ECEn 424
Data Lab: Manipulating Bits

1 Introduction

The purpose of this assignment is to become more familiar with bit-level representations of integers and floating point numbers. You'll do this by solving a series of programming "puzzles." Many of these puzzles are quite artificial, but you'll find yourself thinking much more about bits in working your way through them.

2 Logistics

You may complete this lab working by yourself or you may work in teams of two. All handins are electronic, and only one handin is required per team. Clarifications and corrections will be posted on the Web page for the lab.

3 Handout Instructions

For these labs, you will need a CAEDM account. While you are free to complete the labs anywhere, we can't guarantee that everything will run correctly anywhere other the ECEn Spice (Linux) machines in 425 CB. When in doubt, try it on a Spice machine.

The `datalab-handout.tar` file contains the code you will need for this lab.

Start by copying `datalab-handout.tar` to a (protected) directory on a Linux machine in which you plan to do your work. Then give the command

```
unix> tar xvf datalab-handout.tar.
```

This will cause a number of files to be unpacked in the directory. The only file you will be modifying and turning in is `bits.c`.

The `bits.c` file contains a skeleton function for each of the 15 programming puzzles. Your assignment is to complete each function using only *straightline* code for the integer puzzles (i.e., no loops, conditionals, or switch statements) and a limited number of C arithmetic and logical operators. Specifically, you are *only* allowed to use the following eight operators:

```
! ~ & ^ | + << >>
```

A few of the functions further restrict this list. Also, you are not allowed to use any constants longer than 8 bits. See the comments in `bits.c` for detailed rules and a discussion of the desired coding style.

4 The Puzzles

The specific puzzles you will be solving are all described in `bits.c`. The header for each function specifies what the function is to compute, which operators are allowed, the difficulty rating of each puzzle (the number of points you earn for completing it), and the maximum number of operators you are allowed to use to implement each function. To clarify function operation, you may also refer to the appropriate test functions in `tests.c`. These are used as reference functions to determine the correctness of your functions, but they do not satisfy the coding rules you must observe for your functions.

The puzzles can be divided into three categories: functions that manipulate and test sets of bits, functions that make use of the two's complement representation of integers, and functions that have to do with common single-precision floating-point operations.

For functions in the latter category, you are allowed to use standard control structures (conditionals, loops), and you may use both `int` and `unsigned` data types, including arbitrary unsigned and integer constants. You may not use any unions, structs, or arrays. Most significantly, you may not use any floating point data types, operations, or constants. Instead, any floating-point operand will be passed to the function as having type `unsigned`, and any returned floating-point value will be of type `unsigned`. Your code should perform the bit manipulations that implement the specified floating point operations.

Functions with floats as argments must handle the full range of possible argument values, including not-a-number (NaN) and infinity. The IEEE standard does not specify precisely how to handle NaN's, and the behavior of Intel CPUs is a bit obscure. For this assignment, we will follow a convention that for any function returning a NaN value, it will return the one with bit representation `0x7FC00000`.

For your convenience, the program `fshow` is included in the files you are given for this lab. The program will help you understand the structure of floating point numbers. To compile `fshow`, switch to the handout directory and type:

```
unix> make
```

You can use `fshow` to see what an arbitrary pattern represents as a floating-point number:

```
unix> ./fshow 2080374784

Floating point value 2.658455992e+36
Bit Representation 0x7c000000, sign = 0, exponent = f8, fraction = 000000
Normalized.  1.0000000000 X 2^(121)
```

You can also give `fshow` hexadecimal and floating point values, and it will decipher their bit structure.

5 Evaluation

Your score will be computed out of a maximum of 76 points based on the following distribution:

41 Correctness points.

30 Performance points.

5 Style points.

Correctness points. The 15 puzzles you must solve have been given a difficulty rating between 1 and 4, such that their weighted sum totals to 41. We will evaluate your functions using the `btest` program, which is described in the next section. You will get full credit for a puzzle if it passes all of the tests performed by `btest`, and no credit otherwise.

