CS 107 Midterm Practice

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Disclaimer: These problems do not necessarily emulate the format of midterm problems. For example, the length and difficulty of the problems may differ from the actual midterm (if anything, these problems may be longer and more difficult). There are also more practice problems here than you should expect on the midterm.

Problem 1: Entomology Tooling (Topic: CS 107 Debugging / Tooling)

a. It's 11pm PT on the second late day of CS 107 assign4 and you've just finished writing 120 lines of C code without compiling it (not your best idea). Miraculously, there are no compilation errors when you run `make`. Unfortunately, when you run it on your first test case, all that's printed is `Segmentation fault (core dumped)`. Although it's disappointing, you're still determined to move forward and you want to find the line of code where the segmentation fault occurred as quickly as possible. What tool could you use to find this, and how would you use it?

Do a backtrace within `gdb`.
1) `gdb PROGRAM_NAME`
2) `run ARGUMENTS_TO_PROGRAM` (or `r ARGUMENTS_TO_PROGRAM`)
3) `backtrace` (or `bt`)

It might be reasonable to try `valgrind`, but it's not a direct way to find the line of code where the segfault occurred.

b. Following your answer to part a, you obtain this stack trace:

```
#0  __strcmp_sse2_unaligned () at ../sysdeps/x86_64/multiarch/strcmp-sse2-
unaligned.S:31
#1  0x0000000000400aef in cmp_pstr (p=0x7fffffffccf0, q=0x603240) at mysort.c:34
#2  0x000000000040109c in binsert (key=0x7fffffffccf0, base=0x603240,
p_nelem=0x7fffffffccc8, width=8,
    compar=0x400ab6 <cmp_pstr>) at util.c:30
#3  0x0000000000400cc0 in sort_lines (fp=0x603010, cmp=0x400ab6 <cmp_pstr>,
uniq=true, reverse=false) at mysort.c:90
#4  0x0000000000401018 in main (argc=3, argv=0x7fffffffde48) at mysort.c:149
```

Determine the file, function, and line number (in your code) where the segfault most immediately occurred.

`mysort.c`, in `cmp_pstr`, on line 34. Note that `__strcmp_sse2_unaligned` is not a function in your code – this is part of the implementation of `strcmp` for this system.

c. After studying that line of code, you don't think the root cause of the issue occurs there – you suspect that there's an error in some other part of your code that caused memory corruption, but it didn't cause the program to segfault until the above line. What tool could you use to find the first instance of memory corruption in your program?

`valgrind`

d. Later on, you're investigating a comparison function (one specifically for strings) in your code with the following function declaration:

```
int cmp_pstr(const void *p, const void *q);
```

You've used `gdb` to step into this function. You want to print out the string that `p` refers to. However, when you try to do so, all you get is this:

```
(gdb) print p
$1 = (const void *) 0x7fffffffccd0
```

What's wrong, and how should you change your gdb command so that it prints the string as desired? (Hint: remember that this is a comparison function. What are the arguments in a comparison function?)

Since this is a comparison function, `p` is a pointer to the string you want to print out. The print command only knows that `p` is a `void*`, so it just prints out the value of that pointer. Instead, try `print *(char**)p`.

Problem 2: After reading these problem titles you won't like puns one bit (Topic: Integer Representations)

Fill out the following table. Please use the 0b prefix when writing out binary representations and the 0x prefix when writing out hexadecimal representations. Write out leading zeroes for the given type.

Expression	Decimal Value	Binary Representation	Hex Representation
(signed char)(1 << 7)	`-128`	`0b10000000`	`0x80`
(unsigned char)(1 << 7)	`128`	`0b10000000`	`0x80`
(signed char)(0xF7F)	`127`	`0b01111111`	`0x7F`
(unsigned char)(0xF7F)	`127`	`0b01111111`	`0x7F`
(char)((~1) & (3 | 14))	`14`	`0b00001110`	`0x0E`

Problem 3: I bet Marx has a lecture on the types of classes (Topic: Integer Representations)

You've been hired by Stanford to optimize the memory consumption of their class scheduling system! Your first task is to use a C type to represent which days of the week that a class has lectures. Since there are only 7 days in a week, you decide to use a bitvector to encode this information, where the LSB represents whether there's lecture on Sunday, the next bit over Monday, and so forth. (Remember bitvectors from lecture 3? We used them to represent the set of CS courses taken by a student.) For example, here's how CS 107, which has lectures on Monday and Friday, would look:

