Lab 2

Deadline: Wednesday, July 1st

Setup

To get the starter files for this lab, run the following command in your `labs` directory.

```
git pull starter master
```

If you get an error like the following:

```
fatal: 'starter' does not appear to be a git repository
fatal: Could not read from remote repository.
```

make sure to set the starter remote as follows:

```
git remote add starter https://github.com/61c-teach/su20-lab-starter.git
```

and run the original command again.

Objectives

- TSWBAT perform specific bit manipulations through compositions of bit operations.
- TSW identify potential issues with dynamic memory management.

Exercise 0: Makefiles

As you saw in Lab 01, compiling C programs in the terminal is a tedious and time-consuming operation that requires the running of multiple commands with long series of arguments. While this is doable for simple C programs, for larger and more complex programs with often dozens of files and dependencies, this gets rather unweilding quickly.

For large, complex, programs, most C programmers write what's called a "makefile" to help with compilation. A makefile is a textfile (literally labelled "Makefile") in the code directory that contains a set of rules, each of which has commands that compile the C program for them. Each makefile can contain multiple rules that each compile one or more targets (e.g. an executable) or do a different objective. To compile a target, the programmer just needs to type "make " into their command terminal.

Take a look at the "Makefile" included with this lab, and try to answer the following questions in "make.txt". Feel free to use the internet to figure some of these questions out.

1. Which target is part of a rule that deletes all the compiled programs?
2. Which target is part of a rule that makes all the compiled programs?
3. Which compiler is currently being used?
4. What C standard are we currently using?
5. How would we reference a variable FOO in a makefile?
6. What operating system does the term "Darwin" represent?
7. What line creates the lfsr program from its object files? (Give its line number.)

Makefiles look daunting, but are actually an amazing tool that help save a lot of time!

Exercise 1: Bit Operations

For this exercise, you will complete `bit_ops.c` by implementing the bit manipulation functions `get_bit`, `set_bit`, and `flip_bit` (shown below). You may only use bitwise operations such as and (&), or (|), xor (^), not (~), left shifts («), and right shifts (»). You may not use any for/while loops or conditional statements. You also may not use modulo (%), division, addition subtraction, or multiplication for this question.

```
// Return the nth bit of x.
// Assume 0 <= n <= 31
unsigned get_bit(unsigned x, unsigned n);

// Set the nth bit of the value of x to v.
// Assume 0 <= n <= 31, and v is 0 or 1
void set_bit(unsigned *x, unsigned n, unsigned v);

// Flip the nth bit of the value of x.
// Assume 0 <= n <= 31
void flip_bit(unsigned *x, unsigned n);
```

ACTION ITEM: Finish implementing `get_bit`, `set_bit`, and `flip_bit`.

Once you complete these functions, you can compile and run your code using the following commands:

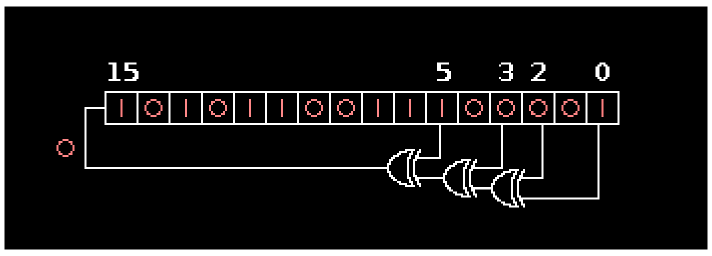
```
$ make bit_ops
$ ./bit_ops
```

This will print out the result of a few limited tests.

Exercise 2: Linear Feedback Shift Register

In this exercise, you will implement a `lfsr_calculate()` function to compute the next iteration of a linear feedback shift register (LFSR). Applications that use LFSRs are: Digital TV, CDMA cellphones, Ethernet, USB 3.0, and more! This function will generate pseudo-random numbers using bitwise operators. For some more background, read the [Wikipedia article on Linear feedback shift registers](). In `lfsr.c`, fill in the function `lfsr_calculate()` so that it does the following:

Hardware Diagram



Explanation

- On each call to `lfsr_calculate`, you will shift the contents of the register 1 bit to the right.
- This shift is neither a logical shift or an arithmetic shift. On the left side, you will shift in a single bit equal to the Exclusive Or (XOR) of the bits originally in position 0, 2, 3, and 5.
- The curved head-light shaped object is an XOR, which takes two inputs (a, b) and outputs a^b.
- If you implemented `lfsr_calculate()` correctly, it should output all 65535 positive 16-bit integers before cycling back to the starting number.
- Note that the leftmost bit is the MSB and the rightmost bit is the LSB.

