C Bootcamp

Day 3

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Slides adapted from Anandha Gopalan's CS132 course at Univ. of Pittsburgh and Pascal Meunier's course at Purdue

Memory management

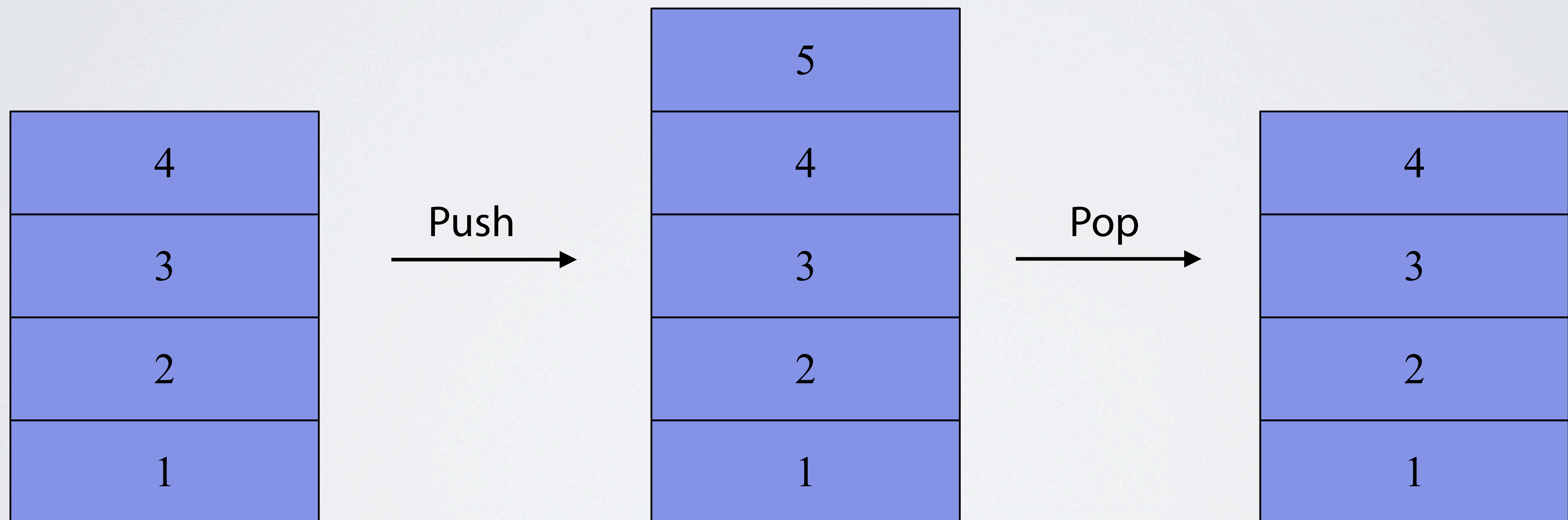
Memory management

- Two different ways to look at memory allocation
  - Transparent to user
    - Done by the compiler, OS
  - User-defined
    - Memory allocated by the user
- Why allocate memory?
  - Required by program for permanent variables
  - Reserve working space for program
- Normally maintained using a *stack* and a *heap*

Stack

A stack is an organized data structure

- Follows the LIFO (Last In First Out) principle
- A data item which enters the stack last is the first to be taken out



Stack variables

```
void foo(int i) {
  int j, k;
  char foo[] = "test";
}
```

Where are `j`, `k`, and `foo` allocated?

How long are they valid references? What is their *scope*?

```
struct mystruct *foo(int i) {
  struct mystruct;
  mystruct.i = 7

  return &mystruct;
}
```

What happens if you try the program above?

Can the caller access `mystruct`?

Heap

A heap is a collection in memory manipulated by the user/system

- No order specified for addition/removal

Dynamic memory allocation

- There are times when we don't know how much memory is required
  - Employee data base doesn't know how many employees will exist
  - Program accepting command line input of different sizes
  - User requests more records to be created

```
printf("Add a new record y/n ?");
scanf ("%c", &response);
if (response == 'y') {
  // we now have to allocate space
}
```

- We use the heap to allocate memory dynamically

malloc

```
void *malloc (size_t size)
```

- Returns a pointer to a contiguous block in memory of `size` bytes
  - For example

```
int *x = malloc(sizeof(int));
```

- Returns a valid address, or NULL if an error occurs
  - *ALWAYS* check the return value of malloc

- Memory is allocated (automatically) on the heap
  - Allocated space is not initialized; contains garbage
  - Contained in the header file: `<stdlib.h>` (usually) or `<alloc.h>`

A void *?

Why is `void *` returned?

