr = &x;
*varPtr = 0;
varPtr = &y;
x = *varPtr;
```

Examples – Ampersand and Asterisk

```
int  x = 5;
int *xPtr;         [* used to

xPtr = &x;         [& used to

*xPtr = 10;        [* used to

cout << &xPtr;     [& used to
```

Examples – Ampersand and Asterisk

```
int  x = 5;
int *xPtr;          [* used to declare ptr]

xPtr = &x;          [& used to get address]

*xPtr = 10;         [* used to get value]

cout << &xPtr;      [& used to get address]
```

Pointer Assignments

Pointers can be assigned to one another using **=**

```
int  x = 5;
int *xPtr1 = &x;  /* xPtr1 points
                     to address of x */
int *xPtr2;       /* uninitialized */


xPtr2 = xPtr1;    /* xPtr2 also points
                     to address of x */
(*xPtr2)++;       /* x is 6 now */
(*xPtr1)--;       /* x is 5 again */
```

NULL Pointers

NULL is a special value that does not point to any address in memory

- It is a “non” address

Uninitialized pointers are like any new memory – they can contain *anything*

Setting a pointer to NULL will prevent accidentally accessing a garbage address (but dereferencing a null pointer will still give a segfault—that’s a Good Thing!)

Pointer Visualization Exercise

```
int  x = 5;
```

variable name	**x**		
memory address	0x7f96c		
value	5		

Pointer Visualization Exercise

```
int  x = 5;
int *xPtr = &x; /* xPtr points to x */
int  y = *xPtr; /* y's value is ? */
```

variable name	x	xPtr	y
memory address	0x7f96c	0x7f960	0x7f95c
value	5	0x7f96c	?

Pointer Visualization Exercise

```
int  x = 5;
int *xPtr = &x; /* xPtr points to x */
int  y = *xPtr; /* y's value is ? */
```

variable name	x	xPtr	y
memory address	0x7f96c	0x7f960	0x7f95c
value	5	0x7f96c	?

Pointer Visualization Exercise

```
int  x = 5;
int *xPtr = &x; /* xPtr points to x */
int  y = *xPtr; /* y's value is ? */
```

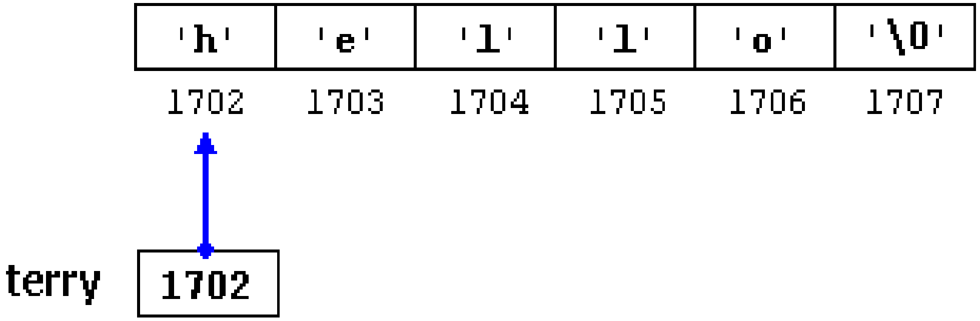
variable name	x	xPtr	y
memory address	0x7[illegible]6c	0x7f960	0x[illegible]5c
value	5	0x7f96c	5

Pointers and Arrays

Arrays are built by pointers

Array name equivalent to address of first element

```
char terry[6] = “hello”;
```



Dynamic Memory and Classes

Dynamically Allocating Instances

Stack:

```
Date today;
```

Heap:

```
Date *todayPtr = new Date(2016,2,7);
```

In both cases, constructor called (different versions, though)

Dynamically Allocating Instances

Stack:

```
Date today;
```

nothing – handled for you

What to do when freeing memory?

Heap:

```
Date *todayPtr = new Date(2016,2,7);
```

call delete and set pointer to NULL

```
delete todayPtr;
todayPtr = NULL;
```

Accessing Member Variables

Objects/structs (non-dynamic)

- Use the “dot” notation

```
today.m_day = 2;
```

Heap (dynamic), or any other pointers

- Use the “arrow” notation

```
todayPtr->m_year = 2015;
```

- Shorthand for “dereference and use ‘dot’”

```
(*todayPtr).m_year = 2015;
```

Passing Class Instances

Stack

Normal variable; works as expected

```
cout << x;
```

Heap

Need to dereference variable first

```
cout << xPtr;         // prints address
cout << *xPtr;        // prints value
```

Destructor

- All classes have a built-in destructors
  - Created for you by C++ automatically
  - Called when instance of class ceases to exist
    - Explicit **`delete`**, or end of program (**`return 0`**)
- Classes can have member variables that are dynamically allocated
  - Built-in destructors do not free dynamic memory!
  - Must code one for the class yourself

Coding Destructors

Named after class, and has no parameters

In source (**.cpp** file)

```
Student::~Student() {
   // free array of class name strings
   delete classList; }
```

In header (**.h** file)

```
~Student();      // denotes destructor
```

Calling Destructors

Stack

```
Student GV37486;
```

Automatically called at end of scope (function);

Heap

```
Student *FY18223 = new Student();
```

Called only when memory is freed

```
delete FY18223; // destructor called
FY18223 = NULL;
```

Segmentation Fault FAQ

- What is a segmentation fault (“segfault”)?
  - It happens when you access a memory address that is not legal (i.e., not in one of: data, heap, or stack)
- Why is my program killed?
  - The operating system shows no mercy (real answer: few other options)
- What causes a segfault?
  - An erroneous pointer

Segmentation Fault FAQ (cont)

Does a bad pointer always cause a segfault?

- No: if the bad pointer coincidentally points into some random-but-legal memory space, you will end up corrupting memory instead

Will dereferencing a pointer after deleting what it is pointing to cause a segault?

- Not necessarily; in fact, usually no; that is why we always set it to NULL

Segmentation Fault FAQ (cont)

Why do you say a segfault is a Good Thing?

It’s not good: just better than bad. Assuming you already have a bad pointer, would you rather:

a) silently corrupt random memory; OR

b) have your program admit it’s broken, and allow GDB to say exactly where?