

(a) (0.8 points) An instruction set architecture has 8-bit operands and produces 8-bit results. The registers are denoted by  $r_i$ , where  $i = 0, 1, 2, \dots$ . There is a carry flag,  $C$ . Consider the following two instructions and their meanings, which are given in parentheses:

`addc r3, r2, r1`      ( $r3 = r2 + r1 + C$ )

`negt r5, r4`      ( $r5 = (\text{one's complement of } r4) + 1$ )

Note that both of these instructions affect the value of the  $C$  flag. (The  $C$  flag will be equal to the value of the carry out of the MSB position when the operation is performed.)

Consider the following program fragment:

```
negt r7, r6
addc r8, r7, r6
```

Construct a table of the following form giving the resulting value in  $r8$  for each of the 256 possible values of  $r6$ :

<b>r6</b>	<b>r8</b>
00000000	
00000001	
00000010	

⋮

(b) (0.8 points) Consider the following portion of an assembly language program for some processor, where the registers are indicated by  $r_i$ , for some integer  $i$ , and where the meanings of the instructions are given in parentheses:

Instruction I1: `add r4, r5, r6`      ( $r4 = r5 + r6$ )

Instruction I2: `sub r6, r7, r5`      ( $r6 = r7 - r5$ )

Instruction I3: `or r4, r6, r4`      ( $r4 = r6 \text{ or } r4$ )

Identify any flow dependences, anti-dependences and output dependences that exist amongst these instructions. (In each case, specify the register that is involved.)

(c) (0.8 points) In interval arithmetic, a real number,  $x$ , is represented by two floating-point numbers,  $x_1$  and  $x_2$ , in the following way:  $x_1$  is a floating-point number that is less than or equal to  $x$ , and  $x_2$  is a floating-point number that is greater than or equal to  $x$ . The real number  $x$  is expressed using the notation  $[x_1, x_2]$ . In interval arithmetic, operations are performed on intervals. For example, real numbers  $x$  and  $y$  would be added as follows:

$$[x_1, x_2] + [y_1, y_2] = [z_1, z_2]$$

The IEEE 754 standard for floating-point arithmetic defines four possible rounding modes: RNE (round to nearest even), RZ (round toward zero), RPI (round toward plus infinity) and RMI (round toward minus infinity). In the above addition example, give equations for  $z_1$  and  $z_2$  and specify the rounding mode or modes that should be applied to these equations in order for the interval properties to be preserved for the sum. Briefly explain your answer.

(d) (0.8 points) Briefly explain the difference between a write-through cache and a write-back (also called a copy back) cache. Also, indicate which type of cache typically requires a higher bus bandwidth.

(e) (0.8 points) A computer with a virtual memory system has the following parameter values: memory is byte-addressable, the virtual address is 40 bits, the page size is 128K bytes and each page table entry is 48 bits. Determine the number of bits in the virtual page number field, the number of bits in the page offset field, the number of page table entries and the total size of the page table.