Computer Organization Principle
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

This is an individual project. All handins are electronic. Clarifications and corrections will be posted on the course Web page.

3   Handout Instructions

Start by copying `datalab-handout.tar` to a 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 for each of the 13 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:

```
 !  ˜  &  ˆ  |  +  <<  >>
```

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

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

Table 1 lists the puzzles in rought order of difficulty from easiest to hardest. 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.

Name	Description	Rating	Max ops
`bitXor(x,y)`	`x || y` using only `&` and `~`.	1	14
`tmin()`	Smallest two's complement integer	1	4
`isTmax(x)`	True only if `x` x is largest two's comp. integer.	1	10
`allOddBits(x)`	True only if all odd-numbered bits in `x` set to 1.	2	12
`negate(x)`	Return $-x$ with using $-$ operator.	2	5
`isAsciDigit(x)`	True if $0x30 \leq x \leq$.	3	15
`conditional`	Same as `x ? y : z`	3	16
`isLessOrEqual(x, y)`	True if $x \leq y$, false otherwise	3	24
`logicalNeg(x))`	Compute `!x` without using `!` operator.	4	12
`howManyBits(x)`	Min. no. of bits to represent `x` in two's comp.	4	90
`floatScale2(uf)`	Return bit-level equiv. of `2*f` for f.p. arg. `f`.	4	30
`floatFloat2Int(uf)`	Return bit-level equiv. of `(int)f` for f.p. arg. `f`.	4	30
`floatPower2(x)`	Return bit-level equiv. of `2.0^x` for integer `x`.	4	30

Table 1: Datalab puzzles. For the floating point puzzles, value `f` is the floating-point number having the same bit representation as the unsigned integer `uf`.

For the floating-point puzzles, you will implement some common single-precision floating-point operations. For these puzzles, 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.

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 `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 100 points based on the following distribution:

36 Correctness points.

39 Performance points.

25 Document points.

Correctness points. The puzzles you must solve have been given a difficulty rating between 1 and 4, such that their weighted sum totals to 36. 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 3 points for each correct function that satisfies the operator limit.

Document points. You need to submit a report document (.pdf) of explanation for the function of your code of each problem. Read the PPT for details.

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 bitXor
```

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

```
unix> ./btest -f bitXor -1 4 -2 5
```

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:

```
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

Please submit your project to Web Learning before **due date**. The project consists of two parts, the source file (bits.c) filled with your code and a document file (.pdf) of explanation for the function of your code of each problem. You shall write the document either in English or Chinese.

Please note that, for fairness, there will be punishment on late submission. The final grade of your submission will be only 80% of the origin grade for the week after the due date and zero after that week (read PPT for details). Therefore, please finish your work on time.

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 */
}
```