Performance points. Our main concern at this point in the course is that you can get the right answer. However, we want to instill in you a sense of keeping things as short and simple as you can. Furthermore, some of the puzzles can be solved by brute force, but we want you to be more clever. Thus, for each function we've established a maximum number of operators that you are allowed to use for each function. This limit is very generous and is designed only to catch egregiously inefficient solutions. You will receive two points for each correct function that satisfies the operator limit.

Style points. Finally, we've reserved 5 points for a subjective evaluation of the style of your solutions and your commenting. Your solutions should be as clean and straightforward as possible. Your comments should be informative, but they need not be extensive.

Autograding your work

We have included some autograding tools in the handout directory — `btest`, `dlc`, and `driver.pl` — to help you check the correctness of your work.

- **`btest`:** This program checks the functional correctness of the functions in `bits.c`. To build and use it, type the following two commands:

  ```
  unix> make
  unix> ./btest
  ```

  Notice that you must rebuild `btest` each time you modify your `bits.c` file.

  You'll find it helpful to work through the functions one at a time, testing each one as you go. You can use the `-f` flag to instruct `btest` to test only a single function:

  ```
  unix> ./btest -f bitAnd
  ```

  You can feed it specific function arguments using the option flags `-1`, `-2`, and `-3`:

```
unix> ./btest -f bitAnd -1 7 -2 0xf
```

Check the file `README` for documentation on running the `b`test program.

- **`dlc`:** This is a modified version of an ANSI C compiler from the MIT CILK group that you can use to check for compliance with the coding rules for each puzzle. The typical usage is:

  ```
  unix> ./dlc bits.c
  ```

  The program runs silently unless it detects a problem, such as an illegal operator, too many operators, or non-straightline code in the integer puzzles. Running with the `-e` switch:

  ```
  unix> ./dlc -e bits.c
  ```

  causes `dlc` to print counts of the number of operators used by each function. Type `./dlc -help` for a list of command line options.

- **`driver.pl`:** This is a driver program that uses `btest` and `dlc` to compute the correctness and performance points for your solution. It takes no arguments:

  ```
  unix> ./driver.pl
  ```

  Your instructors will use `driver.pl` to evaluate your solution.

6 Handin Instructions

When you have solved all puzzles and your solutions pass all tests, submit your bits.c file via Learning Suite. Make sure your source file has been edited to include your name (and your partner's name if you worked as a team). Your source file must be uploaded before the deadline for this lab.

7 Advice

- Don't include the `<stdio.h>` header file in your `bits.c` file, as it confuses `dlc` and results in some non-intuitive error messages. You will still be able to use `printf` in your `bits.c` file for debugging without including the `<stdio.h>` header, although `gcc` will print a warning that you can ignore.
- The `dlc` program enforces a stricter form of C declarations than is the case for C++ or that is enforced by `gcc`. In particular, any declaration must appear in a block (what you enclose in curly braces) before any statement that is not a declaration. For example, it will complain about the following code:

```
int foo(int x)
{
  int a = x;
  a *= 3;     /* Statement that is not a declaration */
  int b = a;  /* ERROR: Declaration not allowed here */
}
```

8 The "Beat the Prof" Contest

For fun, we're offering an optional "Beat the Prof" contest that allows you to compete with other students and the instructor to develop the most efficient puzzles. The goal is to solve each Data Lab puzzle using the fewest number of operators. Students who match or beat the instructor's operator count for each puzzle are winners!

To submit your entry to the contest, type:

```
unix> ./driver.pl -u "Your Nickname"
```

where you substitute any nickname (for your team) of your choosing. Nicknames are limited to 35 characters and can contain alphanumerics, apostrophes, commas, periods, dashes, underscores, and ampersands. You can submit as often as you like. Your most recent submission will appear on a real-time scoreboard, identified only by your nickname. The link for the scoreboard for this semester is given on the Web page for this lab.