CS 105
Lab 1: Manipulating Bits

See class calendar for lab and due dates

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 MUST work in a group of at least two people in solving the problems for this assignment. The only "hand-in" will be electronic. Any clarifications and revisions to the assignment will be posted on the course Web page. **We strongly recommend that you and your partner brainstorm before coding.**

3 Handout Instructions

The materials for the data lab are on the Web at:

`http://www.cs.hmc.edu/~geoff/classes/hmc.cs105.201509/labs/lab01-data/bits-handout tar`

Start by downloading `datalab-handout.tar` to a (protected) directory in which you plan to do your work. Then give the command: `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 programming puzzles. Your assignment is to complete each function skeleton using only *straightline* code (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:

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

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.

IMPORTANT: BE SURE TO PUT YOUR NAMES AND YOUR KNUTH LOGIN IDS IN THE COMMENTS AT THE TOP OF BITS.C!

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.

Name	Description	Rating	Max Ops
`bitNor(x,y)`	`~(x|y)` using only `&` and `~`	1	8
`bitXor(x,y)`	`^` using only `&` and `~`	2	14
`isNotEqual(x,y)`	`x != y?`	2	6
`getByte(x,n)`	Extract byte `n` from `x`	2	6
`copyLSB(x)`	Set all bits to LSB of `x`	2	5
`logicalShift(x,n)`	Logical right shift `x` by `n`	3	16
`bitCount(x)`	Count number of 1's in `x`	4	42
`bang(x)`	Compute `!x` without using `!` operator	4	12
`leastBitPos(x)`	Mark least significant 1 bit	4	6

Table 1: Bit-Level Manipulation Functions.

Function `bitNor` computes the NOR function. That is, when applied to arguments `x` and `y`, it returns `~(x|y)`. You may only use the operators `&` and `~`. Function `bitXor` should duplicate the behavior of the bit operation `^`, using only the operations `&` and `~`.

Function `isNotEqual` compares `x` to `y` for inequality. As with all *predicate* operations, it should return `1` if the tested condition holds and `0` otherwise.

Function `getByte` extracts a byte from a word. The bytes within a word are ordered from 0 (least significant) to 3 (most significant). Function `copyLSB` replicates a copy of the least significant bit in all 32 bits of the result. Function `logicalShift` performs logical right shifts. You may assume the shift amount n satisfies $1 \leq n \leq 31$.

Function `bitCount` returns a count of the number of 1's in the argument. Function `bang` computes logical negation without using the `!` operator. Function `leastBitPos` generates a mask consisting of a single bit marking the position of the least significant one bit in the argument. If the argument equals 0, it returns 0.

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.

Name	Description	Rating	Max Ops
`tmax(void)`	largest two's complement integer	1	4
`isNonNegative(x)`	`x >= 0?`	3	6
`isGreater(x,y)`	`x > y?`	3	24
`divpwr2(x,n)`	`x/(1<<n)`	2	15
`absVal(x)`	absolute value	4	10
`addOK(x,y)`	Does `x+y` overflow?	3	20

Table 2: Arithmetic Functions

Function `tmax` returns the largest integer.

Function `isNonNegative` determines whether `x` is less than or equal to 0.

Function `isGreater` determines whether `x` is greater than `y`.

Function `divpwr2` divides its first argument by 2^n, where n is the second argument. You may assume that $0 \leq n \leq 30$. It must round toward zero.

Function `absVal` is equivalent to the expression `x<0?-x:x`, giving the absolute value of `x` for all values other than $TMin$.

Function `addOK` determines whether its two arguments can be added together without overflow.

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.

6 Advice

You are welcome to do your code development using any system or compiler you choose. Just make sure that the version you turn in compiles and runs correctly on `Wilkes`. If it doesn't compile, we can't grade it.

The `dlc` program, a modified version of an ANSI C compiler, will be used to check your programs for compliance with the coding style rules. The typical usage is

```
./dlc bits.c
```

Type `./dlc -help` for a list of command line options. The README file is also helpful. Some notes on `dlc`:

- The `dlc` program runs silently unless it detects a problem.
- Don't include `<stdio.h>` in your `bits.c` file, as it confuses `dlc` and results in some non-intuitive error messages.

Check the file `README` for documentation on running the `btest` program. 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, e.g., `./btest -f isPositive`.

7 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 `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.

8 Handin Instructions

- Make sure you have included your identifying information in your file `bits.c`.
- Remove any extraneous print statements.
- Use `cs105submit` to submit **bits.c**. You can also run `make submit`.
- If you discover a mistake, simply submit the file again.

9 Notes

DLC requires strict ANSI C. That means you can't do a few things that the GNU C Compiler (gcc) allows. For example, you can't do this:

```
int mask = 0x55 + (0x55 << 8);
mask = mask + (mask << 16);
int shift = (x >> 1);
int sum = (shift & mask) + (x & mask);
```

because in ANSI C all of your variable declarations must come at the beginning of a function. Once you have written a non-declaration statement, you can no longer make any new declarations.

The other point that you must remember is that in ANSI C you cannot make `// comments`.

To help you remember this, the supplied Makefile invokes the `-pedantic` flag, which makes gcc refuse to accept non-ANSI C. For this reason you should compile using make, *not* by invoking gcc directly (which in any case is a bad habit that you should purge from your fingers).

10 More 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 */
}
```