Question 2 (14 points): Two versions of a function that changes the endianess of the elements of an array stored in memory are shown below. Assume that this function is executed in a processor where the ALU instructions (slli, add, srli, or, addi) take, on average, one clock cycle; control-flow instructions (bnez, jalr, blt, jalr) take, on average, three clock cycles; and memory instructions (lw, sw, lbu, sb) take, on average, five clock cycles to execute.

```
ChangeEndianess_B:
                                                                                     265
                                                                                                     mν
                                                                                                               t5, zero
                                                                                                                                                # i <- 0
                                                                                     266
                                                                                                     bnez a1, nextWordB
                                                                                     267
                                                                                                     jalr zero, ra, 0
                                                                                     268
                                                                                             nextWordB:
                                                                                     269
                                                                                                     1bu
                                                                                                              t1, 0(t0)
                                                                                                                                                # t1 <- 0000000 00000
                                                                                     270
ChangeEndianess_A:
    slli t0, a1, 2
add t1, a0, t0
bnez a1, nextWord
                                                                                                               t1, 3(t0)
                                                                                     271
                                                                                                     sb
                                                                                                             t2, 1(t0)
                                                                                                                                                # t1 <- 00000000 00000
                                                                                                     1bu
jalr zero, ra, 0
nextWord:
                                                                                     272
   tWord:

lw t2, 0(t0)

slli t3, t2, 24

srli t4, t2, 8

slli t4, t4, 24

srli t5, t2, 16

slli t5, t5, 24

srli t5, t5, 16

srli t6, t2, 24

or t3, t3, t4
                                                                                                               t2, 2(t0)
                         # t2 <- AAAAAAA BBBBBBB CCCCCCC DDDDDDDD
                                                                                     273
                                                                                                     sb
                         # t3 <- DDDDDDD 00000000 00000000 00000000
                                                                                                              t3, 2(t0)
                                                                                                                                                # t1 <- 00000000 00000
                         # t4 <- 00000000 AAAAAAA BBBBBBB CCCCCCC
                                                                                     274
                                                                                                     1bu
                         t3, 1(t0)
                                                                                                     sb
                                                                                     275
                         # t5 <- 00000000 00000000 AAAAAAA BBBBBBBB
                         # t5 <- 8888888 0000000 8888888 0000000 # t5 <- 0000000 0000000 8888888 0000000 # t6 <- 0000000 0000000 0000000 AAAAAAA
                                                                                                              t4, 3(t0)
                                                                                                                                                # t1 <- 00000000 00000
                                                                                     276
                                                                                                     lbu
                                                                                     277
                                                                                                     sb
                                                                                                               t4, 0(t0)
   or 13, 13, 14
or 15, 13, 14
or 15, 15, 16
or 13, 13, 15
sw 13, 0(10)
addi 10, 10, 4
blt 10, 11, nextWord
jalr zero, ra, 0
                         # t3 <- DDDDDDDD CCCCCCC 00000000 00000000
                         # +5 <- 00000000 00000000 BRBBBBBB AAAAAAA
                                                                                                     addi t5, t5, 1
                                                                                     278
                         # t3 <- DDDDDDDD CCCCCCC BBBBBBB AAAAAAA
                                                                                                     blt t5, a1, nextWordB
                                                                                     279
                                                                                     280
                                                                                                     jalr zero, ra, 0
```

a. (3 points) If the value of a1 is zero, what is the CPI for an execution of ChangeEndianess_A?

Only the instructions in lines 242-245 will execute. Thus, the CPI for this execution is:

$$CPI_{a1=0} = \frac{1+1+3+3}{4} = 2 \frac{clocks}{instruction}$$
 (1)

b. (3 points) What is the CPI for an execution of ChangeEndianess_A in which a1 is very large?

If a1 is very large, then only the instructions inside the loop matter:

$$CPI_{a1 large} = \frac{2 \times 5 + 12 \times 1 + 3}{15} = 1.67 \frac{clocks}{instruction}$$
 (2)

c. (4 points) An execution of ChangeEndianess_A in which the value of a1 is 0x00010000 runs in a 4 GHz RISC-V processor. How long does this execution of ChangeEndianess_A takes? $0x00010000 = 2^{16} = 2^6 \times 2^{10} = 64 \times 1024$

Execution Time =
$$\frac{64 \times 1024 \times (2 \times 5 + 12 \times 1 + 3)}{4 \times 10^{9}}$$
$$= \frac{64 \times 1024 \times 25}{4 \times 10^{9}} = 16 \times 1024 \times 25 \times 10^{-9}$$
$$= 409600 \times 10^{-9} = 409.6 \times 10^{-6} \text{ seconds} = 409.6 \ \mu s$$

d. (4 points) An execution of ChangeEndianess_A and an execution of ChangeEndianess_B receive the same very large value in a1. Both functions run on the same computer with the same clock frequency. Which version is faster and by how much?

Assume that the number of iterations in the loop for both executions is K and that the clock frequency for this computer is F

$$\begin{aligned} &\text{Time}_A &=& (2\times 5 + 12\times 1 + 3)\times \frac{K}{F} = 25\times \frac{K}{F} \\ &\text{Time}_B &=& (8\times 5 + 1 + 3)\times \frac{K}{F} = 44\times \frac{K}{F} \\ &\text{Speedup} &=& \frac{44}{25} = 1.76 \end{aligned}$$

ChangeEndianess_A is 1.76 times faster than ChangeEndianess_B.