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 work in a group of up to two people in solving the problems for this assignment. All handins are electronic. Clarifications and revisions will be posted to the course discussion group.

3 Handout Instructions

You will need the file datalab-handout.tar, which you will find in the ~cs213/HANDOUT directory on the class servers, hanlon.wot.eecs.northwestern.edu, and murphy.wot.eecs.northwestern.edu. This directory will also be visible on the Wilkinson and TLab machines.

Please note that you will hand in your work on murphy.

You will need a (protected) directory on a Linux machine in which to do your work. We recommend that you simply use a class server for this. You can create a protected directory like this:

    unix> mkdir mydatalab
    unix> chmod 700 mydatalab
    unix> cd mydatalab

The chmod command will set things so that only the owner of the directory can read, write, or cd into it. Next, give the command

    unix> tar xvf ~cs213/HANDOUT/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 for each of the 15 programming puzzles. Your assignment is to complete each function skeleton using only *straightline* code for the integer puzzles (i.e., no loops or conditionals) and a limited number of C arithmetic and logical operators. Specifically, you are *only* allowed to use the following eight operators:

\[
! \quad \& \quad ^\mathord{\lor} \quad + \quad << \quad >>
\]

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.

Please be sure to read the README file.

## 4 The Puzzles

This section describes the puzzles that you will be solving in `bits.c`.

### 4.1 Bit Manipulations

Table 1 describes a set of functions that manipulate and test sets of bits. The “Rating” field gives the difficulty rating (the number of points) for the puzzle, and the “Max ops” field gives the maximum number of operators you are allowed to use to implement each function. See the comments in `bits.c` for more details on the desired behavior of the functions. You may also refer to the test functions in `tests.c`. These are used as reference functions to express the correct behavior of your functions, although they don’t satisfy the coding rules for your functions.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Rating</th>
<th>Max Ops</th>
</tr>
</thead>
<tbody>
<tr>
<td>bitNor(x, y)</td>
<td>`~(x</td>
<td>y)` using only ~ and &amp;</td>
<td>1</td>
</tr>
<tr>
<td>bitMask(hb, lb)</td>
<td>Generate mask with 1s between index lb and hb</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>logicalNeg(x)</td>
<td>Compute <code>!x</code> using all legal ops but <code>!</code></td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>oddBits()</td>
<td>Return word with odd-numbered bits set</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>implication(x, y)</td>
<td>Return <code>x-&gt;y</code></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>greatestBitPos(x)</td>
<td>Return mask that marks most significant bit</td>
<td>4</td>
<td>70</td>
</tr>
<tr>
<td>isPower2(x)</td>
<td>Returns 1 if <code>x</code> is a power of 2</td>
<td>4</td>
<td>20</td>
</tr>
</tbody>
</table>

Table 1: Bit-Level Manipulation Functions.

You may find the `ishow` tool to be helpful.
4.2 Two’s Complement Arithmetic

Table 2 describes a set of functions that make use of the two’s complement representation of integers. Again, refer to the comments in bits.c and the reference versions in tests.c for more information.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Rating</th>
<th>Max Ops</th>
</tr>
</thead>
<tbody>
<tr>
<td>subOK(x, y)</td>
<td>Test if can compute x−y without overflow</td>
<td>3</td>
<td>20</td>
</tr>
<tr>
<td>isPositive(x)</td>
<td>x &gt; 0?</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>tmax()</td>
<td>Return maximum two’s complement integer</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>negate(x)</td>
<td>−x without negation</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>sign(x)</td>
<td>Return sign of x</td>
<td>2</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 2: Arithmetic Functions

You may find the ishow tool to be helpful.

4.3 Floating-Point Operations

For this part of the assignment, you will implement some common single-precision floating-point operations. In this section, 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.

Table 3 describes a set of functions that operate on the bit-level representations of floating-point numbers. Refer to the comments in bits.c and the reference versions in tests.c for more information.

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Rating</th>
<th>Max Ops</th>
</tr>
</thead>
<tbody>
<tr>
<td>float_abs(uf)</td>
<td>Compute</td>
<td>f</td>
<td></td>
</tr>
<tr>
<td>float_half(uf)</td>
<td>Compute f/2</td>
<td>4</td>
<td>30</td>
</tr>
<tr>
<td>float_f2i(uf)</td>
<td>Compute (int)f</td>
<td>4</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 3: Floating-Point Functions. Value f is the floating-point number having the same bit representation as the unsigned integer uf.

Functions float_abs and float_half 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 IA32 behavior is a bit obscure. We will follow a convention that for any function returning a NaN value, it will return the one with bit representation 0x7FC00000. Note that float_f2i must return 0x80000000U when given a NaN or infinity as input.

The included program fshow helps you understand the structure of floating point numbers. To compile fshow, switch to the handout directory and type:
unix> make

You can use \texttt{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 \texttt{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.

\textit{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 \texttt{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 \texttt{btest}, and no credit otherwise.

\textit{Performance points.} Our main concern at this point in the course is that you learn enough about data representations to be able to get the right answer for these exercises. However, we also 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.

\textit{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 — \texttt{btest}, \texttt{dlc}, and \texttt{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:

```bash
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:

```bash
unix> ./btest -f bitNor
```

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

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

Check the file README for documentation on running the btest 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:

```bash
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:

```bash
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:

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

Your instructors will use `driver.pl` to evaluate your solution. They will do so on a class server.
6 Handin Instructions

To hand in your work, you will need to be on murphy.

To hand in your work, you should first include a comment at the beginning of your bits.c file that indicates your names and NetIDs. The comment should also indicate any issues you are aware of.

Next, you should create a copy of your file that includes your NetIDs, in alphabetical order, and separated by hyphens, in the name:

```
unix> cp bits.c bits-netid1-netid2.c
```

Finally, copy this file to the class hand-in directory:

```
unix> cp bits-netid1-netid2.c ~cs213/HANDIN/datalab
```

This last command will only work correctly on murphy.

That’s it.

We also strongly suggest you participate in the “Beat the Prof” contest (see below). This will give you feedback about how well you are doing compared to others in the class, and against the instructors’ solution.

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 puzzle solutions. 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"

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. You can view the scoreboard by pointing your browser at

    http://murphy.wot.eecs.northwestern.edu:8080

This link will only be accessible from Northwestern machines.