0	1	0	0	0	1	0
Saturday lecture?	Friday lecture?	Thursday lecture?	Wednesday lecture?	Tuesday lecture?	Monday lecture?	Sunday lecture?

a. Recall that bitvectors are integer types. You want to pick the smallest integer type that has enough bits to represent the above information. Since you're trying to optimize for memory consumption, what type should you pick? Fill out the blank below.

```
unsigned _______char_______
```

b. In part a, we wrote `unsigned` for you. Does the sign of this type matter? Why or why not?

No. We are only interested in the bit representation of this value, not the value itself, so the sign does not matter.

c. You decide to call this type `week_schedule_t`. Write a `typedef` expression so that you're able to use `week_schedule_t` in your code in place of the type from part a.

```
typedef _______________unsigned char week_schedule_t_________________
```

d. Implement the following function, which takes in a `week_schedule_t` and a day of the week (0 = Sunday, 1 = Monday, etc) and returns a boolean representing whether there is lecture on that day for the given class.

```
bool has_lecture(week_schedule_t class, char day_of_week) {


    return ((class >> day_of_week) & 1) == 1;


}
```

e. Suppose you have two `week_schedule_t` values representing two of your classes. What is the real-life meaning of the following bitwise expressions? For example, the bitwise AND of them represents which days of the week you have lectures for both classes.

i. The bitwise OR (|) of the two values

which days of the week you have a lecture for either class

ii. The bitwise XOR (^) of the two values

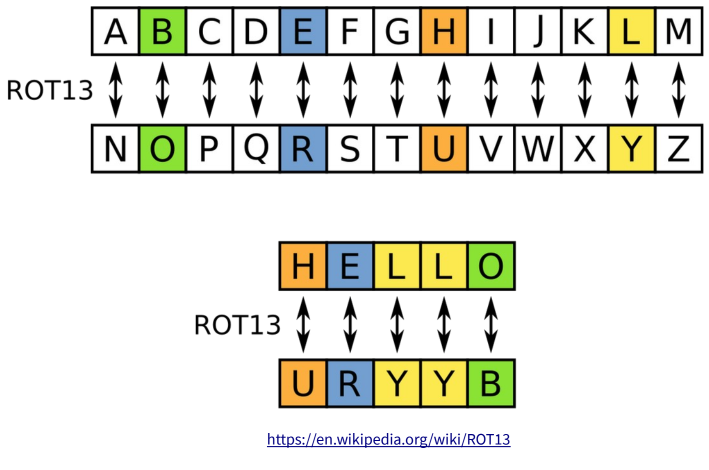
which days of the week you have a lecture for exactly one of the classes

iii. The bitwise complement (~) of the one of the values

which days of the week you don't have a lecture for that class

Problem 4: Still a better encryption scheme than Facebook (Topic: Arrays, Structs, Strings)

ROT13 is a simple, trivially breakable substitution cipher for disguising text. It works by replacing each alphabetical character in the text with the character 13 over (thus, ROTate 13). Refer to the following diagram from Wikipedia:



https://en.wikipedia.org/wiki/ROT13

As in the diagram, "HELLO" becomes "URYYB" since 'H' is 13 characters away from 'U', 'E' is 13 characters away from 'R', and so forth.

You've been given an array of structs where the structs look like this:

```
struct rot13_data {
     char source[10];
     char rotated[10];
};
```

Each `struct rot13_data` contains room for two strings of **at most** 10 bytes (so the string could be shorter, even 1 character or empty!). Each string represents a single word composed of only lowercase English letters – so you shouldn't worry about having to deal with other symbols, like spaces. The `source` field already contains a word, but it's your job to rot13 it to fill out the `rotated` field – it currently contains uninitialized data!

a. Implement the following function, which fills out the `rotated` field with the rot13'ed version of the `source` field for every struct in the given array.