ACTION ITEM: Implement `lfsr_calculate()`, compile `lfsr` and run it. Verify that the output looks like the following:

```
$ make lfsr
$ ./lfsr
My number is: 1
My number is: 5185
My number is: 38801
My number is: 52819
My number is: 21116
My number is: 54726
My number is: 26552
My number is: 46916
My number is: 41728
My number is: 26004
My number is: 62850
My number is: 40625
My number is: 647
My number is: 12837
My number is: 7043
My number is: 26003
My number is: 35845
My number is: 61398
My number is: 42863
My number is: 57133
My number is: 59156
My number is: 13312
My number is: 16285
 ... etc etc ...
Got 65535 numbers before cycling!
Congratulations! It works!
```

Exercise 3: Linked Lists

For this exercise, you will fill in the functions `append_node()` and `reverse_list()` in `list.c`. Don't forget to look at `list.h` to see the definition of the node struct and also to see the general format of a simple .h (header) file!

In `append_node()`, you will append a node to the end of a linked list.

In `reverse_list()`, you will reverse a linked list **in place** (i.e. without creating a new list). For example, the list `1->2->3->4->5` would become `5->4->3->2->1`. HINT: In each iteration of your loop to traverse the linked list, think about what information you need to store in variables before reversing the link so that you can still successfully keep iterating through the list and reversing links. This is a fairly difficult exercise in C; we recommend that you draw a picture if you get stuck because doing so tends to make double pointers seem less intimidating. Please write up what you think the algorithm should be before asking a TA for help. **You can think of the double pointer as simply a pointer to a list of pointers to nodes.**

Why do both of these functions take in a `node**` and not a `node*`? Think about memory management; if the input was a node*, would it be possible to modify the pointer that was passed into the function from, say, the main() function? Remember that C is pass-by-value!

ACTION ITEM: Finish implementing `append_node()` and `reverse_list()`.

Once you complete these functions, you can compile and run your code using the following commands. If you make **any** changes, make sure to run **ALL** of the following commands again, in order.

If you compile and run locally, the test may print out that the next attributes of your nodes are 0x0 and that your test failed. This is completely fine; your tests will pass the autograder. If you'd like to be completely sure that your test passes locally, compile and run your code on the hive machines.

```
$ gcc -c list.c
$ gcc -c test_list.c
$ gcc -g -o test_list test_list.o list.o       # This will create an executable
by linking test_list.o and list.o.
$ ./test_list
```

This will print out the results of the test. To debug, you can run CGDB and step through the test in `test_list.c`.

Exercise 4: Memory Management

This exercise uses `vector.h`, `vector_test.c`, and `vector.c`, where we provide you with a framework for implementing a variable-length array. This exercise is designed to help familiarize you with C structs and memory management in C.

ACTION ITEM: Explain why `bad_vector_new()` and `also_bad_vector_new()` are bad and fill in the functions `vector_new()`, `vector_get()`, `vector_delete()`, and `vector_set()` in `vector.c` (as well as the function headers in `vector.h`) so that our test code `vector_test.c` runs without any memory management errors. Also, implement a rule for the `vector_test` target in the makefile.

Comments in the code describe how the functions should work. Look at the functions we've filled in to see how the data structures should be used. For consistency, *it is assumed that all entries in the vector are 0 unless set by the user. Keep this in mind as `malloc()` does not zero out the memory it allocates.*

For explaining why the two bad functions are incorrect, keep in mind that one of these functions will actually run correctly (assuming correctly modified `vector_new`, `vector_set`, etc.) but there may be other problems. **Hint**: think about memory usage.

ACTION ITEM: Test your implementation of `vector_new()`, `vector_get()`, `vector_delete()`, and `vector_set()` for both correctness and memory management (details below).

```
# 1) to check correctness
$ make vector_test
$ ./vector_test

# 2) to check memory management using Valgrind:
$ make vector-memcheck
```

All the `vector-memcheck` rule does is run the following valgrind command on our executable. For a review, read through Exercise 4 in Lab 1. Explain to yourself what each of the flags mean.

```
$ valgrind --tool=memcheck --leak-check=full --track-origins=yes [OS SPECIFIC
ARGS] ./<executable>
```

The last line in the valgrind output is the line that will indicate at a glance if things have gone wrong. Here's a sample output from a buggy program:

```
==47132== ERROR SUMMARY: 1200039 errors from 24 contexts (suppressed: 18 from 18)
```

If your program has errors, you can scroll up in the command line output to view details for each one. For our purposes, you can safely ignore all output that refers to suppressed errors. In a leak-free program, your output will look like this:

```
==44144== ERROR SUMMARY: 0 errors from 0 contexts (suppressed: 18 from 18)
```

Again, any number of suppressed errors is fine; they do not affect us.

Feel free to also use CGDB or add `printf` statements to `vector.c` and `vector_test.c` to debug your code.

Checkoff

Please submit to the **Lab Autograder** assignment (same as last week!).

Checkoff questions for Exercise 4:

- Explain to your TA/AI why `bad_vector_new()` and `also_bad_vector_new()` are bad. Also, show your TA/AI the output of `make vector-memcheck`.