- `malloc` just allocates memory which consists of some number of bytes
- Memory as such has no data type
- Programmer must associate a data type with the block of memory

How to assign a data type to the memory just created?

- Use type casting

```
double *x; // x is a pointer to double; malloc returns an address
x = (double *) malloc(100); // type casting the memory to be a double*
```

- How many `doubles` can we store? 100/8 = 12
- We can clearly see a pit falls of `malloc` here

```
x = (double *) malloc(100 * sizeof(double)); // better
```

Variants of malloc

```
void *calloc (size_t count, size_t size)
```

- Allocated space is automatically initialized to zero
  - Same as `malloc`, but is contained in `<stdlib.h>`
  - Still have to cast void pointer to correct type

- Advantages over malloc
  - Allocated memory is automatically initialized
  - `size` and `count` are separated, making it easier to use
    - Less prone to making errors on the correct amount and/or count required

```
int *x;
x = (int *) calloc (10, sizeof (int));
```

Freeing memory

- You, the programmer, are in charge of freeing memory
  - Only dynamically allocated memory can be freed (i.e., via `malloc()` or `calloc()`)

```
int x; // memory for x is statically assigned here, cannot be freed
```

- When finished using dynamically allocated memory, free it

```
void free (void *blk);
```

- Good practice to avoid memory leaks.
  - Growing loss of memory due to unreleased locations
  - Could prevent program from running properly, due to lack of memory
  - Can run out of memory

Using free()

```
char *x;
x = (char *) malloc (10 * sizeof (char));
free (x); // frees the memory just assigned
```

Never free a memory block that is not dynamically allocated.

```
int *x;
free (x); // error
```

Never double-free

```
char *x = (char *) malloc (10 * sizeof (char));
free (x);
free (x); // error
```

Never access freed memory

```
char *x = (char *) malloc (10 * sizeof (char));
free (x);
strcpy(x, "welcome"); // error
```

Keep track of your pointers!

Dangling pointers

```
char *x, *y;

x = (char *) malloc (10 * sizeof (int));
y = (char *) malloc (10 * sizeof (int));

x = y; // cannot access what was in x anymore
```

Can easily lead to memory leaks

Writing safe code in unsafe languages (e.g., C)

A few tips

- C provides much less help to the programmer than others
  - You can get yourself into trouble easily
  - Much more liberal with types
- Also, much harder to debug
  - Memory is just an array of bytes
    - Programmer has to assign meaning
  - You can overwrite memory, making the source of problems
- A few tips will make your experience in this class easier

Buffer/array overflows

```
char b[10];
b[10] = x;
```

- Array starts at index zero
  - So `[10]` is 11th element
  - One byte outside buffer was referenced
  - Off-by-one errors are common and can be exploitable!

- Real example:

```
int get_request (int d, char buffer[], u_short len) {
   u_short i;
   for (i=0; i< len; i++) {
   ...
   }
   buffer[i] = ‘\0’;
   return i;
}
```

What happens with an overflow?

If memory doesn't exist:

- Bus error

If memory protection denies access:

- Segmentation fault
- General protection fault

If access is allowed, memory next to the buffer can be accessed

- Can overwrite the heap, stack
- Worst of all options; won’t detect immediately
- Can compromise your program

Preventing buffer overflows

```
void foo(int *array, int len);
```

- Always pass array/buffer length with array
  - Don't assume you know the length
  - Many library functions require you to do this already

```
int foo[3];
for (i=0; i<=3; i++)
  foo[i] = 0;
```

- Remember that last element of `n`-length array is `n-1`
  - Can happen to the best programmers

Dealing with strings

- Recall, strings in C are NULL-terminated `char*`s
  - Most C functions don't guarantee NULL-termination
  - No guarantee that the strings you get are properly NULL-terminated

- Need to carefully read the function description to figure out
  - When it may not NULL-terminate a string
  - How to check for NULL-termination
  - Where to append a NULL character yourself

A few string functions

```
char * strncpy(char * dst, const char * src, size_t len);
```

- `len` is the maximum number of characters to copy
- `dst` is NULL-terminated only if less than `len` characters were copied!
- All calls to `strncpy` must be followed by a NULL-termination operation

```
int strlen(const char * str);
```

- What happens when you call strlen on an improperly terminated string?
  - Strlen scans until a null character is found
  - Can scan outside buffer if string is not null-terminated
- Strlen is not safe to call unless you *know* string is NULL-termined

And a few more

```
char * strcpy(char * dst, const char * src);
```

- How can you use strcpy safely?
  - Set the last character of src to NULL
    - Even if string is shorter than the entire buffer
  - Do not check according to `strlen(src)`!
- Check that the `src` is smaller than or equal to `dst`
  - Or allocate `dst` to be at least equal to the size of `src`