(You may assume without checking that all characters are lowercase English characters.)

```
void rot13_array_fill(struct rot13_data *array, size_t length) {
     for (unsigned int i = 0; i < length; i++) {
          size_t str_length = strlen(array[i].source);
          for (unsigned int j = 0; j < str_length; j++) {
               char source_letter = array[i].source[j];
               if (source_letter <= 'm') {
                    array[i].rotated[j] = source_letter + 13;
               } else {
                    array[i].rotated[j] = source_letter - 13;
               }
          }
          array[i].rotated[str_length] = '\0';









     }
}
```

b. Write code to call this function to determine the rot13 value of “hello”. Yes, you’ll have to make an array containing only one element. Do not allocate any memory on the heap. You may use functions from the C string library.

```
struct rot13_data array[1];
strcpy(array[0].source, “hello”);
rot13_array_fill(array, 1);
```

Problem 5: Nearly Headless? How can your string be Nearly Headless? (Topic: Strings, Pointers)

Let’s define the nearly headless version of a string to be that string, except without the first character. The function `make_nearly_headless` takes in a string as an argument and makes it nearly headless by in-place removing the first character and returning nothing. You may assume the input string is not empty.

```
void make_nearly_headless(char *str);
```

Here’s some examples:

```
char s[] = “hello”;
make_nearly_headless(s);
printf(“%s\n”, s); // Prints “ello”

char s2[] = “nick”;
make_nearly_headless(s2);
printf(“%s\n”, s2); // Prints “ick”
```

a. Implement the function. You should not use any loops (prefer library functions).

```
void make_nearly_headless(char *str) {
     // Subtract 1 for first char, add 1 for NUL terminator
     size_t bytes_to_move = strlen(str);
     memmove(str, str + 1, bytes_to_move);




}
```

`memcpy` or `strcpy` would not work, as the memory overlaps!

b. Determine whether each of the following code snippets would compile and run correctly. If not, briefly explain why.

i.
```
char *s = “hello”;
make_nearly_headless(s);
```

No. The string is stored in read-only memory, so `make_nearly_headless` cannot modify it.

ii.
```
char s[] = “hello”;
make_nearly_headless(s);
```

Yes.

iii.
```
char s[] = {‘h’, ‘e’, ‘l’, ‘l’, ‘o’};
make_nearly_headless(s);
```

No. There is no NUL terminator in this string, so `strlen` will invoke undefined behavior.

iv.
```
char *s[] = “hello”;
make_nearly_headless(s);
```

No. This will not compile, as `char *s[]` expects an array of strings, not a single string.

v.
```
char *s[1];
s[0] = malloc(10 * sizeof(char));
strcpy(s[0], “hello”);
make_nearly_headless(s[0]);
```

Yes.

vi.
```
char *s = malloc(5 * sizeof(char));
strcpy(s, “hello”);
make_nearly_headless(s);
free(s);
```

No. There are only 5 bytes of memory in the block, so `strcpy` will write the NUL terminator into unallocated memory.

vii.
```
char *s = malloc(10 * sizeof(char));
```

```
    strncpy(s, “hello”, strlen(“hello”));
    make_nearly_headless(s);
    free(s);
```

No. `strncpy` will only copy over 5 bytes, which does not include the NUL terminator.

Problem 6: why don’t you just meet me in the middle? (Topic: Generics)

We are interested in the middle element of a generic array. Here, we’ll define the middle as index `floor(num_elements / 2)`, so arrays with both an odd or even number of elements will have a middle element.

For example,

```
int array[] = {5, 4, 3, 2, 1};

int *ptr = get_middle(array, sizeof(int), 0); // “empty array”
assert(ptr == array); // Middle of empty is just the beginning.

int *ptr = get_middle(array, sizeof(int), 1); // “1-element array”
assert(ptr == array);
assert(*ptr == 5);

int *ptr = get_middle(array, sizeof(int), 4); // “4-element array”
assert(ptr == &array[2]);
assert(*ptr == 3);

int *ptr = get_middle(array, sizeof(int), 5); // 5-element array
assert(ptr == &array[2]);
assert(*ptr == 3);
```

However, remember that this function takes in a generic array – so the above should work analogously if we used a string array.

a. Implement `get_middle`, which returns a pointer to the middle element.

```
void *get_middle(void *array, size_t width, size_t num_elements) {
     size_t middle_index = num_elements / 2;
     return ((char*)array) + width * middle_index;



}
```

b. Why did `get_middle` return a pointer? Why couldn't it have returned the middle element itself?

Since the array is generic, the element could be any type with any size, so we wouldn't be able to write a return type for the function (as picking a return type makes it no longer generic). Instead, we return a pointer to the element so that the caller, who knows the actual type, can cast appropriately and dereference the pointer to get the element.

c. Suppose we want to make get_middle not return anything, and instead put the middle element into a location specified by the caller. Modify `get_middle` (including its parameters) to do this. Also show how you would modify the last example from above (the one that passed 5 for the number of elements) to assert that the middle element is 3 (don't heap-allocate memory).

```
void get_middle(void *array, size_t width, size_t num_elements, void *out) {
     size_t middle_index = num_elements / 2;
     void *middle_ptr = ((char*)array) + width * middle_index;
     memcpy(out, middle_ptr, width);
}

int array[] = {5, 4, 3, 2, 1};
int x;
get_middle(array, sizeof(int), 5, &x);
assert(x == 3);
```

Problem 7: The Data is Array-dy Encrypted!
(Topics: Pointers, Generics, Function Pointers)

Your colleague has been working on writing some functions that are able to best-effort decrypt chunks of encrypted data. All of these functions have the same signature – for example, here is the signature of one of their functions:

```
bool decrypt_xor_0xb2(void *chunk_ptr);
```

Having a common function pointer type of `(bool (*)(void*))` means that later we'll be able to write other functions that work generically on any kind of encrypted data as long as an appropriate decrypting function pointer is passed in.

These functions takes in a pointer to a chunk of encrypted data (of unknown type and format, since it's generic). The function will do the decryption, then write the decrypted value back at the pointer. Sometimes decrypting fails, so the return value indicates whether decrypting succeeded.

a. Help your colleague out by implementing the `decrypt_xor_0xb2` function, which decrypts encrypted ints. That is, it takes in a pointer to an `int` that has been previously encrypted. The specific type of encryption is an XOR cipher (https://en.wikipedia.org/wiki/XOR_cipher), but for the purposes of this problem, all you need to do to decrypt the int is to xor with `0xb2`. This operation always succeeds.

```
bool decrypt_xor_0xb2(void *chunk_ptr) {
  int *int_ptr = (int*)chunk_ptr;
  *int_ptr ^= 0xb2;
  return true;


}
```

b. Waking up from an unplanned nap at your computer, you find yourself halfway through writing the `decrypt_all` function, which takes in a generic array of encrypted chunks as well as a decryption function and calls the decryption function on all of them, returning `true` if and only if the decryption was successful on all chunks. Please finish the job!

```
bool decrypt_all(void *data_chunks, size_t num_chunks,
                 size_t chunk_size, bool (*decrypt)(void *)) {
  bool success = true;


  for (int i = 0; i < num_chunks; i++) {
    void *chunk_ptr = (char*)data_chunks + (i * chunk_size);
    success &&= decrypt(chunk_ptr);


  }
  return success;


}
```

c. Let's put it all together now. Suppose we are given a 5-element array of encrypted ints (encrypted via an XOR cipher with `0xb2`) called `encrypted_ints` (of type `int*`). Use the two functions you've previously written to write a line of code that decrypts the array.

```
decrypt_all(encrypted_ints, 5, sizeof(int), &decrypt_xor_0xb2);
```

d. At your next 1:1 with your colleague, you come to the realization that your colleague really goofed – for some reason they interpreted the argument to the decryption function as a “pointer to a pointer to a chunk” of encrypted data, not a “pointer to a chunk” of encrypted data. However, due to your company’s release schedule, it’s too late to fix your colleague’s already submitted code, so you’ll just have to roll with this inconvenience.

Fix your `decrypt_xor_0xb2` so that it follows your colleague’s interpretation of the decryption function’s argument.

```
bool decrypt_xor_0xb2(void *chunk_ptr) {
  int *int_ptr = *(int**)chunk_ptr;
  *int_ptr ^= 0xb2;
  return true;


}
```

e. Fix your `decrypt_all` function to also follow your colleague’s interpretation of the decryption function’s argument.

```
bool decrypt_all(void *data_chunks, size_t num_chunks,
                 size_t chunk_size, bool (*decrypt)(void *)) {
  bool success = true;
  for (int i = 0; i < num_chunks; i++) {
    void *chunk_ptr = (char*)data_chunks + (i * chunk_size);
    success &&= decrypt(&chunk_ptr);
  }
  return success;






}
```